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# The European missile defense folly

## The United States plans to protect itself from emerging missile threats by building a Europe-based missile defense system. Like its predecessors, the system has serious technological deficiencies.

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During 2007, the Bush administration began an aggressive sales campaign aimed at convincing its European allies to accept a U.S. deployment of missile defense components on their continent. The administration's stated objective for a European missile defense system is "to provide a defense of Europe against a limited intermediate and long-range ballistic missile attack from the Middle East and provide additional capability to the current missile defense system located in Alaska and California to defend the United States." The more specific postulated scenario is a missile attack by Iran. Under this scenario, the administration claims that its European missile defense components will provide coverage of northern and western Europe, and as stated, it would also increase the overall probability of successfully intercepting an Iranian ballistic missile launched toward the continental United States.

The Missile Defense Agency (MDA) has described the proposed structure and operation of the system in a series of briefings to European allies. A large X-band radar called the European midcourse radar (EMR) would be deployed in the Czech Republic; a forward-based X-band (FBX) radar would be deployed at an unspecified location near Iran, possibly in eastern Turkey or Georgia; and a launch site with 10 ground-based interceptors would be located in Poland. These new components would be aided by an existing, upgraded early warning radar at the Fylingdales Air Force Base in Britain. (For a detailed breakdown of these radars and interceptors, see "The System's Components," pp. 34–35.)

If the postulated attack were to occur, MDA maintains these radars would work together as follows: U.S. early warning satellites would initially observe the launch and powered flight of the ballistic missile before providing information on its approximate trajectory to the FBX radar so that radar could begin tracking the missile with much greater precision. Next, the FBX would pass its precision tracking information to the EMR, which would now track the warhead and use its high-range resolution to measure a warhead's target details, along with the details of any decoys or other countermeasures. As currently articulated, the FBX radar and EMR are the only radars within the European missile defense system potentially capable of differentiating warheads from countermeasures.

Almost simultaneously, the Fylingdales radar would also begin to track the complex of targets. Unlike the EMR, the Fylingdales radar is powerful enough to search Europe's sky for low-visibility warhead targets at long ranges. Since the EMR is incapable of searching large areas of sky for low-visibility, cone-shaped warheads, all of this highly accurate "cuing" information from the FBX radar, the Fylingdales radar, and the early warning satellites is essential if the defense is to work as intended.

If the EMR succeeds in identifying objects that might be warheads, the interceptors in Poland would be fired toward predicted intercept points. Once the rocket motors of the interceptor burn out, the kill vehicle would be released to select, home in on, and destroy warheads in high-speed collisions. If the interceptors don't successfully engage the warheads, the Fylingdales radar could continue to track them long after they've flown out of the EMR's coverage—information that could support additional interceptors launched from Alaska and California. (For an in-depth description of how the system will operate, see "A Specific Scenario," pp. 36–37.)

But when MDA's description of how the system functions is subjected to a detailed technical analysis, it becomes clear that none of the system's components can work as MDA claims. Specifically, our technical findings conclude:

**Basic countermeasures will topple the system.** It's extremely easy to show that countermeasures such as lightweight balloons and low-powered jammers would render current and future variants of the U.S. missile defense system obsolete. (For an explanation, see "Why Countermeasures Will Defeat National Missile Defense," pp. 38–39.) And it should be expected that nations possessing long-range ballistic missiles will seek to build countermeasures to defeat missile defenses. Given these

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certainties, the issue becomes whether nations with a ballistic missile capability can also build countermeasures. According to U.S. intelligence assessments, the technical capability to build such countermeasures will coincide with the technical capability to build and test long-range ballistic missiles. In other words, U.S. missile defense will be obsolete when emerging threat states such as Iran test their first intercontinental ballistic missile (ICBM).

A September 1999 National Intelligence Estimate (NIE) entitled, "Foreign Missile Developments and the Ballistic Missile Threat to the United States Through 2015," provided a list of countermeasures that the intelligence community concluded would be available to any country that had developed the science, technology, and industrial capacity to build ICBMs. It concluded, "Many countries, such as North Korea, Iran, and Iraq probably would rely initially on readily available technology . . . to develop penetration aids and countermeasures." It added, "These countries could develop countermeasures based on these technologies by the time they flight test their missiles."

Although reported in the 1999 NIE, there was never an attempt to explain the significance of these findings to the nonspecialist audience they were intended to address—particularly Congress. After September 2000, these critically important statements about countermeasures are inexplicably missing from unclassified NIEs. Their omission is troubling and raises questions about the possibility of political tampering with intelligence findings similar to those experienced in the run-up to the Iraq War. In this case, the omissions would be aimed at protecting the missile defense program from valid questions about its efficacy. The opacity of the 1999 NIE on the significance of these countermeasures for the missile defense program also raises questions about whether the intelligence community did its job by stating conclusions without pointing out their significance to decision makers.

**The EMR is substantially underpowered.** The result is a defense system that's unable to provide any discrimination services against missiles launched from Iran to the eastern half

## THE SYSTEM'S COMPONENTS

**European midcourse radar (EMR).** The EMR is scheduled for deployment in the Czech Republic by about 2013. It is a large, fixed-site "phased-array" radar with an antenna diameter of 12.5 meters (41 feet). Phased-array radars are used, at great cost, because they can electronically switch beam directions quickly, allowing them to track many targets simultaneously. Although the range of angles that the EMR can rapidly scan electronically is limited to plus or minus 25 degrees from its boresight, it is mounted on a turntable that can rotate nearly 360 degrees and on a gimbal that provides elevations between 0 and 90 degrees. The EMR will be a rebuilt version of the prototype ground-based radar (GBR-P) that the United States has operated at its ballistic missile test range in the Marshall Islands since 1998. According to Missile Defense Agency (MDA) Director Henry Obering, the GBR-P will be refurbished with "improvements to the software and processing capability."[1]

The version of the EMR to be placed in the Czech Republic is considerably less capable than its imposing physical appearance suggests, mainly because its antenna will contain a much smaller number of transmit/receive (T/R) modules than an antenna of its size can normally contain. These T/R modules both send out and receive the radar energy necessary to perform the required detection, tracking, and discrimination functions. The radar has been designed so that the number of T/R modules could be increased from the current 16,896 modules to as many as 78,848 modules.[2] Moreover, such an upgrade would certainly use more advanced T/R modules, each of which would be two to three times more powerful than the first-generation modules used in the GBR-P.

While public statements indicate that such an expensive upgrade isn't planned, if pursued, it could increase the radar's tracking capability by a factor of about 40–70, depending on the new modules' power. This would transform the inadequate planned version into a more powerful system that could at least attempt to provide some discrimination services (telling warheads apart from decoys, pieces of wire, and other debris and countermeasures) for Iranian warheads aimed at the eastern portion of the continental United States. The upgraded EMR would also be able to provide critical early detection and tracking services for interceptors based in Poland against Russian intercontinental ballistic missiles (ICBMs) launched at the United States from sites west of the Ural Mountains.

**Forward-based X-band (FBX) radar.** Although physically much smaller than the EMR, the air-transportable phased-array FBX radar, which the MDA plans to deploy in southeastern Europe, has significantly higher output power than the EMR because it possesses a larger number of more powerful, later-generation T/R modules. The availability of FBX radars has rendered the GBR-P at Kwajalein unnecessary: "The fixed X-band radar is no longer required at Kwajalein for MDA tests," MDA spokesman Rick Lehner told Inside the Pentagon in March 2007. "If an X-band radar is needed in the future, there are transportable radars that can be placed there."

Because of its close proximity to the anticipated missile launch site (under the postulated threat, somewhere in Iran), the FBX radar would be the first radar to detect the missile and would assist the EMR in detecting the missile warhead. However, the FBX radar can't be relied on to discriminate between warheads and decoys. In many cases, these warheads and decoys will be too far from the FBX radar, resulting in signals too weak to collect the essential high-precision data on both warheads and decoys for any attempts at discrimination.

**Phased-array early warning radar.** In addition to the FBX radar, the large, phased-array radar at the Fylingdales Air Force Base in Britain will perform the critical role of searching large areas of sky for possible targets so that the EMR can know where to look for objects that need to be identified as either warheads or decoys. Without such tracking information, the EMR wouldn't be able to find the appropriate targets. The Fylingdales radar has much higher power and a much larger antenna than either the EMR or FBX radar. In addition, it operates at a much lower frequency than the EMR or FBX radar, where the radar cross section of warheads is more than 10 times larger relative to that at X-band. These factors give the Fylingdales radar a tremendously large detection and tracking range against warheads.

However, the use of such lower radio frequencies by the Fylingdales radar results in a much lower resolution, making it impossible for the radar to discriminate between warheads, decoys, and other objects. Despite this limitation, the initial version of the national missile defense system proposed by the Clinton administration would have relied entirely on the Fylingdales radar and similar radars at Thule, Greenland, and Cape Cod, Massachusetts, to defend the continental United States against an attack from the Middle East. The Fylingdales radar has already been upgraded to support the interceptors currently deployed in Alaska and California.

**GLOBUS II radar.** Based in Vardo, Norway, this large, powerful X-band dish-antenna radar can observe warhead targets at ranges far beyond those of the EMR, making it possible for GLOBUS II to be used in the European missile defense instead of an incapable EMR. In this role, GLOBUS II would work with the Fylingdales radar, and possibly the FBX radar, to perform the critical functions of surveillance, tracking, and discrimination that MDA has described as the function of the combined Fylingdales radar and EMR. If the GLOBUS II isn't used as a partner to the Fylingdales radar, the proposed U.S. missile defense plan for Europe could not function as MDA

Although not a declared element of the proposed European missile defense system, the GLOBUS II radar in Vardo, Norway (bottom), could perform some of the tracking and discrimination functions the Missile Defense Agency envisions for the system. If all goes as planned, a two-stage rocket (top) launched from Poland would carry an infrared-homing kill vehicle tasked with intercepting the target—a warhead.

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has described it to Congress and European allies. Since GLOBUS II isn't a phased-array radar, it would be limited to simultaneous tracking of a few targets at most.[3] Nevertheless, because of its X-band operating frequency and the high signal-to-noise ratios it can achieve against small radar cross-section targets at long range, it could provide precision discrimination data.

**The interceptors.** The European missile defense system will use infrared-homing kill vehicles that will be accelerated to high speeds by a large, highly capable two-stage rocket derived from the Pegasus satellite launch vehicle. The rocket stages used in Pegasus derive from the high-performance upper-rocket stages used by the Minuteman ICBMs. This missile should accelerate the 60-kilogram kill vehicle to a speed of roughly 8–8.5 kilometers per second or higher. Once accelerated onto an intercept trajectory, the kill vehicle is designed to make precision adjustments to its trajectory as it homes in on and destroys targets by direct collision. The MDA says that a total of 10 interceptors will be deployed, all in Poland. Save for possessing two rocket stages instead of three, these interceptors are basically the same as the roughly 25 ground-based interceptors currently deployed in silos in Alaska and California. The removal of the third-stage motor from the European variant gives a shorter powered flight time of about 140 seconds—60 seconds less than the three-stage variant's flight time.

Russia has voiced alarm about the two-stage interceptors—in part because the Russians believe that these fast interceptors, supported by detection and tracking data from an upgraded EMR, could be used to intercept Russian ICBMs launched from sites west of the Ural Mountains. Obering and Keith Englander, his chief scientist, have countered by making a technically implausible claim that the two-stage interceptors based in Poland can achieve a burnout speed of only 6.3 kilometers per second—too slow a speed to engage Russian ICBMs. But data on stage performance provided to the press by the MDA and performance data from publicly available manuals on the performance of the Pegasus-derived rocket stages indicates that the MDA claim of a 6.3-kilometers-per-second interceptor cannot be correct.[4]

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of the continental United States. The sea-based X-band radar in Alaska might be able to collect discrimination data for some of the country's western targets, but all of the current large radars that could potentially support the defense of the East Coast and Midwest—Fylingdales; Thule, Greenland; Cape Cod, Massachusetts; and Grand Forks, North Dakota—operate at low frequencies and won't function without discrimination services from the EMR. All of these low-frequency radars have such poor range resolution that they cannot distinguish between warheads that are meters in length and small pieces of wire.

The EMR is designed to be upgradable, which raises questions about whether the Bush administration is pushing to deploy a lesser EMR in the Czech Republic now as a strategy to commit the country to a course that will be difficult to reverse.

**Vardo will likely be part of the system, too.** Without a drastically upgraded or replaced EMR, the controversial large, dish-antenna X-band radar, called the GLOBUS II, at Vardo, Norway, could perform some of the tracking and discrimination functions the MDA envisions for EMR. The United States moved the GLOBUS II from California to Norway in 1998. Initially, the U.S. and Norwegian governments presented it to the Norwegian people as a space surveillance sensor. But more probably, its major purpose was to gather missile defense discrimination and signature data on Russian warheads and decoys that were being tested on trajectories between the Russian launch site at Plesetsk and the impact area at Kamchatka. When the Norwegian public learned about the radar's true purpose, it caused serious domestic backlash against the government and a series of international incidents with Russia. Currently, the MDA hasn't indicated that GLOBUS II will be involved in the planned European missile defense, but it's the only U.S. radar in Europe that could even attempt to collect discrimination data against a realistic warhead target.

**Generally, MDA has oversold the system.** To wit, the coverage diagrams shown in MDA briefings appear to be based on a warhead radar cross section about 100 times larger than the

## A SPECIFIC SCENARIO

Let's assume that Iran has obtained or produced an intercontinental ballistic missile (ICBM) capable of delivering a nuclear warhead to the continental United States, and in an irrational act of probable national suicide, launches this ICBM at Washington, D.C.

Roughly 60 seconds after Tehran launched such a missile, U.S. early warning satellites would observe the hot exhaust plume from the missile's rocket motor. The United States typically stations several of these satellites at orbital locations that allow them to simultaneously view the Middle East from multiple directions. By using two or more satellites to observe the accelerating missile from different angles, the missile's location—within a volume of about 1 square kilometer—would be obtained.

Within roughly three minutes of the missile's launch, it would be high enough that the curvature of Earth would no longer block it from the view of the forward-based X-band (FBX) radar, which the Missile Defense Agency (MDA) wants to place in southeastern Europe, possibly eastern Turkey or Georgia. Based on information from the early warning satellites, the FBX radar would point its radar beam in the target's expected direction—similar to a giant searchlight. But unlike a powerful searchlight, the radar illuminates targets by radio signals instead of visible light, pulsing its beam to measure range. If the beam is pointed in the

correct direction, a portion of the radio waves from the radar antenna will reflect off the target back to the radar. The size of the reflected signal is determined by the target's radar cross section—an effective reflecting area typically designated in square meters.

Each time a radar beam is pointed at a specific area of the sky, it must "dwell" long enough to collect a suitable number of reflected pulses to detect the target. If the target's location isn't precisely known, the radar will need to search a larger area by dwelling on many discrete areas of sky. If it takes too long to search the potential target area, the target may move out of the search volume and go undetected. Therefore, target acquisition requires that the radar beam be powerful enough to search at sufficient range with sufficient speed to detect the target. If a target's radar cross section is small and its location unknown, the radar will not be able to acquire it, and there will be no way to determine the location of intercept points needed to support the launch of interceptors.

The FBX radar beam would be roughly 10 kilometers (6 miles) across at a range of 1,000 kilometers (620 miles), making it possible for the FBX radar to acquire the accelerating ICBM simply by pointing its beam directly at the volume within which the early warning satellites indicate the missile resides. So, if the reflected signal from the ICBM is large enough, the early warning satellites allow the FBX radar to avoid the difficult task of searching a large area of sky for the missile. Once the target is acquired, a rough estimate of its speed, range, and direction can be determined. With this information, it's straightforward for the radar to repeatedly measure the target's location. As this process of tracking proceeds, the FBX radar can provide increasingly precise measurements of the target's location, speed, and direction. The target's future locations can then be projected forward, giving an interceptor equipped with a homing kill vehicle enough information to look for and acquire the target with its imaging infrared sensors.

After the ICBM finishes its powered flight, the missile's cone-shaped warhead would be deployed. Since the warhead is likely to have a relatively low radar cross section, it poses a challenging detection problem. But because the final stage of the missile booster and the warhead would travel at about the same velocity (unless the attacker took steps to prevent this), they would stay relatively close together as they coast toward the United States. So, even if the FBX radar is unable to detect the warhead, by tracking the final rocket stage, the radar may be able to establish the warhead's approximate location with enough accuracy to support detection by more powerful radars such as the GLOBUS II X-band radar in Vardo, Norway, or an upgraded European midcourse radar (EMR) in the Czech Republic. The initial version of the EMR possesses such limited range that it won't play any useful role in the operation of European missile defense.

As the warhead travels past the FBX radar, it will be high enough for the EMR to attempt to observe it. Several minutes later, it will be high enough for the low-frequency radar at Fylingdales Air Force Base in Britain to detect it, and shortly thereafter, by the GLOBUS II. The task of an upgraded EMR or GLOBUS II is to collect the high-resolution precision data needed to try to determine whether objects are warheads, decoys, or debris. This tracking and discrimination data could then be used to support the launch of homing interceptors—or provide further information to interceptors already launched on the basis of FBX radar data. The data from all three radars could also support the launch of interceptors in Alaska if the European interceptors fail to destroy the target. As the kill vehicle approaches the target, it uses its infrared sensor to home on the complex of warheads, decoys, and other objects associated with the missile's payload. Ideally, the kill vehicle would then pick out the warhead and destroy it in a high-speed collision.

But the above scenario depends on two critical assumptions: The radars will have sufficient ranges to detect the warhead; and the defense will be able to find the warhead among a collection of decoys and other countermeasures. Neither of these assumptions is valid.

The MDA apparently assumes that the warhead's radar cross section will be large—about 1 square meter—making it easy for the EMR to detect it at the expected ranges of the Iran scenario. However, at the short radio wavelengths used by X-band radars (slightly larger than 2.5 centimeters [1 inch]), the radio signals reflect off the warhead much like light reflects off of a mirror. Since the warhead is cone shaped, almost all of the radio energy that falls on the target is reflected in directions away from the illuminating radar. Therefore, over the large majority of viewing angles, the warhead's radar cross section will be miniscule, about one one-hundredth of a square meter or less, relative to that assumed by the MDA.

Given such a stealthy target, at no point in the trajectory of a missile fired from central Iran toward the United States could the EMR detect the warhead. (To the Fylingdales radar, the warhead will likely appear 10 or more times larger; but again, the Fylingdales radar cannot discriminate the warhead from decoys and other countermeasures—only an upgraded EMR could complete this task.) The same holds true for many potential targets in Europe. Further, for European trajectories where the EMR can eventually detect warheads, the detection ranges will often be so short that there would be insufficient time for interceptors to fly to locations where they could hit attacking warheads.

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After early warning satellites detect the launch of an Iranian ballistic missile, the forward-based X-band radar would begin tracking the missile's speed and range. This information would be relayed to either the European midcourse radar or the GLOBUS II, which would try to discriminate between warheads and decoys. If potentially threatening targets are identified, data from these radars could then be used to support the launch of interceptors.

well-known radar cross sections of cone-shaped warheads. In fact, the actual ranges claimed for the EMR and FBX radar by the MDA need to be reduced by a factor of more than three.

**Of course, when necessary, MDA has also undersold the system.** Despite claims to the contrary by both MDA and State Department officials, the interceptors that Washington wants to deploy in Poland are fast enough to catch Russian ICBMs launched from locations west of the Ural Mountains toward the continental United States. The location of the interceptor site in Poland is ideal for this purpose, as is the location of the EMR.

So whether intended or not, the U.S. proposal has the appearance of a missile defense system that's aimed at Russian ICBMs, many of which are already vulnerable to a preemptive U.S. nuclear attack. This creates significant military and political uncertainties for Moscow's leadership, especially if U.S. missile defense capabilities in Europe continue to grow larger and more sophisticated. These factual observations explain the fierce negative reaction in Russia to the proposed Czech and Polish sites. If Russia were deploying such missile defense installations in Canada, it's almost certain that the United States would feel similarly threatened.

The U.S. vow to deploy only 10 interceptors in Poland is inconsistent with the logic Washington has put forward to justify the system's deployment. By definition, a postulated Iranian threat would include an infrastructure, production facilities, and industrial base to build more than 10 ICBMs. Therefore, the 10 proposed interceptors should be regarded as an initial deployment, leaving Russian leaders to contemplate the possibility of a vast expansion in the number of interceptors at the Polish site, and the rest of the world to wonder about the rationality of U.S. leadership that appears to want the unachievable—nuclear supremacy. ■

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## WHY COUNTERMEASURES WILL DEFEAT NATIONAL MISSILE DEFENSE

The most fundamental and unsolvable problem with national missile defense—whether deployed in Europe or domestically—is its inability to circumvent relatively simple countermeasures. The reason for this extreme vulnerability can be traced to a surprisingly simple physical fact: The national missile defense operates against targets at high altitudes in the near vacuum of space, where there is no measurable aerodynamic drag to cause light objects to slow down relative to a heavy warhead. Under these conditions, a wispy feather and 900-kilogram (2,000-pound) warhead will travel along together, meaning any object large enough to contain a nuclear warhead must be regarded as potentially containing such a devastating weapon—even if the object is actually a lightweight balloon serving as a decoy.

To understand why decoys create such fundamental problems for national missile defense, consider the problem Transportation Security Administration inspectors face when trying to determine which suitcases at an airport contain explosives. Since missile defense is restricted to using radars and infrared sensors to view objects at long range, this analogy can be further adapted by assuming that the inspectors at the airport are limited to measuring only the externally observable features of each suitcase (color, size, shape) by visual inspection. As such, they cannot open the suitcases, physically shake them, use dogs to sniff them, or employ X-ray machines to inspect their contents. Of course, unless someone tells the inspectors what features to look for (i.e., yellow suitcases), visually inspecting the suitcases is a useless endeavor.

In missile defense, the process of discrimination is similar. Warheads and decoys can only be identified if the distant radar or the kill vehicle's infrared sensor knows exactly what it's looking for and the enemy takes no measures (either accidental or intentional) to change the objects expected appearance—an unlikely scenario. Adversaries can easily modify a warhead's appearance, enclosing it in a balloon and surrounding it with more balloons of different shapes, sizes, and exterior coatings—all of which travel along with the warhead in the near vacuum of space, creating considerably more potential targets than the missile defense's relatively small supply of interceptors could possibly engage.

In addition to needing detailed prior knowledge of the special features that distinguish a warhead from other objects, the missile defense radar and infrared sensors must be able to measure these features with sufficient precision. This requires high-precision data for each target of concern. Such precision measurements require a considerably stronger signal than is required for detection. As a target gets closer to a radar, the strength of its signal increases; thus, the range at which a sensor can attempt to discriminate between warheads and decoys must be shorter than the range at which the sensor can detect that target. The Missile Defense Agency (MDA) could upgrade the European midcourse radar (EMR) so that its signal strength would allow it to both detect and attempt to discriminate such a warhead target, but even with this upgrade, the EMR is unlikely to be able to successfully discriminate warheads from decoys.

Worse still, decoys aren't the only countermeasure an attacker might use to defeat the missile defense system. Others include:


To both national and European missile defense systems, countermeasures such as large balloons with reflective coating (bottom left) and light, rigid replica decoys (middle) can appear similar to nuclear warheads. Likewise, missile attackers can employ low-power jammers (right), pieces of hardware not much larger than a dime, to generate tens of thousands of false targets to mask a warhead's presence or location. The infrared view from an interceptor kill vehicle (top) shows how warheads and decoys can appear similar when inspected from a 200-kilometer (124-mile) distance.

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**Spin stabilization.** If an adversary can reduce a warhead's radar cross section, the radar's detection range will also be reduced, possibly to the point where the warhead is undetectable. Atmospheric reentry considerations dictate that warheads will have a conical shape, and conically shaped objects naturally tend to have low radar cross sections. An attacker could further reduce the detectability of a warhead by spinning the warhead to stabilize it in an orientation for which its radar cross section will be particularly low. A typical warhead with a radar cross section of about one one-hundredth of a square meter could easily have a radar cross section at least 10 times smaller if it is oriented to minimize the radio reflections back to the radar. Yet another technique to reduce the radar cross section of a warhead would be to cover all or part of the warhead with commercially available radar-absorbing materials.

**Chaff.** Once the warhead has been oriented or modified to make its radar cross section small, wires less than 2 centimeters long can each reflect as much X-band radar energy as the warhead itself. Such wires, known as chaff, can be used to create a cloud of targets so dense that it's impossible for a radar to determine which reflection comes from a warhead and which reflection comes from a piece of wire. One pound of chaff can create millions of separate false targets, and numerous chaff dispensers could be deployed on slightly different trajectories to create clouds of wire similar to the cloud surrounding the warhead.

**Low-power jammers.** These jammers produce an interfering noise signal roughly equal to the reflected signals from a warhead, making it impossible for a radar to determine whether or not a warhead is present. The amount of power needed to achieve this objective is surprisingly small. For example, if the proposed EMR is used to detect the presence of a one one-hundredth of a square meter warhead target accompanied by a 1-watt replica jammer at a range 500 kilometers (311 miles), the jammer could easily generate tens of thousands of false targets to mask the presence or location of the warhead. If the warhead is oriented or covered with radar-absorbing materials to reflect 10 times less energy, the same jammer could generate hundreds of thousands of false targets. Each jammer could be inches on a side, weigh fractions of a pound, and consist of commercially available circuitry and power supplies.

Other countermeasures can also prevent an interceptor's kill vehicle from performing discrimination functions. When the kill vehicle tries to identify and home in on the complex of warheads, decoys, and other objects, each are observed as points of light against the dark infrared background of space. Even in the unlikely case where the X-band radars have somehow discriminated between the warheads, decoys, and other objects, the radar will often not be able to provide the kill vehicle with sufficiently precise location information for it to identify the warhead. Because of this "association" problem, the interceptor must be able to select the right target by conducting its own discrimination. The kill vehicle attempts to do this by examining the brightness and fluctuating brightness of the many points of light in front of it. However, even a minimally capable adversary could easily manipulate the brightness and brightness fluctuations of simple objects. For example, the temperature of different sections of a sunlit spherical balloon in space can be drastically altered by painting it with stripes of different colors. By using different patterns of paint colors, the infrared brightness and fluctuation in brightness of any balloon could be easily altered to make it look more like, or less like, a distant warhead. Warheads could also be placed in balloons that do, or do not, look like warheads, and balloons that each have their own infrared signals could be deployed along with balloon-shrouded warheads.

In these circumstances, each object would look different from all other objects, and it would be fundamentally impossible for the kill vehicle to identify balloons containing warheads from those that are empty.

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compensation had the government been using the patent during the time it was secret. If the government had not used the patent, the inventor would not be entitled to any compensation.

7. Letter from Vannevar Bush to Conway Coe, April 30, 1942, in "BC," Folder 6, "Patent Matters [1941–1945]," Roll 2, Target 1, Frame 9.

8. Ibid.

9. Memo by Shurcliff, May 14, 1942. Emphasis in original.

10. William A. Shurcliff, "Chi[cago] Notes of 5/29/42 and 5/30/42," May 1942, in "BC," Folder 14, "Material [1942]," Roll 3, Target 1; William A. Shurcliff, "Brief History of WAS S-1 Patent Work," compiled from June 2, 1942 through at least September 30, 1942, in "BC," Folder 14, "Material [1942]," Roll 3, Target 1, Frame 154.

11. Memo by William A. Shurcliff, forwarded to both Vannevar Bush and James Conant, "7/1/42 Progress Report on W.A.S. Secrecy Efforts Relating to Patent Applications Bearing on S-1 Subjects," July 1, 1942, in "BC," Folder 147, "Patents [1942–1944]," Roll 10, Target 5, Frame 291; Memo by William A. Shurcliff, "Manner of Obtaining Names for LAI Cards," compiled from June 2, 1942, through August 15, 1942, in "BC," Folder 14, "Material [1942]," Roll 3, Target 1, Frame 150; Letter from William A. Shurcliff to Joseph Morris, National Academy of Sciences, June 25, 1942, in "BC," Folder 14, "Material [1942]," Roll 3, Target 1, Frame 82.

12. Letter from William A. Shurcliff to Vannevar Bush, September 25, 1942, in "BC," Folder 14, "Material [1942]," Roll 3, Target 1, Frame 38.

13. Shurcliff, *A Brief Autobiography*, pp. 59–60.

14. The patent in question (No. 2,297,305) was to Donald W. Kerst for a magnetic induction accelerator—an electron accelerator. "While this particular case is probably not of importance," Bush chastised the Patent Office, "the issuance of the patent indicates that our procedure is not air-tight." Letter from Vannevar Bush to Conway Coe, October 7, 1942, in "BC," Folder 14, "Material [1942]," Roll 3, Target 1, Frame 27. The article mentioning the patent was "Another Bomb Sight is Patented; One Device Corrects Plane's Aim," *New York Times*, October 4, 1942, p. A1.

15. Letter from William A. Shurcliff to Robert Lavender, March 29, 1943, in "BC," Folder 13, "Material from Liaison Office Files—Primarily Shurcliff's Relations to S-1 Activities, Folder No. 1 [1942–1944]" (hereafter "Material [1942–1944]"), Roll 2, Target 8, Frame 840. Shurcliff's concern with the petroleum industry and organic chemistry in general probably stemmed from his correspondence with representatives at Standard Oil Development Co. who had a large contract for developing gas centrifuge enrichment technology (which was not, in the end, used during the war).

16. Letter from Thomas Murphy, assistant commissioner of patents, to Lawrence H. Johnston, May 20, 1953, regarding "Detonating Apparatus" (U.S. Application 165,171; later granted as U.S. Patent 3,955,505). Copy of letter courtesy of Lawrence H. Johnson.

17. Letter from Sol B. Wiczer to William A. Shurcliff, March 16, 1944, in "BC," Folder 13, "Material [1942–1944]," Roll 2, Target 8, Frame 816.

18. William A. Shurcliff, notes, February 1, 1943, in "BC," Folder 13, "Material [1942–1944]," Roll 2, Target 8, Frame 752.

19. Letter from William A. Shurcliff to Carroll L. Wilson, March 20, 1944, in "BC," Folder 13, "Material [1942–1944]," Roll 2, Target 8, Frame 811.

20. Ibid.

21. Ibid.

22. Letter from Carroll L. Wilson to John Lansdale Jr., March 22, 1944, in "BC," Folder 6, "Patent Matters [1941–1945]," Roll 2, Target 1, Frame 77; Letter from John Lansdale to Carroll L. Wilson, April 4, 1944, in "BC," Folder 13, "Material [1942–1944]," Roll 2, Target 8, Frame 808. For more information on Lansdale, see Gregg Herken, *Brotherhood of the Bomb: The Tangled Lives and Loyalties of Robert Oppenheimer, Ernest Lawrence, and Edward Teller* (New York: Henry Holt and Co., 2002), especially pp. 58–59.

23. Shurcliff, *A Brief Autobiography*, p. 187. Shurcliff was later known, among other things, for leading a strong opposition to the use of supersonic transport jets in the United States and for being an expert on solar energy. He passed away on June 20, 2006.

24. Memo from William A. Shurcliff to David Z. Beckler, "Remarks on Shurcliff's Files on S-1-Type Patent Application Data and on Secrecy Recommendations Thereon," October 31, 1944, in "BC," Folder 6, "Patent Matters [1941–1945]," Roll 2, Target 1, Frame 107.

25. "Manhattan District History: Book I—General, Volume 13—Patents," December 13, 1946, in Manhattan Project: Official History and Documents [microform] (Washington, D.C.: University Publications America, 1977), sec. 5, pp. 1–4.

26. For more details on Bush's efforts, see Alex Wellerstein, "Patenting the Bomb: Nuclear Weapons, Intellectual Property, and Technological Control," *Isis*, vol. 99, no. 1, pp. 5–12 (2008).

27. Carol S. Gruber, "Manhattan Project Maverick: The Case of Leo Szilard," *Prologue*, vol. 15, no. 2, pp. 73–87 (1987); Richard Rhodes, *The Making of the Atomic Bomb* (New York: Simon & Shuster, 1986), pp. 503–7.

28. Little has been written on the plutonium patents dispute. There are extensive records of it in the Glenn T. Seaborg Papers, Library of Congress, especially boxes 832–37, and in the "BC" files, among other places.

29. Information on Lavender's earlier navy activities can be found in his biographical statement in: "Statement of Robert A. Lavender, Economic Aspects of Government Patent Policies," Hearing before the Subcommittee on Monopoly of the Select Committee on Small Business, U.S. Senate, 88th Cong., 1st sess., March 14, 1963, pp. 274–81, on pp. 275–76.

30. A provocative article that discusses at length Groves' concerns about the possibility of post-war accountability in general is Stanley Goldberg, "General Groves and the Atomic West: The Making and Meaning of Hanford," in Bruce Hevly and John M. Findlay, eds., *The Atomic West* (Seattle: University of Washington Press, 1998), pp. 39–89.

31. A recent book on the subject of the development of the bomb's "specialness" is Michael D. Gordin, *Five Days in August: How World War II Became a Nuclear War* (Princeton: Princeton University Press, 2007).

32. Memo from Leslie R. Groves and Military Policy Committee to Henry A. Wallace, Henry L. Stimson, and George C. Marshall, "Present Status and Future Program on Atomic Fission Bombs," August 21, 1943, in Harrison-Bundy Files Relating to the Development of the Atomic Bomb, 1942–1946, NARA, Washington, D.C., microfilm publication M1108, Folder 6, "Military Policy Committee Papers—Minutes," Roll 1, Target 6.

33. Vannevar Bush, *Pieces of the Action* (New York: Morrow, 1970), p. 84. In this passage he was specifically referring to the MIT Radiation Laboratory patent program, which also involved assigning patents to the government.

## The system's components

**CONTINUED FROM P. 35**

1. Bettina Haymann Chavanne, "Ballistic Missile Defense Elements Modified for Europe," *Aerospace Daily and Defense Report*, October 4, 2007.

2. Military Electronics Briefing, "BMD X-Band Radars & BMD C4I," Teal Group Corporation, July 2007. Another source describes its upgrade potential as being "greater than 50,000 elements." J. F. Crawford, E. Reed, J. J. Hines, and D. R. Schmidt, "Ground Based Radar–Prototype Antenna," National Conference on Antennas and Propagation, IEE Conference Publication, no. 469, 1999.

3. The European midcourse radar would suffer from a similar limitation if targets are separated by angles greater than 50 degrees.

4. George N. Lewis and Theodore A. Postol, "European Missile Defense: The Technological Basis of Russian Concerns," *Arms Control Today*, October 2007, pp. 13–18.

## Denuclearizing North Korea

**CONTINUED FROM P. 49**

1. The Joint Statement of the Fourth Round of the Six-Party Talks Beijing, September 19, 2005, can be found on the U.S. State Department website, www.state.gov/r/pa/prs/ps/2005/53490.htm.

2. Personal communications with Chinese nuclear specialists, November 2006.

3. Siegfried S. Hecker and William Liou, "Dangerous Dealings: North Korea's Nuclear Capabilities and the Threat of Export to Iran," *Arms*