



Report to the Chairman, Legislation and
National Security Subcommittee,
Committee on Government Operations,
House of Representatives

June 1993

BALLISTIC MISSILE DEFENSE

Information on Directed Energy Programs for Fiscal Years 1985 Through 1993



19980513 262

DISTRIBUTION STATEMENT A

Approved for public release
Distribution Unlimited

Accession Number: 4564

Publication Date: Jun 01, 1993

Title: Ballistic Missile Defense: Information on Directed Energy Programs for Fiscal Years 1985 through 1993

Personal Author: Spencer, J.K.; Walter, C.A.; Baird, T.B.

Corporate Author Or Publisher: U.S. General Accounting Office, GAO, Washington, DC 20548 Report Number: GAO/NSIAD-93-182

Comments on Document: Report to the Chairman, Legislation and National Security Subcommittee, Committee on Government Operations, House of Representatives

Descriptors, Keywords: Ballistic Missile Defense Directed Energy Program FY85 FY93 GAO Chemical Ground Base Laser Space Neutral Particle Beam Acquisition Track Point Technology Evolution Funding Sensor NPB DEW SBL GBL HEL CP

Pages: 00050

Cataloged Date: Jul 14, 1993

Document Type: HC

Number of Copies In Library: 000002

Record ID: 27577



United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-223094

June 25, 1993

The Honorable John Conyers, Jr.
Chairman, Legislation and National
Security Subcommittee
Committee on Government Operations
House of Representatives

Dear Mr. Chairman:

This report responds to your request that we assist the Congress in evaluating the Department of Defense's recommendations for transferring or retaining management responsibility for directed energy technologies in the Ballistic Missile Defense Organization and in determining the future direction of directed energy development. You asked that we provide information on directed energy weapon funding to date, the development status of the technologies, and the additional funding that would be needed for further development of the technologies.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 15 days after its issue date. At that time, we will send copies to appropriate congressional committees; the Secretaries of Defense, the Air Force, and the Army; and the Directors, Ballistic Missile Defense Organization and Office of Management and Budget. We will also make copies available to others upon request.

Please contact me on (202) 512-4841 if you or your staff have any questions. Major contributors to this report are listed in appendix II.

Sincerely yours,

Brad Hathaway
Associate Director, Systems
Development and Production Issues

DTIC QUALITY INSPECTED 4

PLEASE RETURN TO:
BMD TECHNICAL INFORMATION CENTER

U4564
copy 2

Executive Summary

Purpose

Since 1985, the Strategic Defense Initiative Organization (SDIO) has been developing technologies for directed energy weapons—lasers and particle beams. (On May 13, 1993, the Secretary of Defense changed the name of the Strategic Defense Initiative program and office to Ballistic Missile Defense.) Prior to 1985, other Department of Defense agencies and services had been developing the technologies. It was believed they could be the most effective means of defeating the evolving Soviet intercontinental ballistic missile threat that included thousands of nuclear warheads and decoys. The priority of SDIO's directed energy weapon research and development programs decreased following the breakup of the former Soviet Union in 1990 and the 1991 refocusing of the Strategic Defense Initiative (SDI) by President Bush. In 1992, the Congress directed that far-term technology programs (such as directed energy) be transferred from SDIO to the Advanced Research Projects Agency or the appropriate military department unless national security interests dictated their retention.

The Chairman, Legislation and National Security Subcommittee, House Committee on Government Operations, asked GAO to assist the Congress in evaluating the Department of Defense's recommendations for transferring or retaining management responsibility for directed energy technologies in SDIO and in determining the future direction of directed energy development. GAO was asked to provide information on the funding of the directed energy programs to date, the development status of the technologies, and the additional funding that would be needed for further development of the technologies.

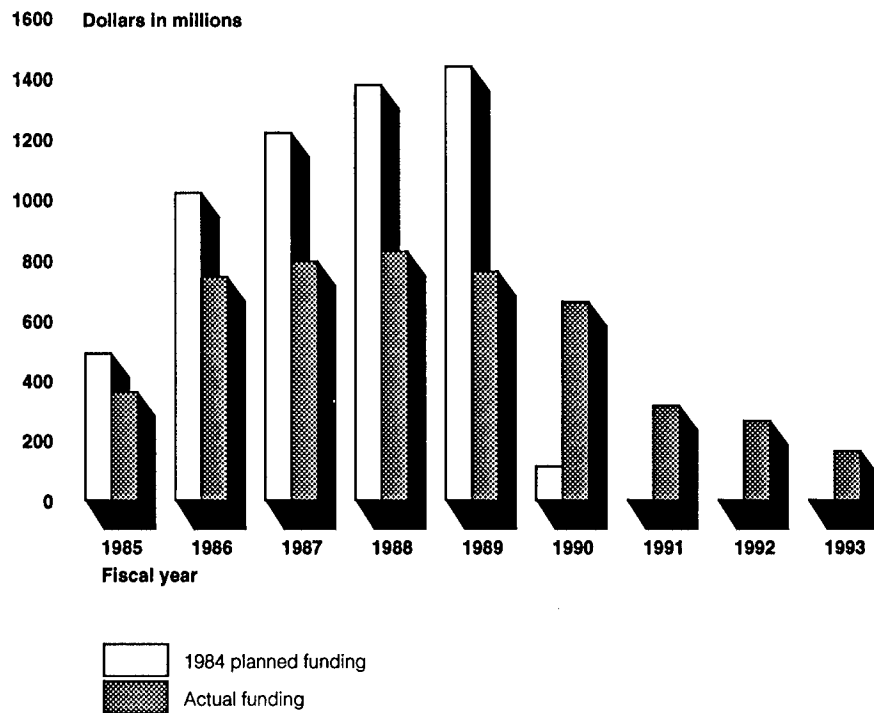
Background

Ongoing development of directed energy weapons technology was centralized in SDIO when it was created in 1984. It developed a directed energy weapons master plan for investing in development of technology that would provide a basis for decisions in 1990-92 by the Defense Acquisition Board authorizing transition to the demonstration and validation phase. The plan specified that about \$5.7 billion would be needed from fiscal years 1985 through 1990 to perform the work needed to make these decisions. In the demonstration and validation phase, SDIO would conduct major ground and system demonstrations.

Through fiscal year 1993, SDIO will have spent about \$4.9 billion for directed energy research and development over 9 years, or about \$800 million less than SDIO's 1984 plan specified was needed over 6 years. SDIO said that this under funding becomes larger if it is recognized that

stretched-out programs cost more than efficiently funded programs and that dollars spent in years after the planned years had been degraded by inflation. Annual funding peaked at \$827 million in fiscal year 1988 and subsequently decreased to \$162 million in fiscal year 1993, as shown in figure 1. SDIO has requested \$103 million for directed energy technologies for fiscal year 1994.

Figure 1: SDIO's 1984 Funding Plan for Directed Energy Programs Versus Actual Funding



The Fiscal Year 1993 Defense Authorization Act directed the Secretary of Defense to transfer management and budget responsibilities for research and development of all long-term technologies not likely to be incorporated into a weapon system within 10 to 15 years from SDIO to the Advanced Research Projects Agency or the appropriate military service. This transfer would include directed energy. Exceptions could be made if the Secretary decided that transfer of a particular technology would not be in the national security interests of the United States.

Management and budget responsibilities for the free electron laser program and for the airborne laser program will be transferred to the Army and the Air Force, respectively, beginning in fiscal year 1994. SDIO is retaining responsibility for the chemical laser program; the neutral particle beam program; and the acquisition, tracking, and pointing program.

Results in Brief

The \$4.9 billion allocated by SDIO for fiscal years 1985 through 1993 for developing directed energy weapons technology was spent primarily on five directed energy programs—space-based chemical laser; ground-based laser; space-based neutral particle beam; acquisition, tracking, and pointing subsystems; and nuclear directed energy concepts.

The development of these technologies has not advanced as quickly as SDIO had planned. SDIO estimates that \$777 million and 4 years are needed to complete the work required for decisions on whether to fund system level demonstrations for the space-based chemical laser; space-based neutral particle beam; and acquisition, tracking, and pointing subsystems. SDIO has requested only \$103 million for all directed energy work in fiscal year 1994, indicating that it may take longer than 4 years to complete that work. The free electron laser was transferred to the Army, which did not provide any funding for it in fiscal year 1994. (See table 1.)

Executive Summary

Table 1: Directed Energy Activities

Dollars in millions

Program	Purpose	SDIO's 1984 funding plan	Allocated through FY 1993	SDIO estimate of	
				Additional funding needed	Additional years needed
Space-based chemical laser	Disable boosters and interactive discrimination	\$1,121	\$873	\$176	2
Ground-based free electron and excimer lasers	Disable boosters and interactive discrimination	1,721	1,244	Program and funding transferred to Army	N/A
Particle beams	Disable reentry vehicles and interactive discrimination	747	840	421	4
Acquisition, tracking, and pointing	Track targets and aim weapons	1,298	1,584	180	3
Nuclear directed energy	Disable boosters and reentry vehicles	136	138	0	0
Other activities, part of 1984 plan (airborne laser)	Concept definition and support	630 (for concept definition only)	206	0	0
Total (1984 plan)		5,653	4,885	777	4
Other activities, not part of 1984 plan	SDI-wide technology	0	343	N/A	N/A
Total (with non-plan activities)		\$5,653	\$5,228		

GAO's Analysis

Chemical Laser

SDIO reports that it has completed three of the four objectives established in the 1984 plan. SDIO has fabricated and tested the Alpha laser beam generator, the 4-meter primary mirror, and the beam control system. The high-power ground integration test of the space-based chemical laser is underway but has not been completed.

Through fiscal year 1993, SDIO will have spent about \$873 million on the space-based chemical laser, about 78 percent of the \$1,121 million it estimated was needed to do the planned research.

SDIO estimates that an additional \$101 million and 2 years will be required to complete the high-power ground integration test. In addition, it

estimates that another \$75 million will be required to complete development, concurrent with the ground test, of several high payoff technologies such as overtone operation of the laser, advanced laser nozzle technology, and a new method of beam control. As these efforts near completion, the space-based chemical laser program will be ready for a decision to initiate the system level demonstration.

Ground-Based Laser

In December 1990, SDIO decided that the free electron laser program would be reoriented toward demonstrating the feasibility of a space-based weapon. At this point, only one of the five objectives included in the 1984 plan for a ground-based laser had been completed: SDIO had selected the radio frequency free electron laser as the beam generator and completed its initial high-power design. Technical progress, however, had been made on several other objectives for a ground-based laser system.

SDIO will have spent \$1,244 million on this program, primarily for the ground-based laser, through fiscal year 1993. This amount represents about 72 percent of the \$1,721 million SDIO believed was needed to do research for a ground-based system through fiscal year 1989.

SDIO is currently developing the free electron laser as a space-based weapon but has not determined the additional work and time required, or the cost, to ready the space-based free electron laser for a system level demonstration. It estimates, however, that after fiscal year 1993 an additional \$63 million and 30 months will be needed to complete the work needed to resolve the remaining physics and engineering issues. The free electron laser could then be upgraded for a system level demonstration. Pursuant to terms of the Fiscal Year 1993 Defense Authorization Act, management and budget responsibilities for this program will be transferred to the Army, beginning in fiscal year 1994. The Army has decided not to fund the effort in 1994.

Space-Based Neutral Particle Beam

SDIO reports that it has accomplished four of the eight 1984 program plan objectives for the space-based neutral particle beam. It developed a lightweight magnetic beam-expander telescope to focus and control the size of the particle beam at the target and the beam sensing technology to sense the direction in which the neutral beam is pointed. SDIO also developed a lightweight foil neutralizer for stripping the electrons from hydrogen or deuterium ions to produce a beam of neutral atoms and a detector to detect the emissions induced when the beam penetrates

targets to enable the particle beam to determine the mass of the target or assess the extent of damage to the target. SDIO's program has not demonstrated beam generation that is scalable to the 1984 program plan beam power goals. It also has not completed integrated particle beam system tests on the ground or in space. In addition, it must yet develop a lightweight source to power the particle beam in space.

Through fiscal year 1993, SDIO will have spent about \$794 million to develop the neutral particle beam, or \$47 million more than it estimated was needed for fiscal years 1985 through 1989 to do the planned research. It also spent \$46 million to develop a ground-based charged particle beam before it canceled that program in fiscal year 1992.

SDIO officials estimate that an additional \$421 million and 4 years are needed to complete the work required to ready the neutral particle beam for a decision on whether to perform a system level demonstration. This includes \$121 million and 3 years to complete the ground integration specified in the 1984 plan, \$40 million to develop the power source for the neutral particle beam, and \$260 million and 4 years to complete a space experiment.

Acquisition, Tracking, and Pointing

SDIO reports that it has met the 1984 plan's objectives for developing pointing and tracking technology and rapid retargeting technology for directed energy weapons. It has not met the objectives for developing long-range fine tracking and fire control software. While not meeting all objectives, SDIO said it has met the basic program goal of resolving technical issues sufficiently to support a space test of directed energy technologies to determine if directed energy weapons are feasible.

Through fiscal year 1993, SDIO will have spent about \$1,584 million developing acquisition, tracking, pointing, and fire control technologies. This amount was about \$286 million more than SDIO estimated was needed to accomplish the objectives. A majority of the funding was spent on a series of space- and ground-based experiments, of which some were completed and some were canceled due to reduced SDIO funding.

SDIO estimates that it will cost \$180 million and 3 years to resolve the majority of the remaining acquisition, tracking, pointing, and fire control technical issues with the High Altitude Balloon Experiment platform. For an additional \$100 million, the technology could be demonstrated in space in conjunction with another demonstration, such as Star LITE.

Nuclear Directed Energy and Other

In its 1984 plan for fiscal years 1985 through 1989, SDIO planned to spend \$136 million for nuclear directed energy. Through fiscal year 1993, it will have spent \$138 million, which is 101 percent of what it had planned to spend. SDIO planned to pursue the development of nuclear directed energy technology to provide (1) a base of knowledge that would permit the United States to better judge potential Soviet capabilities and (2) the basis for a ground-based or pop-up nuclear directed energy capability should it be needed at some point for the strategic defense system follow-on phases.

The plan also included \$630 million for concept definition. For fiscal years 1985 through 1993, SDIO will have spent \$96 million for concept definition, which supports setting performance requirements and technical characteristics for directed energy concepts. SDIO will also have spent \$110 million for other directed energy development and support activities from fiscal years 1985 through 1993. The total of \$206 million it will have spent through 1993 is only 33 percent of what it had planned to spend.

Another \$343 million that was initially allocated to the directed energy program was used to fund SDI-wide technology activities and other efforts. Other program elements were assessed in a similar manner to fund these activities.

Matters for Congressional Consideration

The Department of Defense has decided (1) to have SDIO retain responsibility for development of space-based chemical lasers; neutral particle beams; and acquisition, tracking, and pointing and fire control subsystems and (2) to transfer responsibility for development of the space-based free electron laser to the Army and the airborne laser to the Air Force. The Department of Defense has not prepared a new detailed plan for carrying out its responsibilities for development of directed energy technologies. However, SDIO told GAO that about \$777 million would be needed over the next 4 years to complete certain work. SDIO has requested only \$103 million for all directed energy work in fiscal year 1994, indicating that it may take longer than 4 years to complete that work. The Army has requested no funding in fiscal year 1994 for the space-based free electron laser.

Therefore, the Congress may wish to request that the Department of Defense provide it with a plan that has detailed information about what the Department intends to do with these technologies, the funding needed, and the schedule.

Agency Comments

As requested, GAO did not obtain written comments on this report from the Department of Defense. However, GAO discussed the information contained in the report with responsible SDIO officials and has made changes where appropriate. SDIO officials generally agreed with the information in the report.

Contents

Executive Summary		2
Chapter 1		12
Introduction	Evolution of SDI	14
	Directed Energy Program Funding	15
	Objectives, Scope, and Methodology	16
Chapter 2		18
Space-Based	Program Objectives and Funding	19
Chemical Laser	Program Progress and Costs to Date	20
Program	Work Remaining and Estimated Costs	22
Chapter 3		23
Ground-Based Laser	Program Objectives and Funding	24
Program	Program Progress and Costs to Date	25
	Work Remaining and Estimated Costs	27
Chapter 4		28
Particle Beam	Program Objectives and Funding	29
Program	Program Progress and Costs to Date	29
	Work Remaining and Estimated Costs	32
Chapter 5		34
Acquisition, Tracking,	Program Objectives and Funding	35
Pointing, and Fire	Program Progress and Costs to Date	35
Control Program	Work Remaining and Estimated Costs	38
Chapter 6		40
Nuclear Directed	Nuclear Directed Energy	42
Energy Technology	Other Directed Energy	42
Program and Other	SDI-Wide Technology	43
Activities		

Chapter 7		44
Future of Directed Energy Technology Development	Matter for Congressional Consideration	44
Appendixes	Appendix I: Report on Strategic Defense Initiative Organization Far-Term Technology Transfer	46
	Appendix II: Major Contributors to This Report	50
Tables	Table 1: Directed Energy Activities	5
	Table 4.1: Status of Objectives for NPB	30
Figures	Figure 1: SDIO's 1984 Funding Plan For Directed Energy Programs Versus Actual Funding	3
	Figure 1.1: Phases of a Ballistic Missile Attack	13
	Figure 1.2: Directed Energy Funding Versus Total SDI Funding	16
	Figure 2.1: SDIO Funding for SBCL	18
	Figure 2.2: SBCL Development Plan	19
	Figure 3.1: SDIO Funding for Free Electron and Excimer Lasers	23
	Figure 4.1: SDIO Funding for NPB	28
	Figure 5.1: SDIO Funding for ATP/FC Systems	34
	Figure 5.2: Space- and Ground-Based ATP/FC Experiments	36
	Figure 6.1: SDIO Funding for Nuclear Directed Energy Technology	40
	Figure 6.2: SDIO Funding for Other Directed Energy Activities	41
	Figure 6.3: Directed Energy Funds Spent on Non-Directed Energy SDI-Wide Technology	42

Abbreviations

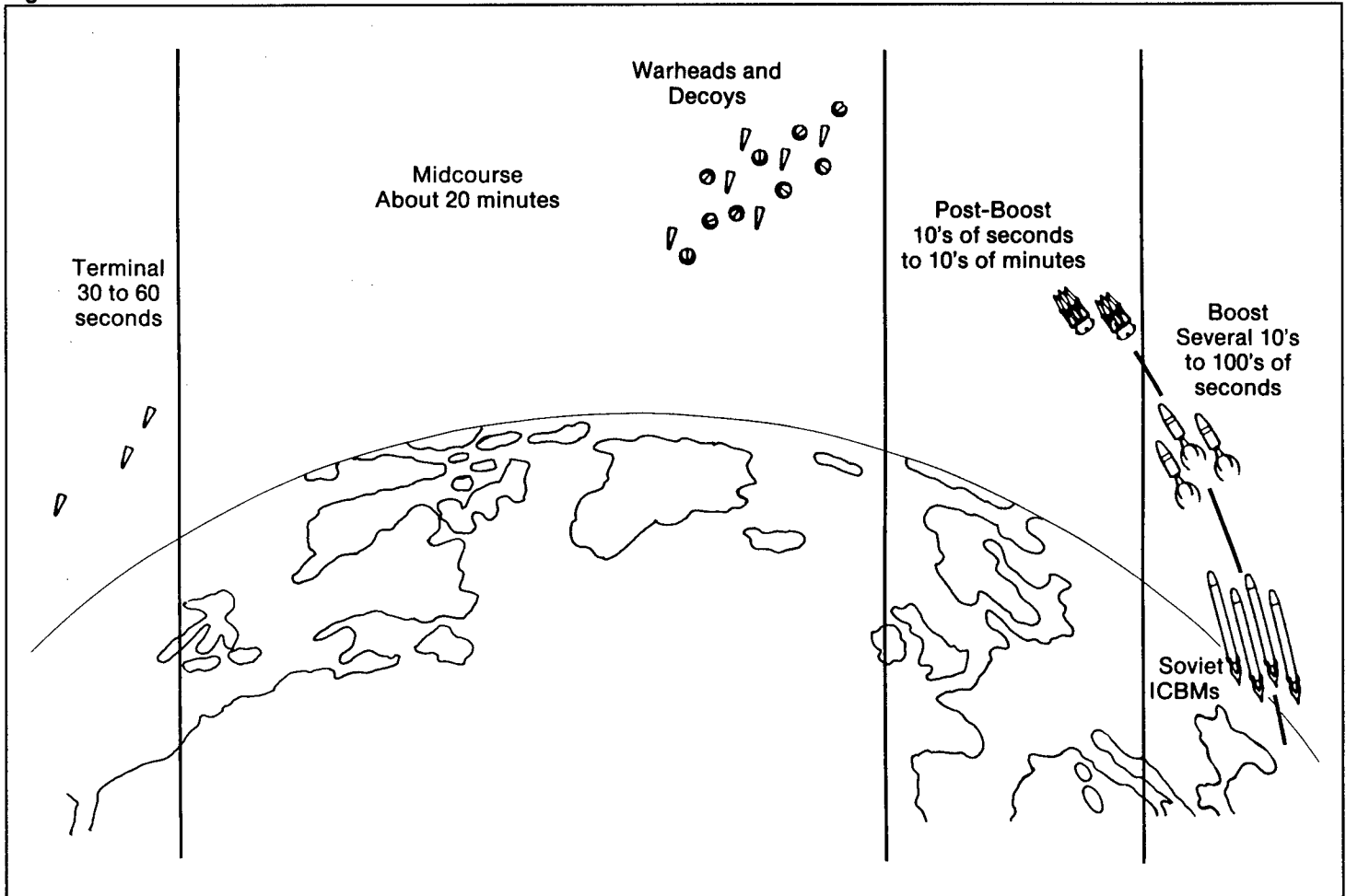
ATP	acquisition, tracking, and pointing
FC	fire control
FEL	free electron laser
GAO	General Accounting Office
GPALS	Global Protection Against Limited Strikes
NPB	neutral particle beam
SBCL	space-based chemical laser
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization

Introduction

The Strategic Defense Initiative (SDI) began in 1984 with the objective of developing a system that could destroy ballistic missiles launched by the former Soviet Union or other countries. The system would initially use kinetic energy weapons and later it would include directed energy weapons such as lasers and particle beams if needed to meet a growing Soviet threat.

The flight of a ballistic missile consists of three to four phases: boost, post-boost, midcourse, and terminal (see fig. 1.1). The boost phase refers to the first few minutes of a missile's flight, while the booster is burning. The post-boost phase refers to the time during which the bus deploys individual multiple reentry vehicles on their individual trajectories and any decoys that may be used. Midcourse is the longest period, when the reentry vehicles and decoys, if used, are coasting along their ballistic trajectories in space above the earth's atmosphere. The terminal phase is the final minute or so when the reentry vehicles reenter the earth's atmosphere near their targets. Directed energy weapons are envisioned for shooting down missiles in their boost and post-boost phases and doing midcourse discrimination (distinguish warheads from decoys).

Figure 1.1: Phases of a Ballistic Missile Attack



Source: Adapted from SDI Technology Survivability and Software, Office of Technology Assessment, May 1988.

The Strategic Defense Initiative Organization (SDIO) was tasked with directing the development of a system to destroy missiles launched by the former Soviet Union. In 1984, it developed a directed energy master plan for investing in development of technology that would provide a basis for milestone I decisions in the 1990-92 time frame authorizing transition to the demonstration and validation phase. In this phase, SDIO would conduct major ground and space demonstrations. The plan covered fiscal years

1985 through 1990, including the estimated costs of \$5.7 billion, and was to culminate in readiness to begin system demonstrations by 1990. The plan envisioned a research program that was technology limited rather than funding limited.

As global events unfolded in the 1990s, however, the SDI mission changed significantly. With the collapse of the former Soviet Union, the massive nuclear threat the system was being designed to deter diminished, while concerns increased about the threat from Third World countries of tactical ballistic missile attacks on U.S. forces or those of U.S. allies and from limited ballistic missile strikes against the United States. SDIO said that directed energy weapons would be effective against targets down to the cloud tops, about 30,000 feet.

Evolution of SDI

In 1984, SDIO believed that directed energy weapons would be needed to respond to an evolving Soviet threat that could include thousands of missiles and warheads, decoys, antisatellite weapons, and other means of defeating the initial ballistic missile defense system. SDIO concentrated its directed energy research and development on five technologies:

- space-based chemical laser weapons;
- ground-based laser weapons;
- space-based particle beam weapons;
- acquisition, tracking, and pointing subsystems for each of the weapons; and
- nuclear directed energy.

In January 1991, following the end of the former Soviet Union, President Bush directed that the SDI program be refocused from deterring a massive Soviet attack to providing protection against limited ballistic missile attacks, whatever their source. The new system was called Global Protection Against Limited Strikes (GPALS). Directed energy weapons were included as follow-on elements in the GPALS system. Research and development of directed energy technology proceeded but on a lesser scale.

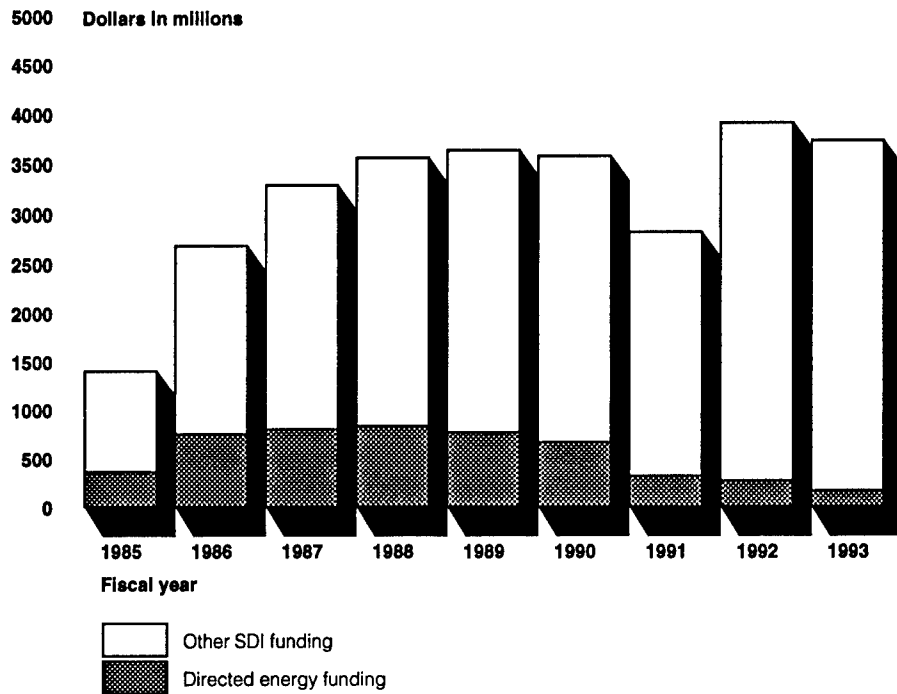
Another change potentially affecting SDIO's directed energy program was made by the Congress in the Fiscal Year 1993 Defense Authorization Act. The Congress wanted SDIO to concentrate on acquisition and deployment of the GPALS system rather than long-term weapons' research and development. Accordingly, the Congress directed the Secretary of Defense

to transfer management and budget responsibilities for research and development of all long-term technologies, defined as those not likely to be incorporated into a weapon system within 10 to 15 years, from SDIO to the Advanced Research Projects Agency or the appropriate military department. Exceptions could be made if the Secretary determined that transfer of a particular technology would not be in the national security interests of the United States. SDIO is to transfer responsibility for the free electron laser program, beginning in fiscal year 1994, to the Army. It also is to transfer responsibility for the airborne laser program, beginning in fiscal year 1994, to the Air Force. It is retaining responsibility for the chemical laser program; the neutral particle beam program; and the acquisition, tracking, and pointing program.

Directed Energy Program Funding

Through fiscal year 1993, SDIO will have spent about \$4.9 billion over 9 years of a planned \$5.7 billion for directed energy research and development, or about \$800 million less than the 1984 plan specified was needed over 6 years. SDIO said that this was nearly all of the national effort in high-power directed energy weapons. SDIO also said that this under funding becomes larger if it is recognized that stretched-out programs cost more than efficiently funded programs and that dollars spent in years following the planned years had been degraded by inflation. In the early years of SDI, the directed energy funding made up nearly a quarter of SDI's total funding. Annual funding peaked at \$827 million in fiscal year 1988 and subsequently decreased to \$162 million in fiscal year 1993, as shown in figure 1.2.

Figure 1.2: Directed Energy Funding
Versus Total SDI Funding



Objectives, Scope, and Methodology

The Chairman, Legislation and National Security Subcommittee, House Committee on Government Operations, asked us to assist the Congress in evaluating the Department of Defense's recommendations for transferring or retaining management responsibility for directed energy technologies in SDIO and in determining the future direction of directed energy development. Specifically, we were asked to provide information on the funding of directed energy programs to date, the development status of the technologies, and the additional funding that would be needed for further development of the technologies. We conducted our work at SDIO headquarters in Washington, D.C.; the Army's Strategic Defense Command in Huntsville, Alabama; Los Alamos National Laboratories in Los Alamos, New Mexico; and Phillips Laboratories in Albuquerque, New Mexico. At these locations, we interviewed officials responsible for directed energy research and development activities and reviewed pertinent documents such as program plans and reports, funding documents, and test result reports. SDIO provided us with its assessment of its progress through fiscal year 1992 in achieving the objectives of its 1984 plan, the work remaining, and the estimated costs and time to complete the additional work. We did not independently verify SDIO's assessment. We conducted our review in accordance with generally accepted government auditing standards.

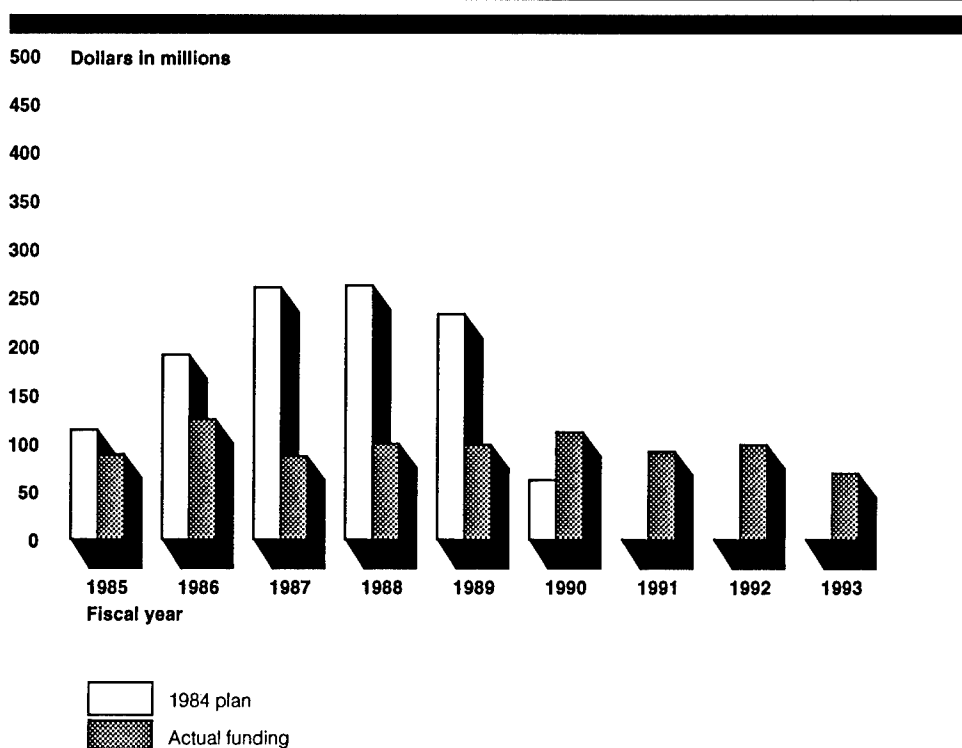
Chapter 1
Introduction

As requested, we did not obtain written comments on this report from the Department of Defense. However, we discussed the information contained in the report with responsible SDIO officials and have made changes where appropriate. SDIO officials generally agreed with the information in the report.

Space-Based Chemical Laser Program

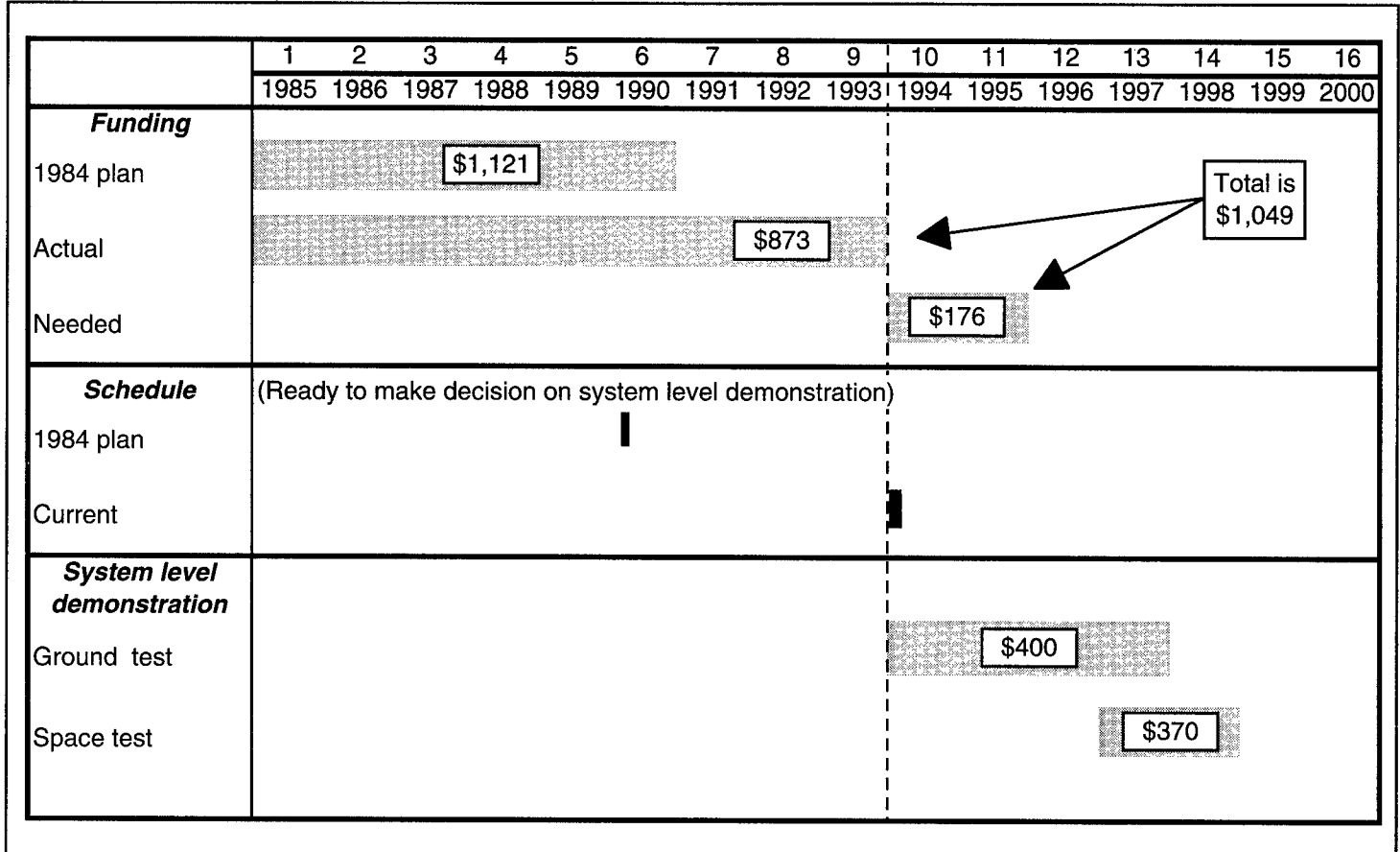
In its 1984 directed energy plan, SDIO planned to develop and ground test the Space-Based Chemical Laser (SBCL) technology by the end of 1990 at a cost of \$1,121 million. Through fiscal year 1993, SDIO will have spent \$873 million (see fig. 2.1) and will have completed all major objectives except the ground test. SDIO estimates that it will take 2 more years and cost \$176 million more to complete the ground demonstration and several advanced technologies. These actions would complete the 1984 plan for SBCL for a total cost of \$1,049 million or \$72 million less than estimated in the plan. SDIO will then decide whether to complete a system level demonstration on the ground at an estimated cost of \$400 million (see fig. 2.2). An optional flight experiment would cost another \$370 million. These system level demonstrations would complete the demonstration and validation phase of development.

Figure 2.1: SDIO Funding for SBCL



Chapter 2
Space-Based Chemical Laser Program

Figure 2.2: SBCL Development Plan (Dollars in millions)



SBCL uses the reaction of hydrogen and fluorine to produce a high-power laser beam. It is being developed primarily to shoot down missiles in their boost and post-boost phases. However, SBCL could also be used to perform active and passive discrimination and to shoot down long-range strategic bombers and cruise missiles since its beam would be effective down to the cloud tops (about 30,000 feet).

Program Objectives and Funding

According to the 1984 plan, SBCL research and development was to have progressed to a point in 1990 where SDIO could make a decision on whether to fund a system demonstration in space. The plan specified that \$1,121 million would be required from fiscal years 1985 through 1990 to

accomplish the research and development needed to make the decision. As a basis for this decision, SDIO was to have completed

- fabrication and testing of the beam generator, called the Alpha laser;
- fabrication and testing of a large, primary mirror, called Large Advanced Mirror Program;
- testing of the beam control system, called Large Optics Demonstration Experiment; and
- high-power integrated testing of the beam generator, large primary mirror, and beam controller on the ground.

The acquisition, tracking, and pointing (ATP) subsystem for SBCL was to be developed under a separate program (see ch. 5).

Program Progress and Costs to Date

SDIO's assessment shows that three of the four objectives have been accomplished. SDIO has fabricated and demonstrated the Alpha laser, the 4-meter primary mirror, and the beam control system. SDIO said the high-power ground integration test of SBCL is underway but has not been completed.

Through fiscal year 1993, SDIO will have spent about \$873 million on SBCL, about 78 percent of the \$1,121 million it estimated was needed for fiscal years 1985 through 1990 to do the planned research.

Alpha Laser

SDIO's primary objective was to develop a chemical laser device that could produce a high-power beam that was scalable to the power needed for laser weapon systems. SDIO planned to complete this ongoing program in 4 years for \$162 million.

During a series of tests from 1990 to 1992, the laser produced a beam with the megawatt class power and beam quality specified by the 1984 plan. The Alpha design is space compatible and directly scalable to weapon-level power requirements. SDIO spent about \$279 million developing and demonstrating the performance of the Alpha beam generator and building the test facility at TRW's San Juan Capistrano, California, test site.

Large Advanced Mirror Program

The primary objective of the program was to design, fabricate, and test a 4-meter active, segmented mirror that demonstrated the technology and

growth potential needed for 10-meter mirrors. SDIO planned to complete this ongoing program in 3 years for about \$16 million.

The program was completed in 5 years, 2 years behind schedule, for about \$28 million. The resulting 4-meter diameter, deformable mirror consists of seven separate segments attached to a common bulkhead; the shape of the mirror can be altered by changing the position of the individual segments. Large space-compatible mirrors are needed to expand and project laser beams on targets. This program demonstrated the technology needed to construct mirrors of 10-meter scale, which significantly exceeds the size needed for laser weapons in GPALS missions.

Beam Control System

The primary objective was to develop and demonstrate a beam control system. Beam control involves sensing and controlling aberrations in the laser beam that are caused by the laser device and the high-power optical elements; establishing the direction of the beam; focusing the beam on the target; and moving the beam from target to target. The beam control system samples the outgoing laser beam, analyzes the sample to detect aberrations in the beam, and communicates corrections to the deformable mirrors and the fast steering mirrors that operate to control the shape and direction of the laser beam. SDIO planned to complete the beam control system in 4 years for about \$59 million.

Testing was accomplished in 3 years at a cost of \$32 million. To reduce costs, the beam control experiments were conducted with a 60-centimeter diameter, segmented, deformable, primary mirror instead of with the 4-meter diameter mirror. SDIO said the resulting beam control system is scalable to a beam control system utilizing the 4-meter mirror. Testing of the 4-meter mirror and the beam control system at high power will now take place during the ground integration test with the Alpha laser.

Ground Test

The objective of the ground test was to demonstrate the integrated operation of the Alpha laser, the 4-meter mirror, and the beam control system. SDIO planned to complete the ground test in 1990 at a cost of \$384 million.

SDIO did not start preparations for the ground test until fiscal year 1990, and it has spent \$161 million since then fabricating hardware for the test. Testing is scheduled to be completed during fiscal year 1995 at the Alpha laser test site in San Juan Capistrano at an additional cost of \$101 million.

A large vacuum chamber is being constructed adjacent to the vacuum chamber for the Alpha laser to house the 4-meter primary mirror and the beam control system during testing. About 85 percent of the hardware needed for the ground test has been fabricated.

Work Remaining and Estimated Costs

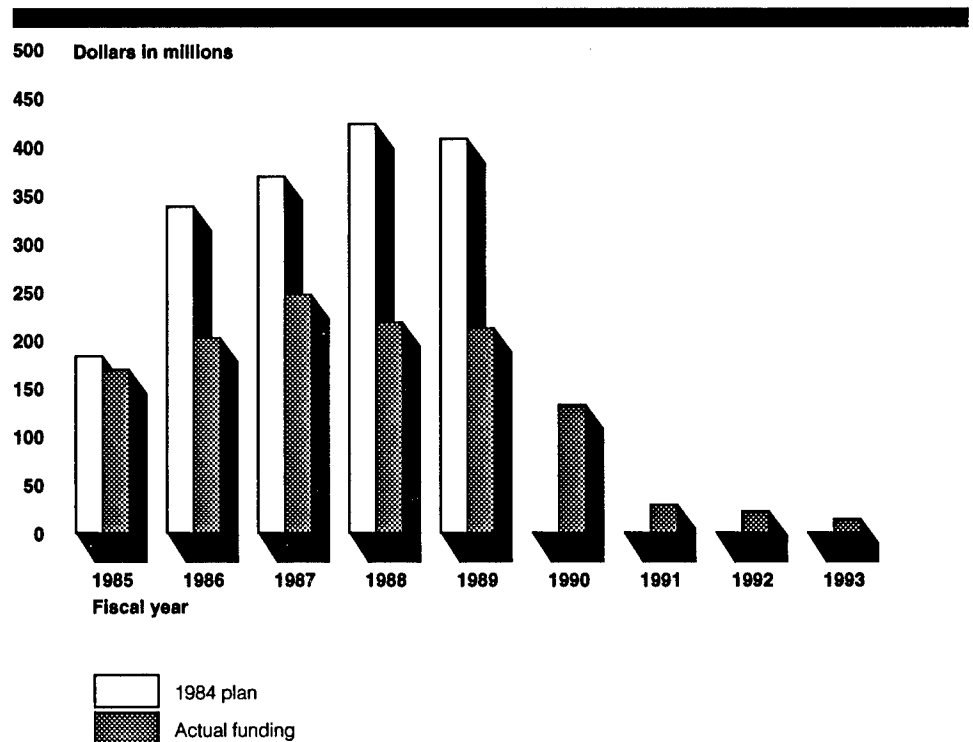
SDIO estimates that an additional \$101 million and 2 years will be required to complete the ground test. In addition, it estimates that another \$75 million will be required to complete development, concurrent with the ground test, of several high payoff technologies such as overtone operation of the laser, advanced laser nozzle technology, and a new method of beam control. As these efforts near completion, the SBCL program will be ready for a decision to initiate the system level demonstration. (See fig. 2.2.)

According to SDIO, the SBCL system level demonstration is planned as a ground demonstration of SBCL in a space configuration with an optional space demonstration. SDIO estimates the ground demonstration will cost \$400 million plus the cost to build or modify an existing ground test facility. SDIO completed a conceptual design and program plan for the system level demonstration during fiscal year 1992. It will use much of the actual hardware from the ground integration test. The optional space demonstration will have a nominal 1-year life on orbit and will demonstrate the critical issues of space operation, including negating boosting solid rocket motors. SDIO estimates that the space option will cost an additional \$370 million. (See fig. 2.2.)

Ground-Based Laser Program

In its 1984 directed energy plan, SDIO planned to build and test a ground-based laser by the end of fiscal year 1991. The estimated cost for fiscal years 1985 through 1989 was \$1,721 million. (See fig. 3.1.) The ground-based system was to be powered by either an induction free electron laser (FEL), a radio frequency FEL, or an excimer laser. In December 1990, after spending 7 years and about \$1,132 million, SDIO decided that the ground-based FEL would be converted to a space-based program. At this point, SDIO had eliminated the excimer laser and the induction FEL as ground-based candidates and had selected the radio frequency FEL as the ground-based beam generator and completed its initial high-power design.

Figure 3.1: SDIO Funding for Free Electron and Excimer Lasers



SDIO has not determined what work is required, how much time is needed, or the cost to ready the space-based FEL for a system level demonstration. Pursuant to the terms of the Fiscal Year 1993 Defense Authorization Act, the FEL has been transferred to the Army beginning in fiscal year 1994.

According to an Office of Secretary of Defense official, the Army plans to cancel the FEL program.

A FEL produces a beam of radiant energy using a high-energy beam of electrons. The electrons travel through a special magnetic field that forces them to oscillate back and forth, causing the electrons to emit radiation. The FEL's primary mission is to shoot down missiles in their boost and post-boost phases. Its primary advantage over the other directed energy weapons is that its output wavelength can be adjusted during operation to select those frequencies that propagate through the atmosphere with minimal problems.

Program Objectives and Funding

According to SDIO's 1984 directed energy weapon plan, research and development efforts on a ground-based laser were to have progressed by 1991 to the point where a decision could be made on whether to proceed with a system level demonstration. At this point, SDIO's research program planned to have

- demonstrated the basic performance levels of (1) excimer and FEL beam generators, (2) a beam director with the capability to provide atmospheric compensation and propagate through the atmosphere at high powers, (3) large space relay optics, and (4) components needed to point relay optics accurately;
- selected the beam generator concept and completed its initial design;
- conducted integrated technology experiments that demonstrated high-power beam generators with a beam director providing atmospheric compensation at high-power;
- determined the feasibility of scaling to full weapon performance; and
- created a mature design of the space segments of the system level demonstration that included relay mirrors and an ATP subsystem with high level of accuracy.

SDIO was developing three different types of beam generators—induction FEL, radio frequency FEL, and excimer gas laser. The ground-based and the space-based laser projects were to share developments in large optics, beam control, and ATP.

The plan specified that \$1,721 million would be required for fiscal years 1985 through 1989 to perform the research and development to ready the ground-based laser for this decision point.

Program Progress and Costs to Date

In December 1990, SDIO decided that the FEL research would be reoriented toward determining the feasibility of a space-based FEL weapon. At this point, only one of the objectives included in the 1984 plan for a ground-based laser had been completed: SDIO had selected the radio frequency FEL as the beam generator and completed its initial high-power design. Technical progress, however, had been made on several other objectives for a ground-based laser system.

SDIO will have spent \$1,244 million on this program, primarily for the ground-based laser, through fiscal year 1993. This amount represents about 72 percent of the \$1,721 million SDIO believed was needed to do research for a ground-based system through fiscal year 1989. Funds were spent on preparing the ground site, conducting a competition for the beam generator, awarding a contract for designing a beam control and director systems, performing experiments on the optics and laser systems, and achieving progress in other technical areas such as atmospheric compensation.

Site Preparation

During 1986 and 1987, SDIO selected the Orogrande site at White Sands Missile Range in New Mexico for the ground-based laser and performed a detailed environmental impact statement. In 1987, SDIO awarded contracts for architectural and construction engineering support and for construction of facilities to support laser development. The facilities' contractor built an access road, three administrative buildings, and a communications center and laid water lines to the site. The facilities' contractor had also completed the designs for all other structures to be built at the site. These contracts were terminated in 1989 due to funding limitations. The facilities cost about \$77 million and are being used by other activities at White Sands Missile Range.

Beam Generator

SDIO conducted competition among three types of beam generators for the ground-based laser: excimer laser, radio frequency FEL, and induction FEL. SDIO designed and built a portion of the excimer gas laser device called Excimer Moderate Powered Raman Shifted Laser Device and installed it at the High Energy Laser Systems Test Facility at the White Sands Missile Range. The objectives of this program were to build and test an excimer laser to demonstrate the technology necessary for a high-power, repetitively pulsed, excimer laser and develop a theoretical model through a series of low-energy experiments. In 1989, SDIO eliminated the excimer laser as a candidate for the ground-based laser beam generator because of

technical difficulties encountered during the White Sands Missile Range test, its low electrical efficiency, and the difficulty in propagating its short wavelength beam through the atmosphere. SDIO spent \$159 million developing the excimer before it canceled the program.

After a formal 2-year competition between teams composed of TRW/Lawrence Livermore National Laboratory and Boeing/Los Alamos National Laboratory, SDIO eliminated the induction FEL technology during fiscal year 1989 and selected the radio frequency FEL technology as the beam generator for the ground-based laser. In 1990, SDIO awarded a contract to Boeing Aerospace/Los Alamos National Laboratory to build a multimewatt radio frequency FEL at the Orogrande site at White Sands Missile Range.

Beam Director

SDIO awarded a contract to Lockheed Missile and Space Company in 1987 for designing beam control and beam director systems for the ground-based laser. Because this contract was awarded before the radio frequency FEL was selected as the beam generator, Lockheed designed beam control systems for both the radio frequency and the induction FELs. The Lockheed contract, after costing \$42 million, was terminated in 1989 due to funding limitations. SDIO also purchased a 3.6-meter diameter, 60-centimeter thick optical glass blank from Schott Glass Works for the ground-based beam director. It was cut into two 30-centimeter thick blanks. One blank is in storage and may be used in a space-based laser test stand in the future. The second blank was given to the Air Force for use in a telescope.

Atmospheric Compensation and Space Relay Optics

SDIO used the existing Mid-Infrared Advanced Chemical Laser and its associated Sea Lite Beam Director to develop and demonstrate technology for atmospheric compensation of a ground-based laser beam director and for lethality, acquisition, and tracking experiments. This deuterium fluoride chemical laser was developed, and it is operated by the Navy at the High Energy Laser Systems Test Facility at the White Sands Missile Range. SDIO spent \$110 million from fiscal years 1985 through 1989 for these technology development efforts. In addition, an experiment called the Sub-scale Atmospheric Blooming Experiment was performed at TRW's San Juan Capistrano test site. It demonstrated that adaptive optics systems can compensate for low-power thermal blooming distortions in the atmosphere.

Other Technical Achievements

Los Alamos and Lawrence Livermore National Laboratories and Boeing Aerospace have achieved advances in the design and operation of FEL devices. Los Alamos demonstrated that (1) the photoinjector could produce electron beams with brightness levels needed for weapon class FELs and (2) efficiency improvements in energy recovery for radio frequency accelerators, which are required for efficient operation in space, could be made. Lawrence Livermore demonstrated high efficiency energy extraction from a device called a "tapered wiggler" operating at short optical wavelengths. Boeing also demonstrated the operation of the FEL's photoinjector system by generating a high-quality electron beam with power in excess of 680 kilowatts for over 3 minutes, making it among the three highest average power electron accelerators in the world. SDIO will have spent \$854 million from fiscal years 1985 through 1993 on FEL device development.

Work Remaining and Estimated Costs

SDIO has redirected FEL research to determine the feasibility of space basing but has not determined the additional work and time required or the cost to ready the space-based FEL for a system level demonstration. It estimates, however, that after fiscal year 1993 an additional \$63 million and 30 months will be needed to complete the work needed to resolve the remaining physics and engineering issues before FEL can be scaled to weapon level power.

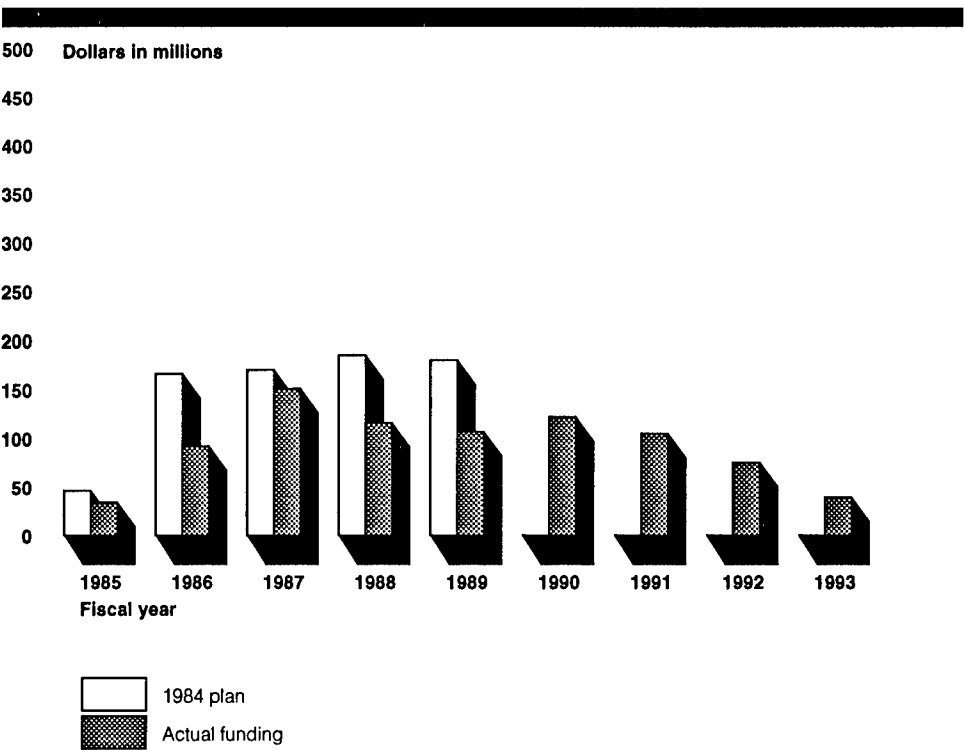
The thrust of the current program is to demonstrate high average power operation and to develop the technology to operate FEL in space, which includes improving system efficiency and developing superconducting and cryogenic accelerators. SDIO's space technology development strategy for FEL requires that the technology for beam control, optics, and ATP be obtained from other directed energy weapon projects (see chs. 2 and 5).

Pursuant to the terms of the Fiscal Year 1993 Defense Authorization Act, SDIO is to transfer the FEL program and its outyear funding to the Army beginning in fiscal year 1994. A report to the Congress on this subject was signed by the Deputy Secretary of Defense on May 7, 1993. (See app. I.)

Particle Beam Program

In its 1984 directed energy plan, SDIO planned to build a space-based neutral particle beam (NPB) and test it on the ground by the end of fiscal year 1992 at an estimated cost of \$747 million through fiscal year 1989. Through fiscal year 1993, SDIO will have allocated \$794 million to this program (see fig. 4.1) and it will not have completed all of the ground and space tests included in the 1984 plan. SDIO allocated an additional \$46 million to develop a ground-based charged particle beam before canceling this program in fiscal year 1992. SDIO estimates that it will take 4 more years and \$421 million to complete the ground and space testing and the development of a lightweight power source for NPB (power source for NPB was initially to be developed under another program). These actions will exceed the objectives included in the 1984 plan. At that point, SDIO will decide whether to propose entering the demonstration and validation phase of development and doing an integrated system level demonstration.

Figure 4.1: SDIO Funding for NPB



An NPB weapon uses a beam that is produced by subjecting hydrogen or deuterium gas to a high electrical charge. The charge produces negative

ions that are accelerated through the weapon assembly and are neutralized as they enter the end of the weapon assembly. In the neutralization process, electrons are stripped from the ions to produce neutral atoms.

The NPB's primary mission is discrimination (i.e., the ability to distinguish reentry vehicles from chaff, decoys, and space clutter). The particle beam causes the reentry vehicle to give off unique emissions that can be detected by another sensor. However, NPBs can also be used to destroy the electronics in missiles. NPB technology is included in the follow-on system architecture for GPALS. SDIO believes that development of its discrimination capability could prove invaluable against future threats.

Program Objectives and Funding

According to SDIO's 1984 plan, NPB development was to have advanced by 1992 to a point enabling a decision on whether to fund an integrated system level demonstration in space. As a basis for this decision, SDIO planned to have demonstrated

- beam generation/conditioning feasibility and scalability with an accelerator,
- lightweight magnetic optics for steering the beam,
- concepts for sensing the beam and boresighting it,
- propagation of a beam from a spacecraft into a space environment,
- feasibility of growth technology that could provide higher brightness beams, and
- integration on the ground of key subsystems of a space-based NPB weapon.

The plan specified that about \$747 million would be required from fiscal years 1985 through 1989 to achieve these objectives. The power system and the ATP system for NPB were to be developed under separate programs (see ch. 5 for ATP information).

Program Progress and Costs to Date

Four of the 1984 program plan's eight major objectives for NPB have been completed (see table 4.1). SDIO said that significant progress has been made on completing the other four. Through fiscal year 1993, SDIO will have spent about \$794 million to develop NPB, or \$47 million more than it estimated was needed for fiscal years 1985 through 1989 to do the planned research. It also spent \$46 million to develop a ground-based charged particle beam before it canceled that program in fiscal year 1992.

Table 4.1: Status of Objectives for NPB

Objectives	Technical objectives completed	
	Yes	No
Generate scalable high-power beam		x
Develop beam neutralizer	x	
Develop lightweight magnetic optics	x	
Develop beam sensing and boresighting methods	x	
Test integrated Ground Test Accelerator on the ground		x
Develop electrical power source		x
Develop sensor to measure effect on target	x	
Test NPB operation in space		x

Beam Generation

SDIO's 1984 program goals were to generate a particle beam in the burst mode with a power of 50-million electron volts and a beam in the continuous mode with a power of 5-million electron volts. The 50-million electron volt goal was replaced in 1987 by a 24-million electron volt goal. SDIO said the change was prompted by concept studies that indicated the 24-million electron volt experiment would demonstrate the requisite weapon relevant objectives. SDIO said that considerable progress has been made toward achieving these goals. Final completion of the 1984 goals will occur with operation of the beamline components that are now fabricated and being installed on the Ground Test Accelerator and the continuous wave deuterium demonstrator.

The Ground Test Accelerator at Los Alamos National Laboratory has produced a 3.2-million electron volt beam in the burst mode. Additional components to increase the accelerator's beam energy to 24-million electron volts have been fabricated and are being added to the accelerator. SDIO plans to perform the 24-million electron volt demonstration during fiscal year 1994, which will accomplish the first objective. According to SDIO, the results of this demonstration will be scalable to higher levels. Subsequently, the accelerator will be used to resolve the remaining high-power beam control issues.

The continuous wave deuterium demonstrator, located at Argonne National Laboratory, will be used to demonstrate the continuous operation of a particle beam accelerator to produce a beam with an energy of up to 7-million electron volts. This demonstration will address not only issues related to the continuous operation of an accelerator such as cryogenic

operation and thermal management but also the use of deuterium particles to enhance lethality. Over 90 percent of the hardware needed for this accelerator has been fabricated. SDIO plans to complete this demonstration during fiscal year 1994.

Beam Neutralization

SDIO has developed lightweight foil neutralizers for stripping the electrons from hydrogen or deuterium ions to produce a beam of neutral atoms. Neutral atoms are unaffected by magnetic fields, so once accelerated and pointed at a target, they will proceed in a straight line. Foil neutralizers are lightweight, have no power requirements, and have been fabricated to weapon-level size.

Magnetic Beam-Expander Telescope and Beam Sensing

A lightweight magnetic beam-expander telescope has been developed to focus and control the size of the beam at the target. In addition, a weapon level beam sensing technology has been developed and tested to sense the direction in which the neutral beam is pointed. The beam sensor can detect the direction of the beam at a very precise level and make corrections to ensure the beam is properly directed at the target.

Sensor for Detecting Emissions

SDIO reported that NPB's primary mission, interactive discrimination, requires that detectors be developed and placed on a separate space platform to detect the emissions induced when the beam penetrates targets. This data is needed so NPB can determine the mass of the target or assess the extent of damage to the target if NPB is used to destroy missiles.

SDIO has investigated several different detector technologies such as multiwire proportional counter detectors, scintillating fiber optics, advanced ionization chambers, and solid state silicon detectors. The multiwire proportional counter detector and the scintillating fiber optics are the preferred concepts because of their proven operational capabilities and low sensitivity to gamma rays. Detector modules based on these technologies have been developed and are scalable to weapon level specifications.

Space Experiments

The 1984 program plan objectives for resolving issues related to operating an NPB in space have been partially completed by three experiments. In 1989, SDIO completed a suborbital NPB space experiment, called Beam Experiment Aboard Rocket, at a cost of about \$60 million at the White

Sands Missile Range. This experiment achieved its primary objective of generating an NPB in space and its secondary objective of resolving a number of space physics issues that were potential obstacles to operating an NPB in space. The second experiment, the Army Background Experiment, successfully measured the natural neutron background of the earth with a neutron detector module developed for NPB applications. The third experiment consisted of three separate shuttle-based space experiments of neutralizer material interactions with atomic oxygen and the space environment. SDIO said the neutralizer material was not adversely affected by the space environment.

SDIO also spent about \$78 million planning another space experiment, called the integrated space experiment, which was to be a shuttle launched experiment to demonstrate NPB technologies on-orbit. This experiment, however, was canceled in 1988 because it was too expensive and the NPB technology was not mature enough to support the specified performance.

Charged Particle Beam

SDIO spent \$46 million to develop a ground-based charged particle beam before it canceled that program in fiscal year 1992. The charged particle beam program, also known as projects DELPHI and MINERVA, sought to develop a ground-based device to be launched upon an attack warning to engage targets at a range of 80 to 500 kilometers. The mission was to interactively discriminate between reentry vehicles and decoys and then destroy the reentry vehicles. When the funding available for particle beam work (both charged and neutral) declined in fiscal year 1992, SDIO decided to cancel the charged particle beam work because the technical risk for the charged particle beam was greater than for the neutral particle beam.

Work Remaining and Estimated Costs

SDIO officials estimate that an additional \$421 million and 4 years are needed to complete the work required to ready NPB for a decision on whether to perform a system level demonstration. This includes \$121 million and 3 years to complete the ground integration specified in the 1984 plan, \$260 million and 4 years to complete a space experiment, and \$40 million to develop the power source for NPB.

Ground Test Accelerator

The Ground Test Accelerator is one of two accelerators SDIO is using to perform ground integrations. It includes all of the major subsystems that will be required for an NPB weapon platform, except parts of the ATP

subsystem. High brightness beams have been demonstrated on this accelerator since 1990. SDIO plans to demonstrate this accelerator at 24-million electron volts in July 1994. The beam control hardware, of which 44 percent has been fabricated, will be integrated with the accelerator beginning early in fiscal year 1995. So far, SDIO has spent about \$333 million developing and demonstrating this accelerator and estimates that an additional \$100 million is needed to complete the beam control demonstration.

Feasibility of Growth Technology

The continuous wave deuterium demonstrator accelerator is demonstrating the technology for the low-energy section of the NPB beamline, including continuous operation, cryogenics, and automated operation with a heavy mass particle (deuterium) beam. This demonstration is scheduled to be completed in 1995 and will require an additional \$21 million.

Space Demonstration

A complete NPB system must be demonstrated in space to resolve the space-related technology problems. The space demonstration is to determine the system's ability to propagate a beam to distant targets and is to also resolve other issues such as spacecraft charging, atomic oxygen effects, and control of effluents.

SDIO is considering two options for the space experiment: an experiment called far-field optics experiment and a larger experiment called Lunar Resource Mapper. The far-field optics experiment would cost about \$260 million and could be launched on a Delta II vehicle and completed in 4 years. According to SDIO, the Lunar Resource Mapper experiment is of greater interest to the scientific community due to its ability to identify mineral resources on celestial bodies at much higher geographic resolution than possible with passive means.

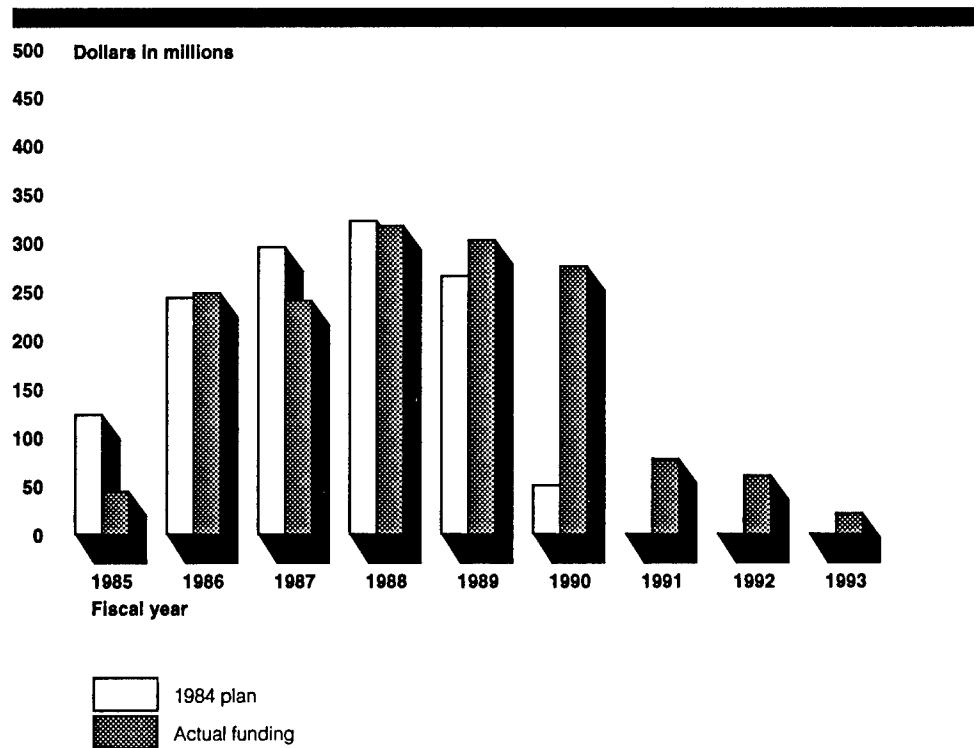
Power Source

SDIO is developing a lightweight system to provide the power needed for the space platform. Such a power system must be capable of providing 20 kilowatts of housekeeping power on a long-term basis as well as megawatt levels of burst power to operate the NPB during a battle. SDIO estimates it will cost \$40 million to complete this program.

Acquisition, Tracking, Pointing, and Fire Control Program

In its 1984 directed energy plan, SDIO planned to develop an acquisition, tracking, pointing, and fire control (ATP/FC) subsystem for directed energy weapons by fiscal year 1990 for \$1,298 million. Through fiscal year 1993, SDIO will have allocated \$1,584 million to this program, accomplishing some but not all of the program objectives (see fig. 5.1). SDIO estimates that it will cost \$180 million and take 3 years to resolve the majority of the remaining technical issues. For another \$100 million, the ATP technology could be demonstrated in space.

Figure 5.1: SDIO Funding for ATP/FC Systems



All directed energy weapons need an ATP/FC system. In general terms, the system must quickly engage a large number of targets by placing a directed energy beam on the aim point of each target. These time and accuracy constraints dictate a rapid succession of handovers from one sensor to another. Each successive sensor in the system has a smaller field of view and greater accuracy.

The system locks on to the infrared signature of a missile (acquisition); calculates the flight path of the missile (tracking); calculates an aim point on the missile and directs the beam to the aim point (pointing); and assesses the results and selects the next target (fire control). Depending on the mission of the directed energy system, the ATP/FC system must perform these functions when ballistic missiles are in their boost, post-boost, and/or midcourse phases of flight.

Program Objectives and Funding

The basic goal of the program was to resolve the technical issues sufficiently to support a space test of a directed energy weapon by 1990. The overall technology performance objectives in the 1984 plan were as follows.

- Reduce the effect on the accuracy of pointing and tracking devices of vibrations caused by operation of the spacecraft and laser to less than 4 inches on the target.
- Develop the capability to rapidly retarget the laser beam from one target to another in less than 2 seconds.
- Develop the capability to track targets at ranges of 2,500 to 3,100 miles at an accuracy of about 4 inches.
- Develop fire control computer software to handle more than 100 targets at a rate of more than one target per second. The fire control functions are missile plume to missile hardbody handover, tracking of multiple targets, target identification, aim point selection, and damage assessment.

The plan specified that \$1,298 million would be required from fiscal years 1985 through 1990 to develop the system components and to fly space experiments to resolve integration and space operation issues. Experiments would permit the space test of a directed energy weapon in 1990.

Program Progress and Costs to Date

SDIO has met the plan's objectives for developing pointing and tracking technology and rapid retargeting technology for directed energy weapons. It has not met the objectives for developing long-range fine tracking and fire control software. While not meeting all objectives, SDIO believes it has met the basic program goal of resolving technical issues sufficiently to support a space test of directed energy technology.

Through fiscal year 1993, SDIO will have spent about \$1,584 million developing ATP/FC technologies. This amount is about \$286 million more

than SDIO estimated was needed to accomplish the objectives. A majority of the funding was spent on a series of space- and ground-based experiments. All major space tracking experiments were canceled before completion due to a lack of funding. However, two space pointing experiments were completed (see fig. 5.2).

Figure 5.2: Space- and Ground-Based ATP/FC Experiments (Dollars in millions)

Fiscal year	Space-based experiments							Ground-based experiments		
	RME	LACE	Talon Gold	Pathfinder	Starlab	Altair	Balloon	R2P2	Space Active Vibration Isolation Project	Space Integrated Controls Exp.
1985			\$25							
1986										
1987	\$262			\$40						
1988					\$603					\$37
1989										
1990						\$16		\$42		
1991										
1992							\$75			
1993										
Status	Completed	Completed	Canceled	Canceled	Canceled	Canceled	Ongoing	Completed	Completed	Completed

Notes:

Relay Mirror Experiment (RME)
Low Power Atmospheric Compensation Experiment (LACE)
Rapid Retargeting/Precision Pointing (R2P2) simulator

Space-Based Experiments

At a cost of about \$262 million, SDIO reported that it completed the Relay Mirror Experiment and the Low Power Atmospheric Compensation Experiment, which were focused on resolving issues related to the ground-based laser program. Each was placed in a separate orbit by one Delta booster in 1990. The Relay Mirror Experiment successfully demonstrated high-pointing accuracy, laser beam stability, and long-duration beam relays. The Low Power Atmospheric Compensation Experiment successfully demonstrated low-power technology to compensate for laser beam distortions, which occur when beams go through the atmosphere from ground to space.

SDIO had spent about \$684 million from fiscal years 1985 through 1991 planning, designing, and fabricating hardware for four ATP/FC space experiments that were canceled before completion for the following reasons.

- Talon Gold was intended to demonstrate precision tracking and pointing in space for targeting satellites and boosters. After spending about \$25 million on Talon Gold, SDIO canceled the experiment because the cost estimates for integration and launch had increased an additional \$500 million.
- Pathfinder was started in September 1985 and was canceled in 1987 because it was too expensive. SDIO had spent about \$40 million on this experiment, which was to address plume phenomenology using a sensor array on the space shuttle.
- The Starlab space experiment was intended to demonstrate precision tracking and would have used the space shuttle to accomplish the experiment. After spending about \$603 million developing Starlab, SDIO canceled this experiment in part because the Challenger accident led to nearly a 3-year delay in the launch date, greatly increasing the overall cost. This coupled with changing priorities in the directed energy program led to changes in requirements and increased costs, which made the experiment too expensive to complete.
- Altair, which was canceled after SDIO had spent about \$16 million in development costs, was intended to demonstrate the same types of technologies as Starlab and was planned to use some of the hardware developed for Starlab. An SDIO official estimated that it would have cost \$330 million to complete Altair.

SDIO replaced the Altair space experiment with a nonspace ATP/FC experiment called High Altitude Balloon Experiment. This experiment is intended to achieve most of the same objectives as Altair but at a much lower estimated cost of \$75 million. Balloons will be used to carry ATP/FC devices to an altitude of about 30 kilometers where these devices will be used to acquire and track missiles in the boost phase. SDIO's program manager for ATP/FC systems told us that SDIO expects this experiment to yield from 80 to 90 percent of the data that would have been obtained from a space experiment.

Ground-Based Experiments

SDIO designed and constructed a Rapid Retargeting/Precision Pointing simulator that emulated the dynamics of a large spacecraft (e.g., motion and vibration). Using this facility, SDIO developed and tested techniques for ensuring the stability,¹ accuracy, and precision of a simulated directed energy weapon's pointing device under rapid retargeting situations. This project demonstrated, within the limits of a ground laboratory, that ATP/FC

¹Stabilization is critical to the speed and accuracy with which a directed energy beam can be pointed and repointed at targets.

techniques should work in space at the levels established in the original program plan. SDIO will have spent about \$42 million on this project from fiscal years 1985 through 1993.

Two other projects also demonstrated ATP/FC techniques. The Space Active Vibration Isolation project developed and tested ATP/FC techniques for negating the effects of spacecraft and weapon vibrations on the pointing device. This project produced hardware and technology that have improved the pointing stability of directed energy devices to below the program goal of less than 100 nanoradians, or about 4 inches from a distance of 1,000 kilometers. This project was followed by the Space Integrated Controls Experiment, which improved the pointing stability even further. SDIO has spent about \$37 million on these two projects from fiscal years 1985 through 1993.

Work Remaining and Estimated Costs

SDIO estimates that it will cost \$180 million and 3 years to resolve the vast majority of the ATP/FC technical issues and perform integrated ATP experiments against real targets from the High Altitude Balloon Experiment platform. This would substantially complete the objectives of the 1984 plan. An additional \$100 million will be needed to demonstrate operation in space, assuming that it would be done as part of another directed energy space experiment such as Star LITE, the experiment planned for the chemical laser. The major technical issues to be resolved over the next 3 years include long-range fine tracking, fire control, integrated ATP/FC, and additional concept development.

For long-range fine tracking, the Solid State Laser Radar Source program produced two laser illuminators. They still need to be tested in realistic target environments to determine their effectiveness in changing conditions and against a wide variety of targets. In addition, their capabilities must also be developed to support aim point selection and maintenance and damage assessment.

Fire control decision software has been demonstrated in computer simulations, but its practicality and robustness have yet to be tested in an integrated field operation. Each of the individual fire control decision algorithms needs to be tested with several sets of scene conditions with real data. Functional integration with sensors and autonomous operation must also be demonstrated. SDIO plans to test the operation of the software on the High Altitude Balloon Experiment platform against boosting targets at the White Sands Missile Test Range.

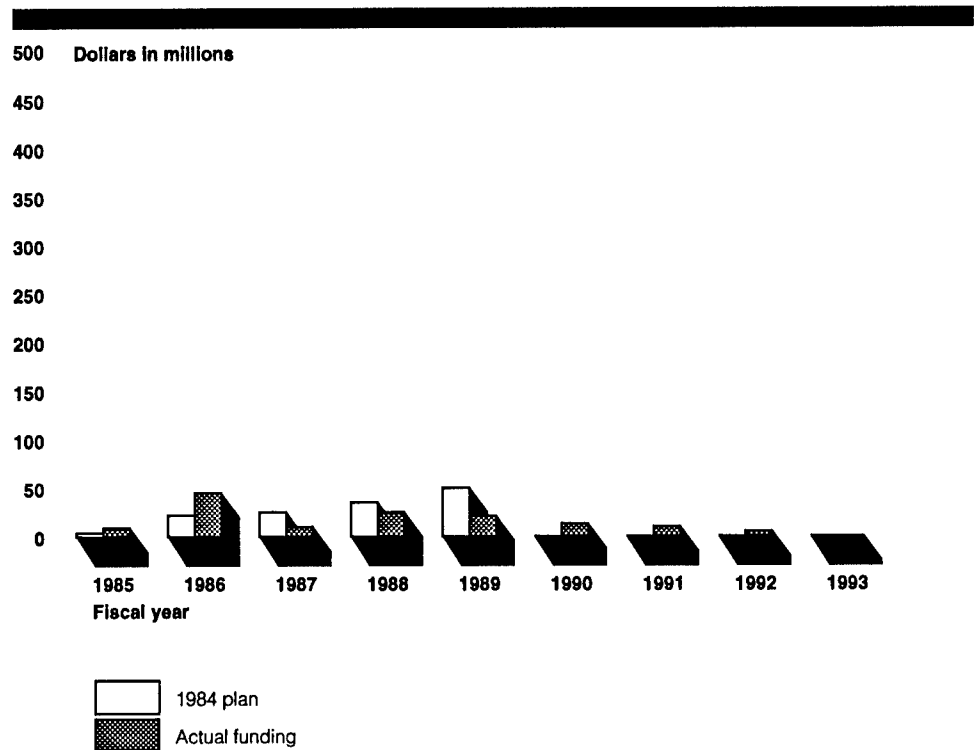
Chapter 5
Acquisition, Tracking, Pointing, and Fire
Control Program

The ATP/FC system must also demonstrate the ability, after being given only the general location, to engage noncooperative targets very quickly. After this is accomplished, the ATP/FC system must be integrated with the high-power beam generation and control technologies to demonstrate platform and high-power compatibility.

Nuclear Directed Energy Technology Program and Other Activities

From fiscal years 1985 through 1993, SDIO will have spent \$138 million for nuclear directed energy technology, \$206 million for other directed energy development and support activities, and \$343 million for non-directed energy SDI-wide technology and other efforts (see figs. 6.1, 6.2, and 6.3).

Figure 6.1: SDIO Funding for Nuclear Directed Energy Technology



Chapter 6
Nuclear Directed Energy Technology
Program and Other Activities

Figure 6.2: SDIO Funding for Other
Directed Energy Activities

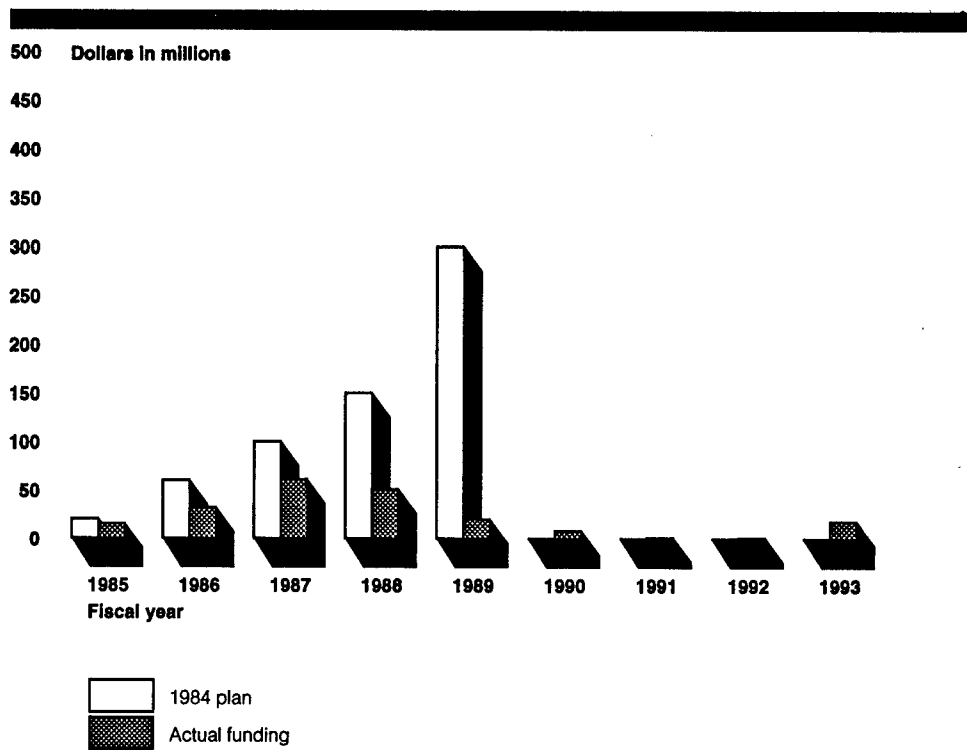
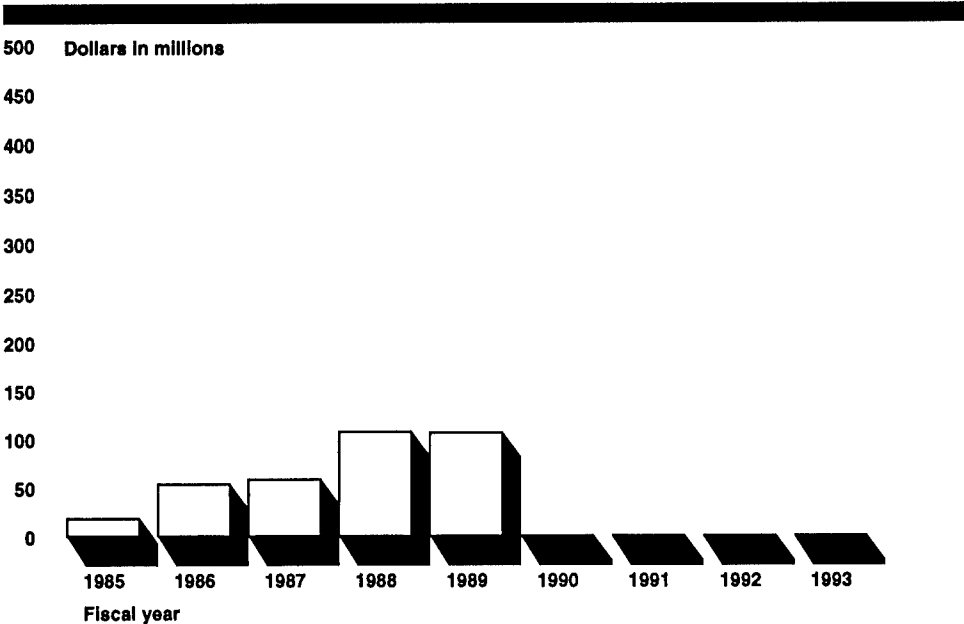


Figure 6.3: Directed Energy Funds
Spent on Non-Directed Energy
SDI-Wide Technology



Nuclear Directed Energy

In its 1984 directed energy plan, SDIO planned to pursue the development of nuclear directed energy to provide a base of knowledge that would permit the United States to better judge potential Soviet capabilities and to provide the basis for a ground-based or pop-up nuclear directed energy capability should it be needed at some point for the strategic defense system follow-on phases. SDIO's contributions included theoretical computational research along with contributions for diagnostic packages for Department of Energy underground nuclear tests and related laboratory experiments. SDIO and the Department of Energy have conducted a cooperative program that has included mission analyses as well as exploring system engineering concerns.

SDIO planned to spend \$136 million from fiscal years 1985 through 1989 performing this research. Through fiscal year 1993, SDIO will have spent about \$138 million.

Other Directed Energy

SDIO will have spent about \$206 million through fiscal year 1993 on directed energy weapons concept definition, operational support costs, and directed energy demonstrations.

Concept Definition

In its 1984 directed energy plan, SDIO planned to spend about \$630 million for directed energy concept definition. From fiscal years 1985 through 1993, SDIO will have spent about \$96 million on directed energy concept definition. Concept definition is applicable to the four principal directed energy concepts: space-based chemical laser, ground-based lasers (FEL and excimer), particle beams (neutral and charged), and nuclear directed energy. Directed energy concept definition efforts support setting performance requirements and technical characteristics.

Operational Support Costs

From fiscal years 1985 through 1993, SDIO will have spent about \$92 million on operational support. This support provides system engineering and program control common to all other projects within this program element. Typical system engineering tasks include review and analysis of technical project design, development and testing, test planning, assessment of technology maturity and technology integration across SDIO projects, and support of design reviews and technology interface meetings. Program control tasks include assessment of schedule, cost, and performance, with documentation of the related programmatic issues. This project also supports funding for civilian personnel and expenses for travel, training, rent, communication, information management, utilities, printing, reproduction, supplies, and equipment.

Directed Energy Demonstrations

SDIO provided \$18 million for fiscal year 1993 to explore other directed energy concepts, including the airborne laser weapon concept for theater missile defense. The speed of light capability of the laser weapon may allow the aircraft-based laser to destroy theater missiles during boost phase at long range, providing a boost phase defense layer that does not require overflight of enemy territory. Experiments, analysis, and technology development leading to the demonstration of the aircraft-based concept are to be performed. This program will be transferred to the Air Force. A small effort is also being pursued toward the development of compact, lightweight, and efficient high-average-power solid-state lasers.

SDI-Wide Technology

From fiscal years 1985 through 1993, SDIO will have spent \$343 million, which was initially allocated to the directed energy program element, for general SDI-wide technology and other efforts. Funds were used for SDI's Innovative Science and Technology and Small Business Innovative Research Programs. Funds were also used for the construction of a research and test facility and to develop generic sensor technologies.

Future of Directed Energy Technology Development

The Congress was concerned that as SDIO transitioned from a broadly based research organization to a focused acquisition agency, maintaining responsibility for research and development of far-term follow-on technologies could distract management and result in funding shortfalls as SDIO's priorities increasingly centered on near-term deployment architectures. Accordingly, the National Defense Authorization Act for Fiscal Year 1993 directed that

...the Secretary of Defense shall transfer management and budget responsibility for research and development of all far-term follow-on technology currently under the Strategic Defense Initiative Organization to the Defense Advanced Research Projects Agency (DARPA) or the appropriate military department, unless the Secretary determines, and certifies to the congressional defense committees, that transfer of a particular far-term follow-on technology currently under the Strategic Defense Initiative Organization would not be in the national security interests of the United States. . . . the term "far-term follow-on technology" means a technology that is not likely to be incorporated into a weapon system within 10 to 15 years after the date of the enactment of this Act.

On May 7, 1993, the Department of Defense notified the appropriate congressional committees that it had decided (1) to have SDIO retain responsibility for continuing development of SBCLS, NPBS, and ATP/FC subsystems and (2) to transfer responsibility for continuing development of the space-based FEL to the Army and the airborne laser to the Air Force. (See app. I.)

The Department of Defense has not prepared a new detailed plan for carrying out its responsibilities for development of directed energy technologies and does not plan to do so. However, SDIO told us that about \$777 million would be needed over the next 4 years to complete certain work. (See table 1.) SDIO has requested only \$103 million for all directed energy work in fiscal year 1994, indicating that it may take longer than 4 years to complete that work. The Army has requested no funding in fiscal year 1994 for the space-based free electron laser.

Matter for Congressional Consideration

In view of the large amount of funding needed to complete these programs and the uncertainty over the time period required, the Congress may wish to request that the Department of Defense provide it with a plan that has detailed information about what the Department intends to do with these technologies, the funding needed, and the schedule.

Report on Strategic Defense Initiative Organization Far-Term Technology Transfer

Report on Strategic Defense Initiative Organization (SDIO) Far-Term Technology Transfer

1.0 Background

The National Defense Authorization Act for Fiscal Year 1993 directs that, "the Secretary of Defense shall transfer management and budget responsibility for research and development of all far-term follow-on technologies currently under the Strategic Defense Initiative Organization to the [Defense] Advanced Research Projects Agency ([D]ARPA) or the appropriate military department, unless the Secretary determines, and certifies to the congressional defense committees, that transfer of a particular far-term follow-on technology currently under the Strategic Defense Initiative Organization would not be in the national security interests of the United States." The Act further states that "far-term follow-on technology means 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."

The Act requires that not later than 90 days after enactment, the Secretary of Defense submit a report to the congressional defense committees identifying: 1) those programs in the Other Follow-On Technologies Program Element which are being transferred to the military departments or the Advanced Research Projects Agency, and 2) those programs being retained in the Strategic Defense Initiative Organization (SDIO).

In order to comply with this direction, the following actions are being taken:

2.0 Programs to be Transferred

Free-Electron Laser Technology

The free-electron laser has considerable promise as a ground, air, or space-based weapon capability, because of its ability to be tuned, as a robust response to new, emerging threats. However, its incorporation in a weapon system is likely more than 15 years away. For this reason, this program will be transferred to the U.S. Army's tech-base program.

Directed Energy Demonstration

This project involves the development of advanced concepts for theater boost phase intercept, including in particular the Airborne Laser. Depending on the technical results achieved over the next 3 to 4 years, this project could continue with an Airborne Laser Demonstration or it could switch to alternate concepts such as high velocity interceptors. In the case of the Airborne Laser, there are a considerable number of issues to be addressed concerning propagation of the laser beam the necessary distance from the aircraft. For these reasons, SDIO has retained

control of the near-term propagation experiments since they are applicable to other SDI requirements. But SDIO will transfer the funds for demonstrator development to the U.S. Air Force. A small portion of this line will also be retained within SDIO to explore with Russia the potential of solid-state laser technology developed within the former Soviet Union.

3.0 Programs to be Retained in SDIO

Chemical Laser Technology

The chemical laser program provides state-of-the-art technology development for all land, sea, air, and space-based high energy laser programs. One application of this technology, the space-based laser, could provide a mid-term answer to global missile defense if appropriately funded. Essentially all basic component technology issues have now been resolved, and a ground-based integrated demonstration is on-going. Given sufficient funding and political acceptability, space laser experiments could be accomplished by the end of the century. Space lasers offer a global answer to boost phase defense against ballistic missiles of all ranges--needed to defeat the likely developing chemical and biological weapon sub-munition threat. In addition to space-laser applications, near-term (5 to 7 years) spinoffs for mobile ground-based lasers or ship-based lasers for cruise missile or point defense applications follow directly from the chemical laser work now being conducted. For these reasons, the chemical laser technology work should remain under SDIO management.

Neutral Particle Beam (NPB) Technology Program

Originally planned as a space-based directed energy weapon, the neutral particle beam is less mature than laser technology. However, at lower powers neutral particle beams have the ability to discriminate, perhaps non-destructively, warheads and other material. The former Soviet Union has developed this technology considerably, perhaps well in advance of U.S. efforts. Since one element of a cooperative global protection system might be a neutral particle beam "inspector", this technology takes on considerable importance. An inspector-level particle beam could be tested this decade and deployed within 15 years. Due to its central role in cooperative U.S.-Russia activities and the near-term potential of this technology, neutral particle beams should remain under SDIO management.

Acquisition, Pointing, Tracking, and Fire-Control Technology

This is necessary supporting technology for all directed energy weapons. It also has considerable near-term potential for SDI's sensor systems. For these reasons this research should remain under SDIO management.

Miniature Seeker Technology Integration

This project includes launching two small satellites per year to demonstrate sensor technologies and to prove out alternate space-based sensor concepts. These concepts, if successful, will be incorporated into SDI sensor systems slated for deployment within 15 years. As such, this project should remain under SDIO management.

Power Technologies

This project is developing advanced solar and space nuclear power systems. These systems, which include the joint U.S.-Russia development of the TOPAZ power system, could produce deployable power sources for both directed energy platforms or active sensors by the end of the decade. Thus, they should remain under SDIO management.

4.0 Programs Completed, Cancelled or Funded in Another SDIO Program Elements

Other projects within the Other Follow-On Program Element such as the Single Stage Rocket Technology program, the Hypervelocity gun projectile (D-2) work, and the Positron Emission Technology (PET) program will complete their current phase of development by 1994. No further work in these areas is planned by SDIO beyond this date. Thus, they will be completed under SDIO.

Two programs listed in the Other Follow-On Program Element in the SDIO report submitted to Congress on July 2, 1992 have been zeroed in 1993 and beyond. These are the Sensors Studies and Experiments project and the Hypervelocity Gun facility project.

Five other programs listed in the Other Follow-On Program Element in the SDIO report submitted to Congress on July 2, 1992 have been reduced, redirected, and moved from Other Follow-on to the appropriate Program Element that each supports. All five of these projects should be retained within SDIO because of near-term payoffs to SDIO. The Interceptor Studies program has moved to the Limited Defense System Program Element to support the Interceptor Component and Lightweight Exoatmospheric Projectile (LEAP) work in that Program Element. The "Navy Exo" program has been moved to the Theater Missile Defense Program Element because it is an early demonstration of lightweight projectile technology using existing Navy boosters. Most of the Lethality program is now oriented towards answering theater lethality questions, so it is now funded principally in the Theater Program Element. The Materials and Structures program has been re-oriented towards demonstrating improvements in materials and structures for Ground Based Interceptors and Brilliant Eyes. This portion is funded

Appendix I
Report on Strategic Defense Initiative
Organization Far-Term Technology Transfer

4

under the Limited Defense System (LDS) Program Element... The remaining portion developing new materials technology is funded under the Research and Support Program Element. Finally, the Launch Services project, which purchases launch vehicles for SDIO technology programs, has been reduced and is divided between the Limited Defense Program Element and the Other Follow-On Program Element according to the payloads it supports.

Major Contributors to This Report

National Security and
International Affairs
Division, Washington,
D.C.

J. Klein Spencer, Assistant Director
Charles A. Walter, III, Assignment Manager

Denver Regional
Office

Ted B. Baird, Evaluator-in-Charge