SCIENTIFIC AMERICAN.COM

October 25, 2004

Holes in the Missile Shield

The national missile defense now being deployed by the U.S. should be replaced with a more effective system

By Richard L. Garwin

This fall, perhaps by the time you read this, President George W. Bush is expected to declare that the first phase of the long-awaited national missile defense is operational. The Pentagon's Missile Defense Agency (MDA) plans to install six interceptor rockets--designed to strike a ballistic missile in midcourse--in silos at Fort Greely in Alaska by mid-October. Ten more will be deployed at Fort Greely and four more at Vandenberg Air Force Base in California by the end of 2005. Over the following years the MDA intends to bolster this rudimentary midcourse defense with more interceptors, advanced radars and surveillance satellites. The reason for the deployment is to counter the threat that a rogue state--namely, North Korea or Iran--will attempt to hit the U.S. with nuclear or biological weapons delivered on intercontinental ballistic missiles (ICBMs).

But despite the more than $80 billion spent by the U.S. on missile defense since 1985, this system will not provide significant protection for many years, if ever. The political pressure to claim that the U.S. is secure against a rogue nation's attack has led to a defense that will not counter even the earliest threats from the emerging missile powers. The MDA's midcourse system is built to intercept long-range missiles fired thousands of kilometers from the U.S.; it can do nothing to stop a short- or medium-range missile launched from a ship off America's coasts. What is more, the interceptor rockets would most likely prove inadequate against long-range missiles as well, because an enemy could easily equip its ICBMs with fundamentally simple and highly effective countermeasures.

A strong defense against ballistic missiles is a worthy goal. The destructive capacity of nuclear warheads is so enormous that it would be unconscionable not to explore methods for preventing them from hitting the U.S. But instead of rushing to construct a flawed system, military contractors, technologists and politicians should pay more attention to evaluating the relative magnitudes of the threats and assessing the capabilities of the proposed defenses. The Pentagon must focus on the more immediate danger of short- and medium-range ballistic and cruise missiles, and the funds now being devoted to the MDA's midcourse defense should be shifted to the development of alternative systems that would have a real chance of stopping ICBMs.

Missile Defense Basics

Missile interception schemes can be divided into three broad categories: terminal, boost phase and midcourse. Terminal defense involves stopping the missile's warhead in the final phase of its trajectory, typically when it is less than a minute away from its target. An important consideration for terminal defense is making sure that the intercept occurs before the warhead gets close enough to damage the target. Thus, the task of protecting a city's buildings and people is far more difficult than that of preserving enough hardened concrete missile silos to retaliate against a first strike (thereby deterring such an attack). When defending a city, the interceptors must preclude a nuclear blast from a larger area and destroy the warheads at a higher altitude. And because a city is much more valuable than a missile silo, the reliability of the intercept must be correspondingly higher.

For example, a one-megaton nuclear warhead would need to be intercepted at an altitude of at least 10 kilometers to prevent the city from being incinerated by the heat of the hydrogen bomb. Further, the interceptor rocket could not be launched until the warhead enters the atmosphere, allowing the defense to distinguish between the heavy weapon and any light decoys accompanying it. These constraints mean that the interceptors cannot be based more than 50 kilometers from the city. So unless the Pentagon is prepared to carpet the nation with interceptors, it is clear that terminal defense is not an appropriate response to the threat of a few nuclear-armed ICBMs. Even a perfect defense of many cities would simply lead to the targeting of an undefended city.

Boost-phase intercept requires disabling the ballistic missile in the first few minutes of its flight, while it is still ascending. This strategy puts high demands on the interceptor. After liftoff, a typical ICBM arcs upward at an average acceleration of about three g's (three times the acceleration of gravity at the earth's surface), reaching a speed of seven kilometers per second in 250 seconds. Suppose the interceptor has 200 seconds to get to the ICBM (that is, it is launched within a minute of the ICBM's launch) and must travel 500 kilometers from its base to hit the enemy missile. The interceptor would be able to cover the distance if it accelerates at a constant rate of about three and a half g's for the first 100 seconds, then moves at a burnout speed of 3.33 kilometers per second for the next 100 seconds. If the interceptor has to fly 1,000 kilometers, the acceleration and burnout speed would need to be twice as great.

The U.S. system will not counter even the earliest threats from the emerging missile powers.

To down ICBMs launched anywhere in North Korea, boost-phase interceptors based on ships off the country's coast or in a neighboring nation might have to travel as far as 1,000 kilometers, so they would need a burnout speed of six to eight kilometers per second. Iran, though, is a much larger country, so interceptors would need burnout speeds of about 10 kilometers per second. And because the interceptors must reach this speed in as little as 50 seconds, they would require an average acceleration of 20 g's. Building such interceptors would not be an insuperable task; in the 1960s the U.S. tested a small missile that briefly accelerated at an average rate of 260 g's. Boost-phase interceptors show more promise than an alternative called the airborne laser, which would attempt to disable ICBMs by focusing laser beams on them as they ascend. Extremely expensive to build and operate, the aircraft-mounted laser would have no effect on missiles more than 300 or so kilometers away.

Boost-phase intercept becomes still more difficult when defending against ICBMs launched from Russia or China. These countries are so vast that offshore interceptors could not reach the missiles while they are ascending. The interceptors would have to be placed in orbit, which greatly increases the expense of the system. Although space-based boost-phase interceptors were part of the original Strategic Defense Initiative proposed by President Ronald Reagan two decades ago, by the late 1990s the Pentagon had focused instead on midcourse systems, which attempt to destroy a missile's warhead while it is hurtling above the atmosphere at the top of its arc. For this reason, the missile defense now being deployed by the MDA is the most mature technology--but it is definitely not the most effective.

Hit to Kill

How would the MDA's system work? The first indication of the launch of an ICBM against the U.S. would come from military satellites designed to detect the hot flame of a large rocket motor. In operation since the 1970s, these Defense Support Program (DSP) satellites are located 36,000 kilometers above the earth in geosynchronous orbits--because each has an orbital period of 24 hours, it remains fixed over a single point on the equator. Together the satellites view almost the entire planet in the infrared part of the spectrum and are thus able to see the launch of every ballistic missile of significant size and range. Each DSP satellite scans the earth's surface every 10 seconds, providing a rough position for the ICBM--to an accuracy of about one kilometer--from the time the missile breaks cloud cover at an altitude of about 10 kilometers until the burnout of its rocket motor some 200 to 300 seconds later. Over parts of the earth there is stereo DSP coverage.

The MDA's system would fire several interceptors against each missile to destroy it in midcourse, long after its engine had stopped firing and its nuclear warhead had separated from the rocket. The intercept would take place in the vacuum of space, hundreds of kilometers above the earth's surface, and the target would be the warhead, which is encased within a reentry vehicle to protect it against the fiery heat of reentering the atmosphere. Because the interceptors must be given a precise aim point in space and time to allow them to home in on the warhead, and because the DSP satellites cannot detect a missile after its rocket engine shuts off, midcourse intercept requires accurate radar tracking of the missile's trajectory.

To cover the North Pacific trajectories that would most likely be used by North Korean ICBMs, the Pentagon originally planned to build an advanced radar station on Shemya Island at the tip of Alaska's Aleutian chain. The strong winds and violent seas of that area made on-site construction difficult, though, so the MDA is now building the $900-million radar on a floating platform off the coast of Texas. On its expected completion by the end of 2005, it will be towed to its operational site near the Aleutian chain. (Until then, the MDA's system must rely on the U.S. Air Force's Cobra Dane early-warning radar on Shemya Island.) The new radar will send out microwaves in the X-band part of the spectrum. With a wavelength of about three centimeters, these waves are shorter than those used by conventional radars. Such short waves are necessary to narrow the radar's beam so that it can pinpoint a missile's warhead amid the "threat cloud," which also includes the ICBM's last rocket stage and, most likely, dozens of inflatable balloon decoys designed to mimic the warhead to radar and even visible or infrared sensors.

Of course, the new X-band radar near the Aleutians would be of no use in protecting the U.S. against ICBMs launched from Iran, which would fly over Europe and the North Atlantic. The MDA plans to remedy this deficiency in the coming years by deploying improved sensors and interceptors at a wider array of sites. Ultimately, the DSP system will be supplanted by a new space-based infrared system consisting of satellites in geosynchronous orbit that will provide better tracking of ICBMs during their ascent. In addition, the Pentagon is developing a constellation of satellites in low earth orbit that would be able to track missiles during the midcourse phase using infrared and visible-light sensors. The communications network that links the satellites, radar and interceptors with the command and control center at Cheyenne Mountain in Colorado will also be upgraded in stages.

Earlier missile defense approaches--the Safeguard system operated by the U.S. in the mid-1970s to protect 150 ICBM silos in North Dakota and the still operating Russian system that defends Moscow--

relied on nuclear-armed interceptors that were designed to detonate once they were close enough to the enemy missile to obliterate it. But guidance systems have improved so much in the past few decades that it has become possible for interceptors to destroy ballistic missiles simply by colliding with them. This technique avoids the need for nuclear detonations in space or the atmosphere that would disrupt communications and pose environmental hazards. In the MDA's system, each interceptor carries a payload called a kill vehicle, which uses infrared sensors to home in on the ICBM warhead. Once the kill vehicle comes close enough that the warhead is in the sensor's field of view, the vehicle can use small side thrusters to put it on a collision course. The Pentagon has demonstrated this so-called hit-to-kill capability in several tests since 1999, although the MDA and its critics agree that the Defense Department did not realistically simulate a ballistic-missile attack.

In this approach, the closing velocity at intercept is so high that the entire kill vehicle becomes an effective projectile. Even a stationary kill vehicle colliding with an ICBM warhead moving at seven kilometers per second delivers a tremendous wallop of kinetic energy--nearly 25 million joules for every kilogram of the vehicle's mass. In contrast, the energy density of high explosive is only about four million joules per kilogram. Adding explosive to the kill vehicle is obviously not necessary; it would be better to add mass in the form of improved guidance systems that would increase the probability of a hit on the target.

Countermeasures
National missile defense must contend with an adversary who has high stakes at risk and does not want our activity to succeed. Thus, it would be false security to field a system that would work only against an opponent who did not make use of readily available countermeasures. One obvious countermeasure would be to reduce the radar and infrared signatures of the ballistic missile and its warhead to make it harder for the interceptors to home in. For example, putting the warhead in a reentry vehicle shaped like a sharply pointed cone and coated with radar-absorbing material could significantly shrink the object's appearance on X-band radar. Also, an attacker could cool the black shroud of the warhead using liquid nitrogen, making it invisible to the kill vehicle's infrared sensor.

Another countermeasure would be to load each ICBM with dozens of decoys designed to look just like the warhead. If the ICBM releases the decoys and warhead at the end of powered flight, the paths of the lightweight decoys would be indistinguishable from that of the heavier warhead when they are traveling through the vacuum of space. The attacker could also put heaters in the decoys to give them the same infrared signature as the warhead. To ease the task of decoy building, the attacker could create an antisimulation warhead--a weapon dressed to look like a decoy. For instance, the warhead could be enclosed in a radar-reflecting aluminized balloon that appears identical to dozens of empty decoy balloons. If the kill vehicles cannot distinguish between the warheads and the decoys, hundreds of interceptors would have to be launched and the missile defense would quickly be overwhelmed.

The fundamental weakness of midcourse intercept is that the countermeasures are all too simple. The money and skill needed to implement them are trivial compared with the effort required to design, build and care for the ICBMs themselves. Unfortunately, the MDA makes the artful assumption that North Korea (which has not yet tested an ICBM capable of carrying a nuclear warhead, although the cia has expected such a test since before 1998) will not field any countermeasures that could defeat the U.S. interceptors. I am so persuaded of the effectiveness of these countermeasures--specifically, decoys and antisimulation balloons--that beginning in 1999 I strongly urged the Ballistic Missile Defense Organization (the predecessor of the MDA) to abandon the midcourse defense and assign higher priority to boost-phase intercept instead.

The only sure way of defeating these countermeasures is to intercept the missile earlier in its flight, because credible decoys cannot be released from the ICBM while the rocket is still firing--they would soon be left behind. An attacker could still attempt to fool the interceptors by launching dummy missiles designed to look like a warhead-carrying ICBM, but because each dummy rocket would have to include at least two stages to be a credible replica, this effort would be considerably more expensive than releasing a few dozen balloons. Another advantage of boost-phase intercept is its ability to stop the delivery of biological weapons, which would most likely be packaged in hundreds of small bomblets that would be released from the ICBM just after its ascent. Because the bomblets would streak separately toward the U.S., no midcourse or terminal defense system could halt such an attack.

Proponents of the MDA's system have argued that they intend to eventually incorporate boost-phase intercept into the national missile defense. But the creation of a layered defense, which attempts to intercept the missile at multiple stages of its trajectory, is not necessarily a cost-effective strategy. Each of the defensive layers has a price, and investing in boost-phase intercept will make the U.S. much safer than using the same funds to build or expand the flawed midcourse system. Unfortunately, the technology development for boost-phase intercept is still in the preliminary stages. My 1999 discussions with missile defense officials were not continued, and the MDA delayed several years before initiating a formal boost-phase program.

In 2003 the American Physical Society (APS) released an analysis of the potential of boost-phase intercept. The study was written by a highly qualified panel of physicists and engineers, many with years of experience in missile defense. Although news accounts claimed the study was negative on boost-phase defense, a careful reading shows that the analysis is in reasonable agreement with my qualitative estimates of 1999. I judged that 14-ton interceptors would be required, with burnout speeds ranging from eight to 11 kilometers per second. The guidance system would home in on the ICBM's flame and then the missile's body, and the interceptor would smash into the missile hard enough to disable its rocket engines. The APS study group analyzed in considerable detail the evasive maneuvers available to the ICBM and the capabilities required of the interceptor to cope with them.

The primary missile threat is not ICBMs, but short-range missiles launched from ships.

The APS group showed how difficult it would be to plan the intercept of an ICBM from North Korea in such a way as to guarantee that the warhead--which might still be functional after the impact--does not strike somewhere in the U.S. or in some other country. (If the ICBM is hit near the end of the boost phase, the warhead might still have enough momentum to reach North America.) In my own writings, I have emphasized that the intercept should still be considered successful if the warhead were to reenter the atmosphere over some random point in the U.S. instead of its target city. Because the average population density of the U.S. is only about 1 percent of the peak density in cities, the intercept would effectively devalue the enemy's missile force by a factor of 100, which should be enough to deter the launch.

Space Wars
As the mda now decides which boost-phase options to pursue, some officials are dusting off the old plans for space-based interceptors that were part of the original Strategic Defense Initiative. The Brilliant Pebbles concept, for example, envisioned a constellation of interceptors in low earth orbit, each equipped with enough fuel to propel itself toward an ascending ICBM and to counter any evasive maneuvers that the missile might attempt. Representative Curt Weldon of Pennsylvania, a strong advocate of national missile defense, recently cautioned supporters of space-based interceptors not to oppose the deployment of land- and sea-based interceptors, because this internecine struggle is likely to delay both programs. But many missile defense supporters make no pretense about their utmost goal--to deploy a system that could counter Chinese and ultimately Russian ICBMs--and only space-based interceptors could achieve that aim.

A space-based system, however, would be extremely costly and vulnerable. If the interceptors were placed in low earth orbit, they would circle the globe every 90 minutes or so; the U.S. would need to deploy more than 1,000 of them to ensure that a sufficient number would be near North Korea when even a single ICBM is launched. Although the space-based interceptors would not have to be as large as those launched from land or sea, they would be useless in orbit without powerful rocket engines to reach the ascending ICBMs in time. The APS group estimated that the interceptors would have to weigh between 600 and 1,000 kilograms. And because it costs $20,000 to send just one kilogram into orbit, the price tag of the space-based intercept system could easily run into the tens of billions of dollars.

Furthermore, the fact that the space-based system could also threaten Chinese and Russian ICBMs may compel those governments to take preemptive steps. China may appear particularly vulnerable because it has only about two dozen nuclear-armed ICBMs capable of reaching North America. If the U.S. puts thousands of boost-phase interceptors into orbit, China would no doubt build more long-range missiles, because the space-based system can be defeated by launching many ICBMs at once from a small region. China would also have every incentive to destroy the orbiting interceptors. Unlike a preemptive strike on land- or sea-based systems, an attack against a space weapon would not result in human casualties and might not be considered an act of war by the international community.

One way to destroy a satellite in low earth orbit is to launch a pellet cloud to orbital altitude to shred the interceptor as it passes through. The Chinese could also use ground-based rockets to shoot down the interceptors one by one. Or they could put microsatellite space mines into orbit, each within a few tens of meters of an interceptor and ready to detonate at a moment's notice. The same countermeasures would be even more cost-effective against another proposal for boost-phase defense, the space-based laser, which would be larger and more vulnerable than the interceptors.

The Weakest Link
Even the leaders of the mda claim very little for the national missile defense that is now operational. Testifying before the House Armed Services Committee last March, Lieutenant General Ronald Kadish, longtime head of the MDA and its predecessor agency, noted that "what we do in 2004 and 2005 is only the starting point--the beginning--and it involves very basic capability." My assessment, however, is that the present missile defense approach is utterly useless against ICBMs of new or existing nuclear powers because midcourse countermeasures are so effective.

What is more, the primary missile threat to the U.S. is not ICBMs. If a nation such as North Korea or Iran is intent on attacking an American city, it is far more likely to do so using short-range missiles launched from ships near the U.S. coasts. In a press briefing in 2002 Secretary of Defense Donald H. Rumsfeld noted: "Countries have placed ballistic missiles in ships--dime a dozen--all over the world. At any given time, there's any number off our coasts, coming, going. On transporter-erector-launchers, they simply erect it, fire off a ballistic missile, put it down, cover it up. Their radar signature's not any different than 50 others in close proximity." Despite this acknowledgment, however, the Defense Department has no system planned for deployment that could defend against these missiles.

The irrelevance of the operational missile defense has become apparent even to longtime supporters of the goal. Conservative columnist George Will recently wrote that "a nuclear weapon is much less likely to come to America on a rogue nation's ICBM--which would have a return address--than in a shipping container, truck, suitcase, backpack or other ubiquitous thing." But even in the unlikely case of an undeterrable ICBM launch from an irresponsible power, the midcourse system is not the best defense. The MDA's efforts should be shifted to boost-phase intercept, and if the goal is to stop ICBMs from North Korea and Iran, then land- or sea-based interceptors show the most promise. In all these cases, the vulnerability of the defending system must be taken into account, which effectively rules out the use of space-based weapons. In missile defense, as in so many other fields, the system is only as strong as its weakest link.