**A new push to erect a ballistic missile shield is technologically more plausible than the 1980s "Star Wars" program. To skeptics, however, the effort remains futile and dangerous**

# Missile Defense Rides Again

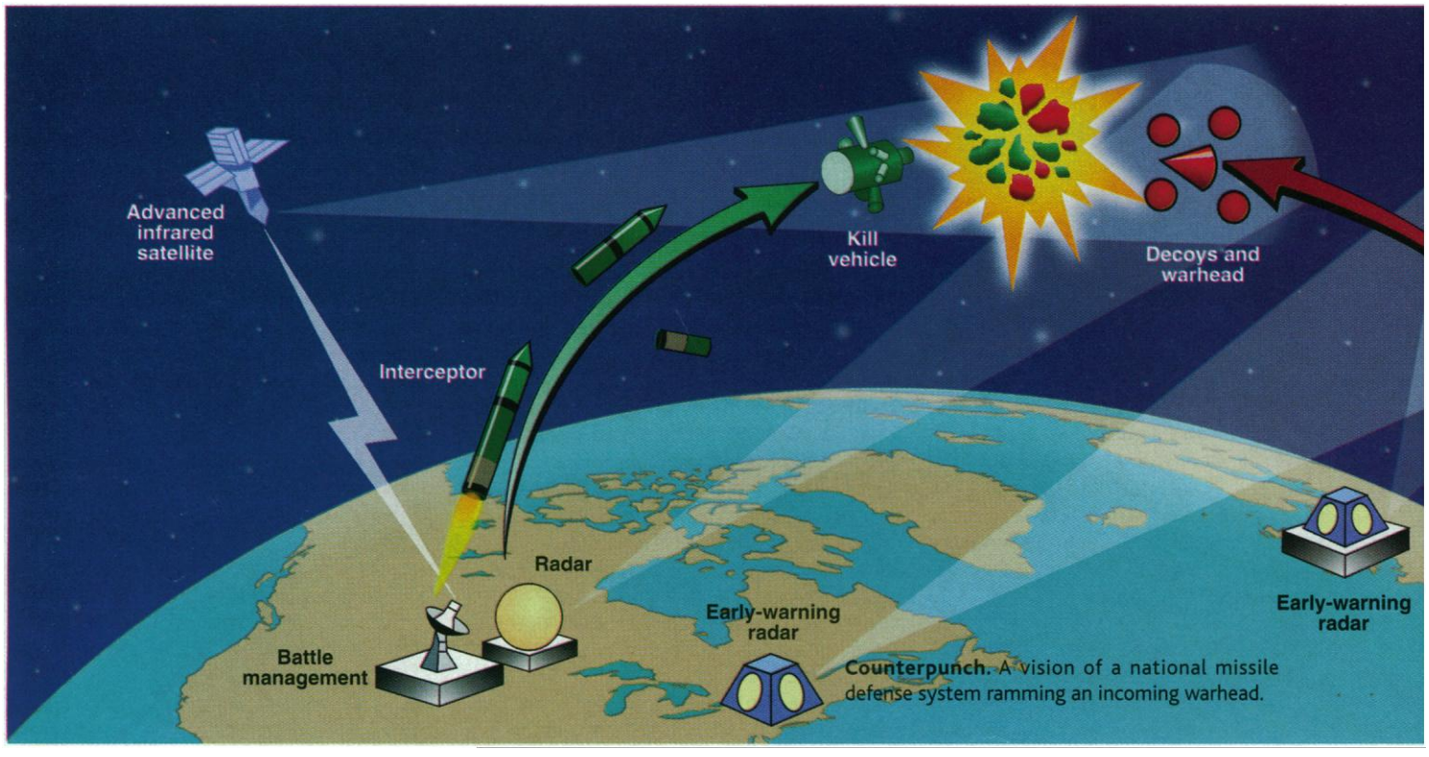
Sometime this summer, two projectiles will collide over the central Pacific Ocean with such fury that they annihilate each other. Or they might miss. Either way, this encounter in the silence of space, more than 100 kilometers above the top of the atmosphere, will be freighted with meaning for the citizens of the globe sparkling below. Some of them will see in this event a clash between good and evil, peace and war, or simply technical know-how and raw destructive terror. Others will view the entire display as a step toward a dangerous and desperate folly.

In literal terms, a mock enemy warhead launched westward from Vandenberg Air Force Base in California will meet a 55-kilogram, thruster-controlled "kill vehicle" outfitted with infrared seekers and fired from the Kwajalein Missile Range in the Marshall islands. Hit or miss, the encounter will mark the first intercept test for components of a proposed system that some believe could shield the United States from a small number of intercontinental ballistic missiles (ICBMs) launched in our direction either accidentally or by "rogue nations."

Major Nickolas Demidovich of the Air Force says the collision will produce "a very bright flash," easily visible to the naked eye from Kwajalein if the intercept is successful and clouds don't block the view that afternoon. That flash would be generated solely by the energy of the collision at more than 10 kilometers per second, not by explosives, says Demidovich, chief of the National Missile Defense (NMD) flight test for the Pentagon's Ballistic Missile Defense Organization (BMDO). "This is pure, kinetic, body-to-body kill," he says.

The flash would fade almost instantly, but its consequences could change the face of global strategy, warfare, and what might be called macropsychology in the 21st century—for better or worse. For if the July test succeeds, it will add technical credibility to a fast-expanding arsenal of missile defense systems, some parts of which have suffered high-profile test failures. Officially, many of these systems have nothing to do with the NMD, which would meet an incoming warhead early enough in its deadly arc to shield the entire country from a limited attack. They are meant to erect missile shields over limited swaths of territory, such as a "theater" of war—not an entire nation. But the slower, shorter range theater interceptors largely rely on the same hit-to-kill strategy as NMD and might even play a role in its shield. NMD "is essentially a theater defense writ large," says John M. Cornwall, a physicist at the University of California, Los Angeles, who teaches and consults on missile defense.

Even before the summer test, missile defenses are getting an enormous political boost from a confluence of domestic and global events. China's alleged theft of nuclear warhead designs from U.S. national laboratories and North Korea's test of a three-stage medium-range missile last August have alarmed politicians and the public. And a report by a commission led by Donald Rumsfeld, a former secretary of defense, has warned that Iran, Iraq, or North Korea could secretly develop ICBMs in the next 5 or 10 years. Reacting to the concerns, last month the Senate passed—by a vote of 97-3—a bill sponsored by Thad Cochran (R–MS) and others that calls for the United States to deploy an NMD "as soon as technologically possible." The Clinton Administration, originally skeptical about national missile defense, has now pledged $6.6 billion in new money for NMD through 2005, adding to the BMDO's current budget of $3 billion to




SOURCE: BMDO

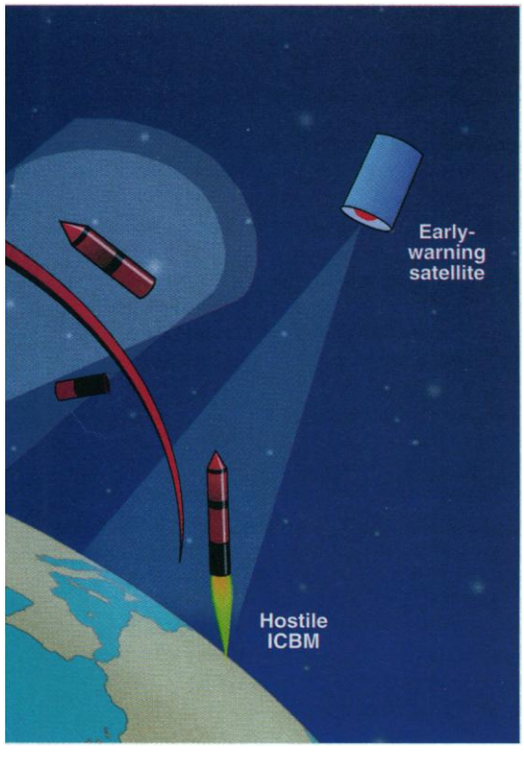
**Counterpunch.** A vision of a national missile defense system ramming an incoming warhead.

$4 billion a year. It has also set a target date of 2005 for deploying an initial, small NMD—providing tests beginning with the one this summer yield promising results.

Supporters of the program believe the technology will live up to its billing. The current missile defense effort has a far more limited goal than the Strategic Defense Initiative (SDI) of the 1980s, which aimed to defend the entire nation against a barrage of thousands of ICBMs launched by the Soviet Union. And it shuns the phantasmagoria of ambitious technologies, from pop-up x-ray lasers to space-based particle accelerators, that gave the 1980s effort the pejorative moniker "Star Wars." The hit-to-kill strategy builds on existing know-how: fast, miniaturized, solid-state hardware like ring lasers for inertial guidance, infrared sensor arrays for seeing targets, and tiny processors for computing trajectories. "This is not Star Wars redux," says a high-ranking scientist at an Energy Department laboratory.

Critics concede part of the point. In spite of the recent test failures, including six straight misses by an Army theater defense system called the Theater High Altitude Area Defense, or Thaad, the hit-to-kill technologies are evolving rapidly. Many analysts agree that the strategy has a better chance of meeting its goals—picking off a few enemy missiles above the atmosphere—than the grandiose Star Wars program did. "At the physical principles level, the device fabrication level, this is obviously easier than some of the stuff they were talking about a decade ago," says John Pike of the Federation of American Scientists in Washington, D.C. But he and other skeptics say the change in technology and scope has not eliminated many of the larger concerns about missile defense.

CREDIT: U.S. ARMY




Any system deployed nationally, they say, will make the world a more dangerous place by alarming adversaries who fear that such a system would allow the United States to launch a first strike, then parry a counterattack. It might also violate the 1972 Anti-Ballistic Missile (ABM) treaty, which now limits Russia and the United States to one fixed land site with no more than 100 interceptors. Conservatives have long viewed the treaty as a needless constraint on the United States' ability to defend itself. But other analysts disagree. "Abrogating the ABM treaty would be politically a disaster," says Dean Wilkening, director of the science program at Stanford University's Center for International Security and Cooperation, as doing so could prompt adversaries to build more weapons in hopes of overwhelming any missile defenses.

**High hopes.** A Minuteman II missile lofts a National Missile Defense sensor in a test flight from Kwajalein in the Marshall islands.

At the same time, many believe that any system, no matter how good, will be porous—vulnerable to crude countermeasures like throwing out dozens of decoys or inflating a huge balloon around a nuclear warhead in space in order to hide its exact position. "The old saying, 'One nuclear weapon will ruin your whole day'—it's really true," says Stephen Schwartz, publisher of the Chicago-based *Bulletin of the Atomic Scientists*. "Nothing works 100%, all of the time," he says—a point that some believe is underscored by Thaad's repeated failures to hit a target uncluttered by decoys. The only proven response to the threat of nuclear or biological weapons is deterrence, says Richard Garwin, a senior fellow at the Council on Foreign Relations and an IBM fellow emeritus. "You can't counter it," says Garwin of the ICBM threat. "You can only lie to the American people. Once you start spending so much money, that's bound to happen."

NMD supporters, however, have a rejoinder that is almost visceral: "It has to work," says Senator Bob Smith, the conservative New Hampshire Republican who has already declared his presidential candidacy for the 2000 election. "We're in a very dangerous and vulnerable situation; we do have nations now that have the capability to reach us," says Smith, who also chairs the Strategic Forces subcommittee of the Senate Committee on Armed Services. The doubters, says Air Force Lieutenant Colonel Rick Lehner, a BMDO spokesperson, are arguing, "if you can't do everything, don't do anything. Obviously we don't agree with that."

### A limited shield

Around the same time that political support for deploying an SDI system evaporated in the early 1990s, public interest in more limited defenses, designed to protect troops or cities against short-range missiles, gained a big boost. The catalyst was the Patriot, a system that received glowing praise during the Gulf War for apparently shooting down Iraqi Scud missiles. Some defense analysts have since cast serious doubt on the Pentagon's claims of a high success rate for the Patriot (see sidebar), but support for theater defenses has gained strength, and many of the technologies developed for these systems lie at the heart of the planned NMD.

The Patriot itself has undergone a radical technological overhaul. Originally designed to punch holes in relatively slow-moving airplanes by exploding near them, the missile has since been redesigned into the lighter, sleeker, and more maneuverable Patriot-3, which rams its quarry. A prototype of the new interceptor nailed three out of four intercept attempts in 1993 and 1994, and the Patriot-3 had a hit just last month.

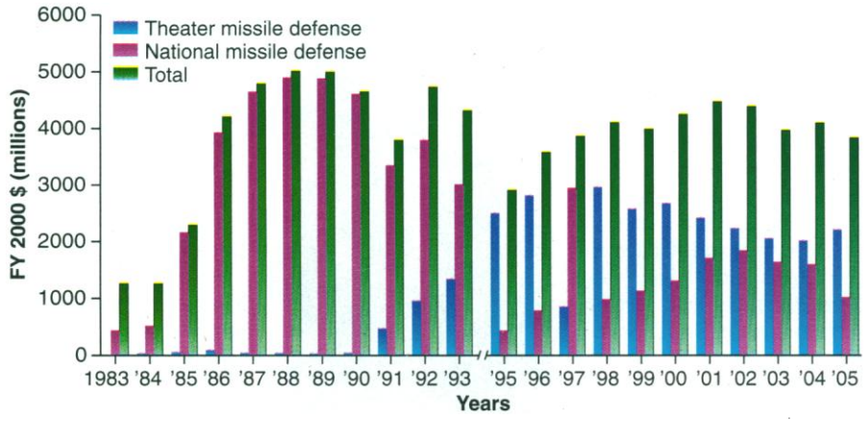
The Patriot-3 trades the original aerodynamic control system of tilting fins for 180 small thrusters, which enable it to make the hairpin turns needed to intercept a missile that has begun to tumble. An onboard, millimeter-wave radar feeds data to processors that not only calculate trajectories and control the thrusters, but also scroll through databases of known missiles to determine how best to ram the target in order to demolish the warhead. If it works as planned, the Patriot-3 (which goes by the acronym Pac-3) would meet and destroy a target at an altitude of 20 kilometers or below as the warhead bore down on a troop emplacement or a city within the protected "footprint."

Unlike the original Patriot, the Pac-3 "was designed from the beginning as an antimissile missile," says George Lewis, associate director of the Massachusetts Institute of Technology's (MIT's) Security Studies Program and a critic of the earlier sys-

tem's performance in the Gulf War. "I can't tell you if this is going to be good enough—but it's better," says Lewis.

Pac-3 would not have to do its job alone. Theater defense systems like Thaad would take an earlier shot at incoming missiles, climbing faster and higher to defend a footprint of a few hundred kilometers. Thaad might get its first warning of an enemy launch from satellite-borne infrared sensors. Eventually the incoming missile would be picked up by Thaad's ground-based "X-band" radar, which operates at frequencies above 10 gigahertz and is being touted as the most powerful radar in the world. High frequencies correspond to short wavelengths, permitting the radar to pick out fine structural details that could enable it to distinguish a warhead from decoys.

The Thaad interceptors, fired from truck-based launchers, would initially rely on the satellite and radar data to close in on their target. As the air thins out with increasing altitude, Thaad's booster rocket falls away from its kill vehicle, whose course is then controlled by thrusters emerging from its center of mass. Thaad has a "sweet spot" for intercept between altitudes of 40 and 100 kilometers, where the air is dense enough to foil light decoys such as balloons but cool and tenuous enough to contrast with the infrared glow of a ballistic missile's warm reentry vehicle. As it enters a "basket" of proximity to the target (the actual distance is classified), Thaad "opens its eyes"—a 256-by-256-element, gimbal-mounted matrix of infrared sensors.




**The fall and rise of missile defense.** Graph tracks the recent growth of theater missile defense funding.

SOURCE: CENTER FOR STRATEGIC AND BUDGETARY ASSESSMENTS; *ATOMIC AUDIT* (BROOKINGS, 1998); STEPHEN SCHWARTZ, ED.; BMDO

"This matrix obviously becomes a picture," says the Army's Colonel Bill Hastie, director of system acquisition in BMDO. "You have the cold background of space, and you have the hot missile coming at you." Just as with the Patriot, says Hastie, onboard processors use this information to home in for the kill.

This multiple-shot strategy relying on both Thaad and Pac-3 would create a leakproof shield in a theater of war, planners hope. "When a missile's coming in, hopefully the upper tier gets a shot at it first. Maybe one or two shots," says Hastie. "And if it hasn't made the intercept, then the lower tier can. To get a high probability of kill … you need more than one shot to do it."

The high-altitude shield, however, faces both technical and political hurdles. Two weeks ago Thaad—after Pac-3, the best developed of a panoply of new theater defense programs—once again failed to hit its target

## Patriots Missed, But Criticisms Hit Home

In the debate about ballistic missile defenses, the Patriot is Exhibit A—for both sides. "Patriot is proof positive that missile defense works," said President George Bush during the 1991 Gulf War. At the time, Army assessments painted the antimissile system as all but perfect at intercepting Iraqi Scud missiles. But the Patriot received quite different reviews from two Massachusetts Institute of Technology (MIT) researchers who analyzed commercial video footage of intercept attempts. They said there was no evidence of a single successful intercept during the Gulf War (*Science*, 8 November 1991, p. 791).

Now a team of physicists and engineers has concluded that the video analysis was probably correct. The team was assembled by the American Physical Society's Panel on Public Affairs (POPA) and was led by Jeremiah Sullivan, a physicist and former director of the Program in Arms Control, Disarmament, and International Security at the University of Illinois, Urbana-Champaign. Accepted for publication at the journal *Science & Global Security*, the team's report analyzes all of the technical criticisms raised against the video evidence. It concludes that those criticisms are "without merit" and goes on to identify "an absolute contradiction" between the Army's scoring of Patriot performance and that video record.

Raytheon Co., the prime contractor for the Patriots used in the Gulf War, has already prepared a rebuttal, which is tentatively scheduled for a subsequent issue of the Princeton-based journal, according to its editor, Hal Feiveson. And the POPA study says nothing directly about the future prospects of the Patriot system, which has been redesigned entirely. But Theodore Postol, one of the MIT researchers, says that the Patriot affair may bode ill for plans to develop more expansive missile defenses to protect soldiers and the country as a whole (see main text). It reflects what he sees as a culture of exaggeration and cover-up that "has a corrupting effect on every aspect of weapons development."

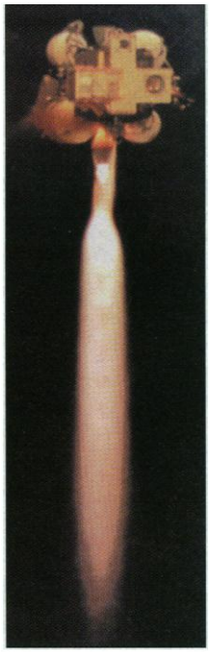
To one degree or another, everyone describes the Patriot as overmatched in its bid to destroy the Scuds. The Gulf War Patriot "was built to intercept airplanes, not missiles," says Brigadier General Daniel L. Montgomery, the U.S. Army's Program Executive Officer, Air and Missile Defense. Traveling at speeds of up to 1.5 kilometers per second, the single-stage Patriot missile homed in on enemy aircraft using ground-based radar, then exploded near the aircraft. By the late 1980s, the system had been adapted to missile defense largely through software changes, and such refinements continued during the Gulf War. But the souped-up Scuds, called Al-Husseins, reentered the atmosphere at about 2.3 kilometers per second, and they often broke up, creating showers of confusing debris from which the warhead would emerge, corkscrewing to the ground.

"The Patriot had no chance, no chance against such a target," says George Lewis, associate director of MIT's Security Studies Program. But U.S. officials initially claimed astonishing results. "The Patriot's success, of course, is known to everyone," said General H. Norman Schwarzkopf on 30 January 1991. "It's 100%—so far, of 33 engaged, there have been 33 destroyed."

That certainty soon began to crumble, even by official accounts. Under criticism by the U.S. General Accounting Office and other agencies that examined the Army data, the Army revised its success estimates from 96% in March 1991; to 69% in May 1991; to 59% in April 1992, when Representative John Conyers (D–MI) led a congressional inquiry into the Patriot's performance. Those fi-

in a test, making a string of six straight misses. The planned Space-Based Infrared Satellite System, an upgraded version of an existing satellite system for detecting the hot plumes of enemy missiles, has also been plagued by technical glitches and delays. A BMDO-sponsored panel, led by retired Air Force General Larry Welch, blamed the Thaad failures on intense political pressure, which is leading to a "rush to failure." Thaad engineers have not had time to understand and correct the failures, which mostly resulted from shorts, contamination, and software problems, the panel concluded. "We are still on 'step one' in demonstrating and validating hit-to-kill systems," according to the report.

Hastie adds that most subsystems—such as launchers and radar—performed well in the tests. But some analysts argue that the series of failures shows just how hard it will be to build a reliable system. Hit-to-kill missile defense, says Pike of the Federation of American Scientists, "is apparently a problem that is extraordinarily unforgiving of error."



**Kill vehicle.** A sensor-laden projectile that would smash enemy warheads.

CREDITS: (TOP) RAYTHEON; (BOTTOM) U.S. ARMY

And theater defenses have begun setting off geopolitical alarm bells as well, because it has become apparent that they might be used to protect entire countries the size of Israel, Kuwait, or Taiwan. Indeed, Israel and the United States are collaborating on an upper-tier defense called Arrow, which Israel may deploy, perhaps in tandem with the Patriot-3, to defend its entire territory. And Japan has agreed to work with the United States in the development of Navy Theater Wide (NTW), a high-altitude interceptor that would travel substantially faster than Thaad for improved range. These developments are causing jitters in East Asia. On 8 March, for example, *The New York Times* reported that Tang Jiaxuan, China's foreign minister, said that including Taiwan in an American missile defense system "would amount to an encroachment on China's sovereignty" and would destabilize the region.

What's more, many of the theater defenses could, at least in theory, contribute to missile defense for the home territory of the United States. Calculations by MIT's Lewis and others suggest that one Thaad system in its basic form could protect a footprint the size of the Baltimore-Washington metropolitan area from an ICBM. But using the full panoply of upgraded early-warning radars and other sensors envisioned for NMD could expand the Thaad footprint enormously, says Lewis. Conservative groups have advocated using the NTW as a U.S. national defense, stationing the ship-based system either along U.S. seaboards or just off hostile coasts to hit missiles while their rockets are still firing. A study sponsored by the Heritage Foundation, for example, envisions 22 shiploads of NTW-style interceptors roaming the seas. And an analysis by the Union of Concerned Scientists (UCS) suggests that a more modest system could easily span the continent. "We've tried to make some estimates of how large the footprints would be," says David Wright, a researcher at MIT and UCS. "Under the best estimates, two or three [ships] could cover the entire U.S."

BMDO downplays such possibilities. At a recent press conference, Lieutenant General Lester Lyles of the Air Force, BMDO's director, had a curt reply when asked about the relevance of the Thaad tests for national defense: "None whatsoever," said Lyles. Adds Lehner, the BMDO spokesperson: "I've not seen anything even discussing" the use or relevance of Thaad for NMD.

Yet the line between theater and national

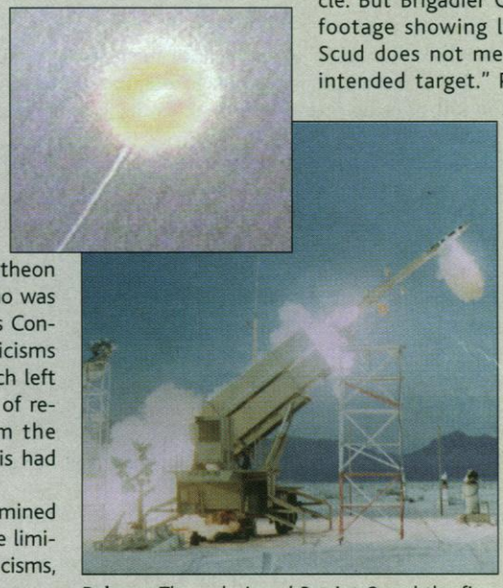
nal numbers, which include estimates of better than 70% success in Saudi Arabia and 40% in Israel, have not budged officially.

According to an analysis published in 1993 by Postol and Lewis and discussed at the Conyers inquiry, however, those numbers were not even close to reality. While the Army based its assessment mostly on inspecting ground damage after the war, Postol and Lewis found commercial videos (often from news organizations) of more than half of the approximately 44 Scuds engaged by Patriots. After taking into account unknowns such as viewing angle and distance and using fixed reference points such as the bright Patriot fireball to compensate for camera movement, the team found no evidence of even one successful intercept.

The video analysis, in turn, was repeatedly attacked as flawed by Robert Stein, now a Raytheon vice president, Peter Zimmerman, a physicist who was recently named science adviser to the U.S. Arms Control and Disarmament Agency, and others. Criticisms centered on the slow video-framing rates—which left 0.033-second gaps in the data—the difficulties of reconstructing three-dimensional events from the videos, and the possibility that Postol and Lewis had consistently misidentified the Scud warheads.

Now the six-member POPA panel has determined that Postol and Lewis correctly accounted for the limitations of the videos. Addressing a long list of criticisms, the panel found that Postol and Lewis had made proper assumptions about the physics and were not likely to have made major blunders like misidentifying warheads. "We don't claim that in every single case they have to be right," says Sullivan. "But being wrong here or there doesn't change the overall physical consistency. It's not a matter of onesies and twosies."

Stein and Zimmerman, who wrote the forthcoming "comment" on the POPA study, both declined to respond for this article. But Brigadier General Montgomery says, "Video footage showing less than full destruction of the Scud does not mean [it] was not deflected off its intended target." Postol responds that there is no way to know just where the highly inaccurate Scuds were going in the first place, let alone whether anything deflected them.



**Reborn.** The redesigned Patriot-3 and the fireball from a successful intercept last month.

The POPA panel has recommended that a third party undertake a joint study using the still-classified Army data and the videos. But with Raytheon turning up as the prime contractor for the "kill vehicle" of the proposed national missile defense, Postol warns that the Patriot episode raises more than technical questions. "Denial of failure leads to institutionalized failure," he says. "And the message, loud and clear, was 'We don't care about the truth.'" **–J.G.**

defenses is also blurring for futuristic Air Force theater defenses that would rely on powerful chemical lasers to destroy missiles when their boosters are still firing. One, the Airborne Laser, would blast missiles from perhaps 300 kilometers away, using an oxygen-iodine laser mounted in the nose of a Boeing 747. Although such systems were heavily criticized as impractical during the Star Wars days, the prototype laser has made dramatic advances in the amount of power it can train on a target, according to sources both inside and outside the military. Testifying before the Strategic Forces subcommittee of the Senate committee on Armed Services in February, Lieutenant General Lyles said that a related program—the Space-Based Laser—could someday " 'thin out' missile attacks" in their early stages as part of a multiple-shot NMD.

**Decisive encounter**

NMD's centerpiece is a separate system: a hit-to-kill interceptor that would function much like Thaad. It would get an early warning of a missile attack from existing or upgraded early-warning radars deployed on America's coasts, as well as from satellites and a new X-band radar tailored for national missile defense. The kill vehicle would then be launched on a three-stage rocket to make an intercept at altitudes of hundreds of kilometers, in hopes of protecting all 50 states.

Those altitudes, high above the atmosphere, may make distinguishing targets from decoys much more difficult for an NMD than for Thaad. Radar-reflecting swarms of aluminum shreds, or "chaff," would float along with the warhead in space, where there is no air resistance to strip them away. "Decoys are a major problem for the sensors," says Gerold Yonas, a former SDI chief scientist who is vice president for systems science and technology at Sandia National Laboratory in New Mexico. In the nightmare scenario, the kill vehicle would confront a swarm of radar-reflective aluminized balloons looping through space, only one of which contains a nuclear warhead.

BMDO officials say they are learning how to sort out decoys, noting that infrared sensors on the NMD kill vehicles, which are being built by Raytheon Systems Co. of Tucson, Arizona, successfully picked targets out of a set of decoys in flyby tests over the central Pacific in June 1997 and January 1998. (Details are classified.) This summer's interception test will also include decoys, although the kill vehicle will be told which mock warhead is the "real" one.

Analysts worry, however, that no matter how sophisticated the sensors, an attacker could find a way to sneak a weapon of mass destruction past them. Early in its flight, an ICBM might release dozens of individual "bomblets," each containing a fearsome biological or chemical warhead, making an effective intercept impossible. Or a disguised ship could simply steam into a U.S. harbor and fire a small nuclear warhead from there. "It has always been very implausible to me that a rogue state would send one or two missiles over here; it would be suicide," says Kurt Gottfried, a Cornell University physicist and acting chair of the UCS. Ensuring that Russia's crumbling early-warning radar does not give false alarms, leading to an accidental missile launch, would be a better way to spend the money, he says, calling NMDs "an ass-backward way of looking at our priorities."

But if ballistic missile defense engineers hit a bull's eye with the summer test, the push to develop and deploy a national defense may be hard to stop. "I have zero doubt that the system will work, ultimately," says John Peller, vice president and program manager for the NMD team at Boeing Co., which last April won a $1.6 billion, 3-year contract to oversee NMD development.

Major Demidovich of the Air Force, who will direct the NMD test, explains that the summer intercept attempt will actually be two tests in one: the actual intercept and a simultaneous "shadow" test on computers, in which the interceptor will get fewer hints about the identity of the target. The shadow test will begin with the launch from Vandenberg in California of a surplus American ICBM—a modified, three-stage Minuteman II missile with the mock warhead and decoys atop it. The stages will burn for about a minute each, and then the target and decoys will separate, eventually hurtling to an apogee of 1600 kilometers before falling back toward Kwajalein, itself about 7000 kilometers west and slightly south of Vandenberg. Satellites, early warning radars, and finally a prototype X-band radar at Kwajalein will track the objects and attempt to pick the target out from among the decoys. In the shadow test, these data will be used to launch and guide a computer-simulated interceptor to its basket in space.

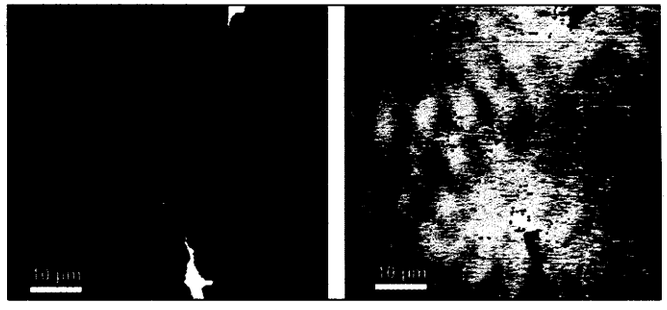
In the real test, which will unfold at the same time, another modified Minuteman II carrying the Raytheon kill vehicle will blast off from Kwajalein about 25 minutes after the launch of the "hostile" missile from Vandenberg. The vehicle will be dropped into its basket and use its infrared seekers to lock onto the mock warhead, firing thrusters for course corrections until, 230 kilometers above the ocean, the two objects violently collide and pulverize each other. Or they will sail silently past each other in space, leaving only questions behind. **–JAMES GLANZ**

ACOUSTICS

# Probing the Shaking Microworld

**With the help of atomic force microscopes, acoustics researchers are using vibration as a tool to study materials' elastic properties on a microscopic scale**

Vibration is the bane of microscopy. When you are trying to image atomic-scale features using instruments such as the scanning tunneling microscope (STM) or the atomic force microscope (AFM)—which scan needle-fine tips across a sample—even the slightest vibration will smear the picture. For one group of researchers, however, vibrations are not a problem: They're the object of the exercise. At a recent acoustics meeting* in Berlin, several European research groups reported techniques that set a sample vibrating with sound waves and then use STMs or AFMs to sense how its atoms are jiggling about, revealing details of the material's local physical properties, such as elasticity.



**Ripple image.** Acoustic waves (*right*) in a gold layer (light brown) on quartz.

CREDIT: CHILLA *ET AL.*/PAUL DRUDE INSTITUTE FOR SOLID-STATE ELECTRONICS

"We have demonstrated that it is possible to image oscillations on an atomic scale," says Eduard Chilla of the Paul Drude Insti-

* The Joint 137th Meeting of the Acoustical Society of America and the 2nd Convention of the European Acoustics Association Integrating the 25th German Acoustics DAGA Conference, Berlin, 14 to 19 March.