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STRATEGIC DEFENSE: THE TECHNOLOGY THAT MAKES IT POSSIBLE

INTRODUCTION

Strategic defense is probably the most exciting and promising defense concept in a generation. At long last, it could end reliance on the balance of terror by giving the U.S. a defense that really defends. What makes this now possible has been the emergence of technologies for constructing weapons systems that can intercept and destroy a substantial portion of an incoming ballistic missile attack. The technological issues related to strategic defense are complex, but the basic operational principles are not.

A multilayered, multitechnology approach to ballistic missile defense (BMD) shows the promise of achieving the capability to intercept a very high percentage of offensive nuclear weapons after they have been launched at the U.S. Attacking ballistic missiles in each phase of their flight with weapons that destroy them in different ways forces the offense to attempt the difficult task of overcoming various threats. This requires various and sometimes self-contradictory countermeasures. Critics argue that strategic defense is not technologically feasible, yet many of the relevant technologies have been researched since the 1960s, and there have been many recent dramatic breakthroughs. From the technological perspective, therefore, the weight of the data supports strategic defense.

SUPPORTING TECHNOLOGIES

Every system of defense against ballistic missiles must perform certain functions to achieve its goal. A system must be capable of: target acquisition (the search for and detection of an attacking object such as an intercontinental ballistic missile or its warheads); tracking (to determine its trajectory); discrimination (to distinguish missiles and warheads from decoys or chaff); and interception (the defensive weapon must be pointed and fired accurately enough to ensure destruction of the offensive weapon). The effectiveness of the defensive operations must then be assessed, and if necessary, the steps repeated and the target attacked again.

These functions use several families of technologies:

Sensor technologies. These acquire and track potential targets. Active radars or passive optical devices that detect infrared energy (heat) can be used to detect objects and form images of them. Lasers can also be used to illuminate and designate targets. Dramatic advances have been made in sensors in the past couple of decades.

Computer technologies. These are critical to all aspects of BMD, including battle management. Signals that are detected must be analyzed rapidly and in detail, and calculations must determine which objects are threatening, what course they will take and so on. These analyses must be performed for each potential target, a number which some claim may be as high as 200,000.[1] The computer breakthroughs of the last decade have improved computing power vastly and reduced computer size, thus alleviating one of the most vexing concerns of BMD critics in the 1969-1972 Anti-Ballistic Missile (ABM) debate.

Communications technologies. Effective communication with defensive systems by military commanders and between the various components of a system will be necessary for battle management and system integration. Substantial advances have been made in communications technologies, particularly with fiber optics--the use of light to transmit data through very fine filaments.

MISSILE FLIGHT PHASES

The most important and controversial family of technologies involves the various mechanisms actually used to destroy the missiles and warheads. These technologies are generally analyzed according to the phase of a flight of a ballistic missile in which the interception is attempted.

Long-range ballistic missiles and their warheads, the intended targets of a BMD system, change character rapidly as they move from one flight phase to another. These changes affect ease

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1 The Defensive Technologies Study Team (the Fletcher panel) reportedly estimated that each enemy missile launched would deliver from "10 to 100 or more" objects that had to be handled by other layers of the defense, and envisioned a 2,000 missile attack. Clarence A. Robinson, Jr., "Panel Urges Boost-Phase Intercepts," Aviation Week and Space Technology, December 5, 1983, p. 50.

of detection and the potential value of the target from a defensive point of view.

The boost phase is a missile's earliest flight segment, starting from launch and extending up to five minutes into flight. During this time, a Soviet missile produces an extremely intense heat (or infrared) signal that can be picked up by a space-based detection and attack warning system. Because it is carrying all of its multiple warheads and decoys at this phase, it is a very high value target.

With booster burnout, an ICBM enters a post-boost-phase, during which it operates a "MIRV bus"--a mechanism that carries all the warheads (known as multiple independent reentry vehicles or MIRVs) and decoys and releases them in a sequence of small, rigorously controlled maneuvers. Because the bus generates small infrared bursts of energy when its maneuver motors fire, detection of it is still relatively uncomplicated. Once the warhead is released, probably accompanied by chaff, decoys, and other objects, its detection becomes far more difficult. The bus then is a high value target that declines in value as it launches each of its warheads on its individual trajectory.

During the midcourse phase, lasting 15-20 minutes, warheads and decoys follow their ballistic trajectories. Discerning threatening from nonthreatening objects by a defensive system could be made difficult by the potentially large number of decoys that might be deployed. Detection and discrimination are further complicated by the fact that warheads and decoys cool rapidly to a temperature very close to that of the surrounding space. The minimal heat generated by such cold bodies can still be discerned by longwave infrared (LWIR) optical sensors. LWIR systems, however, require temperature control to within fractions of a degree if they are to acquire and hold a target. Thus, mid-course interception must deal with the complexities and performance uncertainties of sensor systems, especially LWIR. On the other hand, detection is facilitated by the relatively long period of time available for a search.

During the reentry phase, the warheads reenter the atmosphere. Detection and discrimination again become relatively easy, because of the heat generated during reentry and because lightweight decoys and chaff burn up in the atmosphere leaving only warheads as targets. Reentry only lasts 30 to 100 seconds; thus detection and interception must take place very quickly.

Missiles and their warheads can be attacked during any or all phases of flight. A layered ballistic missile defense system--one that utilizes multiple technologies and attacks targets at different phases of their flight--is considered the most effective. No single layer need be perfect. Each successive engagement reduces the number of targets that the next layer needs to engage, thus enhancing its effectiveness. Measures to counter the defense also become much more complex and costly when they face multiple technologies, each of which must be countered with different and possibly contradictory means.

Boost phase and post-boost phase interception are highly desirable (and possibly critical) for a successful comprehensive BMD system. Destruction in the boost phase destroys a missile's full complement of warheads and decoys and helps simplify the tasks of midcourse and terminal (reentry) interception systems. Destruction of the bus destroys all or a significant fraction of the warheads and decoys and has a similar effect.

BOOST AND POST-BOOST PHASE INTERCEPT TECHNOLOGIES

Immediately after launch, an offensive missile climbs for about 200,000 feet before leaving the atmosphere. During this time, it is relatively immune from attack because U.S. defenses may not be able to react so quickly or because certain defensive technologies cannot penetrate very deeply into the atmosphere. Once the missile or bus reaches space and still is producing a hot plume, however, several defensive techniques then become possible.

Kinetic Kill Weapons

Tiny homing missiles launched from already orbiting carrier satellites could attack an ICBM during its boost phase. Equipped with a tiny warhead that carries its tracking systems, such missiles would crash at high speeds into a booster, destroying it by kinetic energy.

Alternatively, the satellites could carry "Gatling guns," which could fire millions of pellets, creating huge lethal "clouds" through which a booster, a bus, or individual warheads would have to fly. Collision between any pellet and a target would create sufficient impact to destroy the target. The number of orbiting satellites standing on guard could range from 432, estimated by High Frontier (a leading organization advocating strategic defense),[2] each of which would carry 40 to 50 homing missiles, to 1,700, each of which could fire ten bursts of a million pellets in clouds 4,000 feet long and hundreds of feet in diameter.[3]

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2 General Daniel Graham, High Frontier, A Strategy for National Survival (New York: Tom Doherty Associates, 1983), p. 152.

3 Proposed by Fred W. Redding, Jr. at a roundtable discussion on the technologies of strategic defense held at The Heritage Foundation, April 27, 1984. Transcripts of this discussion and a series of other discussions and debates relating to strategic defense will be published by The Heritage Foundation. Mr. Redding is an engineer with DCS Corporation of Alexandria, Virginia.

A variation of these techniques would not place the complex homing optics devices in the satellite-launched minimissile. Instead, the launching satellite would use lasers to illuminate the target. By removing the optics device, the minimissile could carry more fuel and achieve better performance. The optical requirements for such a laser system are well known. Laser designators have been used with tactical weapons systems for almost 20 years.

In many respects, these are the oldest and most developed technologies applicable to boost-phase BMD. Many observers view them as the means of achieving a near-term BMD system using current state-of-the-art technologies.

Electromagnetic Guns (or Railguns)

This technology derives from work on lunar-based or earth-based "mass drivers" for propelling small projectiles to extremely high velocities with electrical induction techniques. A space-based rail gun would use a firing barrel perhaps 100 yards long, made from lightweight trusses, and a power source, such as a turbogenerator or a reactor. Tiny projectiles, possibly weighing less than a pound, could be fired at exit velocities up to 15 miles per second and would be aimed at a booster. With a small homing device and miniaturized impulse motors to correct flight deviations, the projectile would seek out the booster and destroy it with a direct impact.[4]

Such projectiles, however, require resolution of several problems. For example, it may be difficult to miniaturize components that can withstand the shocks and inertial forces of electromagnetic launching and still function during the long coast to their target. Proponents, however, cite such tactical weapons as the Army's COPPERHEAD cannon-launched projectile, a shell which has a set of pop-out wings with control surfaces, an optical homing sensor, and a microcomputer, all hardened to withstand inertial forces as high as 16,000 earth gravities. If the Army can deploy a robust tank-killing shell for use with field artillery, argue rail gun proponents, then designing a miniature homing projectile for rail guns will not be difficult.

Long Wavelength Lasers

A laser is a device that converts energy into coherent radiation--that is, radiation of uniform wavelength. Different kinds of energy can produce lasers, such as chemical, electrical, and nuclear. Longwave (infrared) chemical lasers, now being developed

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4 See Clarence A. Robinson, Jr., "Defense Department Developing Orbital Guns," Aviation Week and Space Technology, July 23, 1984, pp. 61-69; "USAF Studies Hypervelocity Technology," Aviation Week and Space Technology, December 5, 1983, pp. 62-68.

by the Defense Advanced Research Project Agency (DARPA) TRIAD program, combine two chemicals in a highly excited state in a chamber. When the compound leaves the chamber into an area of low pressure, the level of energy in the excited molecules drops because of the loss of pressure, and energy is released. The energy then is drawn off and shaped into a beam by mirrors.

These lasers focus a beam on the surface of the target, heating it to the point of structural failure. This requires that the beam dwell on the target for a short period of time. This means that the beam must follow the target for part of its flight with a minimum of beam jitter, which would spread the energy of the laser over a wider area and reduce the chances of destroying the target.

The advantages of long wavelength lasers include their relatively advanced stage of development (components are currently being tested) allowing, say their advocates, near-term availability. Disadvantages include the unavailability of large, precisely controlled optical surfaces (32.5 to 81.25-ft. mirrors, used to focus the beam, may be required for such lasers) and their vulnerability to direct attack. Such lasers also require considerable quantities of fuel, which must be lifted into orbit from earth.

Long wavelength lasers, like some other space based defenses, are large and potentially vulnerable. The ability of a system to defend itself has thus become a significant determinant of power levels and designs. Anti-satellite weapons that might be used to attack such large systems can be launched from short range, leaving little time to cope with the attack, and can be hardened to laser effects. Effective self-defense may thus require laser brightness higher than can be achieved with long wavelength lasers.

Short Wavelength Lasers

Short wavelength lasers include excimer and free electron lasers. They can be powered by turbogenerators, nuclear reactors, or other power sources. An excimer laser uses two elements (usually a rare gas, such as xenon, and fluorine) that can combine only when one or both elements are excited by a power source. When returned to low energy state, the compound emits laser energy. Free electron lasers use electrical energy--a high energy, accelerated beam of free (i.e., not attached to atoms or molecules) electrons. When passed through an array of magnets that forces the electron beam to undulate in a particular way, it emits laser energy. By altering characteristics of the magnets or the electron beam, the laser can be "tuned" to different wavelengths with different characteristics, such as the ability to penetrate the atmosphere.

Free electron lasers and excimer lasers can be space-based or ground-based. From the ground, they would use a mirror in orbit to reflect the beam to agile "fighting mirrors" also in earth orbit. Ground basing allows for the extremely high power levels (because size and amount of fuel are no constraints) needed for effective self-defense against attack.

Short wavelength lasers offer potentially greater lethality than long wavelength lasers for the same power and mirror diameter. Moreover, they can damage targets through a "pulse" mechanism, in addition to a thermal mechanism. A pulsed laser works by giving the target a physical shock, such as would be produced by explosive evaporation of a portion of the target's surface.

Short wavelength lasers are less vulnerable to countermeasures because of their higher brightness. They are also more efficient, converting potentially as much as 40 percent of their energy into their beam (in contrast to the 5 percent demonstrated so far by the chemical long wavelength laser). A problem, however, is that they require ten times more optical precision (such as mirror finishing and reduction of beam jitters) than long wavelength lasers.

X-ray Lasers

These weapons use a nuclear device to power or "pump" them. An X-ray laser would be composed of a small nuclear device surrounded by as many as 50 slender lasing rods. Once these had been aimed at their target--probably a cluster of missiles reaching the end of their boost phase or MIRV busses--the nuclear device would be triggered. This would pump energy into the lasing rods for the fraction of a second before they themselves would be destroyed in the explosion. This would produce an intense cone of radiation sufficiently powerful to destroy a booster, a MIRV bus, or the warheads themselves, even at long range. Space and submarine basing (allowing the X-ray laser to "pop up" into space on clear indication of attack) have been discussed for X-ray lasers. Because X-ray lasers cannot penetrate the atmosphere, their actual interception of attacking missiles must always take place in space.

X-ray lasers stir controversy, since they use a small nuclear explosion to power the laser. This concern could be offset by the fact that the nuclear explosion creates an X-ray laser that is ideal for hitting large clusters of ICBMs--probably equipped with many megatons of nuclear explosive power aimed at U.S. targets.

Microwave Weapons

Microwave weapons transmit intense beams of microwave radiation, equivalent to a very high powered radar, that destroy a booster's guidance system's electronics. Interception could occur in space or in the atmosphere, since microwaves can penetrate the atmosphere. Unlike most other BMD technologies, microwave weapons are "soft kill" weapons, destroying electronic circuits rather than destroying a booster through impact or heat. They exploit the fact that a missile almost inevitably will have electronic leaky points somewhere on itself or on the MIRV bus. This is particularly the case if the guidance system is carried in the normal fashion in one of the interstage sections between the MIRV bus and the rest of the booster. Once its guidance was knocked out, the booster would veer off course or start to tumble.

Microwave weapons may be powered by chemically powered systems or space-based nuclear reactors. Both technologies are well defined. Space-based nuclear reactors represent one of the oldest space technologies in the U.S. inventory but one that has not advanced recently because virtually the entire space reactor program was shut down for budgetary reasons in 1973 by the Nixon administration. Another potential power source for space-based weapons is the space shuttle main engine reconfigured to power a high-output turbogenerator rather than thrust.

High power levels may require large transmitting structures, which may be vulnerable to attack. This vulnerability and the possibility that the Soviets could insulate the electronics of their booster to protect them from microwave radiation means that microwave weapons probably ought to be supplemented by other boost phase systems.

Neutral Particle Beam Weapons

Particle beams are beams of atomic or subatomic particles. They are generated by producing charged particles and then accelerating and focusing them into a beam by, for example, passing them through an array of electromagnets. After being directed toward the target, the charged particles are neutralized.

Neutral particle beams (NPBs) can be used only in space because charged particle beams are distorted by their own electric charge and by the earth's magnetic field. In the Army's Sipapu project neutral beams were produced by generating a beam of ionized hydrogen--negatively charged with an extra electron--and passing that beam through a material that strips off the extra electron.

NPBs work by penetrating the warhead and destroying internal components. In essence, they deposit a lot of energy in a small space, eliminating the need of some other directed energy weapons, such as long wavelength lasers, to dwell on their targets for an appreciable length of time.

NPB weapons would be large, due to the need for an accelerator and a power source (chemical or nuclear), and thus possibly vulnerable to direct attack. Work is underway on lightweight accelerator designs utilizing laser energy to accelerate the beams, which could substantially reduce the size of such systems.[5]

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[5] Jo Feeney, "Directed Energy," Defense Science and Electronics, November 1983, p. 52.

MIDCOURSE INTERCEPT TECHNOLOGIES

The problem of midcourse interception is dominated by the uncertainties and complexities of detecting cold bodies in space and discriminating real targets from decoys. The important differences between boost phase and midcourse intercept involve sensor technologies.

Many of the kill mechanisms are the same as those used in boost phase intercept. Among them:

Lasers

Midcourse BMD technologies include lasers, particularly those that can produce a pulse of energy sufficient to kill their targets.

Kinetic Kill Systems

Kinetic kill options long have been recognized as some of the most promising for destroying reentry vehicles flying in clutter or accompanied by penetration aids. This approach has been explored since the 1960s in the Homing Intercept Technology (HIT) Program of Project Defender. Midcourse kinetic kill systems can be either ground, air, or space-based. They rely on the energy absorbed by the target warhead, as a result of a direct collision, to destroy the target.

There have been several designs for such systems. The original HIT vehicle, for example, was to weigh one pound and was designed to intercept all targets--decoys as well as warheads.[6] Its size made it ideal for multiwarhead anti-ballistic missiles launched at long range into the "threat tube" through which enemy reentry vehicles would fly on their way to North American targets. However, the increased complexity of designing a maneuverable homing projectile that could detect and discriminate very cold targets against the very cold background of space added weight to the device. HIT vehicles thus evolved with two distinct homing systems--a Miniature Kill Vehicle (MKV) and a Miniature Homing Vehicle (MHV)--increasing their weight to approximately 30 pounds per vehicle. The MKV was cancelled in the early 1970s, to comply with the ABM Treaty restricting multiwarhead ABMs. The MHV is now used on the recently tested F-15 air-launched anti-satellite weapon, but could be used for its original BMD purposes. It could serve as the front of a small minimissile launched from a satellite (as High Frontier has proposed) or a multiwarhead ABM launched from the ground.

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6 John Bosma, High Frontier Supplemental Report, Strategic Defense in Space: A Road Once Travelled? (Washington, D.C.: High Frontier, 1983), p. 19.

The recent successful test by the Army of its homing overlay experiment (HOE) used technologies related to those explored in the HIT program. In the test, the interceptor was launched on a specially modified Minuteman booster after a previously launched dummy warhead was detected by ground radar. The interceptor, carrying longwave infrared sensors, acquired the target at a distance of hundreds of miles and maneuvered itself into an intercept trajectory. Just before impact, a metal umbrella-like net, 15 feet in diameter, unfolded, improving the chances for collision.[7] A direct hit destroyed the target.

"Traditional" Nuclear Systems

In the 1960s and early 1970s, the U.S. developed nuclear weapons for "late midcourse" defense as part of the Army's two-layer ABM system, which was deployed from 1975 to 1976 in North Dakota. The long-range ABM, known as Spartan, carried a 5-megaton nuclear weapon (then the largest in the U.S. inventory) that was designed to produce X-rays. These X-rays would have destroyed approaching warheads by "cooking off" the warhead surface and sending a destructive shock wave into the warhead interior. After Congress ordered the North Dakota site closed, the Spartan went into storage, and its warhead material was diverted to other weapons. At present, the U.S. appears committed to non-nuclear midcourse BMD technologies, given the formidable political difficulties surrounding the nuclear ABM program.

Sensors and Countermeasures

Discriminating real targets from chaff, however, remains a difficult problem for midcourse sensors. Some scientists believe it will be difficult to use sensors capable of the precise discrimination required, especially if the Soviets use decoys heated to the precise temperature of the real warhead or if they use other infrared countermeasures. But thermally controlled decoys pose demanding technical problems in thermal stability, configuration, and operational deployment. Indeed, the U.S. has found the development of penetration aids--long visualized by anti-BMD specialists as a simple task--to be a rigorous, demanding technology that requires constant testing and refinement, with no assurance of successful performance.

There are prospects, moreover, for transferring target acquisition and tracking functions from the space-based defensive system to a "cooperative platform," such as a large aircraft or high-altitude drone carrying a large sensor package. The latter would acquire and track targets in space and then transmit the data to a space-based homing or aiming system. This could solve many of the discrimination and engineering problems associated

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7 Clarence A. Robinson, Jr., "BMD Homing Interceptor Destroys Reentry Vehicle," Aviation Week and Space Technology, June 18, 1984, pp. 19-20.

with operating delicate sensors against large "target clouds" in space that contain hardened nuclear reentry vehicles.

TERMINAL DEFENSES

Terminal defenses were the first techniques explored in the U.S. BMD program. They encounter demanding problems of time, nuclear effects, and very "dirty" operating environments, including dust and debris clouds. Nonetheless, many specialists regard this as perhaps the best developed and most readily available technology.

Nuclear Kill Systems

The Army's 1958-1976 ABM program featured high-acceleration antiballistic missiles such as Nike-Zeus and Sprint that could intercept within the atmosphere. They were armed with nuclear warheads and required very high speeds because of the difficulty of using radar to discriminate genuine attacking warheads from decoys. The solution to this problem in those years was to develop a weapon that was so fast that it could wait until the enemy warhead began reentering the atmosphere. At this point, the decoys, penetration aids, and other debris are stripped off by the atmosphere. The trouble is that by waiting so long, the incoming warhead would be just a few seconds away from its target. This meant that the target had to avoid the blast effects of the U.S. defensive weapons. As a result, the Army's ABMs demanded extremely high speeds, so high that they required heat shields for going up through the atmosphere. Phenomenal burn times and booster performances were achieved not only with Sprint, which could accelerate to 12,000 feet in less than four seconds, but by more advanced boosters such as HIBEX (High-Acceleration Booster Experiment). The UpStage ABM sought to develop extremely maneuverable missiles that could catch maneuvering reentry vehicles.

Such high-acceleration missiles, however, are difficult to control in flight and sometimes could not get sufficiently close to their targets. To ensure that these missiles destroyed even their relatively distant targets, they were armed with nuclear warheads. They also were "command guided" by a sizable radar on the ground. Thus, their overall vulnerability and performance were determined not by the performance of the missile, but by the performance and vulnerability of the ground radars, which were difficult to protect.

Kinetic Kill

The U.S. pursued a non-nuclear, multiwarhead ABM concept from 1959 to 1964 under the Project Defender program. This featured a 50-warhead rocket of light weight that was launched shortly before the anticipated reentry of enemy warheads and heavy decoys. As the "lofter rocket" reached 100,000 to 150,000 feet, it deployed five smaller "dart carrier" rockets, each equipped with ten small "dart warheads"--small rockets that homed in on a reentering warhead and destroyed it with a direct impact. The system proposed to use the thermal heating of a reentering warhead to yield a very simple infrared homing sensor for the dart rocket, for the target would be generating such heat that it could be acquired by any sensor or dart rocket placed in its path. The U.S. reportedly conducted successful flight tests in 1964 of dart rockets against simulated ICBM reentry vehicles.[8]

The Army is currently testing a new interceptor missile that will destroy incoming warheads within the atmosphere through direct impact. These missiles, operating at hypersonic speeds, will use on-board millimeter wave radars to detect warheads and will be steered to their target by more than 100 rocket motors that girdle the interceptor.[9]

Charged Particle Beam Weapons

Charged particle beams are generated in basically the same way as neutral particle beams, except that the charge is not removed. They also kill their target by depositing energy within a target and destroying its internal components. In contrast to neutral beams, charged particle beam weapons are short-range weapons, with a maximum range of 12 miles or so, that provide terminal defense against reentry vehicles or cruise missiles. Both types of particle beam weapons can be rapidly retargeted through magnetic beam control. Beam control for close-in defense is considerably less taxing than that for longer range BMD missions.

The Navy has been a chief sponsor of CPB weapons for shipboard self-defense against cruise missiles, important because the major Soviet antiship cruise missiles now carry nuclear warheads. Since CPB weapons destroy the internal components of a warhead, they can render the warhead inert and avoid the problem of "salvage fusing"--a last-gasp technique designed to detonate a nuclear weapon if its sensors detect that it is under attack and about to be destroyed. This type of defense is a critical necessity when the defender is protecting relatively soft targets, such as ships, which are vulnerable to a wide spectrum of nuclear and nuclear-generated electromagnetic effects.

Simple/Novel Points Defenses

Some technologies are designed to protect only very hardened military targets, such as an ICBM silo. Because these hardened targets can withstand substantial overpressures from a nuclear blast, interception of the incoming warhead can occur at very low levels. Indeed not all warheads need be destroyed; rather a "keep

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8 Bosma, op. cit., p. 4.

9 Clarence A. Robinson, Jr., "Army Testing Hit-to-Kill Radar Guided Interceptor," Aviation Week and Space Technology, July 9, 1984, pp. 38-39.

out" zone must be enforced, outside of which a nuclear blast will be unable to destroy the silo. At this level, moreover, lightweight decoys, unable to withstand the friction of entry, will have burned up in the upper atmosphere, leaving only "real" targets.

Low level point defenses generally use simple kinetic kill to destroy warheads. One possible system, known as "Swarmjet," launches up to 10,000 simple inexpensive rocket projectiles from a series of 10 to 20 launchers. The sheer volume of interceptors provides as much as an 85 percent certainty that the incoming warhead will be destroyed through direct impact.[10] Another possibility is the use of high-fire-rate guns, such as the GAU-8 anti-tank cannon used in the A-10 ground attack aircraft. Deployed in simple silos near a target to be defended and using simple radars, the GAU-8 also could achieve very high kill rates at very low altitudes.

Both of these systems are vulnerable to precursor attacks--low altitude air bursts of incoming warheads that either destroy the radars or create atmospheric turbulence that may prevent the defense projectiles from hitting any warheads arriving just after the air bursts. At the very least, however, they would force Moscow to fire at least several additional warheads at each hardened U.S. target and considerably complicate Moscow's attack calculations.

Dust Defense

The dust defense concept envisions burying small nuclear bombs near a target to be defended. Just before an incoming warhead is to arrive, the buried bomb would be detonated, creating a thick cloud of dust and debris. Incoming warheads could not survive the impacts and friction caused by this. The principal disadvantage to this method of defense is the understandable political opposition to burying bombs and detonating them on U.S. soil.

CONCLUSIONS

Which systems or technologies best will defend the U.S. from missile attack? The final answers are unknown at this time. One thing, however, already is certain: the development and deployment of multilayered technologies, each offering different kill mechanisms, each posing demanding countermeasuring problems to an enemy missile force, potentially can provide a high level of effectiveness in destroying offensive weapons systems. Furthermore, breakthroughs in technology can occur more readily in this

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10 Richard Garwin, Ashton B. Carter and David N. Schwartz, eds., in Ballistic Missile Defense, (Washington, D.C.: Brookings Institution, 1984), p. 395.

multitechnology, multilayered synergistic approach to BMD. The layering of defenses permits second and third tier defenses to compensate for the failures of the preceding tiers. There appears to be an increasing prospect that seemingly marginal breakthroughs in sensors, microcomputers, and flight vehicles might provide the kind of system breakthroughs that will provide the defense with significant advantages over the offense.

Such breakthroughs, however, will not be achieved without significant research. The Reagan Administration's Strategic Defense Initiative will ensure the research needed to determine the viability of a whole range of technological options. Only with this research can the most effective mix of technologies be determined; failure to fund the research at adequate levels foredooms such an effort.

The promise of these defensive technologies is clear. The development of a reliable and safe system of strategic defense, allowing the U.S. to destroy incoming missiles, will permit the U.S. to reduce its terrifying reliance on vast arsenals of offensive nuclear weapons to deter Soviet attack. Instead of a peace based on a balance of terror, Americans can look forward to a peace based on a defense that really defends.

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