What Did We Get For Our $30-Billion Investment in SDI/BMD?

James A. Abrahamson
Henry F. Cooper

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SUMMARY AND CONCLUSIONS

The basic issue addressed by this paper has to do with the value added by the existence of the Strategic Defense Initiative (SDI), acknowledging that, during the same timeframe, something on the order of $30-billion would have been spent pursuing research on the same technologies somewhere in the Department of Defense (DOD) anyway. As is supported in detail in the following text, SDI has been enormously productive by many standards and from many perspectives.

From a geopolitical / geostrategic point-of-view, there is little question but that SDI induced the leadership of the former Soviet Union to return to the negotiating table after their 1983 walk-out and negotiate seriously toward deep reductions in nuclear arms, producing the first nuclear arms control agreements in history to do so. A number of authoritative sources, including former senior Soviet officials, have stated that Ronald Reagan's highly visible commitment to SDI was a significant factor in persuading Mikhail Gorbachev to give up the arms competition and change the course of the former Soviet Union from confrontation to cooperation with the West, hastening the end of the Cold War. What are these achievements worth? Certainly many times the $30-billion invested over the past 10-years. On January 29, 1990, Defense Secretary Dick Cheney announced a $167-billion reduction in the FY1990-94 Defense plan for the next 5-years alone.

From an acquisition management perspective, the SDI Organization (SDIO) created a very effective management team that, over the past 10-years, continuously integrated evolving advances of key cutting-edge technologies into field demonstrations and architectural options that, in turn, rapidly moved the technology out of the laboratory and into innovative acquisition programs. There is little question that the normal process of moving technology out of the laboratory was short-circuited and the "conceptualization-to-realization" time was reduced by years in the SDI program. In our judgment, SDIO's innovation translated into substantial savings--and, more importantly, will provide substantially more capable active defenses to our operational forces years sooner than would have otherwise been the case.

From a technical perspective, remarkable hardware advances, including ones in electronics, sensors and detectors, computers, propulsion, communications, and power, have resulted from SDIO's emphasis on integrating the research activities to maximize overall system performance by increasing critical element performance, miniaturization, producibility, survivability, and overall robustness. Unit size, weight and costs have been reduced, in many cases by orders-of-magnitude, while operational performance characteristics have also increased dramatically, in many cases also by orders-of-magnitude. These advances, which have numerous spin-off applications as well, were integrated into field demonstration experiments that improved the engineering state-of-the-art sufficiently to move into the serious acquisition programs now being pursued to provide active defenses to our military forces.

These geopolitical, management, and technical innovations would never have happened in a program to build defenses against ballistic missiles with "business as usual" in the Pentagon's acquisition process. If the authors had not had the status that came from a very supportive Secretary of Defense with a clear Presidential mandate, efforts to provide effective defenses to protect the American people, our forces overseas, and our allies and friends would have surely been short-lived; they would have sunk under the weight of ideological opposition and an extremely risk-adverse, bureaucratic defense acquisition process.

Notwithstanding the controversy and perceived programmatic turbulence created by this process, the Department of Defense leadership would do well to pattern their efforts to reform the acquisition process after SDIO in order to reduce the costs and time for moving technology into the field. In particular, the Department should exploit SDIO's pioneering efforts to plan during the concept development stage to provide early operational capability through the exploitation of prototypical hardware. This could provide operational capabilities years before the normal acquisition process--which now takes an incredible 15-years or more for major defense acquisition programs, assuring that the technology is years and even entire technology generations out-of-date when systems are finally deployed. With this innovation and the necessary funding, effective defenses could be fielded to begin seriously to protect the American people in this decade.

The annual debate will soon determine how much the United States will spend to defend the United States, our troops abroad, and our friends and allies against ballistic missile attack. Regrettably, this debate will again be volatile, with continuing false "Star Wars" caricatures and even false public accusations in the media. These activities continue in spite of the Clinton Administration's effort to de-politicize the debate by renaming the Strategic Defense Initiative Organization (SDIO) as the Ballistic Missile Defense Organization (BMDO) and giving priority to ground-based systems--particularly Theater Missile Defense (TMD) systems.

In the midst of this debate, continued charges of wasted resources can be summed up in the question, "What have we got to show for the $30-billion we have spent on SDI/BMD?" This fair question deserves a direct answer.

It is appropriate for us, two former SDI Directors, to account for our stewardship. One of us directed the original SDI program to respond to Ronald Reagan's 1983 vision, and the other advocated that vision to the Soviets in Geneva and refocused SDI to account for post-Cold War realities--as directed by George Bush in January 1991, and as largely endorsed by the Congress in the Missile Defense Act of 1991. After discussing the proper framework for addressing this question in the context of the pre-existing programs and budgets that were integrated into the SDI program in 1984, we:

- Review the geopolitical, management and technical consequences of establishing SDI as a high-level organization to integrate all DOD programs in the context of a highly-visible Presidential mandate;

- Describe in some detail how the $30-billion was spent and what progress was made in each of the major elements of SDI research and development; and

- Discuss how the research activity was converted into a serious DOD acquisition program, and how that program evolved to the present day.

POSING THE QUESTION CORRECTLY

About $30-billion would have been spent on most, if not all, of the same technologies had there been no SDI. Thus, the pertinent question is, "What difference did SDI make?"

Programs for the critical technologies were "in the budget" long before Ronald Reagan's March 23, 1983, speech launched SDI. The Fiscal Year 1984 budget and the FY 1984-88 Five Year Defense Plan (FYDP) to support research on these technologies were already in place when Secretary of Defense Weinberger chartered the SDIO a year later on April 24, 1984.

About $1.8-billion in 1993 dollars of already appropriated FY1984 funds were transferred into the SDI budget (along with the corresponding on-going programs) from the Services, DARPA, and other government agencies, as the management of those BMD-related activities was centralized under the SDI Director, who worked directly for the Secretary of Defense. Of these funds, only $50-million was associated with SDI "new starts," primarily studies of system concepts and the critically important function of battle management, command, control and communications (BMC3). Furthermore, about $15-billion in FY1993 dollars was transferred from these pre-existing program plans to the SDI FY1984-88 FYDP--about 70-percent of what was eventually judged to be required and what the President requested for SDI's FY1984-88 funding.

Congress actually appropriated 70 to 80-percent of the President's request for SDI over this FY1984-88 FYDP -- only slightly more than the $15-billion (in FY1993 dollars) planned funding level, had there been no SDI. Furthermore, the General Accounting Office reports that Congress appropriated almost 30-percent less than the

President's budget request for the years FY1985-93,[1] i.e., throughout the Reagan-Bush era.[2] Because of the controversy regarding SDI, it is at least debatable that more than $30-billion might have been spent on these technologies had there been no SDI.

Thus, while it is certainly fair to ask what SDI achieved for $30-billion (of over $40-billion requested), a better question is whether focusing these technology efforts under a single coordinated program with the priority established by the President's personal interest, increased or decreased benefits from the $30-billion investment. Indeed, asking that question might provide insights to help frame future research activities--at a time when the DOD leadership is trying to improve significantly the Defense acquisition process.[3]

GEOPOLITICAL, MANAGEMENT AND TECHNICAL CONSEQUENCES OF SDI

From a geopolitical perspective, SDI led to a sea change in our negotiations with the former Soviet Union and, by informed and authoritative accounts, the end of the Cold War. From a management perspective, forming SDIO stimulated the DOD to integrate a number of existing technology programs and supplement them in the context of an identified goal--pushing already evolving technologies toward practical applications faster than would have been the case if the various programs had been pursued separately. From a technical perspective, significant advances have been achieved--not only enabling fielding of effective defenses in the near future, but also providing substantial spin-offs to the military, civil and commercial sectors.

Geopolitical/Geostrategic Benefits

The advent of SDI created a political firestorm at home and abroad. Because Ronald Reagan's stated objective, if realized, would require changes to the ABM Treaty and its underlying mutual deterrence theory, SDI created opposition in the arms control community which was wedded to both. Nevertheless, in the longer run, SDI precipitated a sea-change in US-Soviet relations and a fundamentally new, and by any reasonable measure, an improved geostrategic environment.

Of greatest importance was the impact of SDI on US-Soviet relations, then characterized by a large component of acrimony. Within three days of Reagan's March 23, 1983, speech, then-General Secretary Andropov declared in a flourish of overstatement that "Should this [SDI] conception be converted into reality, this could actually open the flood gates to a runaway race of all types of strategic arms, both offensive and defensive." This was to be a steady theme, echoed for the next five years, by arms control advocates, who argued (wrongly, it turned out) that SDI would destroy any potential for reductions in offensive nuclear arms.[4]

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[1]*Ballistic Missile Defense, Evolution and Current Issues*, GAO / NSIAD-93-229, July 1993. p.5.

[2]The Clinton Administration reduced the FY1994-99 SDI budget it inherited by about 50-percent (establishing a relatively flat budget profile at the FY1993 appropriated level), in part hoping to break with this unhelpful precedent which had dogged the SDI program. But Congress shows every sign of continuing to cut the FY1994 request by nearly the same percentage as in earlier years.

[3]As discussed later, SDIO pioneered innovative acquisition strategies long advocated by the Defense Science Board and others to move rapidly improving technology from the laboratory to the field. Also as discussed later, the SDI Innovative Science and Technology program is widely recognized as one of the very best in government, and one of the few that has consciously and successfully transferred technology to the civil and commercial sectors.

[4]For example, in McGeorge Bundy, George Keenan, Robert McNamarah, and Gerard Smith, "The President's Choice: Star Wars or Arms Control," *Foreign Affairs*, Winter 1984/85, p. 264, the authors argue, "It is possible to reach good arms control agreements, or possible to insist on the Star Wars program as it stands, but wholly impossible to do both."

In fact, SDI was instrumental in creating the conditions that led to the very first arms control agreements to embody major reductions in offensive nuclear weapons--and even to the end of the Cold War. Soviet concerns about SDI, particularly the space-based defenses,[5] were a primary reason that the Soviets returned to the negotiating table in 1985. (They had walked out of all arms control talks when we began deploying the INF missiles in late 1983.) At the October 1986 Reykjavik Summit, it was this same concern that led General Secretary Gorbachev to offer major reductions in offensive nuclear weapons if SDI testing were limited to the laboratory. By some authoritative accounts,[6] it was Ronald Reagan's commitment to SDI that led Gorbachev to give up the race--contributing greatly to the end of the Cold War, producing historic reductions in offensive nuclear weapons and accelerating the democratization of the former Soviet Union.

With the end of the Cold War came a fundamental change in geopolitical realities--and a consequent redirection of the SDI program. The adversarial relationship between two superpowers began to shift, from confrontation to cooperation, as the former Warsaw Pact, and then the Soviet Union itself, dissolved into independent sovereign states. The US negotiating position since 1985 (deep offensive reductions and cooperation on building defenses) became much more palatable to our former Soviet counterparts and more credible to our allies and friends.

Fundamentally, defenses now can be considered in the context of shared problems rather than in the context of military competition. One common problem is the concern about the proliferation of ballistic missiles that can deliver to great ranges weapons of mass destruction, which are also proliferating throughout the world.[7] Several proliferant states are led by political regimes that are either unstable or driven by ethnic hostilities--or both. Also concerns continue about the accidental or unauthorized launch of ballistic missiles, many of which remain on alert and pointed at the United States.

Consideration of these uncertain conditions led to a Presidentially mandated Independent Review of SDI. It recommended in a March 1990 report to Defense Secretary Dick Cheney that SDI be refocused on these problems, with greater emphasis on defenses against theater ballistic missiles, to provide protection against limited ballistic

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[5]The Soviets had long understood the large force multiplier effects of space systems, and sought, with their "militarization-of-space" arguments, to impede progress in this important area of US technological advantage. This Soviet view was made public when, on June 7, 1989, then Prime Minister Ryshkov defended the budget for the Soviet "military space program" (after years of denying that the Soviet Union even had such a program) before the Congress of Peoples Deputies--live on Moscow television. He strongly advocated continuing such programs (which, from his and Gorbachev's budget numbers, composed over 5-percent of their total military budget), observing that Ministry of Defense studies had shown that military space programs "enhance the combat efficiency of our armed forces by 1.5 to 2 times." The Gulf War demonstrated that the force multiplier is, in fact, much higher.

[6]Marshal Sergei Akhromeyev (former Soviet Chief of Staff, close advisor to Gorbachev, and head of the Soviet Experts Group at Reykjavik) told Ambassador Vernon Walters (who was our Ambassador to the UN at the time of the Reykjavik Summit), that Reagan's refusal to give up SDI at Reykjavik was a "watershed event," by which Walters understood that Gorbachev was then persuaded that the Soviets could not compete. This view is shared by other world leaders, including former British Prime Minister Margaret Thatcher. At a February 1993 Princeton University meeting, former Soviet Foreign Minister Alexander Bessmertnykh (who was close to the US-Soviet negotiations throughout this period) and former Gorbachev aid Anatoly Chernyaev indicated that SDI had a decisive effect on Soviet political and economic calculations that hastened the end of the Cold War. (See press accounts in the February 27, 1993, *Washington Post* and *Washington Times*.) About the same time Russian Deputy Foreign Minister Grigoriy Berdennikov, in an ABC interview in Madrid, said, "The Soviet Union fell precisely because it could not afford 'star wars' and the arms race against the West." Finally, Ambassador Vladimir Lukin (Chairman of the Supreme Soviet Foreign Relations Committee during the 1980s and now Russia's Ambassador to the United States) has observed that SDI accelerated the end of the Cold War "by five years." Reported by Former National Security Advisor Robert McFarlane in his August 24, 1993, Op-Ed in the *New York Times*. (On January 29, 1990, Defense Secretary Dick Cheney announced a post-Cold War defense savings of $167-billion over 5-years.)

[7]If anything, the former Soviet states should have greater motivation for cooperating in building defenses because most proliferant states are closer to them than to the United States.

missile strikes on the United States, our troops abroad, and our friends and allies. After DOD studies of policy and acquisition issues associated with accepting this recommendation, Secretary Cheney sponsored it to President Bush. The President then redirected SDI accordingly in his January 1991 State-of-the-Union message to Congress. This new SDI concept became known as GPALS, or Global Protection Against Limited Strikes.[8]

The wisdom of this redirection was validated by the Patriot-Scud duel of the Gulf War--witnessed first hand by several influential Senators who went into a bomb shelter while visiting Tel Aviv during a Scud attack. In response, Senator John Warner (R-VA), then the ranking minority member of the Senate Armed Services Committee, led in drafting the Missile Defense Act of 1991 which, when passed in late 1991, mandated the development for deployment of advanced Theater Missile Defenses, an initial "treaty-compliant" site of a US Limited Defense System (including space-based sensors), and robust funding for the Space-Based Interceptor (SBI) of the President's GPALS concept as a follow-on technology.[9]

These developments promoted a more positive view in the former Soviet Union regarding the role of ballistic missile defenses. A most significant event came on January 31, 1992, when Russian President Boris Yeltsin, in a speech to the United Nations, advocated even deeper reductions in strategic offensive arms (than in START I) and cooperation on what he referred to as a Global Protection System (GPS) to protect the world community from missile attack--urging that SDI be redirected to take advantage of Russian technology.[10] He and General Shaposhnikov (then Chief of Staff of the Commonwealth of Independent States) made clear in discussions with the press and allies that they intended GPS to be deployed in a multinational context to protect the world community against accidental, unauthorized, and rogue missile attacks.

Yeltsin's dramatic new position reversed the long-standing insistence that we could have offensive reductions <u>or</u> defenses, but not both (and laid waste to the claims of SDI opponents who had argued for years that a cooperative expansion of ballistic missile defenses was non-negotiable). Yeltsin essentially endorsed the formula proposed by US negotiators in Geneva for seven years--deep offensive reductions and <u>cooperation</u> on defenses.[11]

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[8]Regrettably, a misperception developed, exacerbated by SDI opponents, that the "global" emphasis of GPALS was associated with space systems--and, in particular, Brilliant Pebbles space-based interceptors. In fact, GPALS had to do with a shift in focus from almost total emphasis on defending the US homeland against long range missiles from the former Soviet Union to defending against missiles of all ranges launched from almost anywhere in the world toward our troops, allies and friends almost anywhere else in the world as well as the US homeland. So, the G in GPALS really had to do with the inclusion of theater missile defenses into the SDI primary architecture--it had nothing to do with space systems per se, although space systems can support theater missile defenses, as reported in Defense Secretary Cheney's March 1992 Report to Congress on *Conceptual and Burdensharing Issues Related to Space-Based Ballistic Missile Defense Interceptors.*

[9]In response, the Department of Defense provided its fully coordinated acquisition plan to implement the Missile Defense Act in its June 1992 Report to Congress. Although Secretary Cheney's cover letter stated this plan would be executed as a top national priority, the issue of precisely how to proceed remained controversial in the Congressional debate over the FY1993 SDI budget, and a significant cut from the President's request resulted, causing substantial delays as discussed in SDIO's January 1993 Report to Congress in support of President Bush's FY1994 budget request. Nevertheless, Congress reaffirmed the main elements of the Missile Defense Act of 1991 in the FY1993 Defense Authorization Act.

[10]The former Soviet Union never opposed defenses per se, only US defenses. Throughout the Cold War, they always invested as much on defensive as offensive strategic systems (and much more than the US). And, as Mikhail Gorbachev admitted to Tom Brokaw on American TV in 1987, they were doing everything the US was doing with SDI.

[11]As will be discussed later, several areas of technological cooperation have been identified, and active contracts are now in being which employ Russian and US scientists and engineers working side-by-side. Thus, Yeltsin's proposal, which is in the interest of both the US and Russia, is quite realistic--and the initiatives of the Bush Administration to respond favorably should be continued in active discussions with Russia, the other republics of the former Soviet Union and our allies and friends. Indeed, it is unfortunate that more progress was not made during the last Administration.

Yeltsin's proposal had a sobering effect on the already evolving views of our allies and friends, in the wake of the Gulf War and consistent with their growing concerns about proliferating weapons of mass destruction and missiles for delivering such weapons. Clearly, they too have accepted missile defense as a necessary element in the security calculus of the post-Cold War world.[12]

It is hard to argue that focusing a number of technology programs under a high-visibility, Presidentially-mandated SDI program was a bad idea--even if substantial new funding had been required. Without counting the value of the sweeping changes throughout Europe and with our former adversaries, the so-called "peace dividend" from ending the Cold War more than repaid the $30-billion investment of the past decade in just a couple of years and, in 5-years, was over 5-times the total 10-year SDI investment.[13]

When it is also understood that most of the $30-billion would have been spent developing most of the same technologies anyway, it is impossible to see how anyone could fault SDI--especially since there were clear management and technology dividends as well.

Management Benefits

Prior to the formation of SDI with the Presidential mandate, the various technology development activities were proceeding without an integrating focus. For over a decade prior to SDI, the Nation's program to develop ballistic missile defenses had been narrowly directed to develop systems for defending missile silos, not protecting people.[14] Sensor development had been focused almost entirely on providing reconnaissance, surveillance, tactical warning and attack assessment information--all in the context of a strategic concept that relied upon the threat of nuclear retaliation for deterring nuclear threats.

On April 24, 1984, SDIO was created, reporting directly to the Secretary of Defense, to manage the nation's most vigorous and diverse technology research effort. SDI was aimed at nothing less than providing the technical means to underwrite, as noted above, a fundamental shift in national security strategy. SDIO provided "bureaucratic" muscle, forcing the integration of complementary programmatic efforts, along with their supporting technologies, into a comprehensive activity aimed at realizing the President's vision. SDI became a national program for developing various technologies essential to ballistic missile defense, including programs that had been managed separately by the Military Departments, various Defense agencies, and Department of Energy Laboratories.

The nature of the President's challenge required integration of not only existing research and development programs, but also the inventive and innovative efforts of the most creative minds available. Thus, from the outset, SDIO sought a close alliance with academia and the commercial sector as well as the defense industry,

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[12]Authoritative statements by senior European, Israeli and Japanese officials are discussed in depth in *Proliferation and Missile Defense: European-Allied and Israeli Perspectives*, a report by the International Study Group on Proliferation and Missile Defense under the auspices of the National Institute for Public Policy, June 1993. Also, recent Russian views are summarized in Keith B. Payne, Linda H. Vlahos, and Willis A. Stanley, "Evolving Russian Views on Defense: An Opportunity for Cooperation," *Strategic Review*, Vol. XXI, No. 1, Winter 1993, pp. 61-72.

[13]As specified in the *News Release*, Office of Assistant Secretary of Defense (Public Affairs), The Pentagon, January 29, 1990, the Bush Administration's FY1990-94 defense budget showed $167-billion saving as compared to previous 5-year plans. The saving each year after FY1991 exceeded the total 10-year SDI investment and by FY 1994 the annual saving was projected to exceed $60-billion a year--over 10-times the planned annual budget for SDI.

[14]Indeed, the Army's BMD activities since the late 1960s had been focused almost entirely on the Minuteman survivability problem, but always, after the advent of the ABM Treaty, as a less-than-serious alternative to ICBM mobile basing options. Working on this problem simply provided a limited focus for the hundred million dollars or so that was dedicated annually, in effect, to maintaining an ABM technology base as an ABM Treaty safeguard activity.

establishing a vigorous Innovative Science and Technology program, involving about 1000 of the nation's best scientists and engineers.[15] This SDIO program was initiated 3-years before Congress (in Public Law 100-456, the FY1989 National Defense Authorization Act) sought "to ensure the long term qualitative superiority of US weapon systems"--and is widely acknowledged to be the most broad-based, far-reaching government program directed toward those ends.

From the outset in SDIO, those managing research at the cutting edge of technology worked in close proximity to managers exploiting technology to develop "architectures"--and execute major field demonstration experiments and acquisition programs as well. Thus, SDIO created numerous "feedback loops," expediting technology transfer from the laboratory to field demonstrations, to architectural exploitation, and to system applications.

A good example of the results of this management style is the 1986-89 series of orbital experiments designated as Delta 180, 181, and 183. Designed and built from scratch, these missions involved space vehicles in the roughly 6000-pound weight class, cost between $150-million and $250-million each, and were executed from concept-to-launch in 13, 18, and 30 months respectively. These experiments accomplished the first space-to-space intercept, the first measurements of realistic re-entry vehicles during the midcourse phase, and the first observations of booster rockets as targets seen from space. These experiments also flew the first space laser radars and orbited the first actively monitored space materials exposure experiment.

As illustrated in Figure 1, the number of tests and field experiments grew steadily throughout the decade as SDIO moved away from paper feasibility studies, laboratory work, and infrastructure development, toward field demonstrations of SDI-developed technologies, and ultimately toward the demonstration and validation of system concepts.

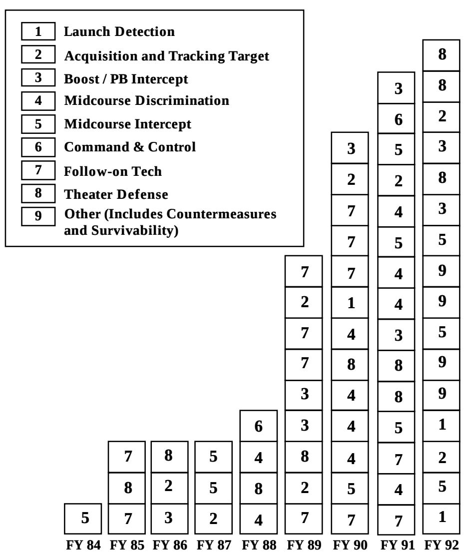

Figure 1. SDI Major Tests and Experiments FY1984-92

Source: Statement by Ambassador Henry F. Cooper before the Committee on Government Operations, US House of Representatives, May 16, 1991.

[15]More generally, SDIO's investments have led to direct employment, on the average, for over 20,000 high technology workers and indirectly provided for many more.

This process was very effective in adapting system architectures to take advantage of rapidly improving technologies.[16] SDIO pursued innovative management and technical approaches that could serve as models for the announced initiatives by Deputy Secretary Perry and Undersecretary Deutch to streamline the Pentagon's excessively bureaucratic acquisition process.

A particularly important innovation was SDIO's successful advocacy of an acquisition strategy by which prototypical hardware can be fielded to provide an early defense capability--many years before normal production lines can be started. Such a system, called a User Operational Evaluation System (UOES), would be developed, tested and evaluated by the operator during the Demonstration and Validation (or DemVal) phase of the normal acquisition process--years before engineering and manufacturing development is completed and production lines begin.

Although similar approaches exploiting prototypical hardware have been repeatedly advocated by the Defense Science Board and others for years, the Pentagon's acquisition community had never warmed to the idea. SDIO not only successfully advocated the UOES approach through a conservative Pentagon acquisition bureaucracy, but also with Congress, which, as part of the FY1993 Defense Authorization Act, approved this approach for the Theater High Altitude Area Defense (THAAD) system. Current plans call for a deployable THAAD prototype system in 1996, whereas the initial operational capability (IOC), using fully developed production line hardware, will not occur until about 2002.[17]

Although this idea may seem novel, it was validated by the common-sense exploitation of JSTARS during the Gulf War--SDIO simply has advocated planning to follow this course well in advance of the need rather than on a rushed, ad hoc basis as was the case in the Gulf War. This approach is entirely consistent with the Clinton Administration's interest in pursuing advanced technology demonstrators and has been welcomed by many in the Air Force and the Navy who are seeking to exploit SDI technology to achieve early theater missile defense capabilities.

SDIO's management approach, which produced management and technical innovations, is illustrative of Total Quality Management (TQM) approaches, and SDIO was doing it before TQM was in vogue. It was successful in producing innovative acquisition programs and stimulating research that benefited other defense programs, and the benefits have not been limited to applications in the defense sector. As discussed in the following section, substantial benefits from the SDI investments also have extended beyond the defense sector, and SDIO's management style assured the civil and commercial sectors gained immediately from these investments.

It is not too much to suggest that SDIO provided the single greatest stimulus to aerospace R&D since the Apollo program. Indeed, SDIO adopted the management style that was routine during the heyday of space missions in the mid-1950s to the early 1970s. SDIO avoided problems associated with diffused responsibility and a lack of clearly defined goals that have plagued aerospace efforts during the past 20-years.

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[16]However, the frequent changes in architectures and associated cost estimates suggested to those who were not close to the program that there were great programmatic instabilities, especially as the program was directed toward entering the Pentagon's normal acquisition process. The public controversy that always surrounded SDI only exaggerated these perceptions of programmatic instability. Nevertheless, and in spite of the programmatic turbulence that resulted from the 20 to 30-percent Congressional budget cuts each year, SDIO made steady progress in moving toward serious acquisition programs, particularly following passage of the Missile Defense Act of 1991.

[17]SDIO also successfully advocated through the Pentagon bureaucracy the UOES approach for a US homeland defense and included it in the Secretary of Defense's June 1992 Report to Congress which laid out the plan for implementing the Missile Defense Act. Regrettably, this plan, which provided UOES options for fielding the initial US site as early as 1997, was not approved and funded by the Congress because of a lack of a perceived imminent threat to the United States. Given the Gulf War experience, the existing and growing threat to our forces abroad, friends and allies is undeniable--hence, Congress approved the early UOES option for THAAD.

Technology Benefits

In 1983, the Fletcher Panel, chaired by former NASA Administrator James Fletcher, reviewed the feasibility of Ronald Reagan's challenge to the technical community and concluded that "powerful new technologies are becoming available that justify a major technology development effort offering a future technical option to implement a defensive strategy."[18] The Fletcher Panel recommended a 5-year research and development plan, estimated to cost $26-billion,[19] to push the key technology areas that are critical to building effective defenses--particularly in the context of defending the United States against massive missile attacks from the former Soviet Union. That plan served as SDIO's starting point.

Throughout the past decade, multiple approaches, many using different technologies, have been demonstrated for each of the critical missile intercept functions. Breakthroughs in miniaturization and weight reduction have increased the performance and reduced the cost of ground-based systems, high speed aerodynamic and exo-atmospheric vehicles, and spacecraft. Concerted efforts in developing manufacturing processes and improving producibility have made it practical to produce economically advanced components in quantity.

To reach this point, most of the $30-billion SDI investment has funded major hardware assembly and field experiments necessary to prove available technologies can be integrated together to operate as an effective defensive system in a hostile and reactive environment. This absolutely essential aspect of the SDI development process will be discussed in more detail in the next section, which gives an accounting for the $30-billion and seeks to rectify a number of misperceptions about the conduct of the program over the past decade and the maturity of demonstrated technologies.

The remainder of this section briefly discusses a few of the most important consequences of SDI's investment in the cutting edge technologies in several areas identified by the Fletcher Panel and other SDI studies as high leverage, or pay-off, areas for investments. <u>The bottom line is that these cutting edge activities have provided key hardware and software innovations, demonstrated them in major hardware integration and field testing programs; such innovations are now being included by contractors in their bids and performance on major defense acquisition programs; and continuing research promises major innovations still to come--many of which also will be exploited by other defense programs and in the civil and commercial sectors.</u>[20]

Electronics. SDIO investments in electronics (the building blocks of computers, guidance systems, sensor readouts, satellite control modules, etc.) have enabled major improvements in capability while reducing size, mass and cost of a variety of key system elements by factors of 20 or more--several new electronic materials promise even greater savings.

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[18]Specific "powerful new technologies" emphasized by Fletcher included BMC3, infrared sensors, hit-to-kill kinetic energy interceptor front-ends, and directed energy systems.

[19]As noted earlier, the actual appropriations for FY1984-89 was considerably less than (when inflation is accounted for, about half of) the $26-billion called for by the Fletcher Panel.

[20]A more complete summary of "spin-offs" is discussed in the annual *SDI Technology Applications Report,* most recently published in August 1992. This report discusses spin-offs according to the categories of health; the environment; energy; consumer products; computers; communications; industry; military, security and aerospace; and scientific research. Also, many technologies developed by SDI were identified by the Synthesis Group led by former astronaut Tom Stafford as being crucial for achieving the goals of President Bush's Space Exploration Initiative. (See *America at the Threshold, Report of the Synthesis Group on America's Space Exploration Initiative,* US Government Printing Office, May 1991.)

Silicon-on-sapphire radiation hard electronics is one example of an area where SDI investments are leading to promising devices and components for future military, civil and commercial satellites that will be exposed to large radiation doses over extended periods of time.

Another interesting example is the development of diamond film. With its $40-million investment in diamond film technology since 1986, SDIO is singularly responsible for fostering a new US industry with the potential of a multi-billion-dollar global market after the end of this century. In military systems, diamond semiconductors promise to outperform silicon, gallium arsenide, and even silicon carbide in almost every way: switching speed, temperature tolerance, breakdown voltage, radiation hardness, power output, ruggedness, etc. Because of diamond's large energy band-gap and other physical properties, diamond electronics have extremely high switching speeds. Also of particular note is that diamond is inherently more radiation-hard than other electronic materials--roughly 4-times the hardness of gallium arsenide.[21]

Sensors and Detectors. SDIO investments in sensors and detectors have produced major improvements. In particular, large (256x256) pixel arrays carrying over 65,000 individual photo-detectors are now manufacturable for mercury cadmium telluride (HgCdTe) and indium antimonide (InSb) focal plane arrays, enabling high signal-to-noise long wave infrared measurements at more practical and less expensive operating temperatures--and these sensors are now being exploited by industrial teams bidding on major defense acquisition programs. Over the past 8-years, <u>the cost per pixel has been reduced by a factor of 20 (and in some cases 100)--and there are prospects for another order-of-magnitude cost reduction</u>.[22]

New InSb sensors give images of such quality and resolution that ground-based telescopes with 1-meter apertures can detect small rockets burning at distances of 2000 kilometers. Also, the 256x256 InSb detector has been integrated with a camera and cryocooler in a 3-pound space qualified package; and the US company that manufactures this technology has reduced the cost from $1M to $35K per unit and has already sold over $20M worth of these cameras in the commercial market.

In the future, four new SDIO-pioneered sensor types promise to further revolutionize the capability and cost of infrared detection for both military and commercial applications such as home protection, non-destructive evaluation on assembly lines, environmental monitoring, auto engine exhaust measurement, etc.

SDIO has also significantly improved adaptive optics to enable effective propagation of laser beams through the atmosphere. This same technology is now being applied on astronomical telescopes to correct for atmospheric turbulence which has long been the limiting factor in ground-based telescope performance--enabling ground-based telescopes to perform as if they were in space. A SDI-developed adaptive optic system has been successfully fitted to the Mt. Wilson 60-inch telescope in California; and that system has already taken images that approximate those that the $3-billion Hubble Space Telescope will be able to take after it is repaired.[23]

With regard to guidance and control, <u>inertial measurement units (IMUs) that weighed over 5-pounds and cost about $100,000 a copy 10-years ago will shortly be replaced with more accurate SDI-developed IMUs that cost about $5000 a copy and weigh 1/4 pound--in a hardened configuration.</u> And by the mid-1990s micro-mechanical

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[21]Diamond also has extraordinary features as a hard, erosion-resistant coating. For example, as a coating for sensor windows on high speed rockets, diamond is optically transmissive while being perfectly capable of handling high heat loads. With its unequaled physical hardness and a coefficient of friction less than Teflon, thin-film diamond coatings make cutting tools and bearings virtually indestructible.

[22]Such sensors are critically important in assuring that the defense can stay ahead of the offense in the critical measure-countermeasure competition in which an effective discrimination capability is essential to the viability of, for example, exo-atmospheric interceptor systems.

[23]R. Jastrow and S. Baliunas, "Mount Wilson: America's Observatory," *Sky and Telescope*, March 1993, pp. 18-24.

IMUs weighing less than half-an-ounce may be available at $500 a copy. A new cryogenic resonant fiber optic gyroscope will weigh less than 30 grams and have extremely low noise and drift rate. An innovative star tracker with wide field-of-view has just been integrated with a space platform and, with its associated advanced silicon charge-coupled device (CCD) detector, weighs less than half a pound. IMUs are, of course, a critical enabling technology for an entire spectrum of high-performance DOD platforms.

Many of these sensor and detector systems will be flown on CLEMENTINE, a SDIO-NASA joint deep-space probe which will expose such very recent innovative technologies to space radiation environments and gather unprecedented fundamental science data on the Moon and a near-Earth asteroid--satisfying many civilian space science objectives as well as performance-validating hardware that may be used in a wide variety of military applications. For a mission cost of only $50-million, <u>CLEMENTINE is exploiting SDI technology and extending the approach of the earlier Delta Series of space experiments to establish a new standard for technically ambitious, low-cost, rapidly-executed, deep-space missions</u>.

SDIO has also exploited the dramatic reductions in weight and cost of SDIO-developed sensors to demonstrate the feasibility of low-cost, low earth orbit space sensors in its Miniature Sensor Technology Integration (MSTI) program. The full-up MSTI demonstrators may, in addition to providing useful data for designing other SDI systems, also serve as a foundation for advanced civil and commercial space platforms upon which can fly a diverse set of high-performance payloads, including remote sensing, communications, scientific instruments, etc. During the past 2-years, SDIO has been exploring possible joint missions with Russia, France and the United Kingdom to exploit this technology in a dual use context--to support ecological monitoring and possible development of the Global Protection System proposed by Russia's President Yeltsin.

Computers. SDIO investments over the past decade have realized for defense applications the same reductions in size and costs, and increases in capability, that is evident in present-day personal computers. In addition, SDIO investments have produced major improvements in novel computers and signal processors that will be exploited by SDI, other military systems, and commercially. For example, the RH-32 (radiation-hardened 32 bit) processor, which is nearly completed, represents an order-of-magnitude increase in capability and reduction in weight from the best of its predecessors.

Still in development are processors that will revolutionize both space and terrestrial computing. For example, the Wafer-scale Associative String Processor (WASP), a complete computer on a 4-inch circle of crystalline silicon, won two DARPA image recognition competitions against the best of DARPA's own very impressive research computers. It is naturally reconfigurable and fault tolerant, meaning that some of its several thousand micro-processors can fail and the computer will continue to function, losing only a small percentage of its speed--with no human intervention necessary in the reconfiguration.

SDIO's artificial neural network (ANN) program has developed silicon chip sets which mimic the circuitry of the human brain, permitting special classes of processing to be done more rapidly than on standard parallel processors, e.g., image recognition, multiple-target tracking, and weapon-target assignment. A recent demonstration showed that the ANN was 100,000 times faster at completing weapon-target pairings than a state-of-the-art parallel processor.

The Nation's first general-purpose hybrid optical/electronic computer will emerge from SDIO's Photonic Computing Program in a few months--accelerating the advent of an era when optics and light will begin to supplant wires and electronics in lighter, less power-consuming, faster computers.

<u>Exploitation of these cutting edge technologies will enable highly autonomous, very effective discriminating interceptor systems that will greatly reduce the logistics support requirements of current generation systems</u>. And there assuredly will be many spin-off applications in the civil and commercial sectors, as well.

Propulsion. SDIO's focus on reducing the size and weight of all components of effective defensive systems has led to major reductions in the size and weight of rocket motors for interceptors. Representative of these advances is the late-1980s state-of-the-art Advanced Liquid Axial Stage (ALAS) axial engine (being used in, for example, in the Light-weight Exo-Atmospheric Projectile (LEAP) program), which is less than 1/10 the weight of the 1970s vintage technologies--with a corresponding reduction in cost. In addition, recent miniature divert propulsion motors fabricated by SDI-funded rocket scientists are 35-percent smaller than their late-1980s predecessors and also permit a 30-percent reduction in total interceptor weight since smaller amounts of higher performance fuels can be used.

SDIO's recent purchase of Russian electric thrusters is catalyzing US industry to make advances in the longevity and performance of such engines for military, civil and commercial space applications. For space missions of a non-time-urgent nature, orbital transfer and inclination changes can be accomplished for a small fraction of the weight and volume (and cost) taken up by today's solar-powered arcjets and Hall thruster propulsion systems.[24] With the Sun providing an inexhaustible supply of electricity, satellites can use these small engines to change orbits or to make up for orbital drag, enhancing and prolonging satellite life by many years and saving billions of dollars.

In the past two years, SDIO has invested $60-million in the Single Stage Rocket Technology (SSRT) program to design, fabricate and flight-test a low-cost reusable rocket, designed to minimize the requirements for costly, manpower-intensive launch support operations while also re-cycling the very expensive rocket systems themselves. If successful, this program will pay for itself many times over in reducing the costs of future SDI experiments. A milestone was reached on August 18, 1993, when SSRT made its very successful initial flight --the rocket lifted some 150 feet vertically, moved to the side some 350 feet and then returned softly to the ground--retaining a vertical orientation for the historic 60-second flight. The objectives of follow-on technology exploitation programs with orbital applications are nothing less than to revolutionize the US space launch industry and to retrieve world leadership in space launch services for the United States.

Communications. SDIO investments since 1984 in a free-space laser communications project have produced a 20-pound optical transceiver with wide field-of-view acquisition and narrow field-of-view transmission capability, enabling lower power highly jam-resistant communications systems. This system is now entering the field testing stage, intended to demonstrate the world's first high data-rate laser communications crosslink. The Air Force is also eager to exploit this SDI technology for rapid downloading of data (approaching data transfer rates of a billion bits per second) from one AWACS aircraft to another during "changing of the guard" procedures--having identified this as a significant issue during Desert Storm.

In radio communications, SDIO's emphasis on moving transmission frequencies from the microwave up to the millimeter wave regime will potentially open new regions of the electromagnetic spectrum for communications and enable major hardware improvements. Communications at 300 GigaHertz up to 1 TeraHertz will reduce the size of satellite antennas by an order-of-magnitude from today's 22-60 GigaHertz systems. To achieve the high switching speeds necessary to move into this regime, SDIO has been sponsoring a major effort in superconducting digital electronics, which switch at clock rates up to 1 TeraHertz--a trillion switching operations every second. This is another high technology industry that has arisen primarily because of SDIO advocacy and support--an industry that will have spin-offs of superconducting electronics to the developers of commercial communications systems and high-speed main-frame computers, helping to keep the United States at the forefront in future telecommunications and processing markets.

Power. Over the past decade, the SDIO power community made major gains in understanding the generation and use of electricity in space, quantifying its improved knowledge with data from several highly successful Space Power Experiments Aboard Rockets (SPEAR) experiments and publishing a spacecraft design book to guide future engineers in managing high voltage and current on future space missions.

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[24]About 25-percent of the weight of a geosynchronous telecommunications satellite is devoted to propulsion systems for orbit maintenance.

Solar cells from SDI research are increasing the efficiency of photovoltaic systems from around 10-percent, where it had hovered for years, to over 30-percent, using novel materials and new solar concentrator designs. When transferred to industry, these advances could significantly hasten the advance of solar power.

SDIO has achieved a four-fold reduction in size and weight of energy storage batteries used to power satellites during the orbital eclipse period. On the civil/commercial side, the resulting technology is a leading contender for use in emerging electric automobile applications. Similarly, SDI research has contributed to a 250-fold reduction in the size and weight of capacitors to store comparable amounts of electrical energy.

Finally, the recent SDIO purchase of the Russian TOPAZ II thermionic nuclear reactor, and continuing joint US-Russian research to exploit this technology that the Russians have already successfully flown in space, will <u>for a relatively minor investment save US industry something in the neighborhood of a billion dollars and a decade of research</u>. The Russians have long used this technology for military applications. Civil space exploration missions, perhaps conducted jointly with Russia (among others), could also exploit this technology. In any case, by "leapfrogging" the development process through this joint effort, US industry could rapidly establish a domestic source capable of producing space nuclear power generators to support either activity.

Closure. Aggressive SDI investments over the past 10-years have resulted in great leaps in capability and manufacturability for key defense system elements, with major reductions in cost, mass, and size. <u>The sustained, focused SDI program challenged the US scientific and engineering communities to attain performance levels that would have normally taken decades under standard R&D investment strategies--and a significant portion of the accelerated progress is in technologies which have multiple military, commercial and civil applications</u>.

SDI technology investments support many of the 20 DOD critical technologies, essential for meeting future military needs, as well as key economic driver technologies in the commercial sector, as identified by the Department of Commerce. Thus, it is not surprising that SDI innovations promise support to other programs in the military, civil and commercial sectors.

SDIO has documented 97 commercial products which have emerged directly from its technology programs, 26 patents granted for commercial applications of SDI technology, 19 new spin-off companies founded to commercialize new products based on SDI technology, and 6 initial public offerings of stock in the last year by small companies productizing SDI technology.

It is ironic that now Congress is at the same time: 1) starting new civilian technology projects, bolstering other existing defense R&D, and encouraging closer links between military and civilian technology efforts and 2) imposing budget constraints that threaten to dismantle the tried-and-proven SDI technology program that rightly should be highlighted to serve as a model for these new initiatives. SDIO's cutting edge technology programs have an impressive track record illustrating how to assure our 21st-century military retains its traditional technological advantage--while also exploiting dual-use R&D and emphasizing the two-way transfer between the defense, civil and commercial sectors. This very constructive R&D leadership know-how should be exploited, not destroyed.

HOW THE MONEY WAS SPENT

In reviewing the programmatic advances of the past decade while considering whether the $30-billion investment in SDI has been justified, it is important to set the record straight on several misperceptions of how the $30-billion has been invested. (See Figure 2.) Then it will be easier to discuss the evolution of system concepts.

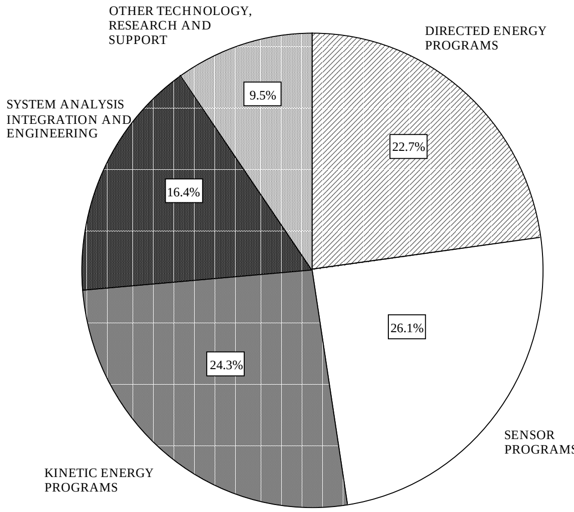

Figure 2. SDI Investments for 1983-1990

Directed Energy Programs

There is a general misperception that the bulk of the SDI program was directed toward work on Directed Energy (DE) systems, such as lasers and particle beams. This misperception conveniently supports the "Star Wars" caricature that has so well served the strategy of those who have wished to argue that an effective defense is a fantasy. In fact, between 20 and 25-percent of the total SDI funding has supported DE applications--and a very small portion of that investment has been on the x-ray laser, a favorite whipping-boy to which skeptics and critics have devoted entire books of ridicule and exaggeration.[25]

Figure 3 compares DE and total SDI funding histories for FY1985-93, which illustrates the sharp reduction in DE funding following the refocusing of the SDI program in 1991 (and the sharp increase in total funding after the Gulf War while DE funding continued to shrink). It should be understood that this reduction in funding for DE programs was not because of any technical failure--indeed the programs have generally been quite successful from a technical perspective.

[25]For example, *Teller's Wars--The Top-Secret Story Behind the Star Wars Deception* (Simon and Schuster, 1992) obviously presents only one side of a technical disagreement (the one opposing investments in the x-ray laser, of course) and uses it to ridicule SDI. The implied suggestion, widely amplified by SDI critics, is that all of SDI was and is a fantasy. Without debating whether the technical proponents of the x-ray laser have merit (they do), it is important to emphasize that President Reagan's instructions included directions that SDI was not to involve nuclear weaponry. In any case, less than 0.2-percent of SDIO's funds were spent researching the x-ray laser--and that work emphasized survivability matters because extensive Soviet research on the x-ray laser might someday have challenged non-nuclear SDI systems under development. It is remarkable that so much media attention has been given to such a minor aspect of the SDI program.

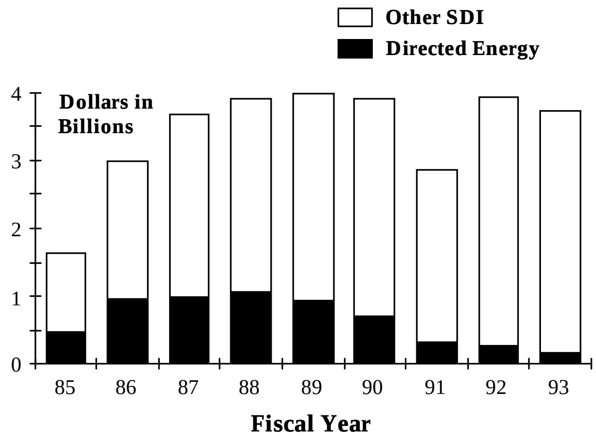

Figure 3. Directed Energy Funding Versus Total SDI Funding

In spite of the general perception that DE system applications can be realized only in the distant future (no doubt, a consequence of the "Star Wars" imagery), the truth is that the technology would support near-term DE deployment options. DE development has been severely restrained by budget realities--for the past three years Congress has reduced support for DE funding to levels below what the nation was spending on this technology before SDIO was formed in 1984. See Figure 4.

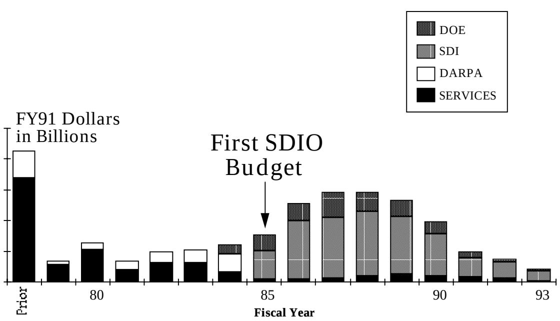

Figure 4. Directed Energy Funding History

Source: Testimony by Ambassador Henry F. Cooper, e.g., before the Committee on Appropriations, US House of Representatives, April 7, 1992.

It is also true that there were large persistent DE funding shortfalls as compared to the President's budget requests. And when Congress appropriated insufficient funds to sustain a planned research and development program, schedule delays and cost growth inevitably followed. This has been a chronic problem for SDI, and many other DOD programs. Even so, as the GAO has reported, many original objectives in the FY 1984 SDI plans for DE technologies have been met.[26]

With the resources available, research is continuing to seek to carry SDI-development of DE technologies forward with a number of important applications in mind. The Air Force is exploring the possibility of using airborne lasers for several applications; possible cooperative research with Russia on solid state lasers (an area where they are the world's leaders) promises possible industrial applications such as in welding and material

[26]*Ballistic Missile Defense: Information on Directed Energy Programs for Fiscal Years 1985 Through 1993*, US General Accounting Office Report to the Chairman, Legislation and National Security Subcommittee on Government Operations, US House of Representatives, GAO / NSIAD-93-182, June 1993.

processing applications; and the Department of Energy is exploring ways to use Neutral Particle Beams to transmutate long-lived radioisotopes contained in nuclear waste into short-lived isotopes--easing nuclear waste storage problems.

Kinetic Energy Programs

There is a similar story for Kinetic Energy (KE) system applications--which were being studied before the advent of SDI and which were supported by about 25-percent of the SDI appropriations during the past 10-years. However, there is a general agreement, even among SDI critics and skeptics, that KE systems can be built in the near future--so there are much better near-term budget prospects for continued KE system development than for DE system applications.

Apparent funding support for theater missile defense (TMD) applications should enable effectively managed TMD acquisition programs. But severe budget constraints now being imposed on efforts to develop a US homeland defense will undoubtedly cause inefficiencies, cost growth, and major schedule slips in any seriously attempted acquisition program. Such inefficiencies imposed by funding constraints in no way reflect failure of the SDI/BMD KE development activities of the past decade.

Proof-of-principle demonstrations that such KE interceptors can be made to work were provided at the outset of the SDI program in 1984 and 1985 by the Homing Overlay Experiment (HOE) and the F-15 ASAT successful intercept of a satellite in low Earth orbit. In both cases, which exploited pre-SDI technologies in programs initiated in the late 1970s, there were successful intercepts in space of targets traveling at speeds of about 7 km/sec--the velocity of an Intercontinental Ballistic Missile (ICBM) and substantially faster than a Theater Ballistic Missile (TBM). The contributions of SDI since these proof-of-principle demonstrations, repeated with more recent vintage technologies during the ERIS tests in the early 1990s, now make it practical and affordable to use modern KE interceptors in building an effective defensive system against ballistic missiles of all ranges.[27]

For example the HOE interceptor, exploiting early 1980s technology, weighed over a ton, whereas today's technology (which exploits the developments summarized in the previous discussion of the technology benefits of the SDI program) makes feasible much more capable interceptors weighing a few tens of pounds. Modern interceptors, now sufficiently mature to enter the demonstration and validation (DemVal) phase of the formal DOD acquisition process, incorporate sophisticated miniaturized sensors and computers, permitting autonomous endgame maneuvers to discriminate and intercept without guidance from a centralized battle manager. <u>These characteristics permit light and mobile, or transportable, wide-area defensive systems with substantially reduced logistics requirements, and perhaps most importantly, open BMC3 architectures that can be easily adapted, modified, tested and exercised on a global basis.</u>

These technological advances, as they have arisen over the past decade, were incorporated into various system architectures that were conceived and evaluated during the first several years of the program. <u>Although the variety of system concepts considered (as technological advances were incorporated) led to the perception of programmatic instability, technological innovation substantially improved prospective system capabilities and reduced estimated costs for a given level of system capability.</u>

[27]Notwithstanding the allegations propagated recently by the New York Times, these experiments were not influenced by any deception program intended to fool the former Soviet Union, the Congress or anyone else. They were conducted in the spirit acknowledged by a 1988 Office of Technology Assessment (OTA) in-depth review of SDI experiments conducted until that time. As stated in a footnote on page 162 of OTA's May 1988 Report to Congress (*SDI: Technology, Survivability and Software*), "These comments on the SDI validation experiments should not be considered as criticism of SDI management. These are all sound experiments, properly designed to collect bits of information necessary on the path to developing a working system. At this time we have no major element of a non-nuclear ballistic missile defense system which has been tested in a system mode with equipment suitable for actual operation." Indeed, the first such tests will be conducted as part of Congressionally-approved programs now in the formal DOD acquisition process.

In 1988, the creators of the Brilliant Pebbles concept were the first to exploit these advances to design a space-based interceptor system which, for the first time, gave real near-term promise of meeting the so-called Nitze Criteria of being survivable from direct attack and cost-effective at the margin in the face of attempts to exhaust the defensive system by increasing the number of offensive warheads it was designed to defeat.[28] Subsequently, these Brilliant Pebbles innovations (which cost just over $1-billion, or about 3-percent of the total SDI funding to date) were incorporated into and benefited all system architectures, including those for theater and US homeland defenses. Furthermore, these technological developments are generally available and will inevitably be exploited to great advantage by other military, civil, and commercial interests.[29]

Sensor Programs

Over 25-percent of the SDI funds have been invested in sensor applications and to support ballistic missile phenomenology experiments to develop a viable discrimination capability, which is critically important to assuring that any theater or US homeland defense can remain viable in the face of offensive countermeasures. With one exception, every investment made in SDI sensor programs continues to contribute to on-going viable DOD acquisition programs.

Because of the critical requirement to provide the necessary data to prove that the discrimination problem can be solved, almost 70-percent of the sensor account has been dedicated to gathering and evaluating target, clutter, and space or atmospheric background data. This research was (and is) necessary to support defensive systems of all basing modes and was initiated as a major investment activity in 1984, before specific system concepts were seriously pursued.

The remaining 30-percent of the SDI sensor funds were devoted to system applications--with space-based sensors receiving about $2 for every $1 spent on ground based sensors.

The largest single sensor system investment (about 3-percent of the total SDI investment) was in the Boost Surveillance and Tracking System (BSTS), which was derived from the Air Force's Advanced Warning System program in 1984--and which is now continuing in the Air Force's Follow-on Early Warning System (FEWS) program.

The Space Surveillance and Tracking System (SSTS) originated from the Air Force's Space Surveillance System in 1984 and has evolved into the Brilliant Eyes system, which will provide improved tracking and discrimination data for both theater and US homeland defenses, as well as accomplish most of the Air Force's wide-area space surveillance missions. The combined investment in SSTS and Brilliant Eyes has constituted under 10-percent of the SDI sensor budget.

Of the 10-percent of the SDI sensor funds spent on ground-based sensors, about $2 was spent developing the Ground-Based Radar (GBR) for each $1 spent on the Ground-based Surveillance and Tracking System (GSTS).

[28]These criteria were stipulated as a necessary condition for the deployment of a defensive system in the FY1986 Defense Authorization Act, and repeatedly referred to in subsequent Congressional hearings. While arguably of critical importance in building defenses to counter a determined adversary, there is no particular reason to require such a condition in the current geopolitical conditions where we are seeking cooperation with the former Soviet Union, arguably the only potential adversary that could compete in an offense-defense race with the United States.

[29]For example, the Space Marketplace Supplement to the June 25, 1993 edition of *Aerospace Daily* (p. 525) contained an article, "Brilliant Pebbles Inspired First Commercial Sensing Venture," which reported that WordView Imaging Corporation, financed with venture capital from Silicon Valley, has the first ever Commerce Department license to launch in 1996 and operate two remote sensor satellites with 3-meter or better resolution, exploiting the same technologies and innovative design concepts that made Brilliant Pebbles a cost-effective concept.

While the GBR remains an integral part of both theater and US homeland defense architectures and acquisition programs, the GSTS, which was created in the context of the Phase I architecture, is no longer a priority objective after the Cold War.

Systems Analysis, Integration and Engineering

Over 15-percent of the total SDI investment, went to support essential systems analysis and architectural studies, system engineering and integration, and system test and evaluation activities. Systems analysis and architectural studies, which have been carried out throughout the entire life of the SDI program, have provided the basis for evaluating the potential of various system options that could be supported by the rapidly evolving technological base. These study efforts have provided the intellectual basis for prioritizing numerous research options on the one hand and, on the other hand, for planning serious acquisition programs that could realize the timely benefits of rapidly evolving technologies--for systems to defend the US homeland and our troops, allies and friends.

Although this activity sometimes resulted in the perception of program instability because of highly publicized changes in direction, it, in fact, was very effective in assuring that cutting edge technologies were directed toward high-payoff system needs--and when R&D succeeded in meeting those needs, the results were rapidly incorporated into serious acquisition planning. Rather than leading to programmatic inefficiencies, as has often been charged,[30] these architectural changes have more than paid for themselves by producing major improvements in the operational effectiveness of evolving system concepts and substantial reductions in cost estimates for a given effectiveness. For example, Figure 5 illustrates dramatic reductions in formal DOD cost estimates associated with the evolution of the Phase I architecture and the 1991 redirection of the SDI program by President Bush. The US-homeland defense cost estimates are reduced by almost a factor of 5.

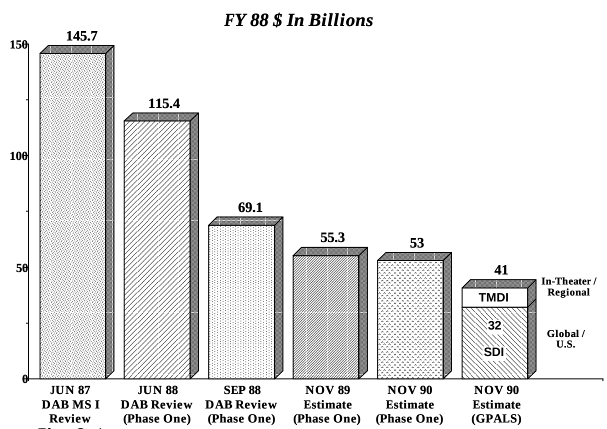

Figure 5. Evolution of Cost Estimates for SDI Acquisition Programs

Source: Testimony by Ambassador Henry F. Cooper, e.g., before the Committee on Government Operations, US House of Representatives, May 16, 1992.

Perhaps the most important single innovation was Brilliant Pebbles, which in 1990 became the space-based interceptor component of the Phase I architecture. Because of Brilliant Pebbles' autonomous operational capabilities, its inclusion reduced the cost estimate for the space-based interceptor component by about $20-billion--and Brilliant Pebbles would be far more survivable, testable, and reliable than its predecessor space-based

[30]See, for example, discussion in the General Accounting Office Report, *Ballistic Missile Defense: Evolution and Current Issues,* GAO / NSIAD-93-229, July 1993--and references to earlier GAO reports.

interceptor system.[31] Furthermore, the technological and architectural innovations that made Brilliant Pebbles viable have been exported to all other SDI systems in an outstanding example of the "open-system" architecture that has driven the personal computer revolution to such a history-making rate of advances. <u>This approach, novel for DOD systems, will lead to less expensive and more robust theater and US homeland defensive systems.</u>

Systems engineering and integration is the glue that holds any serious acquisition program together--and it is far more important for the complex "system-of-systems" called for by the Missile Defense Act to defend the American people, our forces abroad, and our friends and allies around the world. At the heart of making such a system-of-systems viable is a sound Battle Management Command, Control and Communications system, fully tested and demonstrated via rigorous system test and evaluation programs. To accomplish this objective, SDIO has made major investments in the National Test Facility in Colorado Springs, Colorado, numerous test beds around the nation (and abroad), and numerous simulation experiments. If the Nation is to realize the potential benefits of the $30-billion investment, these activities must succeed. Thus, <u>a major investment on this aspect of the SDI program can be criticized only by those who are not serious in seeking to acquire effective defenses against missile attack.</u>

Other Technology, Research and Support

About 10-percent of the total SDI investment has been on research and development for survivability of defensive system elements, lethality (or target kill) technology, advanced power sources for SDI sensors and weapons, innovative launch capabilities, innovative science and technology, advanced materials research, and threat and countermeasures research. As discussed earlier, much of this research has enabled (and will enable) system designers to "leap-frog" over key problem areas--and, in addition, have paid for themselves many times over in commercial spin-off applications alone. Survivability, lethality, threat and countermeasures research provides assurance that defensive systems--and many other DOD systems--can remain effective in the face of stressing countermeasures.

<u>As a consequence of these investments, we are confident that, with the necessary funding, serious acquisition programs can be sustained for both theater and US homeland defenses--and advancing technology can keep the advantage for defensive systems in the inevitable measure-countermeasure competition.</u>

CONVERGENCE ON VIABLE DEFENSIVE SYSTEM CONCEPTS

A high level organization like the SDIO, whose Director had immediate access to and the personal support of the Secretary of Defense, was essential to gaining acceptance of serious ballistic missile defense acquisition programs within the Pentagon's acquisition community.

In his March 23, 1983, speech Ronald Reagan challenged the US scientific and engineering communities to give priority to creating and proving out technologies that could be exploited in developing effective defenses against ballistic missiles--the most dangerous weapons of the modern era. After about four years of research and experimental work, guided by numerous architectural studies, including ones conducted with our allies, SDIO entered a new stage--one moving deliberately toward formal development with the objective of deployment.

[31] Indeed, were it not for political inhibitions regarding space-based defensive systems, even more substantial cost reductions could result from exploiting Brilliant Pebbles technology to provide a US homeland defense sooner and for substantially less money than the ground-based homeland defenses now being pursued--with, we might add, funding inadequate to create a defense for the American people in this decade.

In late 1986, architectural studies focused on a "phased approach" to deploy effective defenses in stages with ever increasing capabilities. Phase I would use Kinetic Energy systems as the first step--and that first step was the smallest judged by the Joint Chiefs to be of real strategic significance. Phase II and subsequent phases would lead to ever increasing capabilities, drawing upon continuing SDI technology advances--particularly those based on Directed Energy systems.

By mid-1987, the Joint Chiefs had agreed on requirements for Phase I that had as their primary objective to enhance deterrence by denying Soviet planners confidence that they could execute <u>any</u> successful war plan based on attacking the United States with ballistic missiles. Deterrence was to be achieved by destroying a significant percentage of a massive attack on the United States involving thousands of nuclear weapons.[32]

The Phase I concept was approved at a Milestone I Defense Acquisition Board review in June 1987, and the SDI program entered a new stage with increasing oversight from the Pentagon's formal acquisition bureaucracy. Although the bulk of the SDI research still continued to press forward the state-of-the-art in the technologies that are critical to building affordable and effective defensive systems, the focus of the program shifted to meeting the rigid demands of the Department of Defense system acquisition process. Over the next 3-years, steady progress was made in refining the Phase I system architecture in directions that increased its survivability and effectiveness--and reduced its cost by nearly two-thirds, as indicated in Figure 5.

Meanwhile, SDI technologists made significant strides forward, particularly in areas that increase the cost-effectiveness of space-based systems. As mentioned earlier, Brilliant Pebbles, as it emerged in 1988, revolutionized the architectural possibilities--and not only for space-based systems. Brilliant Pebbles enabled a much simplified space-based interceptor system which could operate in an autonomous fashion once authorized by an appropriate authority--and it was clear that the electronics, computers, sensors, etc. that had emerged from the SDI technology programs over the intervening years (and had been first expressed in the Brilliant Pebbles concept) would enable substantial improvements in ground-based systems, as well. <u>The SDIO version of TQM (having SDI managers of rapidly advancing technology, architectural studies, and formal acquisition programs working together in very close proximity) was paying major dividends.</u>

At the same time, the major geopolitical changes then apparent to all had a major influence on refocusing the SDI acquisition efforts. The Soviet threat was shrinking as the Warsaw Pact and then the Soviet Union dissolved. President Bush formally directed that an independent review of the SDI program be undertaken--integrating the impact of changing geopolitical/ geostrategic realities, US arms control objectives, and the prospects of rapidly evolving technologies. He also made clear that he believed that SDI was "more important than ever."

The independent review drew upon studies by the Defense Science Board (among others) and of the possible threats to stability in a "new world disorder" that would undoubtedly challenge US security interests in a regional context--as had been stated in the *President's National Security Strategy for FY 1990*. In particular, a 1988 Defense Science Board report had identified as urgent the growing problem of the proliferation of weapons of mass destruction and ballistic missiles. This problem existed in a number of regions around the world--and while the threat did not immediately extend to the US homeland, it was understood to be just a matter of time before new nations gained ballistic missiles with sufficient range to do so.

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[32]In conjunction with achieving the Phase I "deterrence" objectives, the Joint Chiefs called for providing very effective protection to the United States against attacks of limited scope-- perhaps with tens or hundreds of nuclear weapons. Here, as in the later GPALS concept, the objective was to destroy all of a limited number of attacking warheads.

The independent review recommended that this problem be addressed directly by an increased architectural emphasis on defending against theater ballistic missiles[33]--i.e., on theater missile defenses. Furthermore, since it is very difficult to predict when or where such defenses would be needed, it was recommended that SDI be focused of achieving a continuous worldwide, or global, defensive capability. It was recommended that the US homeland defense acquisition activities be integrated into this global architecture and focused on the Joint Chiefs' objective of defending against attacks of limited scope rather than a massive attack from the then-dissolving Soviet Union.[34] Since it was anticipated that theater missile defenses would have to defend against only a few missiles at a time as well, this recommended new architectural mission area was referred to as Global Protection Against Limited Strikes, or GPALS.

In December 1990, after SDIO and the Undersecretary of Defense for Policy reviewed the independent review recommendations, and after a Congressional initiative increased the Department's theater missile defense programs, Secretary Cheney recommended to President Bush that SDI be redirected to meet the GPALS mission. The President thereupon announced in his January 1991 State of the Union speech:

> Looking forward, I have directed that the Strategic Defense Initiative 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.

Almost immediately, the wisdom of this new direction was evident as the world watched the Patriot-Scud duels on CNN each evening in mid-winter 1991. SDIO received a major boost from Congress in its deliberations on the FY1992 Defense budget--providing both funding (which more than recovered from the major FY1991 cuts shown in Figure 3) and direction in the Missile Defense Act. This unprecedented Act, with a sense of urgency, directed development for deployment of both theater and US homeland defenses. With that mandate, SDIO pressed the Pentagon bureaucracy throughout the Spring and Summer of 1992 for streamlined acquisition programs to obtain both theater and US homeland defenses as soon as technically feasible--and with considerable success, as discussed earlier.

In achieving this success, a number of obstacles had to be overcome in a risk-adverse acquisition bureaucracy wedded to the security of meeting administrative milestones, one seemingly: oblivious to the Congressional mandate or the directions of the Secretary of Defense; ignorant of the potential of the cutting-edge technologies to achieve design objectives at reduced costs; committed to sustaining ongoing approaches and programs; and hostile to the innovative design and management concepts being pursued by SDIO.[35] Nevertheless, SDIO persevered and ultimately an agreed acquisition strategy and associated programs responsive to the Missile

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[33]SDIO had initiated architectural studies concerned with theater missile defenses with several of our allies in 1986 and had sponsored limited associated development activities for several years. Improvements to the Army's Patriot system had been sponsored by the Army (with considerable help from a few highly dedicated Senators and Congressmen) rather than SDIO since Patriot was already in production.

[34]While it was generally agreed that the changing geopolitical environment would make a massive attack out of the former Soviet Union very unlikely, the growing and apparent instabilities in the former Soviet Union increased concern about the possibility of an accidental or unauthorized launch of one or some of the missiles carrying these nuclear warheads. Consequently, defending against limited attacks was adopted for the GPALS mission. Given that a single submarine commander could arguably gain and exercise control of the 100-200 nuclear weapons under his immediate command, this was assumed as the basic threat size against which a high degree of protection would be sought.

[35]For example, there was considerable resistance to proceeding with the Theater High Altitude Area Defense (THAAD) system on an accelerated schedule, in spite of explicit guidance from the Congress and publicly stated support from the Secretary of Defense and the Chairman of the Joint Chiefs--not to mention common sense, after seeing the need demonstrated during the Gulf War. Even providing a meaningful set of requirements was difficult--and a major debate was needed to gain approval of an acquisition strategy that planned for the possibility of fielding prototypical hardware early.

Defense Act were successfully staffed through the acquisition bureaucracy from the bottom-up, approved by the all of the Defense acquisition principals, and transmitted to Congress in a June 1992 report. Defense Secretary Cheney's cover letter indicated his directions to the Department that these plans to implement the Missile Defense Act be executed as a "top national priority."

Regrettably, leaks to the press while these plans were being formulated exaggerated the programmatic and technical risks of fielding the initial site of a US homeland defense in the mid-1990s--creating considerable Congressional confusion and hostility to these plans even before they were completed. Thus, they were "dead on arrival" and SDIO's FY1993 budget request was severely cut, causing significant programmatic turbulence, delay and cost growth in what, a year before, had been a Congressionally-mandated program to develop a US homeland defense. Substantially increased budgets were approved for the theater defense programs; so Congress sustained viable acquisition programs for defenses to protect our troops overseas and our friends and allies.

As the SDI baton was passed from the Bush to the Clinton administration, substantial SDI budget increases were proposed to support acquisition plans modified to move ahead as rapidly as feasible with both theater and US homeland defenses, relative to the FY1993 Congressional cuts. Since then, Defense Secretary Aspin has renamed the SDIO as the Ballistic Missile Defense Organization (BMDO) and reduced its previously planned outyear budget by about 50-percent.[36] The top priority theater missile defense programs can remain viable with the acquisition strategies developed over the last several years, provided Congress provides sustained support. However, with the indicated reduction in the level of funding, a new acquisition strategy will be required to sustain any meaningful development of a US homeland defense.

CLOSURE

The SDI program has repeatedly run the political and bureaucratic gauntlet, survived and even prospered thus far because of high-level attention and support. Had not the authors the status that came from reporting directly to supportive Secretaries of Defense, armed with a repeatedly-updated Presidential mandate, the program would have sunk under the weight of the DOD acquisition bureaucracy, whose impeding efforts were egged on and exploited by external political opposition. With that support, we have passed on the technologies and plans to support viable acquisition programs--if the Administration advocates them and if Congress funds them.

The SDIO/BMDO program is now more mature than it was on our watch and, as discussed above, many important milestones have been met. Perhaps it can now proceed successfully as a more traditionally managed program--particularly given Defense Secretary Aspin's stated support for ballistic missile defenses and the interest of Deputy Secretary Perry and Undersecretary Deutch in streamlining the acquisition process for all DOD programs. We wish them and our successor well.

[36]Based on June 1993 briefings to Congress by BMDO Acting Director MG Malcolm O'Neill, e.g., *Ballistic Missile Defense, Information for the Committee on Armed Services*, a briefing to the Subcommittees on Military Acquisition and Research and Development, 10 June 1993.