Statement of Lieutenant General Malcolm R. O'Neill, USA, Director, Ballistic Missile Defense Organization before the Committee on National Security, House of Representatives, April 4, 1995

Mr. Chairman, it is my privilege to appear before this hearing with the Subcommittee on Research and Development today to testify on the accomplishments of the Ballistic Missile Defense program. I am delighted that this Committee has taken the time to hold multiple hearings on the BMD program. However, I am particularly pleased that today we will address the specific accomplishments the Department of Defense and industry have achieved in making ballistic missile defenses a reality.

I believe our investment in the Ballistic Missile Defense (BMD) program over the past twelve years has been sound and fruitful. When and where there has been consensus between the Executive and Legislative branches, our progress has been especially outstanding. With regard to programs such as Theater Missile Defense (TMD), for which deployment is authorized, we are bringing hardware into the field now. With regard to programs such as National Missile Defense (NMD), for which deployment is not authorized, technologies are being readied which will support deployment when and if approved. Overall, as a Nation, we have done what we set out to do twelve years ago -- demonstrate that ballistic missiles of all ranges could be detected, tracked, and destroyed by missile defense weapons. In my testimony today, I hope to demonstrate that we have accomplished this mission and are now beginning to field highly effective missile defenses. Before we discuss the evolution and accomplishments of BMD technology, I think it is important for us to review the historical backdrop, during which the BMD program made its progress.

Historical Context of BMD

Research and development into ballistic missile defense dates back to World War II, in response to German V-2 ballistic missile attacks on London. During the 1950's and 1960's, antiballistic missile interceptor technologies and system concepts were designed to utilize nuclear warheads in order to destroy long-range attacking ballistic missiles. Sensor and guidance technologies were not yet mature enough to permit kinetic energy, hit-to-kill intercept of ballistic missile targets. Significant advances, however, in technologies applicable to ballistic missile defense occurred after the mid-1970's. By the early 1980's the Army BMD program had advanced to the point where it was on the verge of revolutionizing missile defenses by being able to use non-nuclear, hit-to-kill interceptors as the basis for a new approach to BMD. In 1983 President Reagan challenged the U.S. scientific community to investigate the feasibility of developing a defensive system using new technologies to counter ballistic missiles. In response to this challenge, the Department of Defense conducted an intensive analysis of these advanced technologies and established the Strategic Defense Initiative Organization (SDIO) to manage the research effort.

When SDIO was established, the Nation was already spending more than a $1 billion annually on missile defense programs scattered throughout the military Services, defense agencies and the Department of Energy. The core of the "new" BMD program was created by drawing together a number of these projects, with the principal contributions coming from the Defense Advanced Research Projects Agency (DARPA), the three military Services and the Defense Nuclear Agency (DNA). When the organization was created, its charter clearly outlined SDIO's mission:

SDIO shall manage and direct the conduct of a vigorous research program, including advanced technologies, that will provide the basis for an informed decision regarding the feasibility of eliminating the threat posed by nuclear ballistic missiles of all ranges, and of increasing the contribution of defensive systems to U.S. and allied security. Since its inception in 1983, the BMD program has evolved through four distinct phases:

1. a broad-based technology exploration and demonstration program to identify those technologies ready for development to support an initial multi-layer comprehensive defense system, and those promising follow-on technologies that could provide resilience against a full range of responsive countermeasures (1984-1986);

2. a focused development program called Phase One Strategic Defense System, initiated in 1987, and aimed toward a significant ground- and space-based, layered defense capability to augment and strengthen deterrence (1987-1990);

3. the refocusing of the program toward a Global Protection Against Limited Strikes (GPALS) system, which would protect the U.S., our forces overseas, and friends and allies against limited ballistic missile strikes (1991-1992); and

4. the reorientation of the BMD program to focus on acquisition and deployment of highly effective Theater Missile Defenses to protect against the ballistic missile threat that is "here and now," and to maintain a technology readiness program for National Missile Defenses, should the ballistic missile threat to the U.S. emerge (1993-present).

The changes in the program's orientation mirror the changes in the world. When SDIO was chartered, the threat posed by Soviet strategic nuclear forces was ominous. The Soviet Union possessed over 8,000 nuclear warheads on ICBMs and SLBMs. The concern over the growing likelihood of a Soviet first strike capability was prevalent. The Phase One Strategic Defense System was designed to strengthen deterrence -- if the success of a Soviet first strike could be put in doubt, then Soviet warplanners, it was reasoned, would not have confidence in their ability to achieve their objectives.

With the breakup of the Soviet Union and the end of the Cold War, the BMD program was reoriented toward addressing regional threats caused by proliferation of weapons of mass destruction and shorter-range ballistic missiles, and the threat posed by potential accidental or unauthorized limited attack on the U.S. arising out of the political instability among the states of the former Soviet Union. The Department's new approach was embodied in a concept called Global Protection Against Limited Strikes (GPALS), which integrated theater and strategic defenses and emphasized global protection of forward deployed U.S. forces, power projection forces, and other U.S. overseas interests against theater-class ballistic missiles; and the U.S. against a long range limited attack.

Today, the BMD program is structured to respond to the "here and now" theater ballistic missile threat and an uncertain, but evolving, threat to the United States. The current program is founded upon the President's endorsement of the 1993 Department of Defense Bottom Up Review and the Missile Defense Act of 1991, as subsequently amended in Fiscal Year 1993, 1994, and 1995 National Defense

Authorization Acts. The Ballistic Missile Defense Organization (BMDO), established in May 1993, manages, directs and executes the BMD program to achieve the following objectives:

1. Enable deployment of an effective and rapidly relocatable advanced theater missile defense capability to protect forward-deployed and expeditionary elements of the Armed Forces of the United States as well as friends and allies of the United States;

2. Develop options for, and deploy when directed, an antiballistic missile (ABM) system that is capable of providing effective defense of the U.S. homeland against limited attacks of ballistic missiles, including accidental, unauthorized launches or deliberate attacks;

3. Demonstrate advanced technologies -- as options for enhanced initial BMD systems -- such as space-based defenses and their associated sensors that could provide an overlay to ground-based interceptors; and

4. Continue programs of basic and applied research to develop follow-on technologies for both near-term and future technology insertion options and new system options to sustain a highly effective missile defense capability.

Throughout this time of change -- the decline in the Soviet threat, the rise in missile proliferation and use among the Third World, the program's orientation and level of funding -- SDIO and now BMDO continued to succeed in achieving their objective of developing and demonstrating the defensive technologies required to defeat ballistic missiles of all ranges. Today, BMDO is harnessing these technologies to support deployment of improved theater missile defense systems for the warfighter. I am particularly proud that we are making missile defense a reality today.

Development of BMD Systems and Entering the Acquisition Process

When technology success meets a valid military need, the result is often a decision to move a system concept into the formal acquisition process in order to capitalize on that technology. System acquisition activities do not make the headlines as often as spectacular technology breakthroughs, but it is this disciplined process that results in fielded military capability. The formal acquisition process is where we find out if those promising technologies will work as part of a larger system. It is here where we look at the practicality of a concept -- can industry produce it in sufficient quantities, is it supportable under harsh field conditions, and is it affordable? System acquisition is also where the operator gets involved -- does the system meet operational needs, will it perform as advertised and can the average soldier operate it? To underscore the commitment of the BMD program to the acquisition of Theater Missile Defense, BMDO has budgeted 80 percent of its Fiscal Year 1996 funds for this purpose.

BMD Hardware in the Field

Today, we are making near term improvements to existing air and missile defense systems to enhance their abilities to defend against shorter-range tactical ballistic missiles. In this sense, we are literally making ballistic missile defenses a reality as we speak. As part of this phase of TMD improvement, we have deployed TALON

SHIELD/JTAGS, U.S. Marine Corps HAWK upgrades, and PATRIOT PAC-2 Quick Response Package (QRP). The first of the PATRIOT PAC-2 Guidance Enhanced Missiles (GEM) are being delivered. We have also deployed the Extended Air Defense Test Best (EADTB), which serves as a critical support tool. Each of these have significantly improved our Nation's TMD capabilities over those that existed during Operation Desert Storm. These upgrades are a direct result of investment in the BMD program and, in some cases, are direct benefactors of our past technology development efforts. I think you will agree when I say we are making great strides in putting TMD "rubber on the ramp" for the warfighter. I would like to provide a quick overview of just a few of these near term improvements.

Talon Shield/Joint Tactical Ground System (JTAGS): These systems use Defense Support Program (DSP) satellite data, newly developed algorithms and upgraded processing hardware -- developed under the BMD program -- to significantly improve the accuracy and timeliness of early warning information of ballistic missile launches to U.S. forces overseas. In October 1994, the U.S. Air Force activated the first Attack and Launch Early Reporting to Theater (ALERT) squadron with an operational version of the BMDO-developed TALON SHIELD system at Falcon Air Force Base, Colorado. The ALERT squadron just recently achieved its initial operational capability. JTAGS, also developed by BMDO, is a complementary tactical mobile DSP ground station for use in the theater. The U.S. Army has deployed several prototype units overseas to support the warfighter.

HAWK Air Defense System: The U.S. Marine Corps and BMDO have jointly funded improvements to the Marine Corps' HAWK system. The HAWK system has been modified and tested to intercept short-range ballistic missiles. This will represent the only organic TMD capability for the Marines and will provide them with some operational flexibility when Army or Navy TMD assets at not available. Last September, two LANCE target missiles were successfully intercepted by the modified HAWK system in an operational test by Fleet Marine Forces at White Sands Missile Range, New Mexico. BMDO and the Marine Corps jointly funded upgrades and modifications to the TPS-59 radar, the HAWK command and control system, and a communications interface between the two. Modifications to the TPS-59 radar will result in tactical ballistic missile target detection at long ranges and high altitudes. Upgrades to the HAWK missile fuze and warhead enable the system to provide a credible defense against tactical ballistic missile targets. Over one-third of the active Marine Corps HAWK equipment has been modified to provide this short-range tactical ballistic missile defense for expeditionary Marine forces. The entire fleet inventory will be modified with this capability by the end of Fiscal Year 1996.

PATRIOT Quick Response Program (QRP): The PATRIOT QRP was instituted in 1991-1992 and is already deployed and operational. This program, designed to identify and quickly field improvements to address lessons learned from Operation Desert Storm, included upgrades for rapid, accurate fire unit emplacement; a capability to remotely launch PATRIOT missiles up to 12 kilometers from the radar which increases the defended area; and radar enhancements to improve tactical ballistic missile detection and increase system survivability. BMDO funded nearly 60 percent of the QRP program.

PATRIOT Guidance Enhanced Missile: In February of this year, the U.S. Army took delivery of the first PATRIOT Advanced Capability-2 Guidance Enhanced Missile (GEM). The GEM incorporates improvements to the PAC-2 missile receiver to enhance its effectiveness and lethality against SCUD-class ballistic missiles. With the GEM improvements, existing PAC-2 missiles will significantly increase their defended areas and improve their lethality. We will field about 350 PAC-2 GEM missiles which will provide the principal improvement to our existing tactical ballistic missile defense capability until PAC-3 begins deployments in Fiscal Year 1998. BMDO funded nearly 90 percent of the GEM program.

Extended Air Defense Test Bed (EADTB): The EADTB provides a BMDO-developed high fidelity, flexible, user-friendly, computer-based simulation tool for traditional air defense experiments with the added complexity of Theater Missile Defense threats. It is oriented to large scale scenarios for system analysis and Cost and Operational Effectiveness Analysis (COEA) support. The system will be capable of analyzing full theater-level scenarios and will permit evaluation of extended air defense systems. Initial node installations are complete at SHAPE Technical Center, the Hague, Netherlands; Advanced Research Center, Huntsville, AL; and Army Air Defense Center, Fort Bliss, Texas. In the Hague, representatives from all sixteen NATO nations can participate, by means of EADTB, in interactive modeling, simulation, wargaming and virtual prototyping of TMD systems in order to determine the best TMD solutions for the alliance.

TMD Systems Currently in the Acquisition Process

Following these near-term enhancements, we have established a set of "core" TMD systems that are currently in the Department of Defense acquisition process. The core includes the PATRIOT Advanced Capability-3 (PAC-3), Navy Standard Missile II Block IVA (Navy Area Defense), and Theater High Altitude Area Defense (THAAD) systems. The variety of scenarios and threat characteristics (maximum/minimum ranges, reentry vehicles, radar cross sections, reentry vehicle temperatures, etc.) and the characteristics of the defended area (military forces, population centers, ports of debarkation, etc.) require complementary systems for complete and cost-effective defenses. Therefore, we are developing a core set of systems which will begin deployments by the end of this decade and will greatly improve our defense against the existing theater ballistic missile threat. These systems, which are in the acquisition process today, are benefactors of the technologies we have developed over the past twelve years.

PAC-3: Last year the Department selected the Extended Range Interceptor (ERINT) missile to satisfy the PAC-3 requirement to provide significantly improved capability against theater missile threats. PAC-3 represents a significant upgrade to an existing air defense system to specifically handle stressing theater ballistic missile threats. The selected PAC-3 missile uses hit-to-kill technology to destroy attacking tactical ballistic missiles and was selected principally for its lethality against these missiles, especially those carrying weapons of mass destruction.

The technology for the ERINT, as well as THAAD, missile has its roots in the BMD program. The development of hit-to-kill interceptor technology for TMD systems evolved from the SDIO's Flexible Lightweight Agile Guidance Experiment (FLAGE) technology demonstrations in the mid-1980's. This program originally started in the Army as the small radar homing intercept technology interceptor (SRHIT). Originally designed to test technologies for a point defense system to protect ICBM fields from strategic ballistic missile attack, the proof-of-principle test vehicles demonstrated small, transportable defenses well suited to tactical missile defense. SDIO funded a test series which demonstrated the use of radar seekers and thruster/attitude control rockets required for hit-to-kill guidance against tactical ballistic missiles. In June 1986, a FLAGE hit-to-kill test vehicle intercepted a target that was travelling over

2,100 miles per hour. In May 1987, a FLAGE hit-to-kill test vehicle destroyed a short-range surface-to-surface LANCE missile. The intercept occurred at an altitude of 16,000 feet. This marked an important milestone in the development of hit-to-kill TMD interceptors because the LANCE missile replicated the radar signature and performance of a tactical ballistic missile. Later that year, the ERINT program began as a development effort to refine the hit-to-kill technology.

In November 1993, ERINT scored the first of three successive direct hits on its targets. During this flight test ERINT collided with and destroyed the warhead of a STORM target vehicle. The warhead contained a cluster of 38 pressurized, water-filled containers designed to simulate toxic chemical submunitions. The second flight test in February 1994 pitted the ERINT against a similar missile carrying a simulated unitary chemical warhead. Again, the force of the impact destroyed the target. These intercepts took place six miles down range and six miles high. The enhanced lethality of ERINT against tactical ballistic missiles, especially those with submunition warheads, was a key element in the selection of ERINT as the missile of choice for PAC-3. Lastly, in June 1994, ERINT completed its third straight successful test flight when it destroyed a drone. The purpose of the test was to demonstrate the accuracy of ERINT's guidance system against a maneuvering air-breathing target, such as a cruise missile. The success of the ERINT program, which built upon a foundation of hit-to-kill technology demonstrations, will bring protection to our warfighters as we begin to field the PAC-3 system in Fiscal Year 1998.

Other improvements to the PATRIOT system that comprise the PAC-3 enhancements will result in: increased firepower and lethality; increased battlespace and range; enhanced battlefield awareness; and improved discrimination performance in the face of challenging countermeasures. Many of the PAC-3 system components are responsible for improving the PATRIOT system and enable it to achieve a hit-to-kill. I would like to highlight just few examples. For instance, the PAC-3 inertial measurement unit (IMU), which serves as the "inner ear" of the missile, sensing attitude and motions, assists in guiding the missile from launch point to where the seeker can "lock" on the target. The ring-laser gyro IMU emerged from the BMD technology program and was specifically designed to be small, lightweight and low-cost in order to be used on missiles. We intend to use this IMU on PAC-3 and THAAD.

Similarly, the PAC-3 attitude control section features 180 small solid rocket motors that provide a much more agile missile than the PAC-2 missile, which relies solely on tail fins to maneuver. This agility translates directly into improved accuracy and lethality of the missile. Again, this specific technology was borne out of the BMD program.

The new ceramic radome for the PAC-3 missile is lighter and less expensive than the older radome flown just last year. Meanwhile, it provides a protective covering for the PAC-3 system which is more transparent to the system's radar seeker. The ceramic radome is a high temperature, high strength ceramic composite that has improved performance characteristics in every critical area. The PATRIOT system's leading edge technology in electronic components comprise the heart of the PAC-3's radar upgrades. They accomplish three major improvements: first, allowing engagements of stealthier targets; secondly, producing a more lethal intercept and; lastly, improving system reliability.

Navy Area Defense: Modern Navy doctrine requires contributions from combatant vessels to achieve and maintain battlefield dominance "from the sea" for all littoral operations. Sea-basing of TMD allows our Nation to take advantage of the strength and presence of our naval forces. Navy vessels that are routinely deployed world-wide are currently in potential threat areas or can rapidly be redirected or repositioned. The Navy Area Defense program, previously referred to as Navy Lower Tier, represents another cost and operationally effective opportunity for us to upgrade an existing air defense system (as we did with PATRIOT) and give it substantial TMD capabilities as quickly as possible. BMDO and the Navy have been working together to develop an enhancement to the AEGIS/STANDARD Missile air defense system that would provide a tactical ballistic missile defense capability -- similar to that provided by PAC-3 -- from the sea. The Nation has already invested over $40 billion in the AEGIS Weapon System found on more than 50 AEGIS cruisers and destroyers that contain over 5,000 vertical launch system (VLS) cells. The AEGIS ships that will be equipped for a TMD capability will require no additional manning and already have the complete infrastructure for training, logistics, and engineering in place and operating. Hence, we are able to leverage off the Nation's past investment in the AEGIS fleet and provide a substantial near-term payoff in TMD capability.

The Navy Area TBMD program focuses on developing modifications to the existing AEGIS Combat System, which includes changes to the STANDARD Missile, to extend its robust anti-air warfare capabilities to tactical ballistic missile defense. These modifications will enable tactical ballistic missile detections, tracking and engagement with a modified STANDARD Missile II Block IV. This area defense system will provide AEGIS ships the ability to conduct lower-tier, or endo-atmospheric, intercepts of tactical ballistic missiles. Improvements to the STANDARD Missile, such as development of the infrared seeker, will incorporate technology from past BMD programs. These include seeker component improvements in track processing, aimpoint selection, cooling bottle winding technology, cooling valves and cooling system. The seeker, along with other modifications, will allow the STANDARD Missile to engage tactical ballistic missiles.

Theater High Altitude Area Defense (THAAD): The THAAD system is the centerpiece of the core TMD program. It is designed to engage the full spectrum of theater ballistic missile threats and to expand the footprint of the defended area. The THAAD system is comprised of an interceptor, the TMD Ground-based Radar (GBR), and command and control equipment. THAAD will provide the unique capability for wide area defense against ballistic missiles at higher altitudes and longer ranges with a lethal hit-to-kill interceptor. Neither the PAC-3 nor the Navy Area Defense systems can provide this kind of long-range defense.

The THAAD missile design utilizes various technologies developed in past BMD programs to achieve hit-to-kill accuracy and yet maintain a small configuration well suited to the THAAD operational requirements. The missile consists of a single-stage solid propellent rocket booster motor and a kill vehicle which separates from the booster prior to impact. The booster uses state-of-the-art composite case construction to minimize weight. Such composite materials are derived from the BMD materials and structures program to develop strong, yet lightweight, materials. A deployable flare at the aft end of the booster provides added stability in certain flight regimes. A thrust vector control system is used for attitude control during boost phase. This important component has lineage in SDIO's High Endoatmospheric Defense Interceptor (HEDI) and Exoatmospheric Reentry Vehicle Interceptor System (ERIS) programs. The interstage at the forward end of the booster contains a separation motor which ensures positive kill vehicle separation.

The kill vehicle is integrated into a biconic structure which mates to the booster interstage. During flyout, the seeker window is protected from the severe flight environment by a two-piece clamshell shroud. The shroud is ejected just prior to seeker acquisition by inflating metal bladders in the nose cone to impart the required separation velocity. Shroud technology, used here in THAAD, has been developed by the U.S. Army under the auspices of BMDO. The seeker window is a rectangular sapphire plate mounted in the forecone. Again, the seeker window technology is a legacy of the seeker windows developed for the HEDI program. The mid-wave infrared seeker is mounted on a 2-axis stabilized platform to isolate the seeker measurements from vibration and other disturbances. The seeker design includes an all-reflective optical system and platinum sillicide staring focal plane array. This sensitive staring focal plane array, which serves as the "eyes" for the THAAD interceptor, emerged from BMD sensor technology efforts over the last ten years. A ring-laser gyro inertial measurement unit (IMU) is mounted on the platform to measure and stabilize the platform motion and serve as a reference for seeker measurements. This IMU -- used in both THAAD and PAC-3 -- was originally developed under the SDIO D-2 hypervelocity projectile program. The IMU is a very low-mass, highly accurate (low drift rate of 3 degrees per hour) system. Throughout the D-2 testing the laser ring gyro IMU proved itself to be very reliable. Aft of the seeker is the bi-propellent divert and attitude control system. An integrated avionics package contains four reduced instruction set computers to provide the processing speed required for hit-to-kill guidance.

The radar element (TMD-GBR) in the THAAD system meets an immediate requirement for a more capable wide-area defense radar in the theater. It provides surveillance and fire control support as an integral part of the THAAD system, and cueing support to lower-tier systems such as PATRIOT. The TMD-GBR utilizes state-of-the-art radar technology to accomplish its required functions of threat attack early warning, threat cueing, and launch and impact point estimation. In particular, TMD-GBR will be able to provide a capability to perform threat classification against tactical ballistic missiles, and kill assessment after intercept.

The Theater and National Missile Defense Ground-based Radar programs have evolved using technologies developed by SDIO, BMDO, and ARPA, as well as from commercial off-the-shelf equipment. The common core software processing programs resident in the TMD and NMD radars were developed in the SDIO program. The Terminal Imaging Radar (TIR) program, initiated under SDIO, developed imaging and discrimination techniques, and the radar scheduler functions. These are some of the most complex functions a BMD radar system must perform. In addition, SDIO and BMDO have funded several radar component technologies used in our ground-based radar systems. These include advanced X-band Solid-State Transmit/Receive (T/R) modules and waveform generators, and the Lexington Discrimination System used by MIT/Lincoln Labs to validate real-time imaging and processing algorithms. Our technology program also has been the cornerstone of radar survivability initiatives in the area of anti-radiation missile countermeasures and camouflage, concealment and deception technologies for TMD-GBR. BMDO has also invested in the 10 watt and 20 watt T/R module program that evolved out of advances made under the ARPA Gallium Arsenide Monolithic Microwave Integrated Circuit program.

The NMD and TMD GBR programs also make maximum use of commercial off-the-shelf equipment. The prime power unit is composed of commercial generators and alternators. The electronic equipment unit uses commercial computers and the massively parallel processor systems for signal and data processing, and commercial high speed data recorders.

Battle Management/Command, Control, Communications & Intelligence: Establishment of effective BM/C3I for TMD is one of the most important functions of the BMDO and is essential to fully exploit the full capabilities of the core TMD weapons systems. Successful BM/C3I increases the time available to engage hostile missiles, increases the effective allocation of interceptors, and reduces the potential for "leakers" -- attacking missiles that penetrate our defense. It is truly the element which most solidifies the jointness of theater missile defense. Within the context of putting BM/C3 "rubber on the ramp," we have successfully demonstrated the timely digital dissemination of launch warning into theaters, established message standards critical for the development of the Joint Data Net, and demonstrated prototype command and control centers for TMD. This Fiscal Year we will see significantly increased activity in BM/C3I as we extend the early warning demonstrations into fully operational systems, implement message standards in developing Command and Control (C2) host platforms, and support integration of JTIDS terminals into TMD C2 centers and C2 systems, such as the Air Force Contingency Tactical Air Planning System (CTAPS) and the Navy Joint Marine Command Information System (JMCIS). As always, BMDO will seek to minimize costs by taking advantage of planned theater air defense BM/C3I improvements and encouraging joint solutions for joint requirements wherever possible.

Advanced Theater Missile Defense Capabilities

BMDO is also developing advanced TMD capabilities. This includes the Navy Theater Wide Defense (Navy Upper Tier); Medium Extended Air Defense System (MEADS) -- which you will recall as Corps SAM; and Boost-Phase Intercept (BPI). These systems are currently in the concept exploration phase and a decision to proceed with further development will be based on a rigorous acquisition decision process. For the purpose o f today's hearing, I would like to just briefly discuss how these programs take advantage of past BMD technology developments in order to provide improved TMD capabilities by addressing specific military requirements.

Navy Theater Wide Defense: The Navy Theater-Wide Defense program will provide an upper-tier Navy tactical ballistic missile defense capability. The Navy Theater-Wide system, which could be among the first deployed missile defense systems in a regional crisis, could provide extensive areas of protection. Specifically, Navy Theater- Wide could provide critical wide area defenses early in a conflict -- allowing U.S. and/or coalition forces to fight their way into a theater of operations while under the protective cover of missile defenses. This program is the second evolutionary stage of the joint BMDO-Navy TMD program and will build on the baseline Navy Area Defense (lower-tier) system. The Navy Theater-Wide system will use an interceptor with exoatmospheric capability, such as the BMD technology program-developed Lightweight Exoatmospheric Projectile (LEAP), or a marinized version of the THAAD interceptor missile.

BMDO and the Navy have demonstrated the integration of BMD-developed technologies into existing missiles. The LEAP and Advanced Solid Axial Stage (ASAS), both developed under the SDIO and BMDO programs, were recently flown aboard modified TERRIER missiles during tests at sea.

The LEAP is a miniaturized kinetic kill vehicle that, once delivered on a path towards the ballistic missile target, detects, acquires, and homes in on that target. LEAP destroys the target missile by force of impact. Efforts to pursue advanced, lightweight, low-cost components for space-based and ground-based ballistic missile defense interceptors have generated significant progress in the LEAP program over the past few years. The LEAP program has succeeded in developing several miniature kill vehicles all weighing under 20 kilograms. These LEAP vehicles have undergone a series of hover tests to demonstrate their abilities to "fly" and, using optical seekers, acquire and track ballistic missile targets. (LEAP technology development is discussed in further detail in the Advanced Technology section.)

The ASAS is a state-of-the-art space rocket motor that provides the LEAP with its final axial boost towards the target. The ASAS program was initiated in the late 1980's to support the Space-based Interceptor program with a robust, storable solid axial propulsion system. The focus of the ASAS program was to minimize weight and cost, while maximizing performance. By 1992, technology development was completed and all that remained was integrated stage testing. Due to funding constraints, the program was temporarily stopped. However, the LEAP program resumed program funding since the ASAS technology provided an upper stage capability suitable for the Navy LEAP experiments. The combination of the Navy's STANDARD Missile and the ASAS provides sufficient propulsion to boost the LEAP kill vehicle beyond the atmosphere to intercept longer-range theater-class ballistic missiles far from their intended targets.

A cost and operational effectiveness analysis (COEA) is in progress to assess interceptor alternatives. The Theater-Wide Defense interceptor will be integrated into the existing AEGIS Weapon System that will be modified for the Navy Area Defense (lower tier) program.

Boost-Phase Interceptor: Ballistic missiles, regardless of their range, are best targeted and countered during their boost-phase. The ability to intercept a missile while boosting provides a deterrent to launch or, in the event of a launch, will destroy a target while still over enemy territory potentially allowing the debris to fall back on the aggressor. BMDO and the Air Force, supported by the Army and Navy, are currently executing a kinetic energy boost-phase interceptor program to demonstrate the concept.

Critical to the BPI program is the development of the advanced kill vehicle in the BMDO Atmospheric Interceptor Technology (AIT) program. The AIT program has its roots in the successful HEDI program which demonstrated the principle of hypersonic target acquisition and tracking in the atmosphere. Leveraging off past investments in cooled window technology, lightweight thermally protected structures, strapdown seekers, miniaturized electronics, and lightweight gel propellant divert and attitude control systems provide a lightweight kill vehicle with the capability of performing hypersonic, hit-to-kill intercepts of ballistic missile targets in the endoatmosphere. Combining this kill vehicle with the ASAS rocket motor technology from the LEAP program could permit the high velocity flight at low altitudes necessary for the BPI system.

Benefits From Participation in the ARROW Program: The United States is continuing a cooperative BMD program with Israel through the Arrow Continuation Experiments (ACES) Program. As demonstrated graphically during the Gulf War, Israel is highly vulnerable to attack from tactical ballistic missiles due to its close proximity to potential aggressor states in the Middle East. Consequently, the development of highly capable missile defenses is a priority for Israel, and is embodied in the Arrow missile program. The U.S. has been a partner in the development of the Arrow missile because it is in our national interest that Israel acquire a robust missile defense capability.

As the Arrow System moves toward deployment, the U.S. has continued to invest in the program because of the valuable technical input that the Arrow program is making to our own developing TMD systems. Some examples of important technology infusion from Arrow include: lethality data applicable to the Navy Area Defense (lower-tier) program on the effectiveness of blast fragmentation warheads against chemical bulk and submunition weapons; development of optical window technology applicable to both THAAD and Navy Area Defense programs; hypersonic test data that helps validate U.S. computational fluid dynamics codes being used by the THAAD and Navy Area Defense programs; data from stage separation at high velocities and dynamic pressures that benefits the THAAD program; and interoperability development that will allow synergistic operations of Arrow with U.S. TMD systems, if required in future contingencies.

National Missile Defense Programs

The major technology breakthroughs of the first four years of the BMD program proved the feasibility of strategic National Missile Defense and led to a decision to move specific systems into the Department's acquisition process in June 1987. The first system architectures consisted of boost, midcourse and terminal sensors, space- and ground-based interceptors, and battle management/command, control, and communications (BM/C3). It relied on kinetic energy weapons and was known as Phase I. Phase II and subsequent phases would draw from continuing technology advances, particularly in directed energy. The primary objective of Phase I was to enhance deterrence by denying Soviet planners confidence that they could execute any successful war plan based on attacking the United States with ballistic missiles. Phase I was well into the demonstration/validation phase of acquisition as the decade drew to a close. But the threat started to change -- the Soviet Union was in the process of dissolving and theater ballistic missiles were proliferating. This led to a new architectural concept known as Global Protection against Limited Strikes, or GPALS. GPALS focused on achieving worldwide defensive capability against attacks of limited scope. It retained most of the elements of the Phase I architecture, and moved several theater systems and the space-based weapon, known as Brilliant Pebbles, into acquisition. Reassessment of the threat as part of the Administration's Bottom-Up Review led to a decision to transition all ground-based NMD systems from formal acquisition to a technology readiness program (TRP). The objective of the TRP is to mature the system elements and maintain a readiness posture to respond to future strategic threats against the United States. NMD system elements include the Ground-based Interceptor, Ground-based Radar, the Space and Missile Tracking System (SMTS) midcourse sensor, and BM/C3. I would like to summarize the progress we have made in each of these programs and in developing and maturing their ability to deliver future military capability. I will also describe a major investment we have made for the testing of the NMD system.

NMD Ground-Based Interceptor (GBI): Our Ground-based Interceptor program is developing, demonstrating, and validating the technology and components for a state-of-the-art, cost effective, lightweight, non-nuclear, hit-to-kill missile to intercept and destroy ICBM reentry vehicles targeted against the United States. This program consists of two efforts: the Exoatmospheric Kill Vehicle (EKV) and the Payload Launch Vehicle (PLV).

Our EKV efforts concentrate on the difficult technical issues of the interceptor front end. Early system objectives for research and development are to expand the engagement envelope through improvements to on-board sensor acquisition range, target selection capability, and divert velocity. These improvements will require iterating design, fabrication, and testing over the next three to four years.

Our PLV efforts take advantage of readily available and proven booster stacks (decommissioned Minuteman II second and third stages) for EKV flight testing at the U.S. Army Kwajalein Atoll missile range (USAKA) in the Republic of the Marshall Islands. This low cost approach allows us delay development of an optimized GBI booster, and focus our efforts and investments on the kill vehicle's development.

The GBI program has considerable historical legacy from over 20 years of technical efforts on non-nuclear exoatmospheric hit-to-kill interceptors. The U.S. Army's Homing Overlay Experiment (HOE) first demonstrated the concept of exoatmospheric hit-to-kill. The program, which spanned the period of Fiscal Years 1978 to 1984 consisted of four flights tests and demonstrated the principle of hit-to-kill using a very capable, albeit expensive, heavy and sophisticated kill vehicle. A successful intercept was demonstrated in June 1984.

The Exoatmospheric Reentry-vehicle Interceptor Sub-system (ERIS) program followed the successful HOE test series. The ERIS program demonstrated the feasibility of using low-cost, high-performance, supportable components. The program culminated in 2 flight tests. The first in January 1991 met all test requirements including a successful hit-to-kill intercept. The second in March 1992 was partially successful. Overall, the ERIS program was considered successful and achieved its objective of demonstrating our ability to intercept strategic ballistic missile targets with non-nuclear interceptors. However, during such technology demonstrations, while we strive to meet our test objectives of successful intercepts, it is important to realize that we learn much from our failures. Detailed analysis of telemetry data and test results teach us how to improve our technology, system integration and test operations.

In addition to the direct legacy of the successful HOE and ERIS demonstration programs, the GBI program has also benefitted from technologies and lessons learned resulting from the HEDI, Brilliant Pebbles and LEAP programs. In addition, component technology developments from the BMD technology program have "fed" the GBI program. Guidance and control technology development efforts, such as the Interferometric Fiber Optic Gyroscope (IFOG) Inertial Measurement Unit, have resulted in lighter-weight, lower-cost guidance and control units while improving overall performance characteristics. High performance, radiation hardened electronics have been developed which demonstrate high throughput, low power consumption, and fault tolerance characteristics necessary for GBI applications. Focal plane array technologies, such as PET and SHIELD, have demonstrated our ability to produce long wave, and very long wave (LWIR and VLWIR) detectors for use in GBI sensors. Materials and structures technology development, such as Beryllium mirrors, has resulted in the development of improved structural components to reduce GBI kill vehicle weight and improve performance.

Another example of direct component legacy from BMD is the Signal Processing Packaging Design (SPPD). It was initiated to address the requirement for the Space-based Interceptor (SBI) program, which needed a lightweight, compact, high throughput signal/data processor. The SPPD program was designed to provide a very high throughput (300 to 400 MOPS), very low mass (75 grams), high density processor. The program was completed in Fiscal Year 1992, on schedule, with delivery and testing of two prototypes for approximately $6 million. This technology has subsequently been incorporated into one contractor's concept for the Exoatmospheric Kill Vehicle for the NMD Ground-based Interceptor.

Without the investments we made in these programs, and the critical knowledge gleaned from these efforts, our current GBI efforts would be much further from fruition. For instance, interceptor technology developments over the past ten years have allowed a size reduction from 2500 kilograms (HOE) to 160 kilograms (ERIS) to 45 kilograms (EKV) in order to perform similar hit-to-kill intercept missions. Since weight and cost for a complete weapon system are directly proportional, BMD interceptor costs have become manageable.

NMD Ground Based Radar (GBR): The NMD Radar Technology Demonstrator (NMD RTD) provides the NMD System with a prototype element test article for use during integrated flight testing. The NMD RTD is a scaled version of a deployable NMD GBR. This Radar Technology Demonstrator design converts the TMD-GBR demonstration/validation radar hardware to a larger, limited field-of-view radar which will have sufficient range to support NMD requirements. It will provide surveillance and fire control support during integrated flight testing of the EKV with in-line BM/C3 processing and control.

The NMD RTD directly leverages progress from the TMD-GBR program. The RTD utilizes state-of-the-art radar technology such as solid state transmit and receive modules, data processing hardware, beam control and tasking software, and discrimination and kill assessment algorithms and software developed under the TMD-GBR program. This program structure, by leveraging from TMD developments, provides a cost-effective method for resolving the NMD-GBR critical issues and allows us both flexibility and limited liability as this program evolves.

Over the last 10 years the NMD Ground Based Radar (GBR) program has evolved significantly. Our efforts began with an X-band, phased array radar development program in the mid-1980's. This program, the Terminal Imaging Radar (TIR) program, began developing software operations and applications processing and radar imaging techniques for NMD radar. However, a testbed radar was needed and the GBR-X program was started in the late 1980's. The GBR-X provided for the functional demonstration and validation of the midcourse radar requirements, and formed the basis for growth and technology infusion to a deployable system. The program completed its Critical Design Review, 40 percent of its software built, and procured several long lead items before it was canceled in 1990.

The software techniques developed under the TIR and GBR-X programs now make up the common core of application and operations processing software used in the current "Family of Radars" program. In 1991, the program was restructured into the Family of Radars program which developed radars for both the NMD and TMD, based on common software and hardware. In 1992, the Family of Radars demonstration/validation contract was awarded which included the NMD-GBR demonstration/validation (termed the GBR-T) at USAKA. In 1993, the GBR-T completed its Preliminary Design Review, and 60 percent of its software built, before the program was terminated following the guidance of the Bottom-Up Review. However, the guidance provided for continued technology development to resolve the long pole issues associated with deploying an NMD-GBR.

In 1994, the technology development program was expanded into the National Missile Defense Radar Technology Demonstrator (NMD-RTD) program. This program continues to resolve the long poles associated with deploying an NMD-GBR which includes algorithm development, real-time software and hardware-in-the-loop simulations, and finally a radar technology demonstration at USAKA. The radar technology demonstration, upon completion of the TMD-GBR demonstration/validation program, takes existing TMD-GBR demonstration/ validation hardware and refurbishes it into a larger, limited-field-of-view radar with sufficient ranges to support NMD requirements. The NMD-RTD is a Solid State, X-band, phased array, single face/circular field-of-view radar with a 2,000 kilometer-plus range.

In January 1995, the NMD-RTD completed its Systems Requirement Review. To date approximately 80 percent of its software has been developed. The TMD-GBR demonstration/validation system is assembled and currently undergoing near field testing at the contractor's facility. This is the same hardware and software being utilized by the NMD-RTD program. In addition, site preparation at USAKA has begun for future NMD-RTD testing.

Battle Management, Command, Control and Communications (BMC3): BM/C3, as it applies to the National Missile Defense, consists of three distinct activities: battle management software development; Command Center design and tools for the user to exercise human-in-control; and Communications support to provide essential and timely information.

Investment in NMD BM/C3 has produced functionally and technically correct software code for ballistic missile defense battle management. The code has been used for demonstrations of missile defense using real data and operating at geographically distributed locations under very dynamic field conditions. This code supports the resolution of technical issues, such as sensor data fusion, discrimination, and communication management. The investment in software serves as the basis for the TMD battle management, as well as for the development of operational software for NMD. This approach has also supported the resolution of critical technology issues such as software reuse. Investments in command and control have produced designs and prototypes for command decision aids that allow the users of our NMD systems (USCINCSPACE and other regional commanders) to manage the effective engagement of hostile ballistic missiles. The BM/C3 demonstrator at the National Test Facility (NTF) has been used to refine the NMD Concept of Operations (CONOPS). In the area of communications, we have focused on identifying all potential commercial sources of communications support, and in the production of a working prototype of a NMD communication suite. The effort has been highly successful in that we have identified a communications architecture that will depend on only a limited amount of unique development.

National Test Facility: From its earliest beginnings, SDIO recognized the challenges inherent in testing a system that would defend against nuclear missiles. Live fire tests, the "proof of the pudding" for most acquisition programs, were just not "in the cards" for strategic missile defense systems. A first-class modeling and simulation facility - the NTF - has been established near Colorado Springs, Colorado, to address this need. The NTF is the hub of the National Test Bed, a distributed network of computers and models which can run the most complicated simulations of national and theater defense systems. One of the major nodes of the test bed that many of you may be familiar with is the Advanced Research Center in Huntsville, Alabama. These distributed facilities can integrate actual hardware in what we call hardware-in-the-loop testing. We have also developed the capability to run very sophisticated wargames at the NTF. It is here that USCINCSPACE and his staff can explore their information and decision aid needs for managing the BMD battle. The NTF is a magnificent facility with tremendous capabilities for BMDO and other DoD customers. Past BMD investments in this area have made it so.

Space and Missile Tracking System (SMTS): The Space and Missile Tracking System (SMTS) -- previously known as Brilliant Eyes, and now the Low Earth Orbit (LEO) component of the Air ForceÕs Space Based Infrared System (SBIRS) -- is a passive sensor element designed to perform ballistic missile boost and post-boost phase acquisition and tracking and midcourse phase tracking and discrimination in the NMD and TMD Systems. It is derived from earlier SDIO development efforts of the Space Surveillance & Tracking System (SSTS). In addition to capitalizing on SSTS technology, it also takes advantage of past BMD programs, such as Brilliant Pebbles and Ground Based Surveillance and Tracking System (GSTS) technology investments, to optimize system performance for the numerically reduced threat we currently face.

The BMD program has been working on space-based infrared tracking for many years. We have focused on technology development, phenomenology data collection, and experiments supporting system development. In 1984, development of the Boost Surveillance and Tracking System (BSTS) was started as part of BMD. BSTS was to serve as a replacement for the current missile early warning system, the Defense Support Program (DSP), which had been providing space-based infrared data since the early 1970Õs. BSTS was also to serve as the first surveillance tier of a BMD system. The second surveillance tier was to be the SSTS, more recently referred to as Brilliant Eyes and now as the Space and Missile Tracking System, which would provide midcourse tracking and target discrimination. SDIO moved out quickly with these programs, progressing the designs and performing ground tests and demonstrations. However, changes in threats and ballistic missile defense architectures, as well as increased interest in developing for the U.S. Air Force a replacement for DSP, resulted in the transfer of the BSTS program to the Air Force as the Follow-on Early Warning System (FEWS). FEWS evolved into the Alert, Locate and Report Missiles (ALARM) program, which was then incorporated as the high component of the current SBIRS program. The SSTS program evolved into the Brilliant Eyes program, recently renamed the SMTS, with scaled down performance requirements but very similar sensor designs.

In addition, SDIO pursued through the U.S. Army a ground launched probe, called the Ground-based Surveillance and Tracking System, which used passive infrared sensors and served as a gap filler for SSTS in the face of a massive ICBM attack. This program was terminated due to changes in the threat and the system architecture. But the passive sensor development progress that GSTS demonstrated greatly facilitated SMTS development. For example, the light-weighted beryllium optics fabricated and tested under the GSTS program are very similar in size and optical prescription to what the SMTS will use. These state-of-the-art optics demonstrated the producibility of advanced beryllium optics necessary for SMTS. Another example is the sophisticated tracking and discrimination algorithms and testbed development. The GSTS sensor contractor, Hughes, is one of the SMTS sensor subcontractors and the tracking and discrimination expertise in the Army and MIT/Lincoln Laboratory continued to be utilized by the SMTS program office.

The SMTS program has also utilized previous technology miniaturization developments from the Space-based Interceptors program. Processors and cryocoolers developed under the Brilliant Pebbles program are baselined by one of the SMTS contractors in their objective system. Other experiment and testbed developments, which add to the general advancement of passive infrared sensor development, include the Airborne Surveillance Testbed, Midcourse Space Experiment, Spatial Infrared Imaging Telescope (SPIRIT) series, and others which provide integration lessons learned and data to help steer future programs.

The NMD program elements are currently postured to be able to reenter the formal DoD acquisition process, if the ballistic missile threat to the U.S. emerges. The engineers and scientists who have analyzed, developed, built, and tested hardware and software under these previous programs bring along essential knowledge and "know how" to attack our current issues and solve our problems for the NMD program. These people and knowledge are vested in our military, civilian, and industrial team. Based on our combined technology and systems developments, I am confident that we can deliver a significant military capability by the early part of the next decade if a decision to deploy is made. This defensive capability is only possible because of our steady investment in ballistic missile defense technologies and systems.

Advanced BMD Technology Programs

The BMD technology program has served us well over the past twelve years. We have witnessed rapid development of critical component technologies. As you have seen today, many of these technologies are now infused in our current acquisition programs. During the past twelve years, we have invested in sensors and detectors; guidance and control; computers and signal processors; communications; power; propulsion; and materials and structures technologies. All of these areas have witnessed tremendous technical advancements based on our collective investment in BMD. We have also focused our efforts on developing advanced technology concepts which could provide clear technology answers to tomorrow's threat developments.

LEAP Technology: The goal of the LEAP program, as originally conceived and begun in 1986, was to develop and integrate the world's first advanced, miniature kinetic energy interceptors and associated technologies; and then to demonstrate their capabilities through extensive ground testing. The technologies were intended to enable development of ground-and space-based systems in support of the then-proposed Strategic Defense System architecture. Although aggressive design objectives were established, the original design goals did not necessarily evolve from stringent system requirements. Instead, near-term vehicles were developed to demonstrate the validity of fully integrated miniature interceptors and to represent a step on the path towards an operational KKV system. Because of this flexible development approach, even though the missile defense architecture has changed in response to the changing global environment, the LEAP program has been able to maintain a robust, supporting technology focus.

Over the past ten years, the LEAP program has achieved dramatic successes in the development of advanced interceptor technologies and in the reduction of interceptor size and weight. During the course of the program, BMDO demonstrated important, new manufacturing techniques for LEAP. Tremendous advances have been made in the process of welding small, high-pressure-tolerant tubing and tanks; precise fabrication and machining of 3-D carbon-carbon thrust chambers and complex metallic/composite components; the creation of fast-response, miniature valves and nozzles; and the manufacturing of compact, high-density electronics.

The LEAP program has progressed from a series of highly successful hover tests at

BMDO's National Hover Testing Facility at Edwards Air Force Base, California. These hover tests allowed the completely integrated LEAP vehicle to lift itself off of a test stand and hover autonomously in free flight using its divert and attitude control system propulsion systems. While in unencumbered free flight, the LEAP acquired and tracked a scaled infrared target and performed a series of maneuvers as dictated by the particular objectives of specific tests. Following the successful hover test series and initial integration flight experiments with modified U.S. Navy TERRIER missiles, the LEAP program has become a candidate for the Navy Theater-Wide Defense program, which was discussed earlier.

Advanced Interceptor Technology: Patterned after the LEAP development strategy, the AIT program was initiated four years ago to address the kill vehicle design requirements of operating within the atmosphere (below 70 kilometers) at high velocities. This strategy has resulted in a robust kill vehicle technology development program that will support future TMD requirements to counter the potential evolution of the threat to enhance performance. AIT kill vehicles expand on the legacy of lightweight integrated vehicle technologies developed in the LEAP program and hypersonic atmospheric ballistic missile target acquisition and tracking technologies developed in the HEDI program. These kill vehicles incorporate cooled windows, strapdown seekers, miniaturized electronics, thermally protected structures, and lightweight gel propellant divert and attitude control systems to provide the capability to perform hypersonic hit-to-kill intercepts of ballistic missiles in all phases of their flight trajectories in both the exo- and endoatmosphere. The program has completed cooled window development and fabrication, window aero-thermal testing based on component technology investments in 1990. Seeker detailed designs have been completed and prototype seeker fabrication has been initiated.

Directed Energy: The BMD program has demonstrated most of the key building blocks needed to build a deployable space-based laser (SBL), which represents one of the most mature of our advanced technology concepts. The space-based chemical laser program was initiated by DARPA in the late 1970's and was transferred to SDIO in 1984. Each of the SBL subsystems has been successfully demonstrated with hardware that is traceable and scalable to an operational system. The high-energy beam generator, named Alpha, has demonstrated megawatt-class lasing in numerous tests beginning in 1991 and currently performs at near-weapons class efficiency. Beam control and telescope technologies were demonstrated in the Large Optics Demonstration Experiment (LODE) in 1987 and in the four meter diameter Large Advanced Mirror Program (LAMP) in 1989. Since then, improved mirrors and optics have been tested. The high-energy beam LAMP mirror is the largest mirror built for use in space -- the previous record is Hubble's 2.4 meter mirror. The LODE program has developed a beam control system for maintaining the brightness and stability of the high power beam. High performance components for the Acquisition, Tracking, Pointing and Fire Control (ATP-FC) system have been fabricated and successfully tested.

A space experiment named Relay Mirror Experiment (RME), launched in February 1990, successfully demonstrated critical pointing and tracking technologies for both space-based and ground-based elements of Directed Energy Weapons (DEW) concepts. Over the course of months, in consistently successful relay experiments, sensors aboard the orbiting RME spacecraft simultaneously tracked two independent ground beacons, and the orientation of a 60 centimeter diameter flat mirror was controlled to reflect a laser beam transmitted from one beacon site to a remotely located target board at the other beacon site. This demonstrated high pointing accuracy, laser beam stability, and long-duration beam relays. The RME experiment provided a significant contribution to gaining confidence from the design of target acquisition subsystems for DEWs.

Building on past accomplishments and investments, BMDO's Directed Energy program continues the process of integrating high-power chemical laser components and technologies developed over the past ten years specifically for accomplishing the boost-phase intercept mission from space. In the Alpha Lamp Integration (ALI) experiment, the existing megawatt class Alpha laser, the 4 meter LAMP primary mirror, and beam alignment and control technologies are being integrated for a ground demonstration of a complete high energy laser beam train. While not a fully operational system configuration, ALI will demonstrate the integrated performance of near full scale SBL subsystems. ALI subsystems are, in fact, fully scalable and traceable to those required to destroy ballistic missiles during their vulnerable boost phase, prior to their ability to maneuver, release decoys, or deploy multiple chemical, biological, or nuclear munitions. The ATP-FC program will, due to funding reductions in the Fiscal Year 1995 Defense Authorization Bill, close out in Fiscal Year 1995. Component technology efforts are currently focused on demonstrating the high precision, inertial reference unit and the laser illuminator needed for ATP. Together, ALI and ATP successes would have led to a start on an operationally configured, fully integrated ground demonstration of a high energy laser system.

Throughout the BMD program significant advances have been made in the state-of-the-art for Free Electron Laser (FEL) and Neutral Particle Beam (NPB) technologies. These efforts have been terminated, however, as their military applications have sharply decreased with the changed world environment and the diminished strategic nuclear t hreat.

Added Benefits from BMD Technology Investments

I would like to take a moment to describe our accomplishments in an area where SDIO and BMDO have perhaps the best record in the Federal government. This is our success in "spinning off" many of the fruits of our excellent research programs into commercial, civilian, and other military applications. We have had an aggressive technology transfer program for over eight years now, and our record of success is well documented in our report to Congress.

SDIO and BMDO have pushed the state-of-the-art during the last 10 years in sensors, navigation and guidance, propulsion, electrical power, and communications. These advances have resulted in more than order-of-magnitude improvements in performance, weight, volume, and efficiency for these systems. These successes have not gone unnoticed by the Services and other Defense Agencies. The Air Force and the Airborne Reconnaissance Office have shown great interest in the BMDO-developed laser satellite communications system. The Army has leveraged our investment in electric guns of various types for their electric armaments program. New infrared detectors using novel materials, like indium antimonide and gallium arsenide quantum wells, promise to reduce the cost of infrared sensors by more than an order of magnitude over today's cameras, reshaping the entire military sensor and seeker market. We have shrunk the size and weight of inertial measurement units for navigation to less than a tenth of the 1983 state-of-the-art, meanwhile improving their performance. We invested in revolutionary technologies like wide bandgap semiconductors, multi-chip modules, artificial diamond films, and all-optical communications networks using wavelength division multiplexing years before ARPA started major programs in these areas.

Through our outreach efforts, we have also established working relationships with many non-DoD government departments who wish to exploit our advanced technology for other applications. For example, we work with the Department of Health and Human Services using our image processing expertise for improving digital mammograms. We are presently talking with the Department of Transportation about highway safety and traffic monitoring using our sensors and laser radar technology. We have a long-standing technology transfer relationship with NASA, as was recently highlighted by the successful transition of our revolutionary CLEMENTINE deep space satellite technology to their small satellite program. Recently, we have agreed to a demonstration of our advances in multi-level computer security for the Small Business Administration.

Most of our efforts in technology transfer, however, are focused directly on the private sector, predominantly the small business entrepreneur. Since our technology transfer program began in 1985, SDIO and BMDO technology have contributed to 187 new products commercially available today, 34 new companies which have spun off to bring new products to the market, 289 patents granted with 195 more pending, and 356 new ventures of various types -- for example, strategic alliances, licensing agreements, partnerships, or cooperative agreements -- have formed. As best as we can track, these companies have raised over $200 million in matching private capital. Seven of these companies have gone public with a market valuation today of $400 million.

This level of achievement is possible because we consider the potential market as a factor in our selection of what missile defense technology to sponsor. Why is this important to BMDO? It will take about five to ten years for many of these new innovations to be adopted by military systems -- far too long for most companies to wait to become profitable. If we want our successful inventors and engineers and their technology to be around when we need them most, they must become commercially viable to other customers. Commercial success today ensures defense technology availability tomorrow. In addition, the job creation and taxpayer return on investment in missile defense technology resulting from our technology transfer program represents an added bonus for BMDO and the Nation.

The costs for BMDO to support such an aggressive technology transfer program is surprisingly modest -- we spend less than a tenth of one percent (0.1%) of our annual budget on this effort. We have fine-tuned the process of successful technology transfer without diverting substantial funds from our prime mission, developing effective and affordable missile defenses for the country. At this point, I would like to present three specific examples of successes that small companies have had in the marketplace based on missile defense research sponsored by SDIO and BMDO.

SatCon Technology Corporation, of Cambridge, Massachusetts, received BMDO funds to develop vibration control technology to improve the precision of BMDO tracking and pointing systems. They then combined this vibration control with magnetically levitated bearing technology to eliminate vibration and reduce friction in flywheel energy storage devices, compressors, and other rotating machinery. SatCon aggressively pursued commercial markets with their military technology through several joint ventures. It entered a joint venture with Advanced Medical Systems, Incorporated, to develop, manufacture, and market an advanced heart pumping system used for cardiovascular circulatory support and hemodialysis. SatCon also teamed with Chrysler Corporation to develop an innovative drive train and advanced power steering systems using its bearing and vibration control technology. These systems will be tested in Chrysler's high-performance race cars soon. SatCon also joined with Mainstream Engineering Corporation, another small business, to develop a high-speed compressor with a motor that rides on frictionless magnetic bearings. This compressor could be run directly off an automobile's electrical system, removing mechanical drag from the main engine and substantially improving mileage, while eliminating the need for chloro-fluorocarbons in the auto's air conditioning. Starting with six employees in 1986, SatCon has grown to 120 today. The company went public in 1993, raising $8.8 million in an Initial Public Offering and an additional $14 million since. Annual revenues are now over $20 million.

In response to a BMDO need to view missiles, decoys, and battlefield deployments in three dimensions, Reveo, Incorporated, of Hawthorne, New York, devised a monitor for producing 3-D visual displays. Known as Multi-Mode Stereoscopic Imaging, this technique produces high-quality color stereo pictures for electronic video, computer graphics and other display formats at a competitive price. The technology produces hard-copy, display, or projected images of both still and moving pictures, yet can be viewed from any angle with special glasses or at a given position without glasses. Reveo spun-off a subsidiary, VRex, Incorporated to commercialize its 3-D technology for entertainment, advertising, training and simulation, medical diagnostics, and computer-aided design. At the 1993 COMDEX show, VRex introduced the world's only 3-D notebook computer, winning the "Best of COMDEX 93" award from BYTE magazine. VRex is adding other 3-D stereoscopic devices to its product line and plans to develop a family of stereo films and film processing products. Reveo holds five patents with several more pending. It has grown from six employees in 1991 to 40 today, and anticipates $5 million in commercial sales in 1995.

BMDO funded electromagnetic high-force actuators, or HFA's, at Aura Systems, of El Segundo, California, to test our rocket thrusters on LEAP projectiles. Aura has exploited this technology to construct the InteractorTM, a vest used in virtual reality systems to provide physical sensations corresponding to what is happening on the video screen, adding another dimension to existing visual and auditory stimuli. The Interactor received an "Innovation 94" Design and Engineering Award from the Electronics Industry Association. Aura is applying HFA technology to electromagnetic valve actuators to replace cam shafts, rocker arms, and push rods to open and close engine valves. This will result in an engine which produces more horsepower, uses less fuel, and produces lower levels of pollutants than today's engines. Finally, Aura has entered into a joint venture to manufacture HFA-driven audio speakers which produce 6 times less harmonic distortion and no perceptible magnetic interference at 2/3 the weight of speakers today. Aura Systems was founded in 1987, and now employs over 200 people. It has 34 U.S. patents in hand or pending in electromagnetic technology.

I think our success in technology transfer -- to other military programs, other Federal agencies and the commercial sector -- is something in which we should all be proud.

The Legacy of SDI/BMD: Making Ballistic Missile Defenses a Reality

Our investment in missile defense programs for the past twelve years has paid significant dividends. The BMD program has advanced the state-of-the-art of a wide range of technologies that are essential to missile defense and important to other segments of defense and to industries in the commercial sector. Investment in BMD has enabled the program to accomplish what it was chartered to do: demonstrate that ballistic missiles could be detected, tracked, and destroyed by missile defense weapons. This accomplishment has been achieved by a focused and sustained effort to identify the concepts and technologies required to defend against ballistic missiles, rigorous testing of those technologies, integration of technologies into defensive systems, and refinement of those systems to make them affordable and practical. We are now at the point in time where we can field that which we have proved. Our investment in missile defenses has seeded a systems development program that is already putting real, improved hardware into the hands of the warfighter. As my Air Force colleagues like to say, today we are putting "rubber on the ramp" for missile defense systems.

Taking the long view, yesterday's investments in BMD have made these developments possible. Today's reoriented missile defense program is tailored to the future defense needs of our country. Building upon a strong foundation of earlier accomplishments, BMDO is clearly on the path to providing protection for our forces deployed overseas, our friends and allies, and our families here at home. Mr. Chairman, that concludes my prepared testimony. I look forward to answering your questions.

In the Summer of 1993, HOE became the center of controversy when the New York Times charged that the test had been "rigged" to deceive the Soviet Union and in the process also deceived the U.S. Congress. An investigation, conducted under the direction of Secretary of Defense Les Aspin, concluded that although a seperate deception program was indeed in place in the Department of Defense, the SDIO and Army test had not been rigged to distort the results achieved in the HOE test. These findings were later confirmed by an independent review completed by the GAO. (see: United States General Accounting Office, Ballistic Missile Defense: Records Indicate Deception Program Did Not Affect 1984 Test Results, 7/94, GAO/NSIAD-94-219.