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STATEMENT ON THE STRATEGIC DEFENSE INITIATIVE INSTITUTE

BY

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DEPUTY FOR PROGRAM AND SYSTEMS

STRATEGIC DEFENSE INITIATIVE ORGANIZATION

BEFORE THE

SUBCOMMITTEE ON OVERSIGHT OF GOVERNMENT MANAGEMENT

COMMITTEE ON ARMED SERVICES

UNITED STATES SENATE

MAY 6, 1987

Thank you for the opportunity to appear before you today, Mr. Chairmen, to discuss what I consider to be an extremely important topic -- a Federally Funded Research and Development Center (FFRDC) for the Strategic Defense Initiative. This is not a new subject, as you are well aware, but I would like to review the requirement for the FFRDC.

The mission of the Strategic Defense Initiative Organization (SDIO) is to objectively assess technical questions relating to strategic defense in order to provide the President and the Congress with the necessary information to reach a national decision on strategic defense. This includes conducting a long-range, directed research program toward what may be an extremely complex and far-reaching system. The requisite research is likely to be correspondingly complex. Programs must be carefully crafted to strike the right balance among pure research, applied experiments, development of research results, and feasibility demonstrations.

The SDIO does no research itself; it is the managing agent for the SDI research program. By itself this is a significant task. A great variety of individual, parallel research efforts must be directed and coordinated to produce integrated results. A common data base must be maintained to avoid unnecessary overlap or duplication of efforts, and to facilitate cross-information between research projects. In addition, design development and definition of the system architecture requires ongoing, continuous study and analysis, including cost, technology, and performance trade-offs among system elements.

The SDIO requires technical support in these areas to properly carry out its SDI program management functions. The accelerating rate of research and the evolution of the Program require that the SDIO focus on actual program management, and that the necessary technical support, systems integration, and program evaluation and analysis be provided on a long-term, continuous, conflicts-free basis rather than in a piecemeal, ad hoc manner. There is an immediate need for continuous access to the highest quality engineering and scientific talent to provide dedicated support to the SDIO.

On 1 March 1986, the Department of Defense completed an evaluation of the alternatives for satisfying the requirements. The alternatives examined were:

o Government organizations, including expansion of the present SDIO staff; a military service organization, or a new DoD field agency.

o For-profit firms, including large industrial firms; small-to-midsize System Engineering and Technical Assistance (SETA) contractors; or a new consortium of such firms or contractors, either U.S. or foreign.

o Non-profit firms, including existing Federally Funded Research and Development Centers; a new division within an existing FFRDC; a new FFRDC; universities; and private not-for-profit laboratories/corporations, new or existing.

The results of the evaluation can be summarized as follows:

o The use of a government organization to provide the special technical support needs of the SDIO was found to be undesirable because: (1) it would be difficult to attract, retain, and manage the required number of highly qualified scientific and engineering personnel; and (2) the needed personnel buildup could not occur or respond in sufficient time to meet changing requirements.

o The use of for-profit firms was found to be undesirable because of the conflicts of interest inherent in the for-profit organization, the probable inability to ensure total objectivity and independence of thought; and the negative business impact on such a firm through its necessary dedication to SDIO technical support alone; and the inability to guarantee access to industry proprietary information.

o Of the various not-for-profit alternatives examined, a new FFRDC ranked highest. The FFRDC mechanism was considered to offer quick, responsive handling of SDIO needs, while allowing considerable freedom in establishing salary structures and a working environment conducive to attracting scientific and engineering talent. While an existing FFRDC or other non-profit organization could, potentially, provide capabilities and staff more readily, none have the breadth of specialized expertise to undertake major SDI technology program review and oversight. Any existing organization, including an existing FFRDC or national laboratory, will necessarily have ongoing work and a deeper background in one technology or another. In addition, no existing organization is in a position to offer the desired degree of dedication to, and exclusive focus on, the SDI Program. Establishing a new FFRDC, specifically oriented to SDIO technical support needs, was found likely to result in greater responsiveness and support than attempting to reorient an existing FFRDC.

Establishing a new FFRDC, free from commercial ties and dedicated exclusively to the SDI technical functions, is the best alternative to meet that requirement. Accordingly, the Defense Department moved to create a new FFRDC--to be called the Strategic Defense Initiative Institute (SDII)--with funds appropriated for the SDI Program. Originally, the goal for initial operation of the SDII was the end of FY 1986. The SDIO announced its intent to establish a new FFRDC in the Federal Register and the Commerce Business Daily with three sets of announcements over a 90 day period ending June 16, 1986.

As the DoD moved to create the SDII, questions about the decision to establish a new FFRDC surfaced. The SDIO, in response to letters to the SDIO Director, answered questions and addressed issues in several information briefings to professional and personal staff of the Congress, and continues to provide full disclosure of information about the need for and intended mission of the new FFRDC.

Because of these issues, the DoD was cautioned against proceeding further to establish the new FFRDC by the end of 1986. Subsequently, legislation was enacted in the FY 1987 DoD Authorization Act and the Continuing Resolution prohibiting the new FFRDC until authorized with funding appropriated in separate legislation. Further, both the DoD and the Comptroller General were directed to provide detailed reports on the issues.

At the request of certain members of Congress, the Congressional Research Service (CRS) examined the actions to establish the FFRDC and reported (30 May 1986) pros and cons of the initiative. The central conclusion of the CRS report stated:

"Given DoD's stated mission (of technology evaluation and system integration), desired organizational characteristics (of being competent, continuous, and conflicts free), and institutional constraints (especially their purposed inability to hire qualified people in-house), the decision to establish a new FFRDC is consistent."

The Comptroller General evaluated (report dated 17 November 1986) the options and plans for SDI technical support. The Comptroller General's findings are entirely supportive of the selection of a new FFRDC to perform the needed technical support, ranking that option as first among eight alternatives in terms of effectiveness. (Tied for effectiveness with establishing a new FFRDC was a new division within an existing FFRDC/national laboratory, although many of the GAO sources offered disadvantages with that alternative.)

In response to draft legislation precluding establishment of the FFRDC until a full DoD report was prepared, a comprehensive report of alternatives was provided to the House and Senate Armed Services Committees on 8 August 1986. A full cost comparison analysis was completed and provided as a supplement to the report to the two Committees on 20 October 1986. Most recently, the DoD submitted to the Congress, on February 25, 1987, a complete report to satisfy all known questions and issue regarding the establishment of the FFRDC.

The SDII will be a systems engineering/systems integration group. The SDIO will retain all management and decision responsibility for the SDI Program. The SDII is being established for a very specific purpose--to provide scientific and technical support to the SDIO for evaluating and integrating research. The SDII is not to perform any oversight or policy functions. Those functions, in whole or part, are the role of other organizations, including the Congress.

To meet these technical support needs and provide the SDIO with objective, conflicts-free advice, we remain convinced that a new organization exclusively dedicated to these narrow functions is absolutely essential. We feel that reports by the Congressional Research Service and the Comptroller General support our responses to the criticisms and issues raised about our course of action for a new FFRDC.

Mr. Chairmen, I submit that we have a valid requirement, we have studied the alternatives to satisfy the requirement, and we have selected the prudent decision. We have tried to be open and candid, and to provide to the Congress complete information on every occasion. We need to move ahead with actions to establish the new FFRDC as its need is immediate. I ask the support of these Committees for the authorizing and appropriating legislation to allow us to proceed. This completes my opening statement and I welcome your questions.

SDI

A TECHNICAL PROGRESS REPORT

SUBMITTED TO

THE SECRETARY OF DEFENSE

APRIL 1987

BY

THE DIRECTOR

STRATEGIC DEFENSE INITIATIVE ORGANIZATION

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I. INTRODUCTION

The Strategic Defense Initiative (SDI) is conducting a vigorous research program to provide the basis for strategic defense options that can be used to eliminate the threat posed by ballistic missiles, and thereby:

- Enhance deterrence,
- Strengthen strategic stability,
- Increase the security of the United States and its allies.

The SDI seeks, therefore, to provide sufficient technical knowledge to support an informed decision on whether to develop and deploy a defense of the U.S. and its allies against ballistic missiles.

This report presents an update of significant technical progress that has occurred in the SDI research program over the past year.

A. TECHNICAL PROGRESS

As illustrated by examples in this report, the SDI program is pursuing a broad range of technologies to provide for initial defensive options and at the same time to evolve advanced technology to provide a thoroughly reliable defense against a reactive threat. Architecture studies of strategic defense system concepts continue to identify functional and performance requirements, and the technical content of the research projects has been focused to resolve the key issues associated with future development of systems to meet those requirements. Criteria for evaluating the usefulness of candidate systems are military effectiveness; system survivability; and cost effectiveness to ensure the ability to maintain defensive capabilities more easily than countermeasures could be taken to try to defeat them. Although the funding for the SDI program has been allocated in accordance with these criteria, substantial budget cuts have increased risks and caused delays in accomplishing objectives.

The SDI research program has also been adjusted in the past year to reflect the evolution from conventional technologies to advanced technologies that can be introduced into architectural concepts as they mature.

B. MANAGEMENT PROGRESS

Progress in the SDI program has depended upon a network of executing agencies including the military services and government agencies. These organizations are currently responsible for managing many hundreds of SDI contracts. Management improvements include simplified and responsive direction and a highly competitive approach to a broad range of research. Universities are involved mostly with unclassified research aimed at bringing basic research as well as innovative, novel ideas to bear on SDI objectives. Because of the generic nature of many areas of SDI research, it can be expected to provide beneficial spin-offs to other areas of military security and to the civil and scientific sectors.

In July 1986, the SDI Organization was restructured to identify the importance of a systems approach to planning the program. Two deputy directors, one for Programs and Systems and one for Technology, now provide independent viewpoints necessary to balance the research program and emphasize the interactive systems requirements for future development and deployment.

C. ALLIED PARTICIPATION

In March 1985, the Secretary of Defense invited allies to participate in SDI research with the belief that the SDI program and Western security as a whole could be strengthened by taking advantage of allied excellence in many areas of SDI research. Agreements have been concluded in the form of bilateral Memorandums of Understanding with the United Kingdom, the Federal Republic of Germany, Israel, and Italy. Others are consulting on the possibility of participation in SDI research. Some governments that have decided not to negotiate such agreements with the U.S. do permit participation in SDI research by their private sector. Overall, allied research participation is already making important contributions to the SDI program.

D. DEFINITIONS

The descriptions of technical accomplishments that follow are grouped with respect to their related strategic defense functions. These functions of a strategic defense system are briefly explained below.

BM/C^3 - Battle Management/Command, Control, and Communications is the "brains" or nerve center of a defensive system and involves the following functions:

- Battle Management: The threat assessment and resource allocation that are necessary to operate the defense system.
- Command and Control: The exercise of system control and weapons release in response to battle management assessments.
- Communications: The transmission and reception of data and command and control information between many elements of the defense system.

- Kill Assessment: The evaluation of the outcome of any engagement to destroy or otherwise disable missile and warhead reentry vehicles.

Sensors - Often referred to as the "eyes" of a defense system, they perform the following functions:

- Surveillance: The search for potential threat objects.

- Acquisition: The detection and recognition of threat objects.

- Tracking: The determination of the trajectory of threat objects of interest.

- Discrimination: The identification of threat objects (reentry vehicles, post-boost vehicles, or boosters) from decoys and debris.

- Kill Assessment: The determination of post engagement target damage or trajectory change.

Weapons - Weapon systems perform the following functions:

- Fire Control: The processing of target position data required for weapons release, intercept calculation, and weapon guidance.

- Target Kill: Damage or destruction of targets inflicted by directed energy or kinetic energy weapons.

Key Support Technologies - These are essential technologies which have application to multiple aspects of the defense system and without which the system could not be developed, deployed, or maintained. They include technologies applicable to:

- Survivability: The ability of the defense system to withstand determined attempts to overcome it and continue to function effectively.

- Lethality: The ability of the defense weapons systems to destroy threat missiles and their supporting systems.

- Power: The provision of sufficient energy to operate the system as and when required.

- Materials and Structures: The development, design, and analysis of advanced materials and structures to build system components that have the physical properties necessary to perform their mission.

- Logistics and Supportability: The provision of support to the system with the necessary supplies and transportation, both on the ground and in space.

- Space Transportation: The development of low-cost means of transporting future SDI systems or other U.S. military or civil payloads into their required orbital positions.

The next four sections describe examples of SDI progress in BM/C^3, Sensors, Weapons, and Key Support Technologies, respectively. Highlights of progress in the Innovative Science and Technology effort are contained in Section II E. Information about the highly successful Delta 180 experiment flown in September 1986 is contained in Section II F.

II. SIGNIFICANT TECHNICAL PROGRESS

A. BATTLE MANAGEMENT/COMMAND, CONTROL, AND COMMUNICATIONS (BM/C^3)

BM/C^3 is one of SDI's key research thrusts. This technology area has the challenge of providing new approaches to a vastly more complex set of requirements than has been applied to previous military systems. Options such as centralized, hierarchical, and distributed networks for command and information flow are being investigated to manage data to and from sensor and weapon systems. New research for software development using artificial intelligence techniques was initiated in the past year. This research is intended to provide automated ways to produce rapidly the trustworthy, complex software needed to control a defense system. In short, BM/C^3 technology experiments will provide the foundation for measuring the validity of architectural concepts. A National Test Bed (NTB) is being developed to conduct complex BM/C^3 and system-level validation experiments.

1. Eastport Study Group on Battle Management and Command/Control

The Eastport Study Group, composed of nine prominent computer and command/control experts from leading research and educational institutions, met during the summer of 1985. They identified computation and communication requirements for strategic defense battle management and outlined a research and technology-development program to implement the recommendations.

The panel concluded that BM/C^3 for a strategic defense system is feasible, both in hardware and in software; however, it will be a complex task requiring extensive testing, simulation, and modification to evolve into a robust system. The panel was firmly convinced that the usual approach of overlaying software on a designed hardware system would not be satisfactory for SDI and strongly recommended that the system architecture consider battle management from the beginning. The panel also voiced the concern that a conventional, tightly coordinated architecture would create software problems which might never be solved and recommended that an architecture be developed which did not involve tight coordination between the various command, weapon, and sensor elements. SDIO is implementing these recommendations and will conduct simulations to test their validity.

2. C³ Test Bed

The U.S. Army Strategic Defense Command has developed a distributed test bed to examine the effectiveness of different battle management concepts. Network development will start in 1987 with a ground-based system using conventional technology for simulations of SDI architectures. In FY88, the "SDI Net" will be upgraded with high-performance network technology and a communications emulator. This test bed will be incorporated into the National Test Bed as it is developed. Figure 1 illustrates a simulated engagement as shown on a computer display from the C³ Test Bed.

Figure 1 Simulated Engagement Under Distributed BM Control Showing Soviet Attack on U.S.

3. National Test Bed

The National Test Bed will consist of a number of geographically separated experimental facilities that will be electronically linked to simulate a layered ballistic missile defense system. The purpose of the NTB will be to provide a comprehensive capability to compare, evaluate, and test defense system architectures and BM/C^3 concepts and to evaluate technology subsystems in a system framework. Central to the NTB will be the National Test Facility (NTF). The NTF will have a large computer simulation capability and a prototype command center. Voice and data communications will interconnect the other elements of the NTB.

During the past year, progress toward definition and acquisition of the test bed has been made and a formal management organization was established. A series of "horse race" contracts were awarded to conduct a preliminary design study for the NTB. Contractors have preliminary interactive and geographically distributed simulations already in operation. The next phase of the NTB effort includes developing an interim NTF which can rapidly evolve into the fully capable NTB. Initial operating capability should be in 1988. Additional capability will be added incrementally to support BM/C^3 analysis, high fidelity simulations, hardware-in-the-loop experiments, technology validation experiments, and man-in-the-loop experiments.

B. SENSORS

Progress has been made in building an airborne optical surveillance capability to acquire, track, and discriminate targets in order to pass information to ground-based radars.

Wind tunnel tests have been conducted to evaluate the effects of sensor windows and covers on aircraft as well as sensor performance. Initial detectors have been fabricated and are being tested. Technology efforts are also under way to improve data collection capabilities of ships that view Soviet missile tests. These same technologies can be applied to improving ground-based radars for future defensive systems.

Sensors on surveillance satellites could potentially generate an enormous amount of information each second in a battle environment. Consequently, real-time signal processors now being used for conventional sensors systems may eventually have to be improved by factors of 10 to 100 to meet SDI requirements. Research is aimed at providing rapid handling of large amounts of data from sensor arrays in a fault-tolerant, autonomous manner using low power in space. Additionally, advanced infrared (heat-detecting) arrays must operate at very low temperatures to reduce intrinsic detector noise. Advances have been made in making more efficient cryocoolers, which are special refrigerators needed to lower the temperature of sensors to several hundred degrees below zero Farenheit.

1. Airborne Surveillance Experiments

The Airborne Optical Adjunct (AOA) is an experimental aircraft that will be used to conduct experiments to acquire targets optically at long ranges, then track, discriminate, and hand over these targets to a ground-based radar. It will provide data necessary for the future development of airborne optical systems for the terminal phase of a layered defense system; it will also provide valuable data for the development of larger, space-based optical sensors.

Fabrication of critical components, including telescope optics, data processor hardware, and platform modification components began in 1986 and is scheduled for completion in mid-1987. The components will be positioned as shown in Figure 2. Focal-plane detector arrays have been built, tested, and accepted as flight hardware. Full-scale mock-ups of the sensor, sensor cupola, and interior equipment layout for the Boeing 767 aircraft are complete. The sensor integration laboratory, which will test the sensor on the ground, is under construction. It includes the modified Portable Optical Sensor Tester (POST) coupled to an optical beam expander.

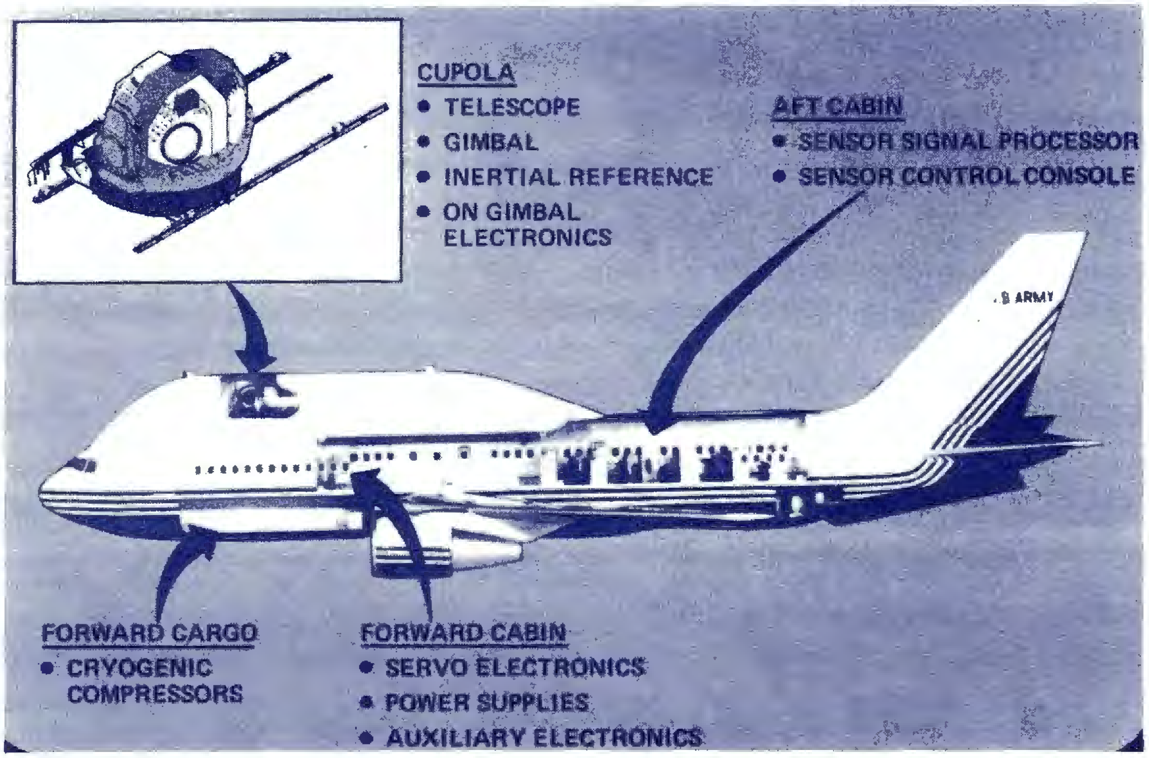


Figure 2 Airborne Optical Adjunct

In a related effort, the Optical Airborne Measurement Program (OAMP) will provide a research platform to conduct experiments that can be used to design future defensive systems by collecting data from Soviet ballistic missile tests. The OAMP sensor subsystem, shown in Figure 3, is in the final stages of assembly and test prior to being installed in the aircraft.

OAMP Aircraft   Detector Assembly

Figure 3 Optical Airborne Measurement Program (OAMP)

The NASA Kuiper Airborne observatory has been used to collect high-resolution ultraviolet and infrared imagery of U.S. missile plumes during the rocket boost phase. Figure 4 is an example of the results. These data have increased our ability to model plumes and to determine missile body location relative to the plume.

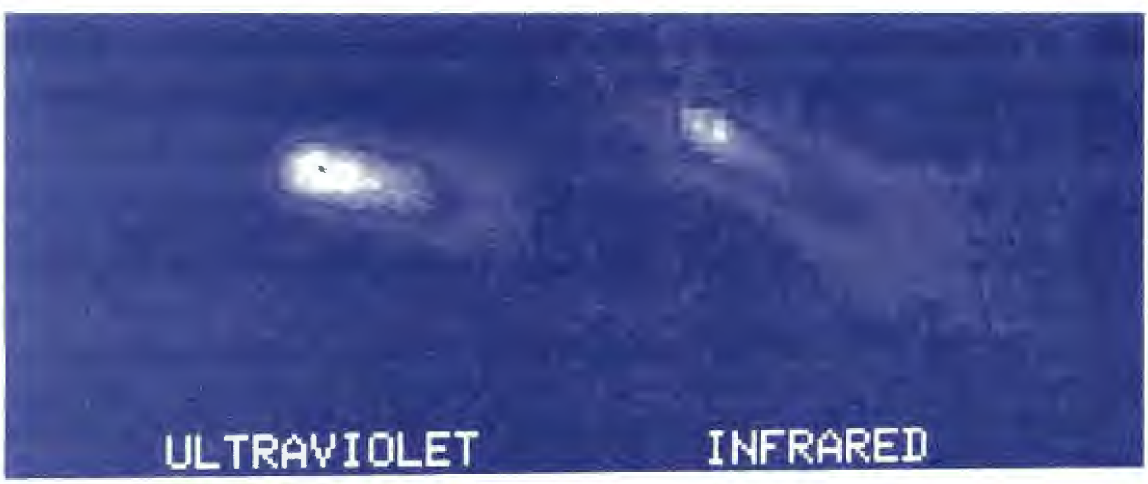
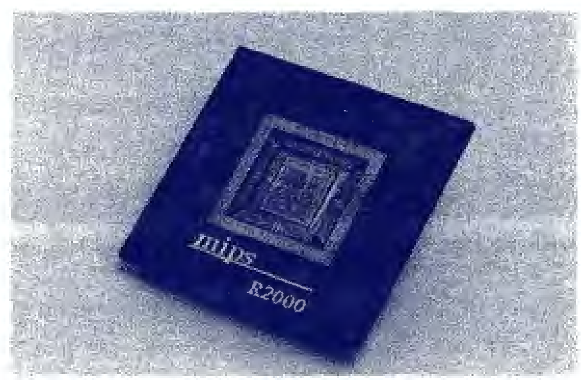


Figure 4 Plume Radiance Observation Experiment (PROBE)

2. Advanced Signal Processor Technology

a. Space-Qualified Supercomputers. Current system design concepts require a general purpose data processor operating at supercomputer performance levels on airborne and space-based platforms. SDIO has initiated efforts to substantiate estimates that Very High-Speed Integrated Circuit (VHSIC) hardware and new computer architectures will significantly improve performance. Recent design studies indicate, for example, that a VHSIC central processor would operate 20 times faster than the industrial standard. Projects are under way to validate these throughput estimates (Figure 5) and to fabricate a VHSIC reduced-instruction-set processor in 1987. With concomitant progress in radiation-hardened electronics, SDIO can expect space-qualified data processor systems within the next few years.

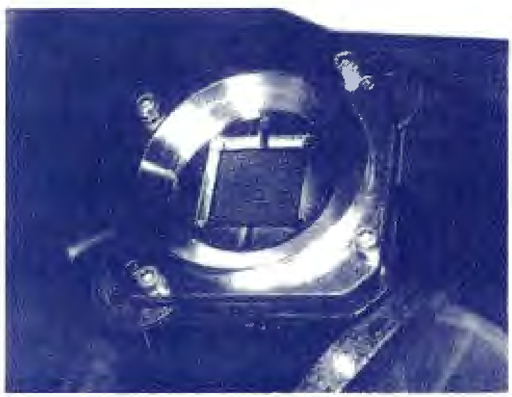
NEW COMMERCIAL COMPUTER THAT EQUALS THROUGHPUT OF FIVE VAX 11/780s USING SINGLE CHIP 32-BIT CPU



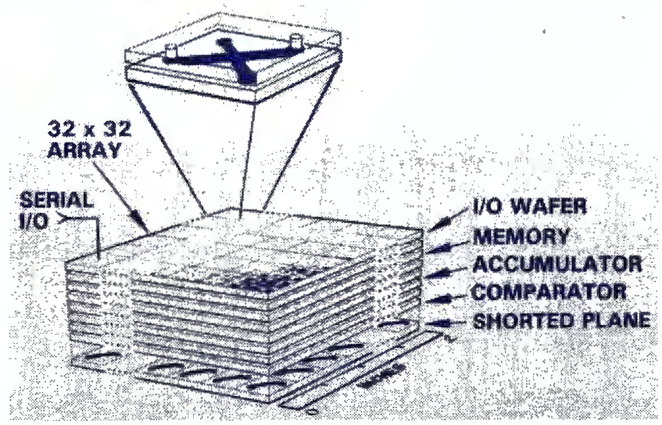
• 32-BIT CPU RUNS AT FIVE MILLION INSTRUCTIONS PER SECOND (5 MIPS)

Figure 5 Advancements in Supercomputer Technology

b. Novel Processing. Hardwired data processors, which currently achieve throughputs of one million operations per second, are too slow for many SDI needs. A one-hundred to one-thousandfold improvement can potentially be obtained through advanced electronics and packaging. A three-dimensional computer with stacks of wafers (Figure 6) offers substantial speed improvement over standard two-dimensional computers. This past year, a five-wafer stack was assembled with greater than 99 percent yield.



FIVE WAFER STACK WITH
1024 FEEDTHROUGHS (99% YIELD)

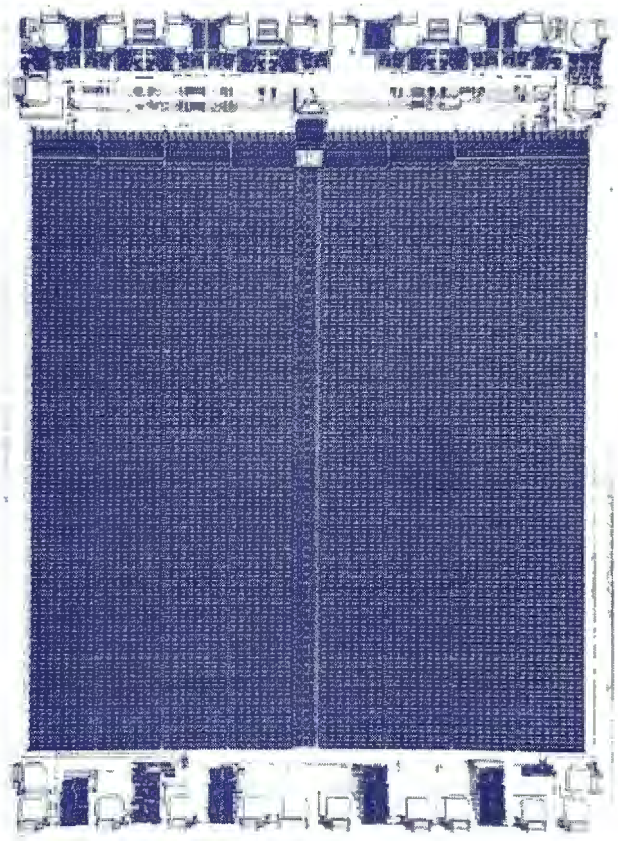


3-D COMPUTER STACK

Figure 6 3-D Microelectronic Computer

c. Radiation-Hardened Electronics. Gallium Arsenide (GaAs) integrated circuits consume less power and are less susceptible to radiation damage than silicon circuits. The SDI GaAs program, managed by DARPA, emphasizes radiation hardness, low power consumption, and complex, highly integrated components for strategic spacecraft applications. SDIO has funded GaAs pilot production lines, which have recently manufactured the largest and most complex GaAs memory and logic/arithmetic chips in the United States. This major milestone recaptures for the United States the lead in developing state-of-the-art GaAs digital circuit technology, a position lost to Japan around 1982. Fabrication of the first GaAs single-chip microprocessor was also accomplished. This first chip operates as fast as a similar silicon chip, but uses one-tenth the power.

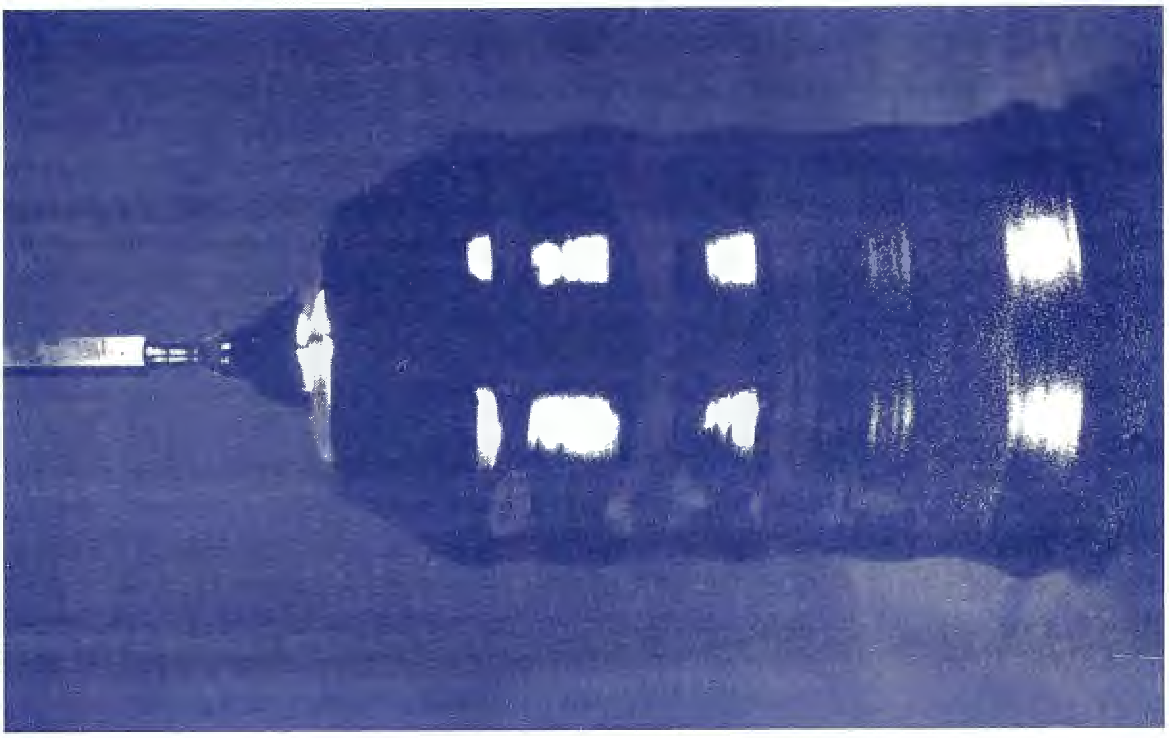
A different form of materials processing may be required if VHSIC technology is to meet SDI radiation tolerance requirements. Silicon-on-Insulator (SOI) material (Figure 7) offers significant promise to provide electric isolation and high radiation tolerance. This year SDI successfully fabricated the first commercially designed memory chips on a SOI material. This chip shows greater radiation resistance and higher speed than the standard commercial part.



16K CMOS/SOI SRAM
DESIGNED WITH 1.25/1.5 μm RULES

Figure 7 Silicon-on-Insulator Technology

d. High-Quality Semiconductor Materials. The successful fabrication of large-scale integrated circuits with useful yields depends in large part on the materials used. Historically, the growth of high-quality, single-crystal semiconductor materials has been an art rather than a science. Digital growth process controllers have produced an ingot, shown in Figure 8, that is reproducible. This will result in uniform crystals containing fewer flaws than before, leading to more reliable circuitry.



INGOT: 3.8 kg
LENGTH: 100 mm
DIAMETER: 80 mm

Figure 8 Digital Growth of Gallium Arsenide Crystals

3. Cryocooler Technology Development

Space-based sensors used for midcourse surveillance need long-wavelength infrared (LWIR) detectors to detect the radiation from relatively cool targets after they have completed their boost phase of flight. These sensors need to operate at extremely low temperatures to minimize the detector internal electronic background. To achieve these temperatures, a three-stage cryocooler based on the Vuilleumier (VM) thermal cycle has been designed, fabricated, and tested.

The VM cooler (see Figure 9) is undergoing longevity tests and is being operated at higher-than-normal speed to simulate a five-year life test. Upon completion of the life test, it will be examined in detail to compare wear and contamination to system requirements. The VM cooler offers promise that the long-life, high-reliability cryocooler required for mid-course sensors is possible.

An alternative two-stage cryocooler has recently been developed for use with LWIR sensors. It uses helium as the working fluid. This high-efficiency, all-metal heat exchanger will soon begin a 5000-hour system-level test.

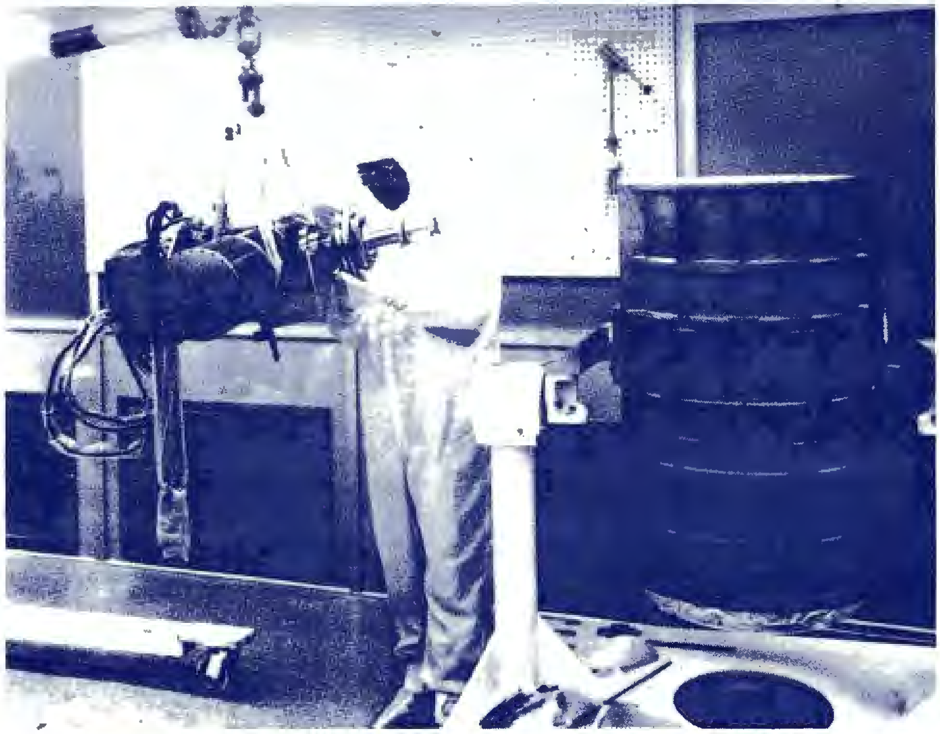


Figure 9 Mating of Cryocooler (Left) to Telescope (Right)

4. Focal Plane Array Technology

Focal plane arrays are used as detectors in space-based sensor systems. Detecting and tracking low-intensity targets in varying space and earth infrared backgrounds require highly sensitive arrays with good efficiency and with low-noise electronic readouts. A number of improvements in LWIR focal plane array technology are described below.

Tests using blocked-impurity-band (BIB) detectors like the one in Figure 10 have shown high sensitivity and efficiency, as well as low noise, nuclear radiation hardness, and stable, predictable performance.

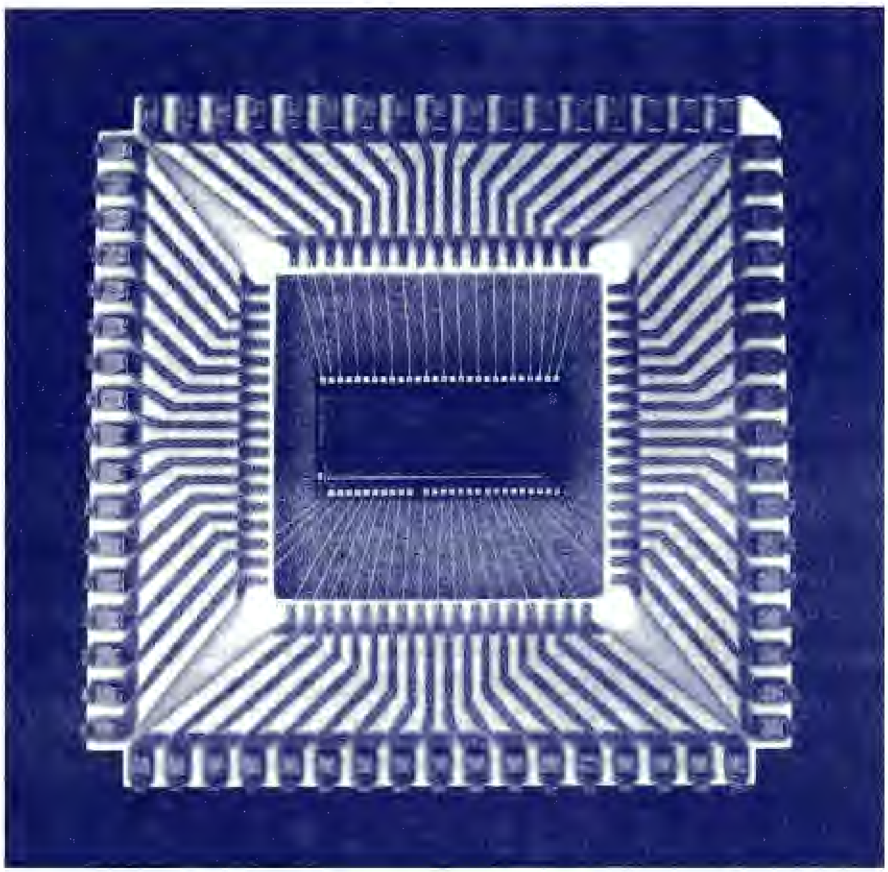


Figure 10 Blocked-Impurity-Band Detector

Standard infrared detectors exhibit anomalies and are extremely noisy in a radiation environment. Impurity Band Conduction (IBC) devices reduce such problems. IBC LWIR subsystems have been fabricated, tested, and evaluated. They include detector arrays capable of detecting a wide range of infrared wavelengths and readout devices capable of operating at cryogenic temperatures.

With proper design, LWIR detectors could be constructed that could operate in multiple wavelength bands for discrimination in the midcourse and terminal phases. The SDI PATHS (Precursor Above The Horizon Sensor) project is aimed at designing such detectors and demonstrating that IBC detector technology can be produced in quantity.

Another high-sensitivity LWIR detector that can operate over a wide range of infrared wavelengths with extremely low background noise has been developed. The solid-state photomultiplier (SSPM), shown in Figure 11, is capable of detecting single photons and is hardened against the effects of radiation.

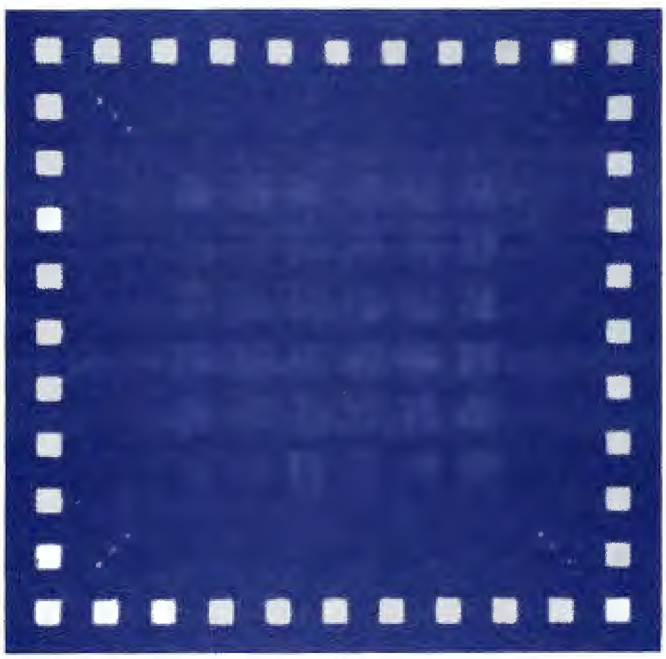


Figure 11 Solid-State Photomultiplier (SSPM) Test Array

5. Advanced Radar Technology

The SDI concept of a multitiered defense system requires a combination of sensors to provide highly reliable, timely information on reentry vehicles among thousands of other objects such as decoys, penetration aids, debris, chaff, and countermeasures. This implies the need for agile sensors that can rapidly view the entire threat. Phased-array radars meet this requirement and use a relatively mature technology. The phased arrays proposed will need radiating elements with low-cost, high-performance, monolithic integrated circuit transmit/receive modules.

State-of-the-art transistors (Figure 12) have been developed which may be used in highly integrated, low-cost packages that incorporate many transmit/receive functions into a single block for a phased-array antenna.

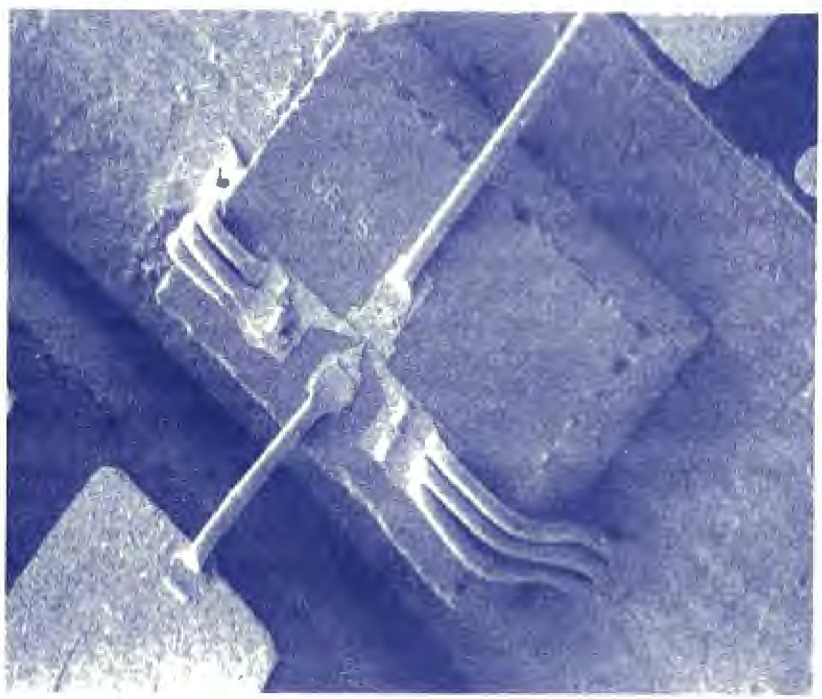


Figure 12 State-of-the-Art Transistor

The development of these high efficiency transistors will allow construction of larger, more reliable phased-array radars. This technology can lead to true solid-state radar systems. In addition, small radar modules (Figure 13) have been developed to demonstrate that the technology exists to construct lightweight, high-power systems. Previous modules have been limited to less than two watts. This project developed chips which, when combined in pairs, generate 10 watts of power. These are the first such modules to demonstrate this power level. This technology will be used for future development of up to 20-watt, high-efficiency radar modules.

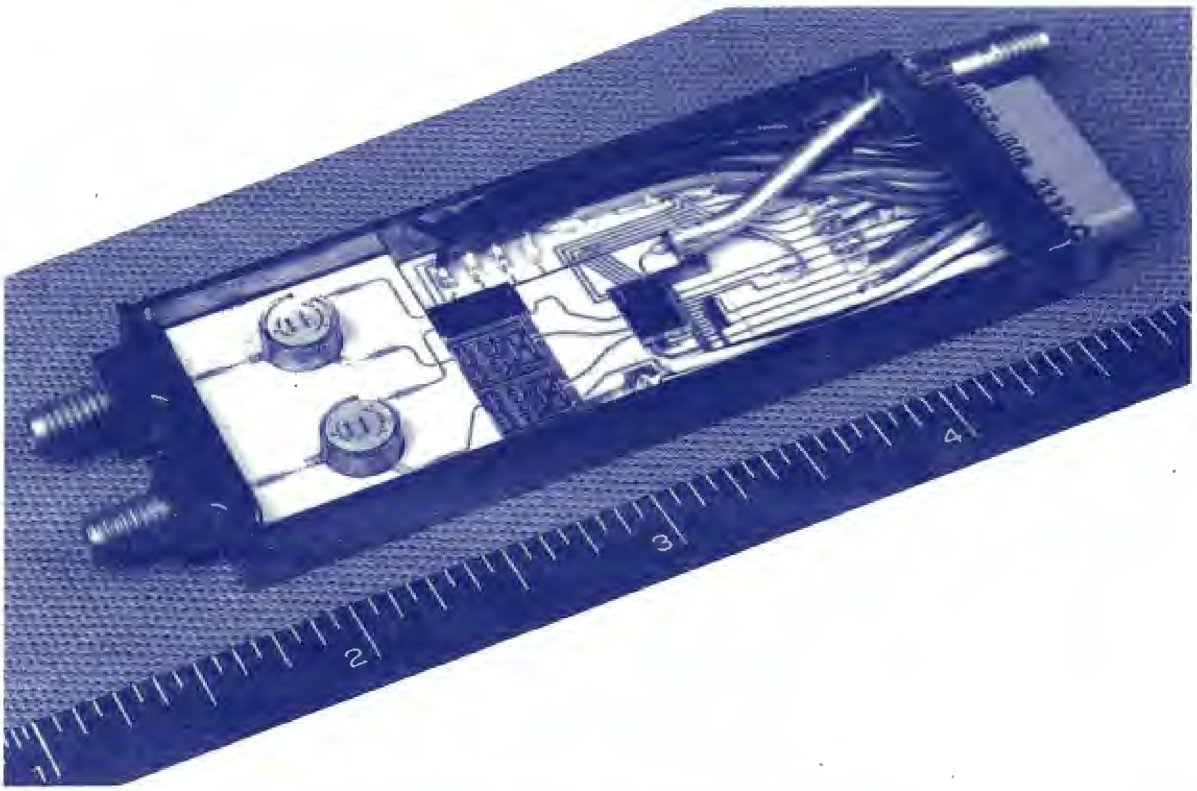


Figure 13 Radar Module for Large Phased-Array Systems

C. WEAPONS CONCEPTS

Intercept and kill of boosters, PBVs, and RVs can be accomplished by Kinetic Energy Weapons (KEW) that impact the target and also by Directed Energy Weapons (DEW) that cause thermal and impulse loading to destroy the target structure or disturb electronic systems. In addition, various KEW and DEW energy sources are being developed to conduct interactive discrimination experiments to help solve the critical problem of distinguishing real targets from decoys/penaids and space debris, especially in the midcourse phase of a ballistic missile's flight.

In general, the technology for kinetic energy defensive weapons is more mature than that for DEW. Challenges remain for kinetic energy technology to provide weapons with greatly reduced size and cost. SDI progress in this area is evidenced by the significant number of highly successful KEW flight experiments performed in the last two years. In addition to weapons using rocket propulsion, significant progress has also been made using electromagnetic launchers (EMLs). At the end of 1985 at least 16 EML facilities were in operation. DEW technology is progressing along several paths: thermal lasers, impulse lasers, and neutral particle beams, all of which show promise.

As previously mentioned, ground- and space-based weapon systems require target track information which is integrated into the overall battle management function. The SDIO has initiated a coordinated effort to design experiments to resolve important tracking and pointing issues. The focusing of combined experiments involving both tracking targets with sensors and pointing of weapons toward targets is an example of integrated experiments which resolve critical issues. Previous research had concentrated on independent sensor and weapons performance.

1. Kinetic Energy

a. Exoatmospheric Reentry-Vehicle Interceptor Subsystem (ERIS). On June 10, 1984, the Homing Overlay Experiment (HOE) intercepted and destroyed an incoming mock warhead in the midcourse regime. In demonstrating a successful intercept, the HOE resolved many critical issues associated with nonnuclear defensive weapons. This important milestone was reported earlier.

Following the HOE success, the U.S. Army Strategic Defense Command (USASDC) began the Exoatmospheric Reentry-Vehicle Interceptor Subsystem program, with the objective of developing and functionally validating technology advances adaptable to a low-cost, ground-launched interceptor. The key issue of the ERIS program is achieving low life-cycle cost per kill using advanced technologies.

Analysis, simulations, and flight test results are being used to develop an ERIS baseline concept and a Functional Technology Validation (FTV) design (Figure 14). The latter will use available components, where technically feasible, to

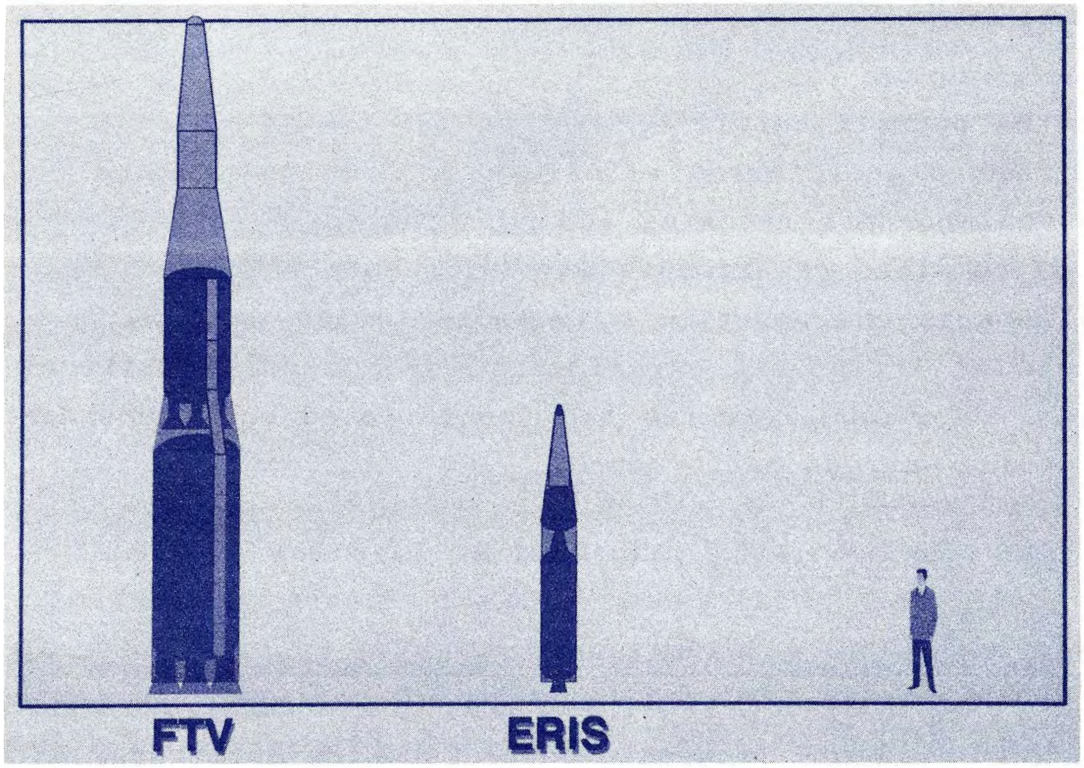


Figure 14 ERIS FTV vs. Baseline Air Vehicle

validate the baseline concept in actual flight tests. Critical algorithms, such as end-game homing, have been checked by simulation against a variety of threats to verify performance. An innovative lethality-enhancement device with attached kill fragments has been tested in the laboratory to simulate an actual engagement. Continuing trade-off studies and tests will refine the ERIS baseline concept.

b. Flexible Lightweight Agile Guided Experiment (FLAGE). On April 20, 1986, a FLAGE flight vehicle directly impacted a 44-inch diameter aluminum sphere at 12,000-foot altitude. This experiment achieved the guidance accuracy required for a nonnuclear intercept of an incoming warhead within the atmosphere. In a second test on June 27, 1986 at White Sands Missile Range, a ground-launched FLAGE destroyed a target moving at more than three times the speed of sound. The FLAGE, which was launched 22 seconds after the target was released from an aircraft (Figure 15), used its on-board radar guidance system to lock onto the target and guided

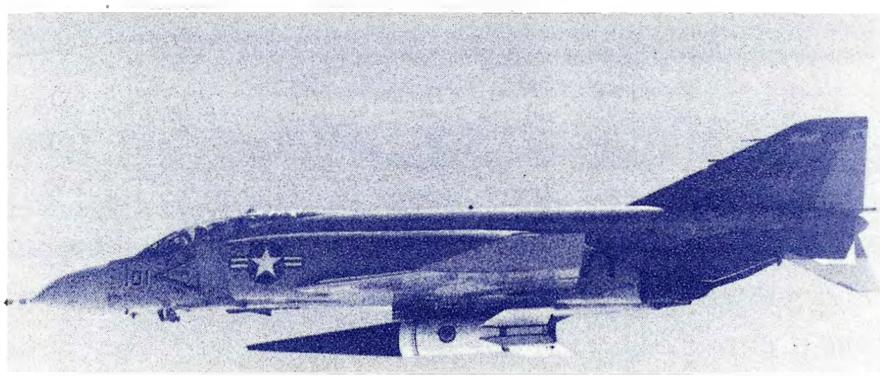


Figure 15 FLAGE Target on Launch Aircraft

itself to the point of impact by firing 216 azimuthally mounted shotgun-shell-size solid rocket motors. Although this intercept took place at 12,000 feet (Figure 16), it demonstrated technologies for guidance, maneuvering, and destruction which are applicable for longer range experiments, as well as a concept for intercepts outside the Earth's atmosphere.

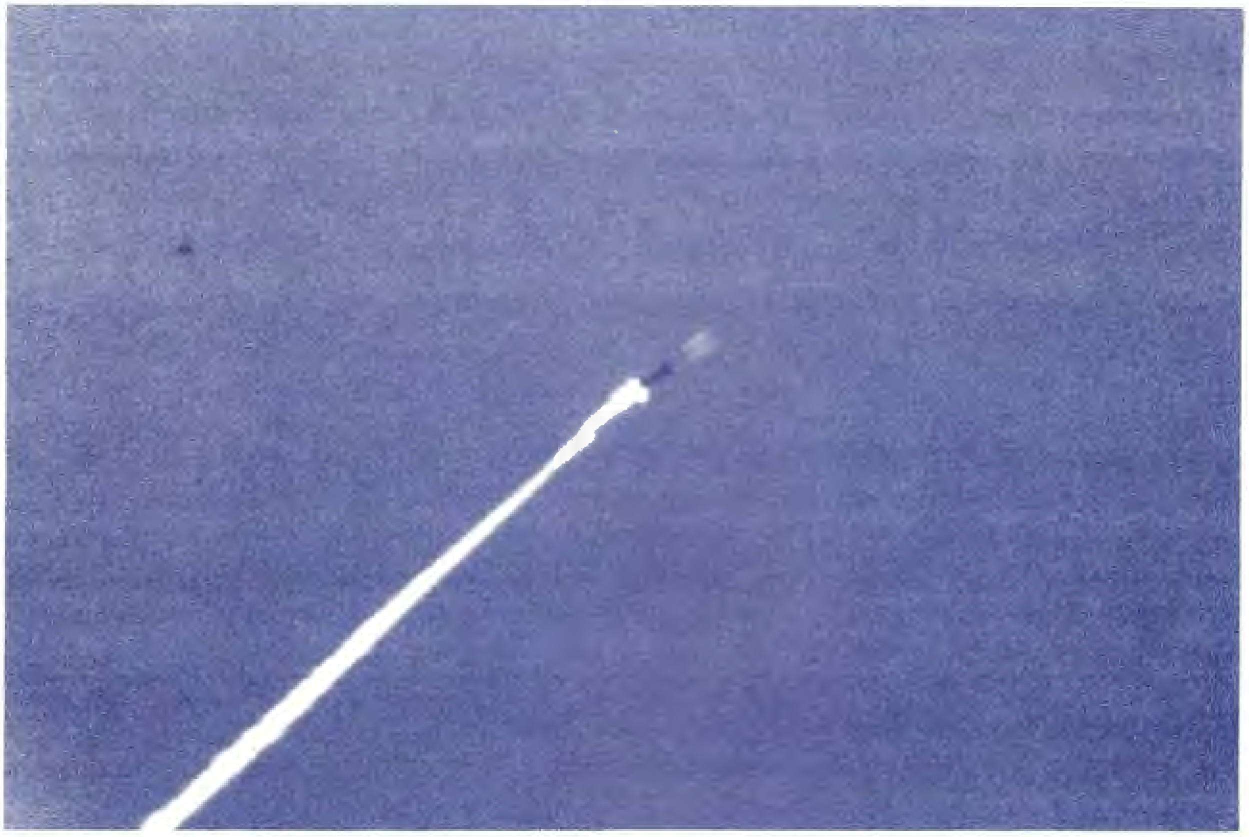


Figure 16 FLAGE Target Intercept

c. High Endoatmospheric Defense Interceptor (HEDI). During the past year, the HEDI program demonstrated significant progress in subcomponent technologies for nonnuclear intercept and target kill within the atmosphere. In a series of wind tunnel experiments, the program showed that the boresight error for varying interceptor configurations could be predicted and measured. Measurements gave line-of-sight deviations over a wide range of conditions at Mach 10. Three different forebody shapes with five different look angles were measured.

A major concern has been the potential catastrophic damage to the optical sensor window during hypervelocity flight through the atmosphere. The HEDI program demonstrated, in wind tunnel tests, that an optical window could be cooled in the stressing aerothermal environment of a high endoatmospheric intercept (Figure 17). Several cooling methods were investigated, and one, a slot method using nitrogen as the coolant, was found to be very effective.

Figure 17 HEDI Window Test

d. Rocket-Propelled KEW. A 5-pound-thrust Attitude Control System (ACS) engine (Figure 18) was successfully fired on May 27, 1986. The test demonstrated engine durability, injector stability, and repeatable thruster performance. This low-weight, fast-response engine design can be used to maintain vehicle stability for space-based kinetic-kill weapons.

Figure 18 Attitude Control System Engine

e. Electromagnetic Launcher. In the EML rail gun and related technology areas (see Figure 19), SDI research resulted in a number of important advancements. One rail gun program achieved velocities above 8 km per second for relatively large projectiles. In another, several materials were tested for suitability as insulators in electromagnetic gun systems. Two materials exhibited no degradation after 300 shots. These results show promise in solving the rail erosion problem. Other experiments investigated a new cryogenic inductor capable of storing more than 15 megajoules of energy. In the critical area of projectile guidance, a new type of silicon focal plane array using miniaturized electronics was successfully tested. The array survived an electromagnetic gun acceleration of over 100,000 g's.

Figure 19 Electromagnetic Rail Gun

2. Directed Energy

a. Acquisition, Tracking, and Pointing. Laser beams (weapons and designators) must be kept very stable in the presence of disturbances and during high-rate slewing maneuvers. A benchmark tracking and pointing demonstration device successfully met its laboratory precision pointing goals in December 1985, thus demonstrating several key aspects in the understanding of how to point a weapon or sensor in space with the precision necessary for directed energy systems. A series of these experiments will pave the way for a tracking and pointing experiment due to fly on the space shuttle in 1989. Components to be tested include fast-steering mirrors (Figure 20), focal plane arrays, wave-front sensors, and precision optical alignment devices.

Figure 20 Fast–Steering Mirror

b. Atmospheric Compensation. Turbulence in the atmosphere distorts a ground-based laser beam, thereby reducing its effectiveness as a weapons device. One way of maintaining a high-quality beam through the atmosphere is to continually adjust the beam director optics to compensate for the turbulence. In an extensive series of experiments (Figure 21), a visible, low-power laser beam, using an adjustable beam directing mirror, was sent from a fixed ground site to various airborne and space targets, including an aircraft, the space shuttle, and sounding rockets. The experiments resulted in preserving a high-quality beam at the target.

Figure 21 Atmospheric Compensation Experiment

The correction process highlights the considerable progress made in developing adaptive optics for atmospheric compensation. The adaptive optics mirror was fabricated using 69 actuators to change the shape of the mirror, a technology scalable to much larger sizes (Figure 22). In addition, several new programs were begun to develop technology that could be used for adaptive optics systems having between 10,000 and 100,000 compensating actuators.

Figure 22 Beam Control Mirror

c. Laser Technology

(1) Single Lasers. The technical feasibility of a chemically powered laser as a candidate for space-based lasers will be initially evaluated using ALPHA, a high-power, hydrogen fluoride laser, in a ground facility designed to simulate the vacuum conditions of space. The FY86 effort has centered around fabricating and integrating the cylindrically shaped laser and test facility and building the laser's gain generator. Figure 23 shows the test facility under construction in Capistrano, California, which is scheduled for completion in 1987.

Figure 23 ALPHA Test Facility in Capistrano

(2) Coupled Lasers. Brightness levels for BMD missions may require the mutual coherence, or phasing, of

several lasers. The first experimental demonstration of mutually coherent operation of six single-line carbon dioxide lasers, and the first experimental demonstration of mutually coherent operation of two multiline deuterium fluoride chemical lasers (Figure 24) recently occurred. This work is a step toward demonstrating the feasibility of lasers for both ground- and space-based laser applications.

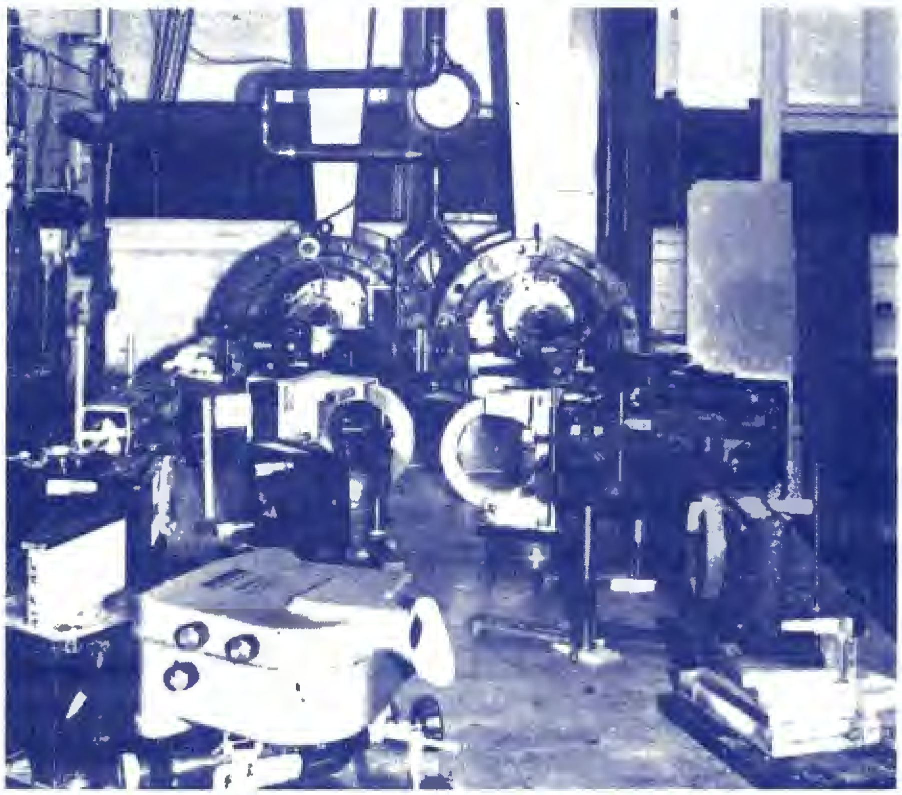


Figure 24 Coupled Chemical Laser Demonstration

(3) Large Optics. A complete set of cooled optics was fabricated for the ALPHA program. Two components are shown in Figure 25. Optics up to 1.25 meters in diameter that maintain their surface figures to fractions of visible light wavelength under high-power laser irradiation have been successfully designed and fabricated. The mirrors represent a major advancement in the state-of-the-art for large metallic optics and form the key components of the optical resonator.

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Figure 25 ALPHA High-Power Laser Optics

An alternative way to preserve high-power laser beam quality as it propagates through the atmosphere makes use of nonlinear optical phenomena such as stimulated Brillouin and Raman scattering. Such approaches may reduce complexity yet improve performance. The research facility (shown in Figure 26) for studying such phenomena at significant power levels has been completed at the Capistrano test facility.

d. Free Electron Laser (FEL) Technology. FELs offer the potential for developing a short-wavelength ground-based laser weapon that could penetrate the atmosphere. The wavelength can also be adjusted to maximize effectiveness. Two types of electron accelerators are under investigation for this highly promising area: the Induction Linear-accelerator FEL (ILFEL) and the Radio Frequency FEL (RFFEL).

An infrared free electron laser experiment, called PALADIN, is being constructed. Figure 27 shows a five-meter section of the "wiggler" component undergoing tests prior to installation. Installation and preliminary experiments are now under way.

Figure 26 Nonlinear Optics Research Facility

Figure 27 PALADIN Free Electron Laser Experiment (Five-Meter Section of "Wiggler")

Experiments using an ILFEL facility have demonstrated efficiencies up to 40 percent for converting electron-beam energy to coherent radiation. The instantaneous output power was about two hundred times the output of the Mid-Infrared Advanced Chemical Laser (MIRACL) at White Sands, New Mexico, National Test Range.

Three RFFEL contractors have also had considerable success. One has nearly completed a new experimental FEL and the other two have made record progress on existing FELs in the area of energy recovery. Energy recovery is critical to realizing the high efficiency potential of the RFFEL concept (Figure 28).

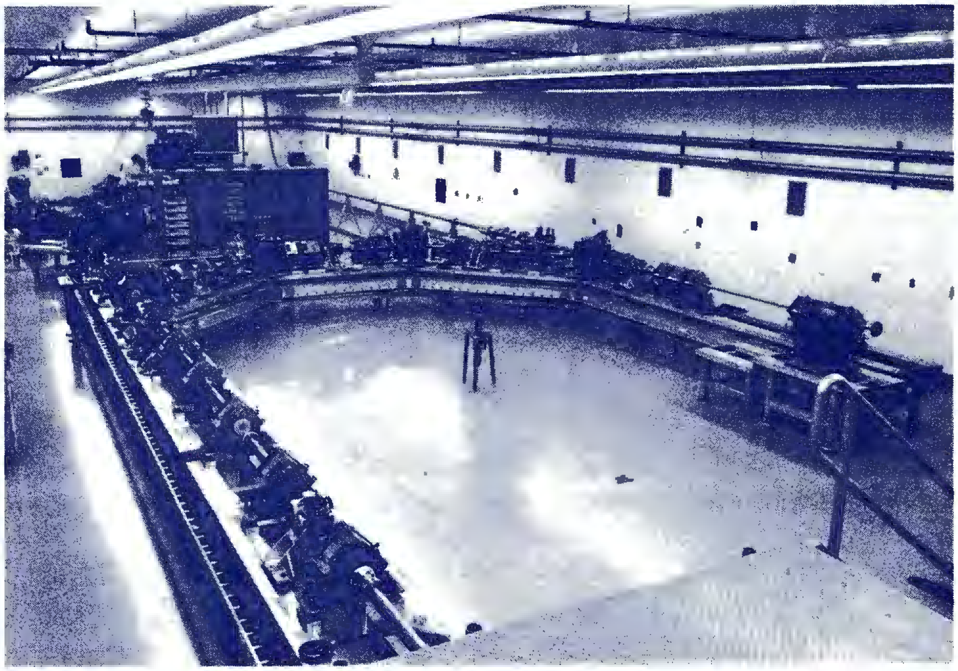

Figure 28 Radio Frequency Free Electron Laser

Because both the peak and average power of free electron lasers have increased, mirrors and coatings to handle high powers without damaging the optics are being improved.

A recent experiment, shown in Figure 29, demonstrated the use of grazing-incidence optics to reduce the power density on the mirrors in a high-power laser. At the shallow incident angle, the area of the beam footprint increased fourteenfold, permitting a corresponding increase in laser energy before damage to the optics occurs.

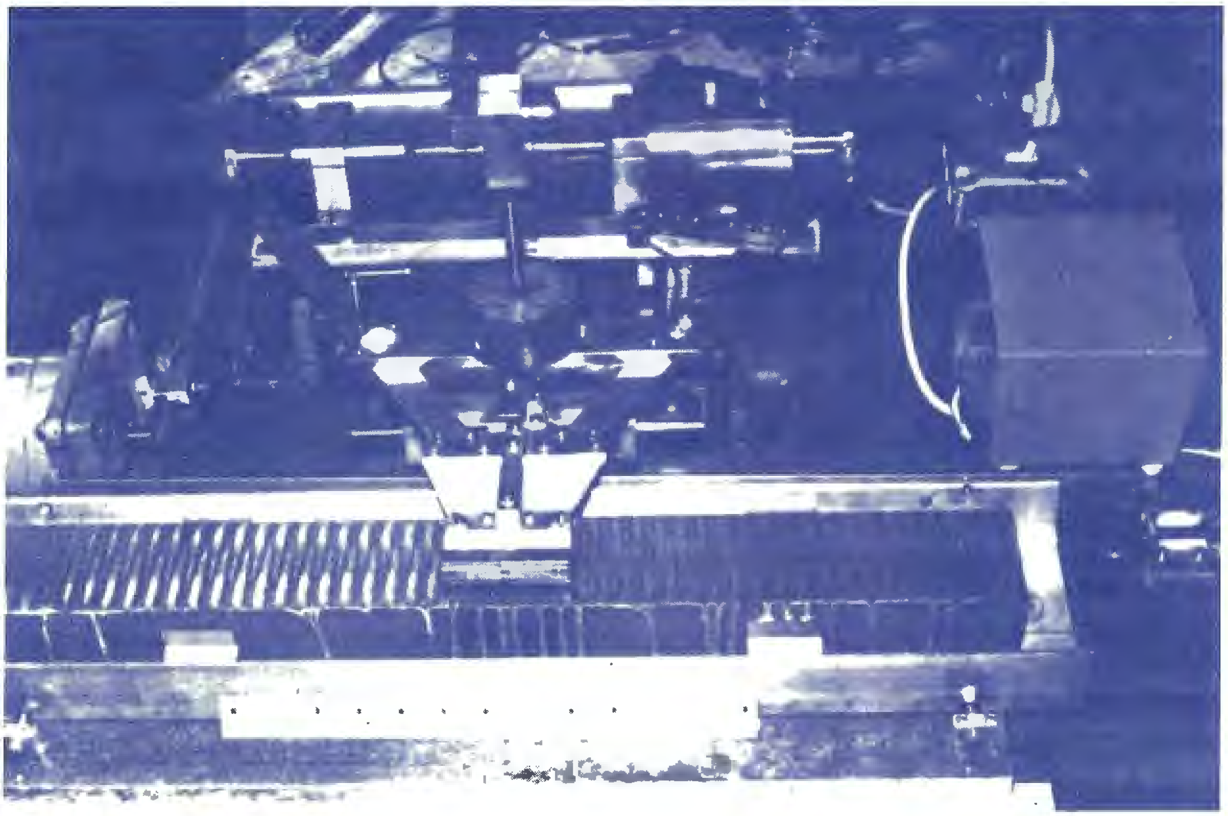

Figure 29 Grazing Incidence Optics in a High Power Laser

Cooling the optics can also reduce the damage by high-power, short-wavelength lasers. Three configurations with the potential to provide such cooling to more than five times the current state-of-the-art have been designed and subscale samples are under fabrication for verification testing.

e. Neutral Particle Beam (NPB) Technology. The NPB is a promising directed energy device which could have applicability as a weapon and as an interactive discriminator. As a weapon it could cause electronic upset or physical damage. The reaction of the target to low energy particle beams is mass dependent and may provide an excellent mechanism for discriminating real RVs from decoys or debris.

Experiments over the past several years have successfully demonstrated that high-brightness negative-ion beams, which serve as the source for producing neutral particle beams, could be produced in a compact accelerator four meters in length (Figure 30). Recently an increase in the energy of the particle beam, two and one-half times that of previous experiments, has provided evidence that high power NPBs are a viable option for space-based strategic defense.

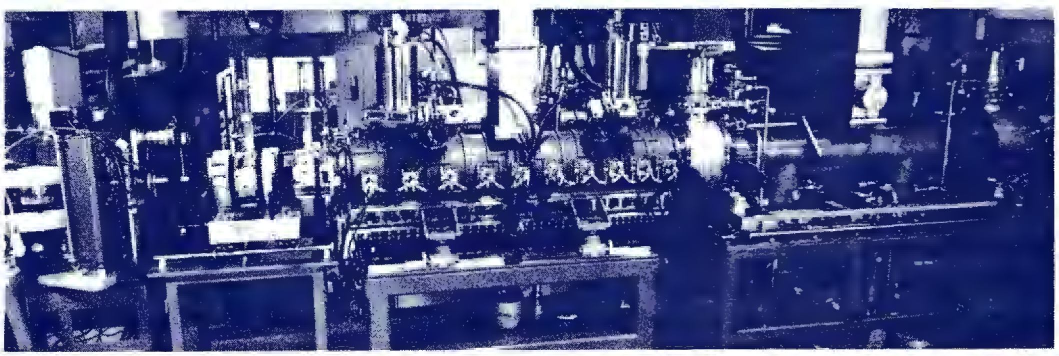

Figure 30 Neutral Particle Beam Accelerator Test Stand

D. <u>KEY SUPPORT TECHNOLOGIES</u>

Key support technology activities applicable to multiple aspects of the SDI program are Survivability, Lethality, Power, Materials and Structures, Space Transportation, and Logistics and Supportability.

All system architecture study contractors have concluded that several survivability measures will be necessary to protect a strategic defense against attempts to overcome it. Many of these, including shielding and tactical positioning and maneuvering, are being investigated.

The lethality project is aimed at conducting research on the physics of kill mechanisms, target damage at different energy levels, and hardening an adversary could apply to targets to resist defense weapons. The same basic materials research in the lethality technology program is applicable to the survivability of U.S. defense systems. Research in the lethality and survivability programs is closely coordinated.

Space-based electrical power generation is another key technology area that will require considerable improvement over current capabilities. The goal is to enable future defense systems to function reliably for long periods of time, and be compact enough to be economically placed in orbit.

A new program on advanced materials and structures to reduce weight and improve structural integrity primarily for space systems applications has been initiated in FY87.

1. Survivability Research

Analyses from the architecture studies have shown the need for multiple measures to protect satellite systems and communications links by proliferation, distribution of functions, use of defense weapons, and other techniques. The analyses indicate that the cost of including survivability measures in strategic defenses are similar to those of ground, sea, and air forces and may form a substantial portion of the cost of the systems. Inclusion of survivability requirements at an early stage in satellite design is also being addressed.

As an example of progress in survivability technology, Figure 31 shows a star tracker that is used in attitude and navigation systems and is hardened to be survivable against nuclear weapon effects. This technology will also be applicable to laser communications, target tracking, spacecraft position determination, and array/structure alignment control.

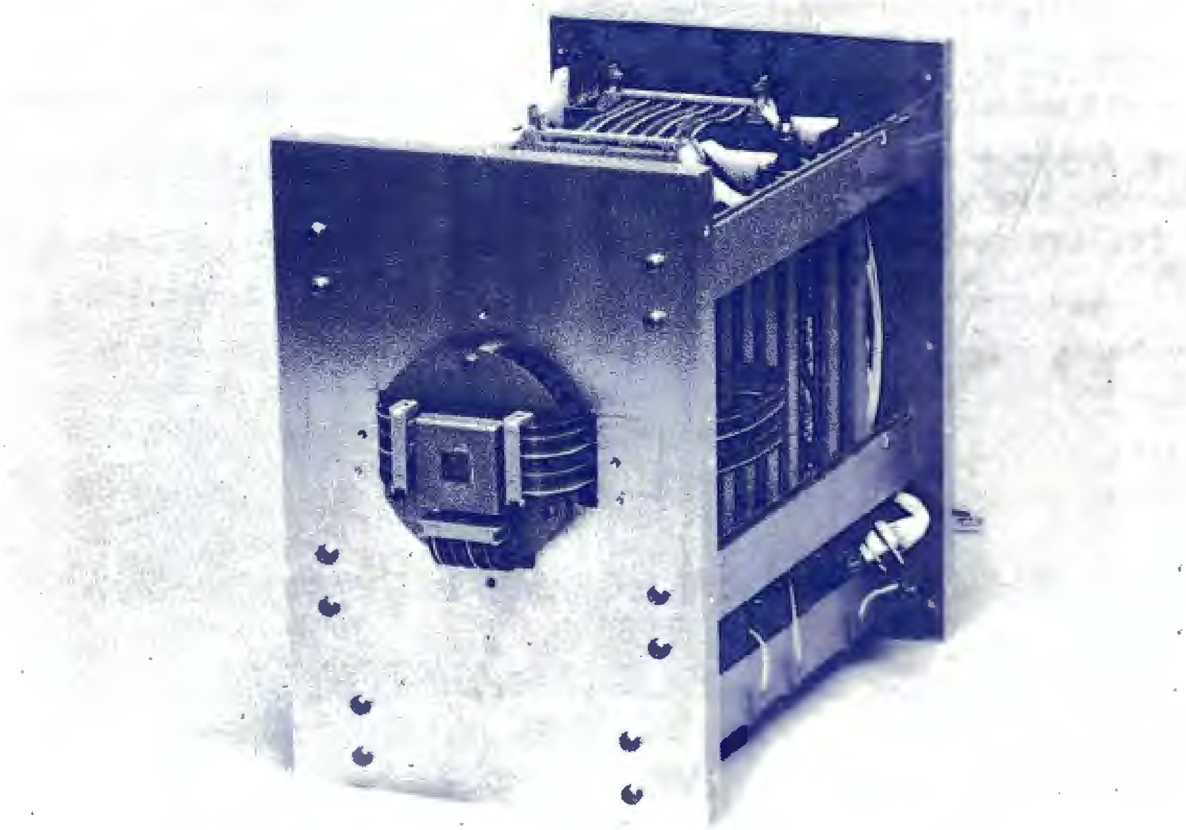

Figure 31 Star Tracker

2. Lethality

During the fall of 1985, the Lethality and Target Hardening program conducted several ground experiments firing lightweight projectiles at model replicas of Soviet missiles, solid-fuel motors, post-boost vehicles, and reentry vehicles. Test results showed excellent agreement with present analytical models. Model post-boost vehicles were destroyed, and solid-fuel motors failed catastrophically.

A lethality experiment using the Mid-Infrared Advanced Chemical Laser (MIRACL) device was conducted in 1985 at White Sands Missile Range. The target, a Titan booster rigged to simulate the loads of a thrusting booster, was destroyed (Figure 32). Recently, a high intensity test series, designed to determine if new materials for laser hardening can work as effectively as some theorists have predicted, was completed using the MIRACL laser.

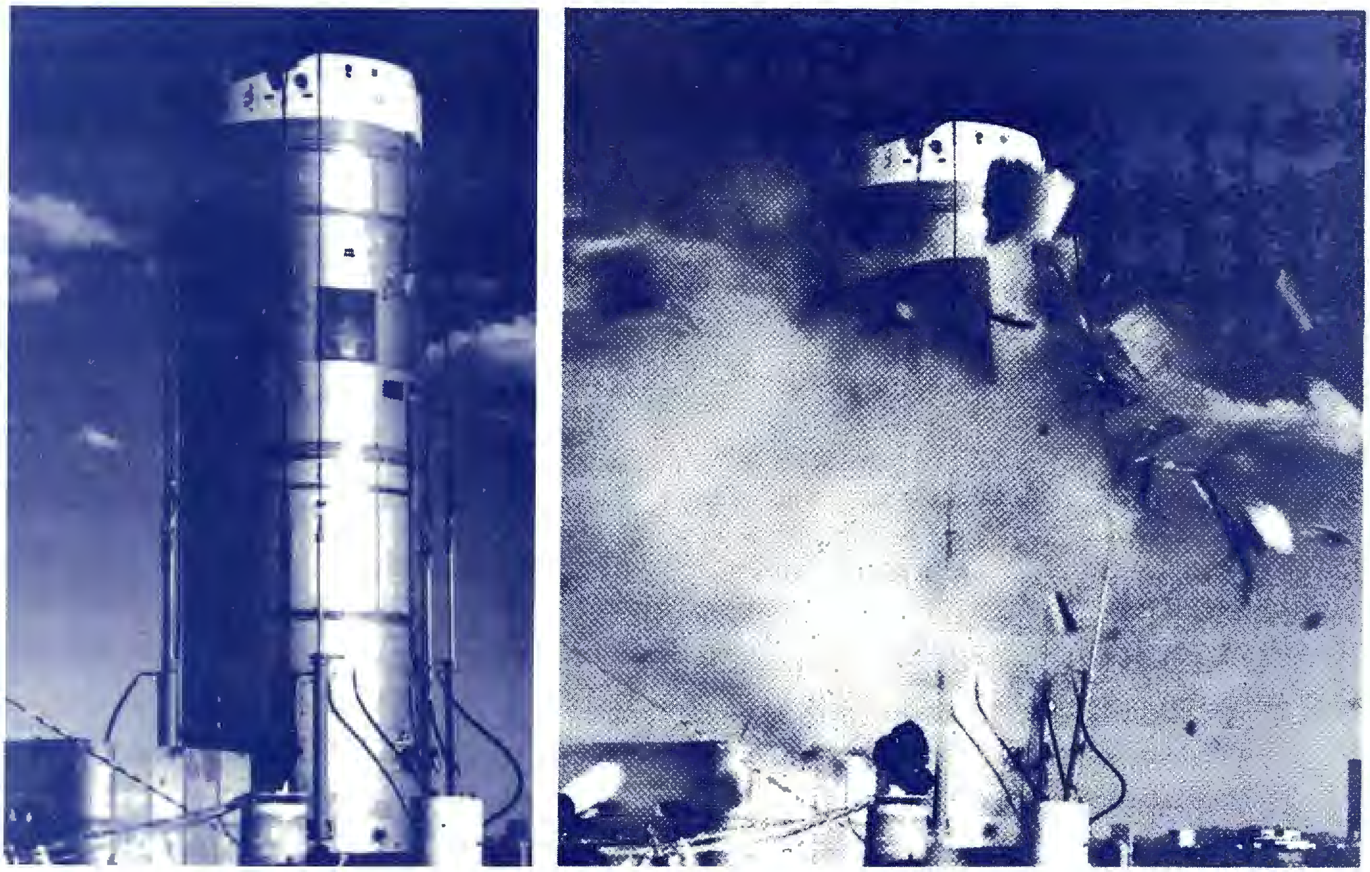

Figure 32 Laser (MIRACL) Device Lethality Experiment

During July 1986, the first Particle Beam Lethality Experiment was performed. This experiment, conducted at a dedicated radiation effects facility, irradiated a subscale reentry vehicle with a high-intensity proton beam. The preliminary results indicate that the high explosive contained in the reentry vehicle was highly vulnerable to the particle beam.

3. Power

Space-based power for weapons systems will need to provide hundreds of megawatts of electric power for the duration of an engagement -- far beyond current engineering experience. The multimegawatt power program is investigating power system concepts and critical technology needs for both prime power and power conditioning.

Because of its long development time, the nuclear portion of the program is necessarily a long-term effort. Information on reactor technology will come from the joint SDIO-DoE-NASA SP-100 space reactor program, intended to supply base-load power for space platforms, and from the joint SDI-DoE nuclear multimegawatt prime power program.

The nonnuclear portion of the program is near term and is assessing candidate power supply concepts and related technologies. Critical power conditioning technologies include switches, RF sources, inverters, capacitors, and high-voltage components. Among the power supply concepts are rotating machines, electrochemical systems, and magneto-hydrodynamic (MHD) devices. Experiments involving selected concepts such as the MHD generator shown in Figure 33 have been successfully conducted.

4. Materials and Structures (M&S) Program

Four studies conducted during 1985 recommended an absolute and critical need for an SDIO centrally managed Materials and Structures program. Each study identified pertinent critical technologies which could be "show stoppers" (e.g., weight, structural response, settling time).

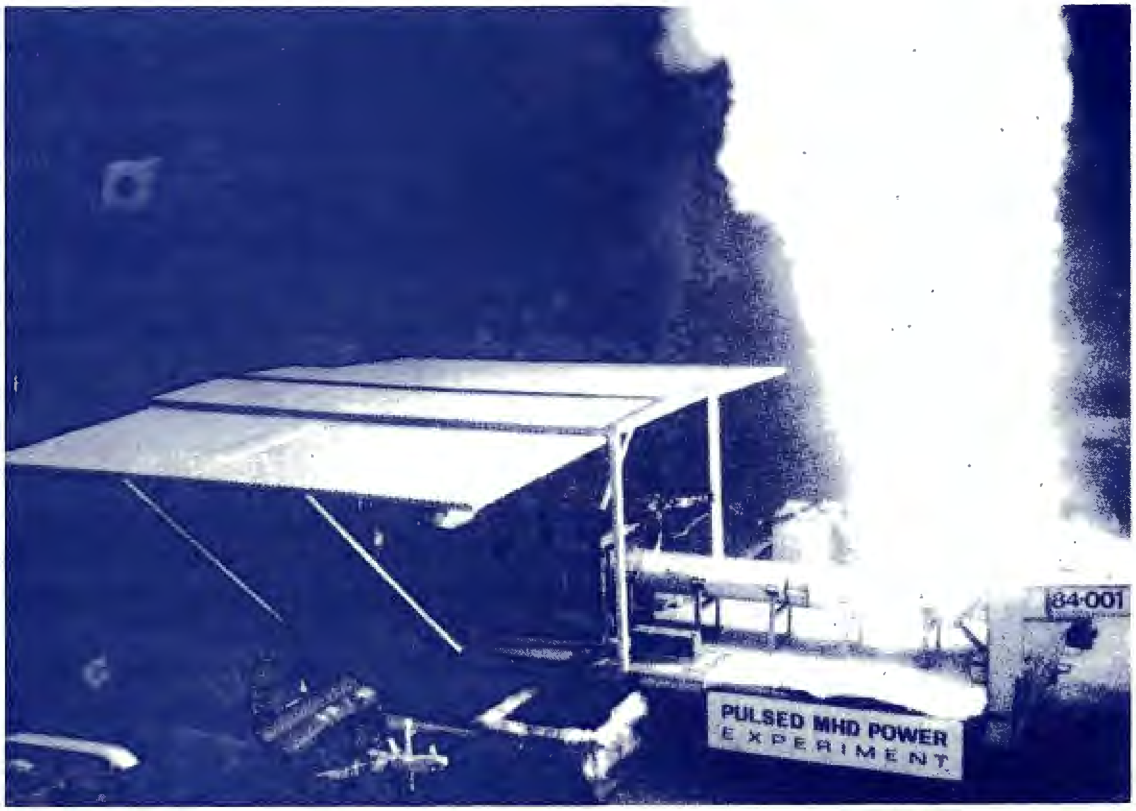

Figure 33 Multimegawatt Pulsed MHD Power Experiment

The M&S program has established six technology panels staffed with experts from DoD, NASA, DoE, SDIO, and other agencies, to address critical enabling technologies in the following areas: structural materials, tribological materials, lightweight structures, thermal management materials, power materials, and advanced optical materials. The panels are reviewing the various agencies' technology base programs relevant to unique SDIO requirements. In addition, they are reviewing SDIO efforts being conducted within the various agencies for common M&S requirements. The results of these reviews will be incorporated into the M&S FY87 program and five-year technology plan.

5. Logistics and Supportability

The SDI Supportability Research Policy created the Integrated Supportability Working Group (ISWG) to address support requirements for SDI and provide the forum for logistics integration across all elements of the program. Research on logistics technology issues is necessary to assure that any defense architecture being considered could be deployed, operated, and maintained at an affordable cost.

A six-month effort was conducted to review ongoing and planned logistics research, analyze the evolving SDI architectural options and their support requirements, and estimate the logistics technology investments needed to accomplish the required tasks. The research identified 18 logistics technology issues, such as Servicing Fluids and Maintaining Sensors and Mirrors in Space; prioritized these issues; and laid out an investment profile for their funding. These issues were applicable across many program elements. Further research is planned to reevaluate the issues and the assumptions of the study and to provide initial funding toward their solution.

E. INNOVATIVE SCIENCE AND TECHNOLOGY

The rapid advancement required in some areas of SDI technology to keep pace with potential evolving threats and the need to develop affordable systems dictate the pursuit of innovative, high-risk/high-payoff research. If successful, these efforts may result in capable technology that can be utilized earlier and at reduced budget levels. The following are examples of such efforts.

1. Advanced Capacitor Technology Development

The SDIO is jointly sponsoring with the Defense Nuclear Agency two capacitor development programs: the Rep-Rated Long Life Capacitor Development and the Ultra-High-Energy-Density, Super Capacitor Development.

The objective of the Rep-Rated Capacitor Program is to provide energy storage for both ground-based and space-based systems through low-energy, fast-discharge capacitors capable of continuous operation at high repetition rates for years. Since the program's inception in 1984, the life of these capacitors has been extended by a factor of 11 while maintaining high energy densities. Experiments are also yielding improved radiation hardness and reliability.

The Super Cap Program, begun in 1985, is investigating low-repetition-rate, fast discharge capacitors designed for electromagnetic launcher applications. A factor of two increase already has been achieved in energy storage density over commercial capacitors. These metal-insulator-metal capacitors have small volume, light weight, low power loss, low contamination rate in space, and long lifetime.

2. Gamma-Ray Laser Development

Since 1978, gamma-ray laser research has been conducted based upon converting long-wavelength radiation incident upon nuclei of atoms to shorter wavelengths. A gamma-ray laser could be used to beam high-energy radiation into targets with a power exceeding by a large factor that of other longer wavelength lasers. The central problem of a gamma-ray laser has been to identify the proper materials from which such a laser could be constructed. Recently, a breakthrough occurred when it was found that the recoil of the nucleus due to gamma-ray emission could be compensated for by using an external laser as an additional energy source.

3. Microminiature Refrigeration

A prototype microminiature refrigerator, which is the size of a quarter and can cool an infrared detector, has been designed (Figure 34). This refrigerator may be a key element in enabling large-array detectors to be cooled effectively in space.

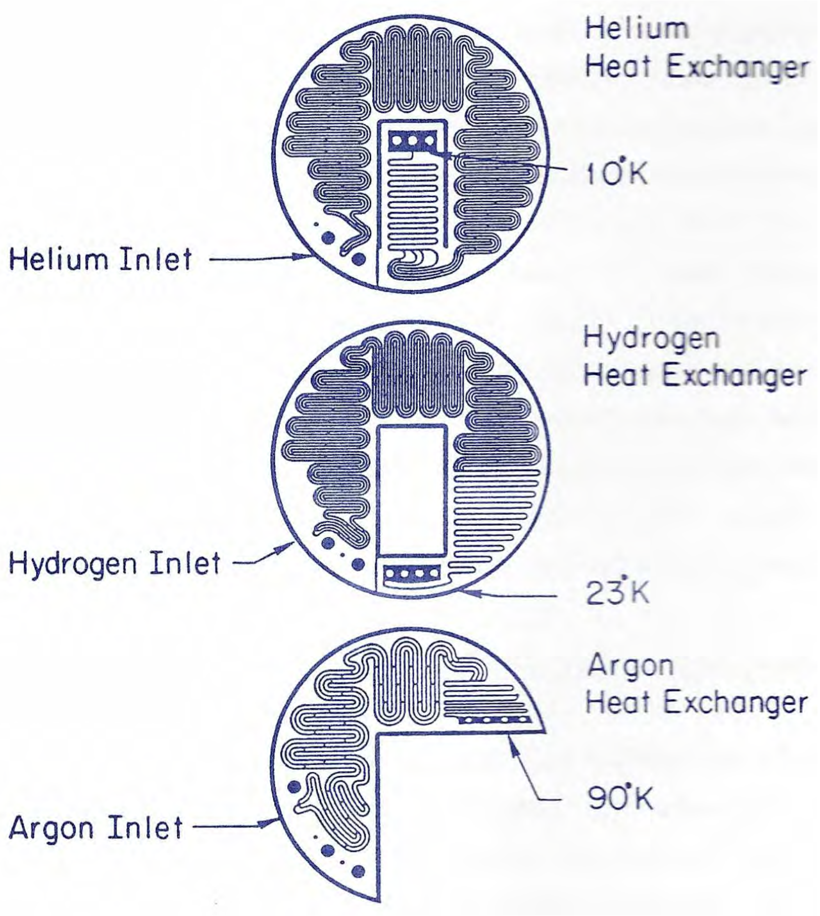

Figure 34 Prototype Microminiature Cooling Elements

The refrigerator has three stages that use argon, hydrogen and helium to cool to 10°K. These microminiature refrigerators will weigh less than 2 grams (0.1 oz).

4. Composite Materials

Graphite-reinforced composites have displayed a high resistance to high-power laser penetration. When hit with a projectile, the reinforced ceramics do not shatter. When punctured by a projectile, cracks do not propagate. The area around the hole is destroyed, but the rest of the structure is unaffected. This class of material holds promise for large space structures. It is lightweight, can dissipate a large amount of solar heat and laser energy without altering its shape, and retains that shape when hit by a projectile.

A new composite material, lithium alumina silicate glass reinforced with silicon fibers, is under investigation for potential use in high mechanical and thermal stress applications in space, such as may be found in directed energy weapons. The composite material has a fracture toughness close to that of aluminum but with a lower density. Its ceramic properties give the composite material excellent heat dissipation.

5. Insulating Polymers

A new insulating polymer was designed totally by computer simulation and then synthesized in the laboratory. The synthesized polymer has demonstrated the designed-in electrical properties, making it possible to begin to construct new high-energy-density, super capacitors.

6. Rail Gun Technology

A test facility for high-energy rail guns as a power conditioning facility was demonstrated in December 1985.

This facility uses newly developed technology in high-energy-density capacitors (Figure 35). It is the first rail gun where the advantages offered by capacitors are utilized to produce the extremely high energy previously available only with compressors or generators. This system allows rail gun issues to be separated from problems of power-source development.

Figure 35 Rail Gun Test Facility

F. TECHNOLOGY INTEGRATED EXPERIMENT

A technology integrated experiment incorporating a number of technology subsystems in an experiment to verify interoperability between the subsystems, test their integrated performance, and test each individual component's performance was conducted on September 5, 1986.

A Delta 180 rocket was launched from Cape Canaveral carrying instruments to obtain data for characterizing rocket plumes during the boost phase, to study rocket signatures during the close-in phase of space intercept, and to validate guidance laws using actual accelerating vehicles. All three missions were successfully accomplished, and the results have provided data critical to the design of small kinetic energy weapons. The experiment utilized an SDI satellite, shown in Figure 36, carrying a Phoenix missile air-to-air radar tracker and a Delta second-stage rocket modified to carry advanced infrared sensors, the first laser radar ever flown in space, a Maverick air-to-ground missile IR imaging system, and two cameras.

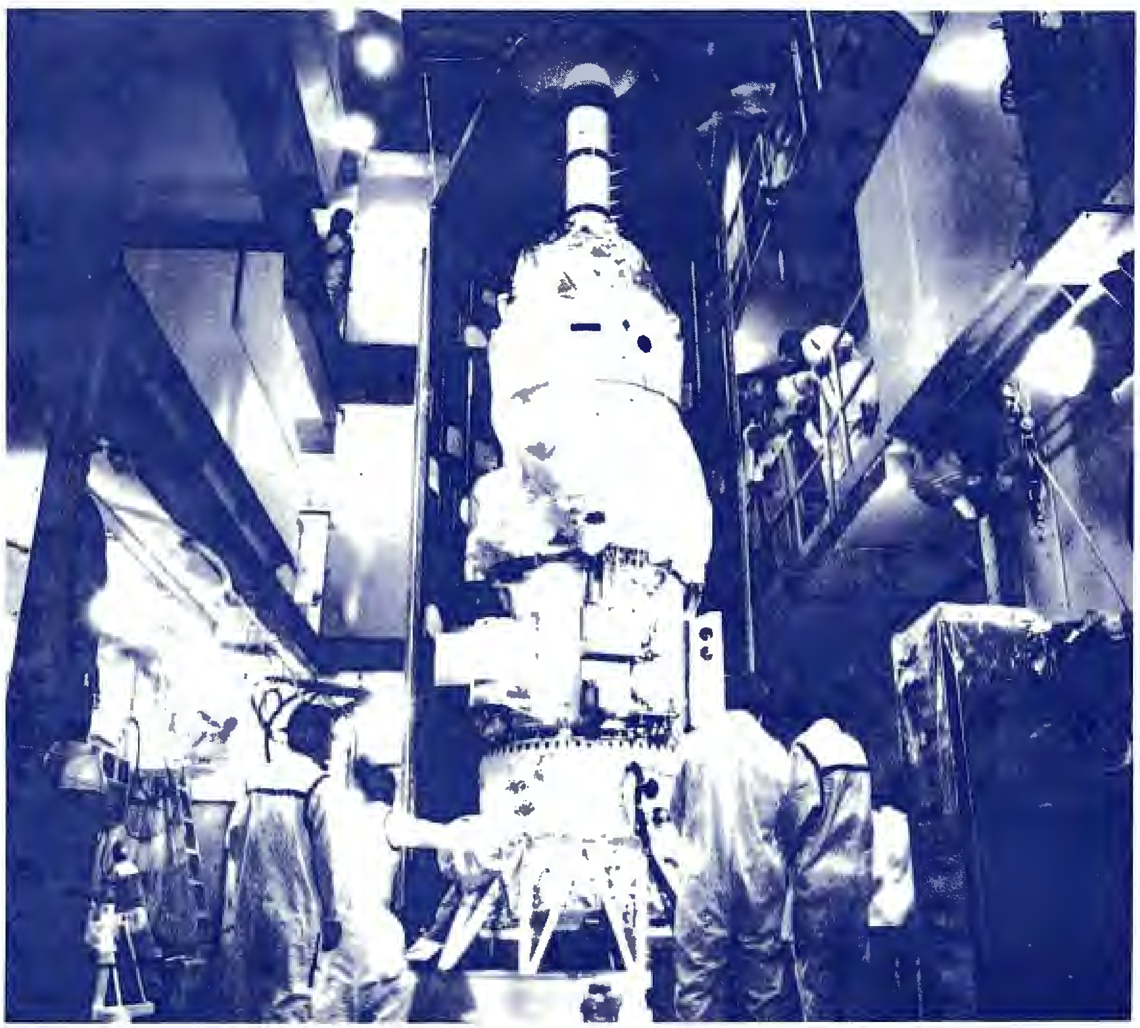

Figure 36 SDI Satellite Experiment on Delta 180

The successful target intercept at a closing rate of 6500 mph, shown in Figure 37, was made possible by the high accuracy of the Phoenix air-to-air radar. The mission was supported by six aircraft airborne around the world, 38 radars, 31 satellite communications links, and the simultaneous coordination of four

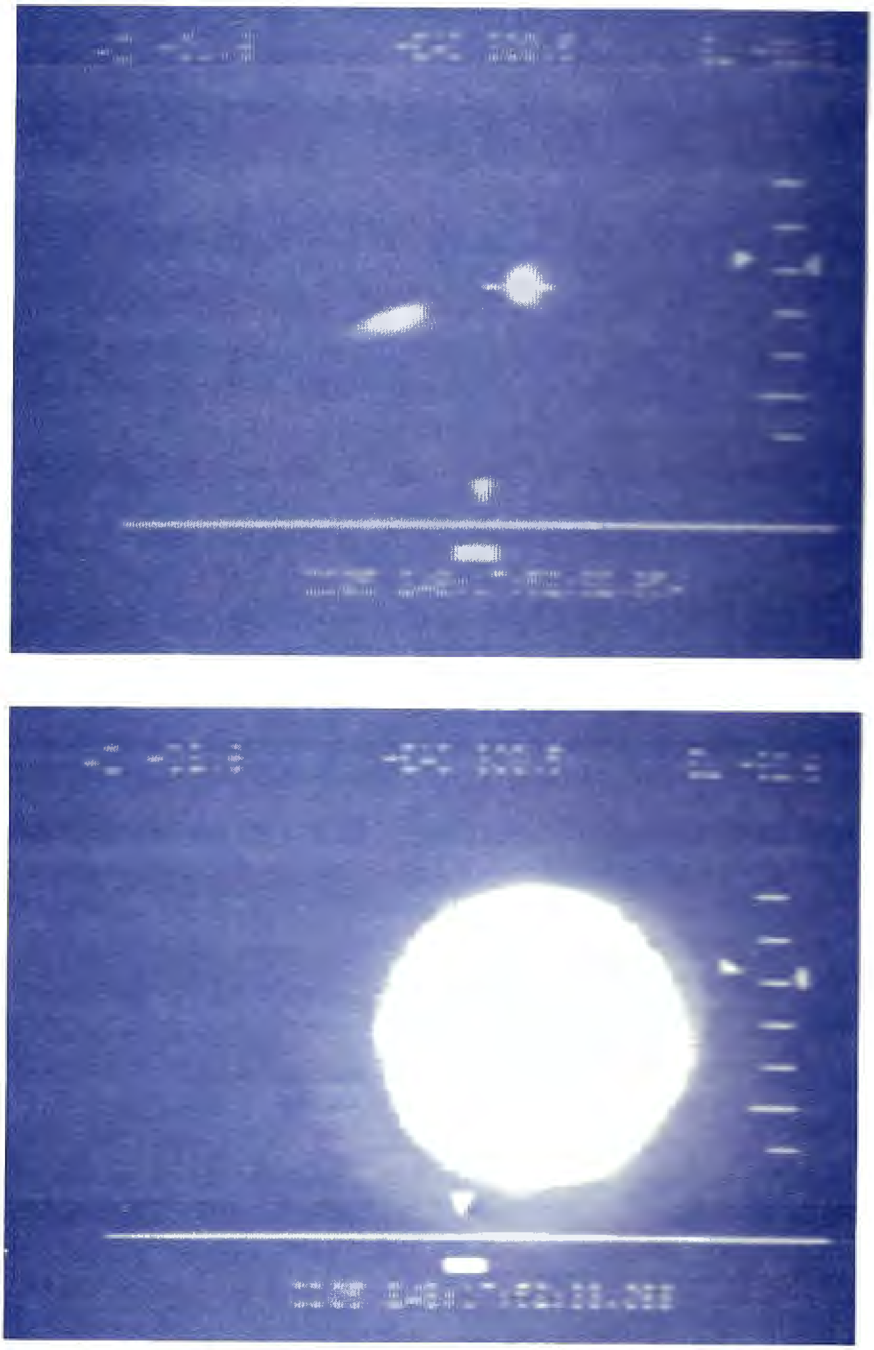

Figure 37 Delta Target Closure (Top) and Intercept (Bottom)

U.S. test ranges. Additional integrated experiments testing other new technology developments relevant to a strategic defense capability for the boost phase are now being planned.

III. SUMMARY

Over the past 18 months, significant progress has been made toward establishing the basis for a decision to proceed with full-scale development and deployment of a defense against ballistic missiles.

Continuing studies of defense architectural options have provided information on specific issue and technology trade-offs that are key to determining the feasibility of strategic defense concepts. Battle management simulation efforts are under way and the electronic advances needed to support the actual fielding of C^3 systems are progressing rapidly. State-of-the-art development for computer speed and capacity is within an order of magnitude of required levels to satisfy near-term battle management requirements.

Research in advanced signal processors and cryocooler technology needed to support the space operation of infrared sensor systems has progressed to the point where several technology integrated flight experiments are planned.

Kinetic energy weapons technology for ground-launched, rocket-powered interceptors has been developed and is ready for validation testing. Considerably more research is required to reduce the size and cost of electromagnetic launchers and to develop adequate power systems for their use in future weapons applications.

Directed energy weapons technologies are less mature than those involved in kinetic energy weapons. Additional research is required to develop lasers and particle beams into high brightness weapons applications. Low power devices including excimer, chemical, and free electron lasers and neutral particle beams are being built and will be available for testing the feasibility of interactive discrimination of targets from decoys as well as determining the scalability to weapons level output. The Department of Energy is continuing its research on the X-ray laser.

Lethality investigations have led to a better understanding of the basic phenomenology of interactions between weapons and targets. This research has also been applied to the resolution of survivability issues for U.S. and allied systems.

The SDI program is now engaged in cooperative research projects associated with allied participation in the program. These joint efforts are introducing new approaches to solving technology problems.

Technical progress achieved in the SDI program to date is leading to validation experiments, such as the Delta 180 technology integrated experiment. System-level validation experiments such as those being planned for the National Test Bed are intended to provide confidence in making a decision on whether to proceed with development of a strategic defense system. These experiments will be the next step in meeting SDI objectives.