National Missile Defense:
Prospects and Problems

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ABSTRACT.

From a perspective of 50 years of involvement with nuclear weapons and ballistic missile offense and defense, Richard Garwin will discuss the need for missile defense, the properties of systems that can work, and the Achilles heel of the national missile defense now being deployed. That problem for a US defense facing a potential North Korean or Iranian ICBM is countermeasures that would make it impossible to defend against even a few missiles. For delivery of germs by ICBM, the efficient countermeasure is tens or hundreds of bomblets, reentering individually. For nuclear weapons, the countermeasure of choice is antisimulation balloons around the warhead, with many accompanying decoy balloons. Although the midcourse-intercept system being deployed will not be effective, the threat in any case is from short-range missiles launched from ships off US shores, against which no defense is being deployed.

INTRODUCTION

I am delighted to be able to be with an engineering group to talk about national missile defense. My degree in physics is from an engineering school, now Case Western Reserve University. Much of my experience and many of my contributions have been in engineering and technology, rather than in scientific research, and I believe I am best at solving or avoiding engineering problems.

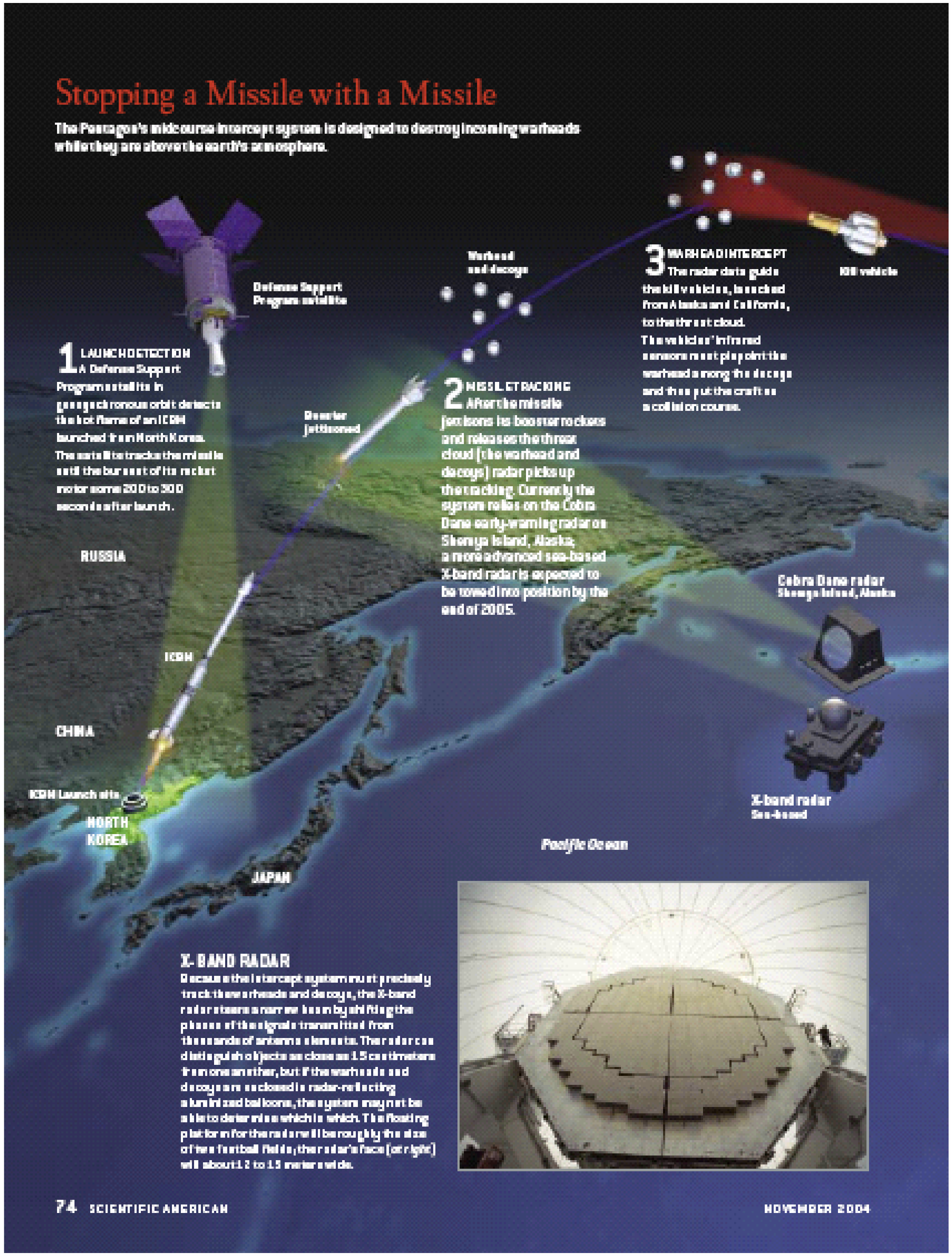
It was 55 years ago that I went for the first of many summers at the Los Alamos National Laboratory, where I worked on nuclear and thermonuclear weapons and, soon, with other groups on classified studies of missiles, missile defense, discrimination of warheads from decoys, and the like. In fact, that was half of my life for the last 50 years.

I speak with relief to an engineering group in view of the lack of numeracy of The New York Times and of many of the decision makers in our government. For instance, on January 31, 2005, The New York Times editorial comment on the new jumbo A280 airbus had it "30,000 tons heavier" than the Boeing 747. In its correction of February 2, The New York Times noted that the A280 was "hundreds of thousands of pounds heavier" in some configurations, and "It's an aircraft, not an aircraft carrier."

Then, too, engineers are better able to distinguish a goal from a fact, despite the aphorism, "Where there’s a will there’s a way."

Having introduced and used nuclear weapons in warfare in 1945, the United States at that time understood their effectiveness in destroying cities and people. It worked hard to strengthen its nuclear offensive force and was chastened when the Soviet Union tested its first nuclear explosive in 1949. The United States was deploying air defenses of the continent at a tremendous pace, with fighter aircraft and interceptor missiles armed with nuclear warheads to counter Soviet bombers. I worked for about a year in 1953-54 on Project LAMP LIGHT, with the goal of extending the computerized ground environment and defensive capabilities to the sea lanes of approach of Soviet bombers, not without commenting to the project leaders in 1953 that by the time we would have anything deployed from our efforts, the threat would be Soviet missiles rather than bombers. And I have worked ever since to try to realize an effective defense against nuclear-armed missiles.

In fact, where there is a will there are multiple ways, more or less costly or effective. The damage from nuclear-armed intercontinental ballistic missiles (ICBMs) could be prevented at various stages:


Stopping a Missile with a Missile
The Pentagon's midcourse intercept system is designed to destroy incoming warheads while they are above the earth's atmosphere.
Defense Support Program satellite
Warhead and decoys
1 LAUNCH DETECTION A Defense Support Program satellite in geosynchronous orbit detects the hot flame of an ICBM launched from North Korea. The satellite tracks the missile until the burnout of its rocket motor some 200 to 300 seconds after launch.
Booster jettisoned
2 MISSILE TRACKING After the missile jettisons its booster rockets and releases the threat cloud (the warhead and decoys) radar picks up the tracking. Currently the system relies on the Cobra Dane early-warning radar on Shemya Island, Alaska; a more advanced sea-based X-band radar is expected to be towed into position by the end of 2005.
3 WARHEAD INTERCEPT The radar data guide the kill vehicles, launched from Alaska and California, to the threat cloud. The vehicles' infrared sensors must pinpoint the warhead among the decoys and then put the craft on a collision course.
Kill vehicle
RUSSIA
ICBM
CHINA
ICBM Launch site
NORTH KOREA
JAPAN
Pacific Ocean
Cobra Dane radar
Shemya Island, Alaska
X-band radar
Sea-based
X-BAND RADAR
Because the intercept system must precisely track the warheads and decoys, the X-band radar steers a narrow beam by shifting the phases of the signals transmitted from thousands of antenna elements. The radar can distinguish objects as close as 15 centimeters from one another, but if the warheads and decoys are enclosed in radar-reflecting aluminized balloons, the system may not be able to determine which is which. The floating platform for the radar will be roughly the size of two football fields; the radar's face (at right) will about 12 to 15 meters wide.
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KILL VEHICLE
Built by Raytheon, the 64-kilogram kill vehicle is about 140 centimeters long and 60 centimeters in diameter. Its infrared seeker, designed to guide the vehicle toward its target in the final seconds before the intercept, is attached to a telescope (top of photograph at right). The vehicle has four side thrusters for adjusting its course.
Kill vehicle
Boosters jettisoned
Interceptor
Boosters jettisoned
Launch site Fort Greely, Alaska
COMMAND CENTER
Command and control for the intercept system will be based at the U.S. Air Force's Cheyenne Mountain Operations Center near Colorado Springs, Colo. During tests of the missile defense system, officials monitored the operations from a control room at Kwajalein Atoll (below).
Interceptor
CANADA
U.S.
Command Center Cheyenne Mountain, Colo.
Launch site Vandenberg Air Force Base, Calif.
Pacific Ocean
Hawaiian Islands
INTERCEPTOR ROCKET
The first of the interceptor boosters, a 17-meter-long three-stage rocket, was installed in July in its silo at Fort Greely, Alaska. A total of six interceptors will be deployed at Fort Greely by this fall and 10 more by the end of next year. Four interceptors will be based at Vandenberg Air Force Base in California.
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- By persuading states not to develop nuclear weapons.

- By persuading them not to develop missile-delivery capability.

- By destroying the industrial plants before they can produce nuclear weapons or missiles.

- Destroying the missiles at their launch sites before they can be launched.

- Destroying missiles in boost-phase, after they are launched, but before they reach a speed that will carry them to their target.

- Destroying the missiles and the warheads in mid-course as they fall through space or fly through the atmosphere.

- Destroying warheads in terminal phase, as they streak through the atmosphere toward their targets.

- Interfering with or preventing the detonation of the nuclear warhead itself, when it is within effective range of its target, which might be as little as 200 meters, for some hard targets.

For each of these phases there are different approaches to its accomplishment. For instance, boost-phase intercept might be based on the ground, on the sea surface, in the air, or in space. From space, one could use hit-to-kill interceptors (as from the other options for stationing) powerful lasers, or even a nuclear warhead.

It is important to note that these stages in the life of a missile-delivered nuclear warhead are sequential, and that effective interference at any one stage eliminates the necessity of interfering in another, although it is often said that "layered defense" is more effective and cheaper than a high-confidence defense at a single stage. That statement is problematical.

But the offense has other options, as well, and all credible options must be blocked if U.S. cities and population are to be defended against the nuclear (or biological) threat. For instance, the 1998 (Rumsfeld) Commission to Assess the Ballistic Missile Threat to the United States emphasized that any of the states that might develop ICBMs to carry nuclear warheads or germs against the United States could sooner deliver those same or larger payloads more accurately, more economically, and probably more reliably by the use of short-range missiles launched from aircraft near U.S. shores or from ships.

I begin with a description of the fundamentals of a mid-course intercept program. This is the most mature approach, if not the most promising. Effective defense in this case begins with the means for knowing that a missile has been launched, and its general direction.

It continues with the detection of the warhead or warheads, and the allocation of intercepting resources. The interceptor must then be guided (or self-guided) to collision or at least to the neighborhood of its prey.

The current system relies on the DSP (Defense Support Program) satellites that have been operated by the United States since the early 1970s and that see the launch of any ballistic missile of reasonable size almost anywhere on Earth. The existing DSP system scans the entire visible face of the Earth from geostationary orbit each ten seconds and locates intense infrared sources with a pixel approximately 1 km in size. Of course, geostationary satellites cannot see the polar regions, and other satellite orbits are used to cover that hole.

For more than 100 years it has been known and for more than 50 years demonstrated that an efficient way to reach the speeds required to throw a payload through space to land half-an-Earth away is by staged rocket propulsion. The rocket equation tells us that the mass of the rocket when it has exhausted its propellant is exponentially small in the ratio of velocity gain to exhaust velocity.

$$dP/dt = 0 = +V_e \Delta M + M\Delta V \qquad (1)$$

states that the overall momentum P of the universe remains constant, in that the sum of the momentum of the ejected mass and the increased momentum of the spaceship of mass M (due to its increased velocity as a result of the expulsion of the gas) remains zero in the reference frame moving with the spacecraft before the mass was ejected. Eq. 2

$$dV/dM = -V_e/M, \; dV/V_e = -dM/M, \qquad (2)$$

$$\Delta V/V_e = -\Delta \ln M; \; M_o/M_f = e^{\Delta V/Ve}$$

relate the increase of spacecraft speed with the mass ejected, and the initial mass of the rocket Mo to the final mass Mf, with the velocity gain ΔV and the exhaust velocity Ve.

More generally, an exhaust speed of the order of 3 km/s could propel the empty rocket, motors, and any payload to orbital speed of about 8 km/s, and with a burnout mass that is 7% of the launch mass--less a correction for atmospheric resistance and for "gravity loss" because of the effect of Earth's gravity during the rocket burn. Unfortunately, rocket structure and motors are more nearly in the range of 10% of the initial mass, so even a zero-payload single-stage rocket could not reach orbit or even intercontinental distance.

Tsiolkovsky and Robert Goddard independently hit on the idea of staging, so that each stage could carry 1/e of its launch mass to a speed equal to the exhaust speed of, say, 3 km/s. That 37% burnout mass plus payload could be composed of 10-15% structure and 27-22% payload, which would be another single-stage or multi-stage rocket. The tool of staging means that there is no limit to the speed that can be obtained with practical rocket propulsion and structure fraction, although the payload is ultimately very small.

Nevertheless, the efficiency of the process is quite good-- a daunting challenge for those who wish to replace rocket propulsion by some other means of achieving high velocity for payloads traveling through space. Since the kinetic energy of the payload is proportional to the square of its speed, the exponential decrease in mass with added velocity is compensated to a considerable extent as shown in the following equation and table.

From “Space Technology: Myth and Promise” (1988) See www.fas.org/RLG

TABLE 1: For final velocity $\mathbf{V_f}$ achieved by rocket propulsion with exhaust velocity $\mathbf{V_e}$ = 3 km/s, the payload fraction is μ and the fraction of fuel total energy present in the payload kinetic energy is

$$\varepsilon = (\tfrac{1}{2}V_f^2 M_f) / (\tfrac{1}{2}V_e^2 (M_o - M_f))$$

V_f	3	6	9	12	15	18 km/s
α	1	2	3	4	5	6
μ	37%	13.5%	5.0%	1.83%	0.67%	0.248%
ε	59%	62%	47%	30%	17%	9.1%

Of course, the offense needs not only to determine the necessary speed but to build the rockets, obtain the fuel, and produce and test the guidance systems that will bring the payload to the desired speed and orientation with the accuracy required to miss a target by less than 10 km, 1 km, or even 100 m, in current advanced generations of ICBMs.

The task of the defense is more complicated, in that it must react to a launch at the time chosen by the offense.

If there are no countermeasures, which we will discuss in a moment, the defense must test, procure, and base a sufficient number of interceptors so as to carry out the intercepts in good time. The interceptor speed must be adequate to carry it in the available time to the region of the ICBM trajectory, and at a precise time to intercept. That ICBM trajectory needs to be determined accurately in order to plan the intercept, and the interceptor must be guided not only to intercept the trajectory, but to do so at a time when the target missile is there. The closing velocity can well be 10 km/s or more, and the velocity along the trajectory more than 7 km/s. Thus 0.01s error in a hit-to-kill intercept could correspond with a miss distance of 70 m-- hence the choice of a self-homing interceptor that could obtain a miss distance of 10 cm against a symmetrical target. But if the visible (or infrared) target is a large shapeless balloon, where should the KV aim to collide with the RV itself?

Early U.S. ICBM defensive systems such as SAFEGUARD relied on interceptors capped with nuclear explosives. In fact, SAFEGUARD, deployed and operational for a brief period in 1975, based in North Dakota 20 long-range interceptors armed with 5-megaton thermonuclear warheads. These could be used to destroy an incoming warhead or cluster of warheads and "decoys" in space at a distance of thousands of km. A second layer of intercept was provided by 80 SPRINT interceptors, armed with so-called "neutron bomb" warheads, with the purpose of intercepting individual offensive warheads within the atmosphere as they approached their targets.

In this case, the purpose of the system was to defend a wing of 150 Minuteman offensive missiles, in order to preserve the deterrent against a fancied Soviet disarming threat.

SAFEGUARD made no sense even from the beginning, because it was totally reliant on the performance of both of its radars-- a long range detection radar and a shorter range radar for precision engagement and interceptor tracking and command. These radars were highly visible and hardened to a far lesser extent than the Minuteman silos they were protecting. To protect the silos, it was crucial that both radars survive; whereas it would have made little difference if 60% of the silos had been destroyed (implying the successful guidance and explosion of some 90 Soviet ICBM warheads). Evidently, the Soviet Union could have concentrated a relatively few warheads against the radars, and then had a free ride to destroy the wing of Minuteman missiles.

If Soviet forces had had the capability to do that in the first place, it would not have been significantly diminished by the SAFEGUARD defensive system.

My proposal was to deploy a very special purpose missile defense system that would be adapted to the unique target characteristics. It would destroy the nuclear warheads within a km of the silo. I had several candidate proposals, but there was no interest in a technologically unchallenging approach.

The situation against which the National Missile Defense System is being deployed is very different. It is built to operate against a relatively few (perhaps up to five) first-generation ICBMs that might be launched from North Korea or ultimately from Iran. And, of course, 1990s technology is a lot more capable than 1960s technology as regards sensors and computers. Thus it is entirely feasible to strike a well-defined object on a ballistic trajectory in space by colliding with it, rather than having a warhead on the interceptor that explodes and propels fragments or pellets to destroy the target. Since we already know that a 1-kg mass at 3 km/s has as much energy as 1-kg of high explosives, it is clear that each kg of interceptor structure or sensor would carry the explosive clout of more than 10-kg of HE with a collision at relative speed 10 km/s against a heavy warhead.

In order to achieve this actual collision with an accuracy of better than 1 m at a range of thousands of km, it is clear that any initial aim could not be sufficiently accurate. The interceptor itself must have sensors and a guidance package that can close the loop and correct for initial errors of direction or timing so as actually to enter into collision with the warhead. This marvelous technology has been demonstrated several times in the vacuum of space at interceptor-like speeds. For a successful intercept, however, there must also be "threat assessment" and discrimination against the other objects that might have been launched--intentionally or unintentionally-- from the ICBM.

Much of the staging "hardware" is left behind and does not achieve threat speed. This includes the shroud that is used to protect the warhead as it is accelerated to high speed within the atmosphere. Absent a shroud, the dynamic pressure of the atmosphere could injure or destroy the warhead, as could the aerodynamic heating on ascent, as evidenced on descent in the Columbia space shuttle loss of February 1, 2003. The shroud is jettisoned early on, however, in order to minimize the burden on the launching rocket by reducing the mass that must be accelerated to the intercontinental speed.

In its reentry vehicle for protection against the fierce heat of penetrating the atmosphere at very high speed, the warhead is typically severed from the remaining structure and third-stage engine. It is up to the offense as to whether these pieces are themselves fragmented by explosives, pushed out of the way by a tiny rocket, or modified to serve as primitive decoys to present a credible threat that must be attacked with the limited stock of interceptors.

In our March, 1968 article in Scientific American, Hans Bethe and I showed what would be required to defend against ICBMs carrying nuclear warheads. We emphasized that there are some simple countermeasures that could be used by the offense, and that the design of a defense must take that into account from the word go. This is an inconvenient fact, and whenever a defensive program is mounted, a good deal of the effort is devoted not so much to solving the countermeasures problem by design or by counter-countermeasures (CCM), but to an effort to deny that the problem exists.

Against its better judgment, the Administration of President Bill Clinton was forced to commit to the development and likely deployment of a National Missile Defense. Failing to get the Defense Department and the Ballistic Missile Defense Organization (BMDO) to take seriously the threat of simple countermeasures, in April 2000 eleven of us published a substantial report, sponsored by MIT and the Union of Concerned Scientists.(1)

The countermeasures that I discuss here are those that I have emphasized in my congressional testimony on missile defense, and first is the sure-fire countermeasure in the case of bacteriological warfare payloads, of fragmenting the payload into individual small reentry vehicles ("bomblets"). For delivery of a nuclear warhead (to my mind, a less likely threat from North Korea), the countermeasure of choice is the antisimulation balloon, surrounding the warhead to make it look just like the cheapest possible decoy in space-- the inflated aluminum-coated Mylar balloon.

Unfortunately, the decision makers in the Pentagon and the White House are largely non-technical people, as is the case in Congress, and it was therefore necessary to spell out what is known to every fledgling aerospace engineer-- including those in North Korea, Iraq, and Iran. So we used published information from NASA and from the U.S. program in order to scope the problem of a reentry vehicle that would protect a BW payload against any rise of temperature during the fierce heat of reentry. Here are some of the Figures.

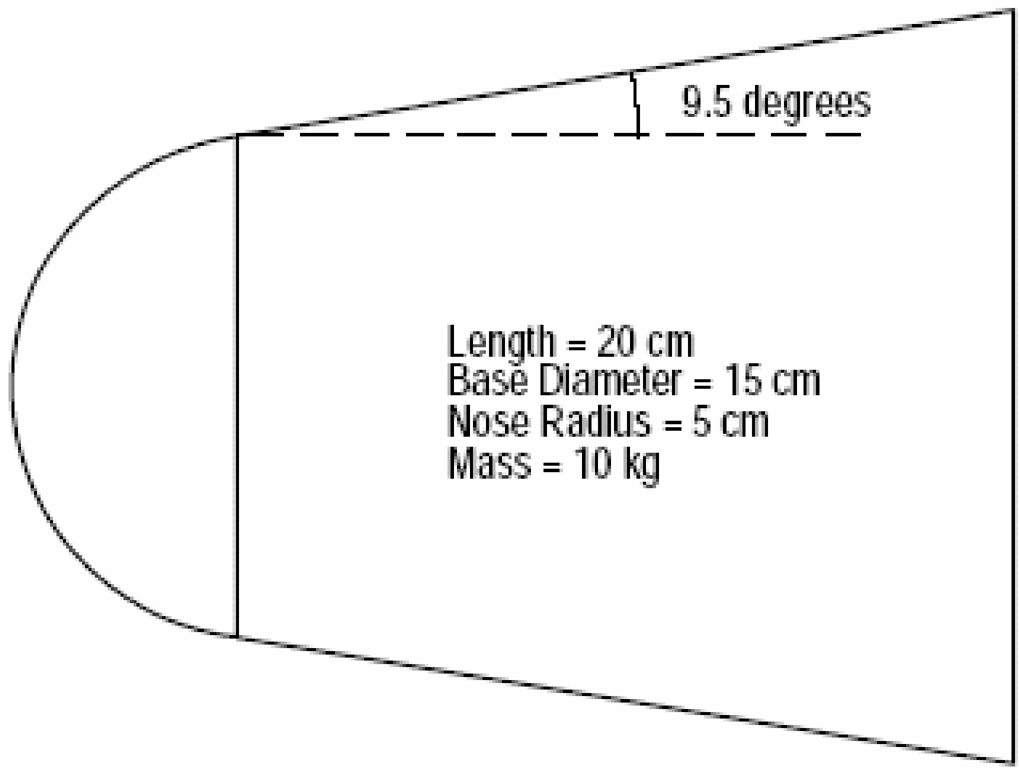


Figure 7-1. The configuration used for calculating the heating of a conical bomblet. *It has a nose radius of 5 cm, a base diameter of 15 cm, a length of 20 cm, a cone half-angle of 9.5 degrees, a mass of 10 kg, and a ballistic coefficient of 12,000 N/m² (250 lb/ft²).*

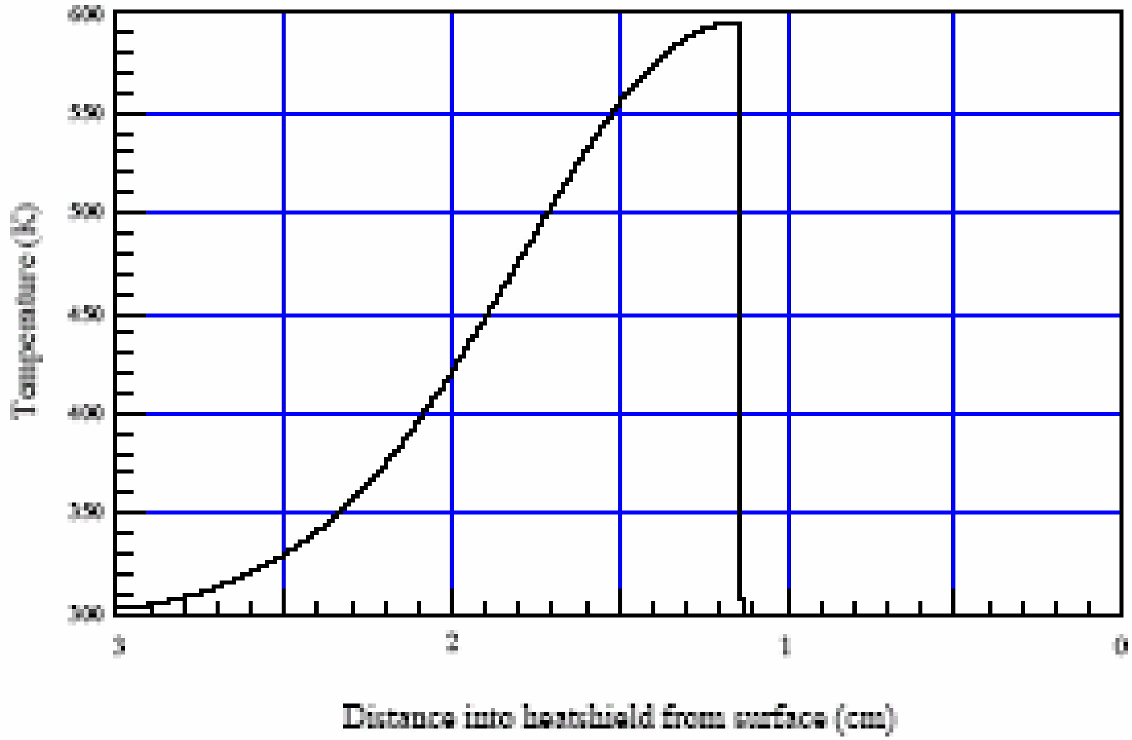


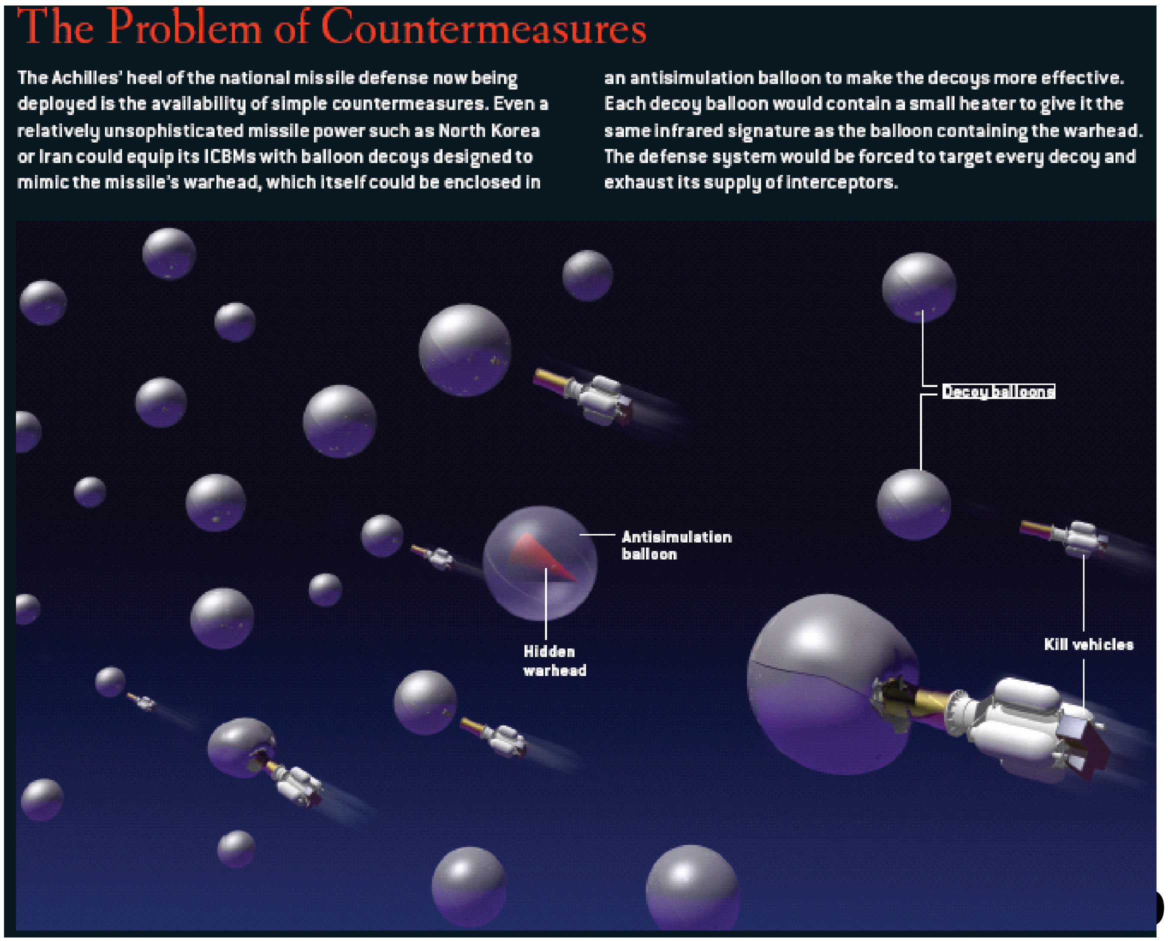
Figure F-13. Temperature profile in the heatshield at the nose of the conical bomblet when the bomblet hits the ground.

For a BW payload, the countermeasure does not depend upon deceiving the defense; it simply provides far more equivalent threat aim points than there are interceptors.

For a decade or more I was on the White House Strategic Military Panel of the President's Science Advisory Committee (PSAC). In the mid-1960s we met for two days every month and continually reviewed the experimental data and programs for discrimination of decoys from real warheads. Lincoln Laboratory and other contractors did a marvelous job on designing, deploying, and operating radars to detect small differences between decoys and warheads-- differences not only in the body itself, but in the wake produced. Those who were designing the countermeasures in order to have credible decoys made advances of their own.

Our judgment, reflected in the SAFEGUARD system, was that discrimination was feasible in the low atmosphere, but was not feasible in the vacuum of space. At that time we discussed the powerful impact of antisimulation, rather than the "simulation" that was in vogue at the time. In the decoy field, "simulation" refers to the crafting of a decoy so that in every observable respect it resembles an RV. The simulation decoy for the Minuteman warhead has appeared on the contractor's website, together with a real-time video of its deployment and inflation in space. But such verisimilitude requires either advanced theory or complicated experimental verification on the large scale, and even in space; it is thus not suitable for a small fledgling nuclear power.

These problems can be avoided by antisimulation decoys that can be tested in a small vacuum chamber.(2) Accordingly, our 11-member group selected antisimulation in the form of spherical balloons for a non-spinning RV, such as the early U.S. Polaris warheads. Here are some of the figures and a discussion from our 2000 report:



Illustrator: Al Kamajian.

“Holes in the Missile Shield,” by R.L. Garwin, *Scientific American*, November 2004.

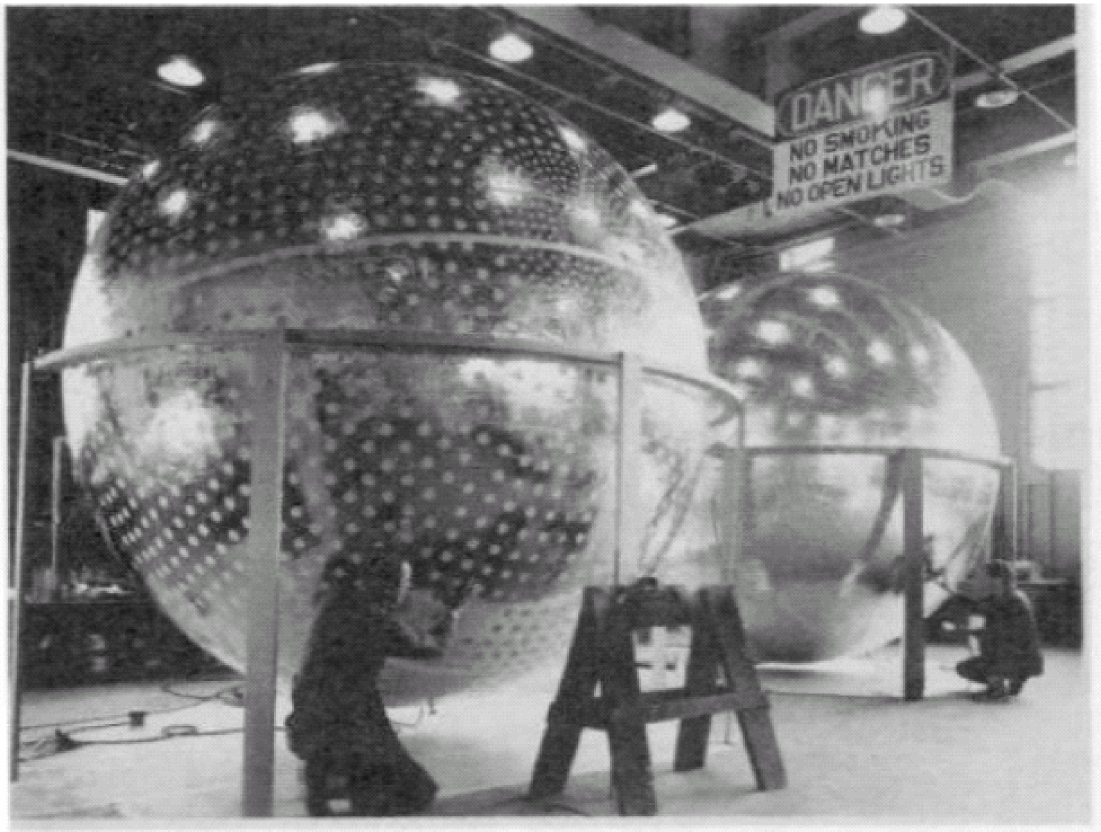


Figure 8-1. A photograph of one of the NASA Air Density Explorer inflatable balloon satellites.

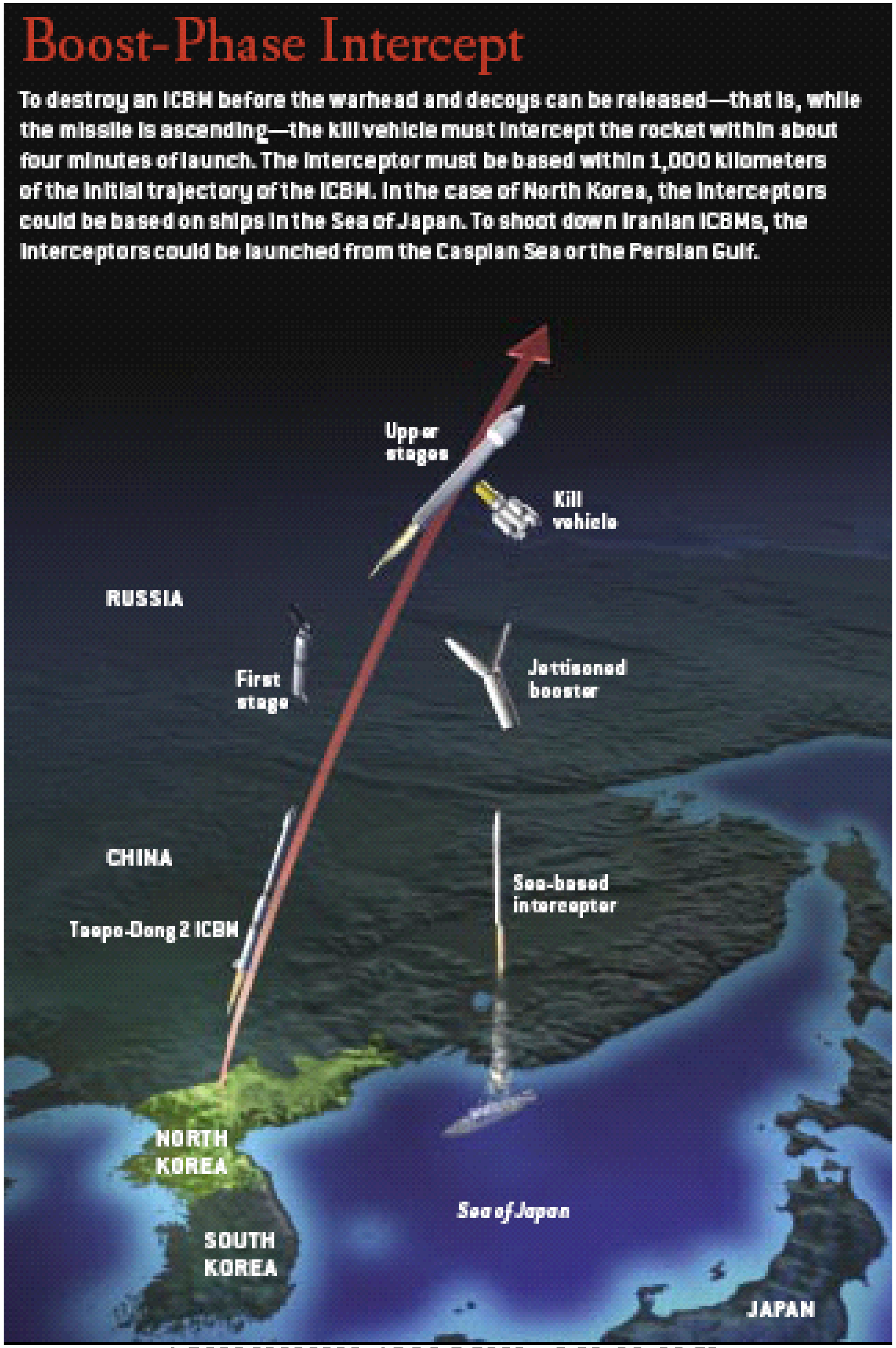
Many of you will recall the Strategic Defense Initiative (SDI) launched by President Ronald Reagan in his televised address of March 13, 1983. This aimed to deploy a defensive system against Russian ICBMs that would confidently protect against every one of 6000 nuclear-armed RVs aimed at the United States. That lofty goal had many problems, among which were the vulnerability of the system and the unrealism of the goal. I recall debating many proponents, including President Reagan's Science Advisor, Jay Keyworth, and arguing that while SDI was not going to work, there were many other prospects for protection, including deterrence and pre-boost-phase intercept, known as "preemption."

Those are still the most important approaches to protecting the United States and its allies against ICBMs, BW, and nuclear weapons in the hands of other states.

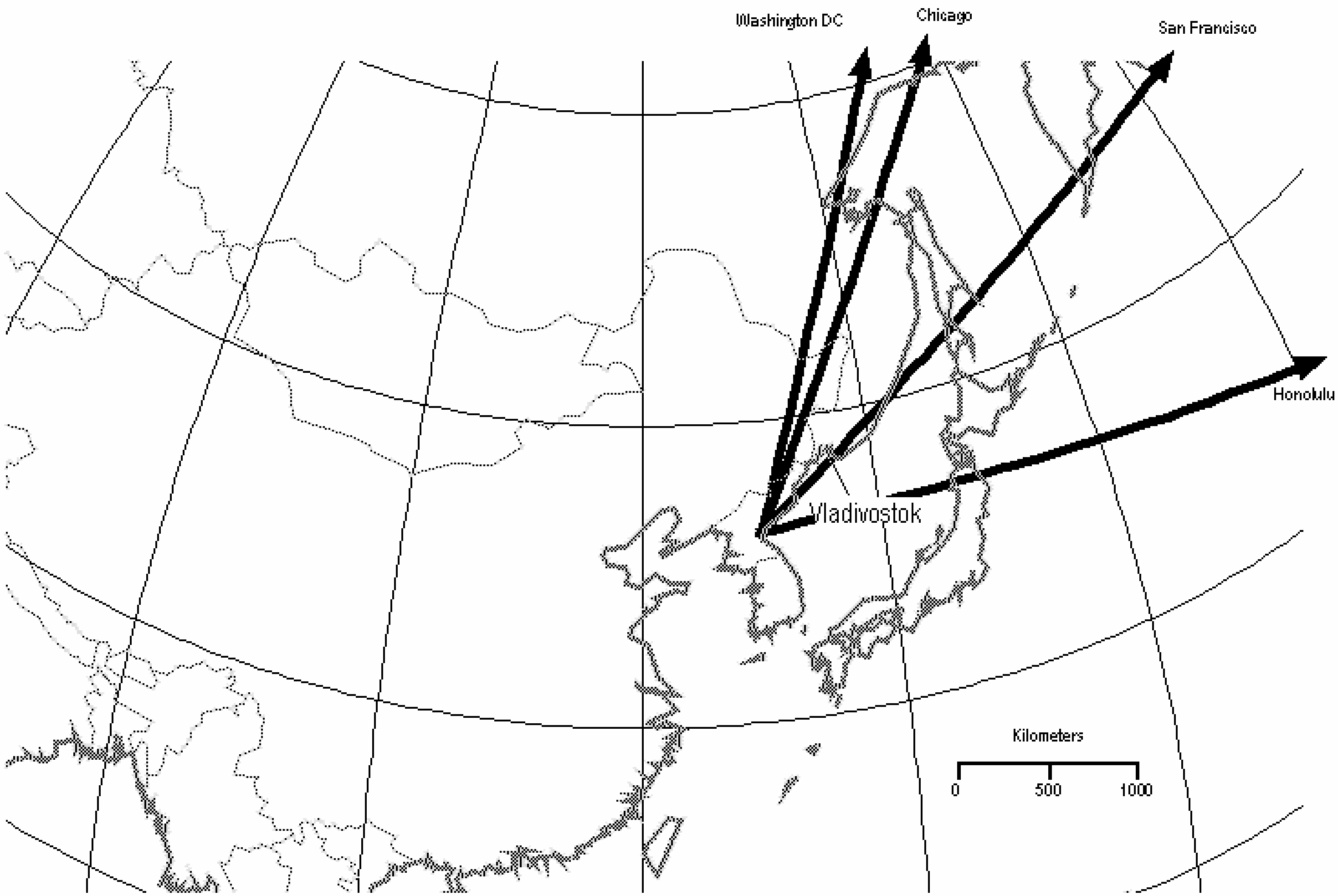
Given the propensity of U.S. Congress for high-tech muscular solutions, it seemed to me that something was needed that could work against the prospective North Korean ICBMs, in contrast to the mid-course system that was bound to fail in the face of countermeasures. So since 1999 I have publicly advocated boost-phase defense in these particular cases, as detailed in many of my articles.

Naturally, I have similarly advocated such systems to BMDO and its successor, the Missile Defense Agency (MDA), and with some success in that they now have an active program. However, it was clear to me that little progress would be made on boost-phase intercept (BPI) without national priority, and this would not be forthcoming while mid-course intercept was presented as a viable program.

Here are a few graphics detailing the BPI system that I advocate.


Boost-Phase Intercept
To destroy an ICBM before the warhead and decoys can be released—that is, while the missile is ascending—the kill vehicle must intercept the rocket within about four minutes of launch. The interceptor must be based within 1,000 kilometers of the initial trajectory of the ICBM. In the case of North Korea, the interceptors could be based on ships in the Sea of Japan. To shoot down Iranian ICBMs, the interceptors could be launched from the Caspian Sea or the Persian Gulf.
Upper stages
Kill vehicle
RUSSIA
First stage
Jettisoned booster
CHINA
Sea-based interceptor
Taepo-Dong 2 ICBM
NORTH KOREA
Sea of Japan
SOUTH KOREA
JAPAN

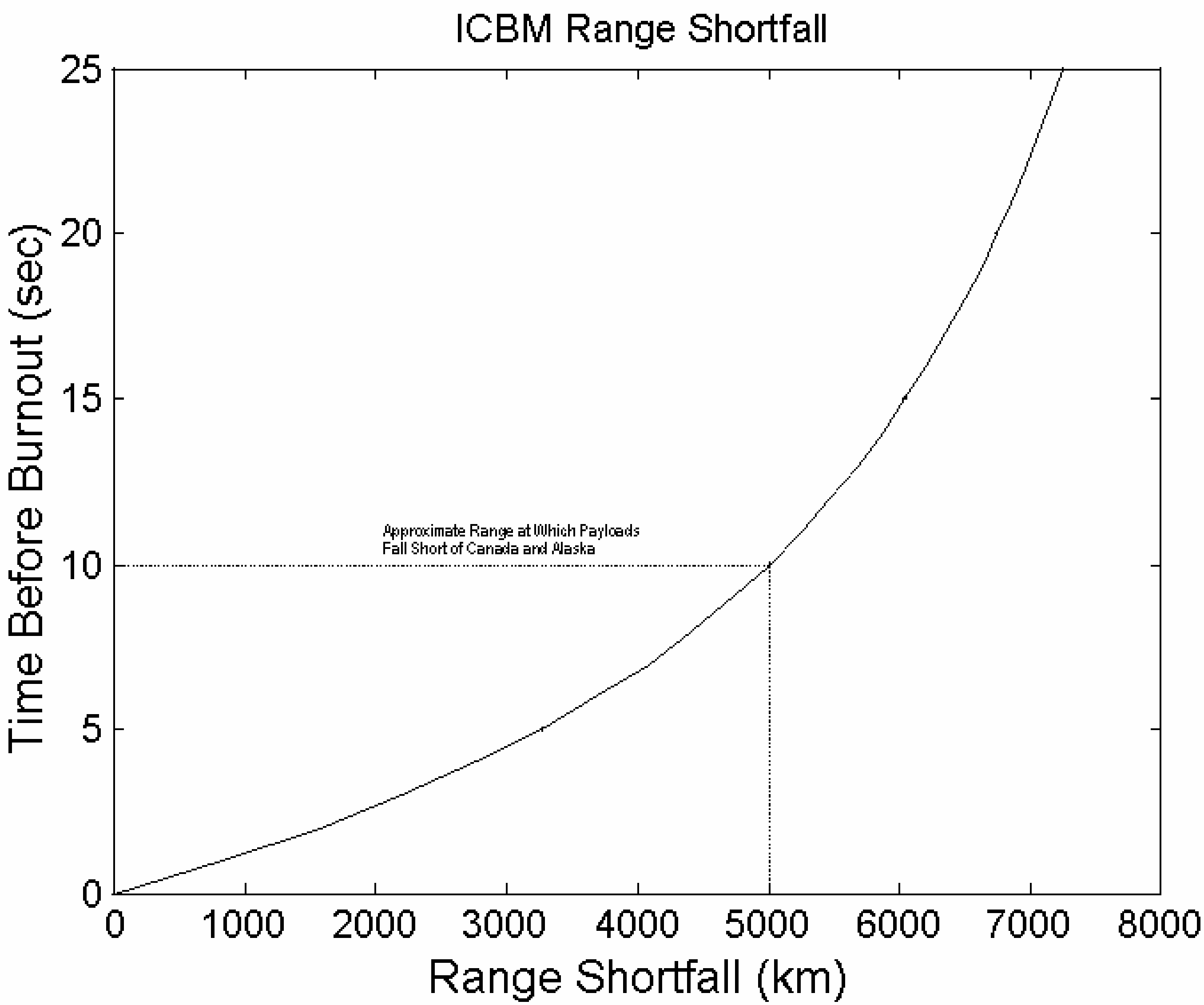
Ground-Trace of North Korean ICBM for Attacks on Washington, Chicago, San Francisco, and Honolulu

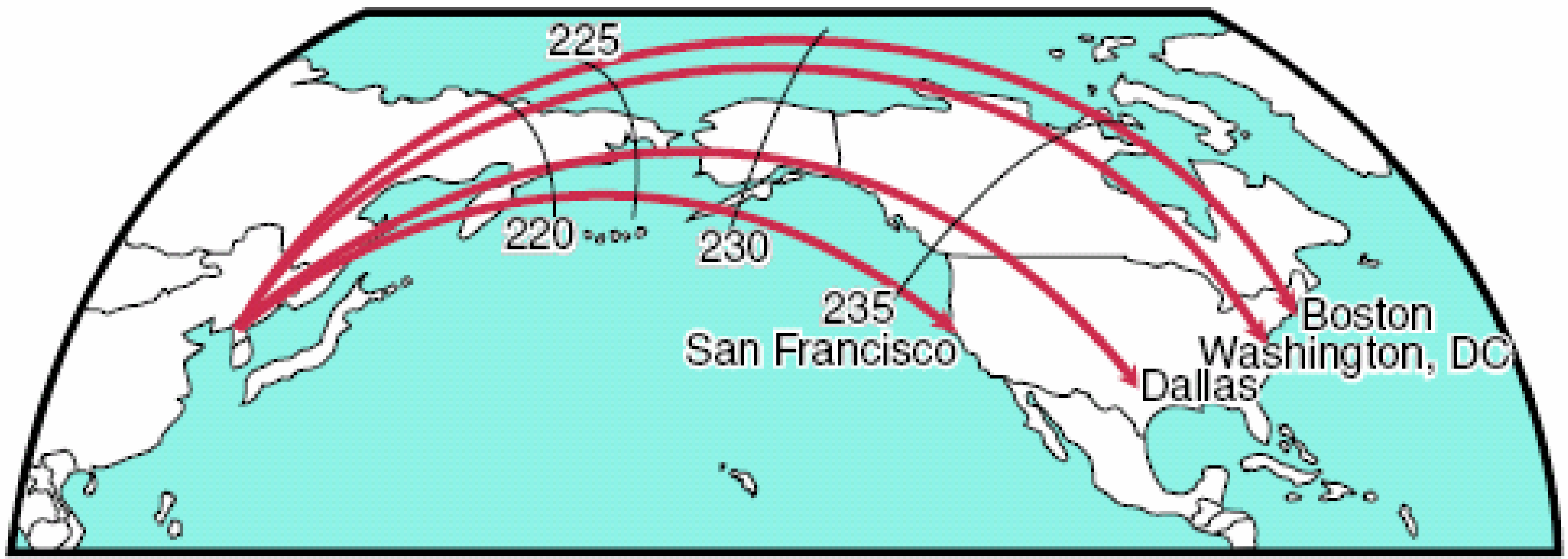


North Korean Launch Site to
Chicago=5244.69nmi, 10,524.02km
Minimum Energy Loft Angle = 21.37 degrees
Velocity at Ground = 7.28 km/sec
Range Angle=94.52 degrees
Time of Flight = 33.22 minutes

North Korea Launch Site: 39.6N, 127.3E
Chicago: 41.85N, 87.65W
San Francisco: 37.75N, 122.45W
Washington, DC: 38.9N, 77.0W
Honolulu, 21.3N, 157.9W

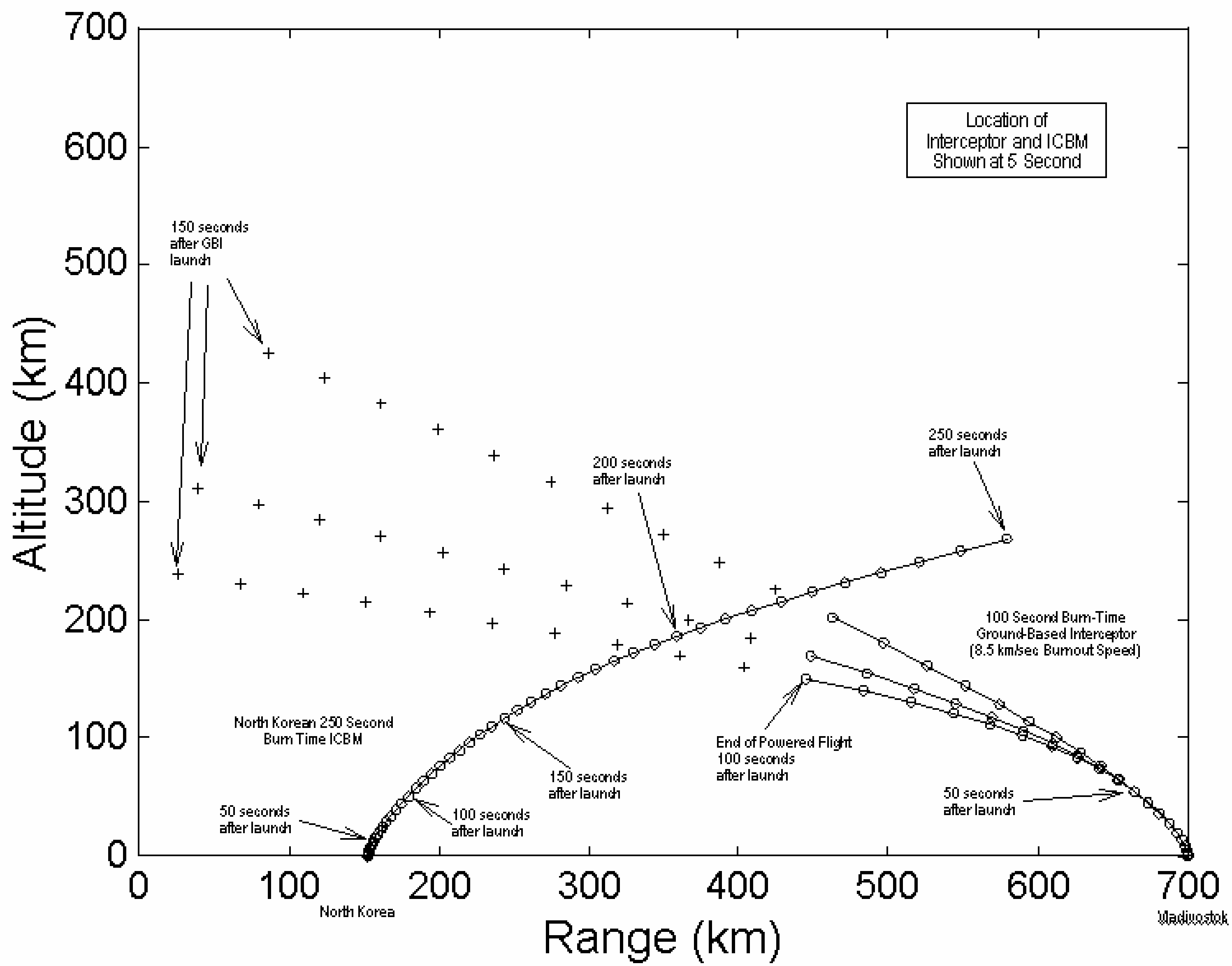
Range Shortfall of Intercepted North Korean ICBM for Various Intercept Times Prior to Burnout





APS Study Group

Powered Flight Profiles of North Korean 250 Second Burn-Time ICBM and Russian-US 100 Second Burn-Time Ground-Based Interceptor



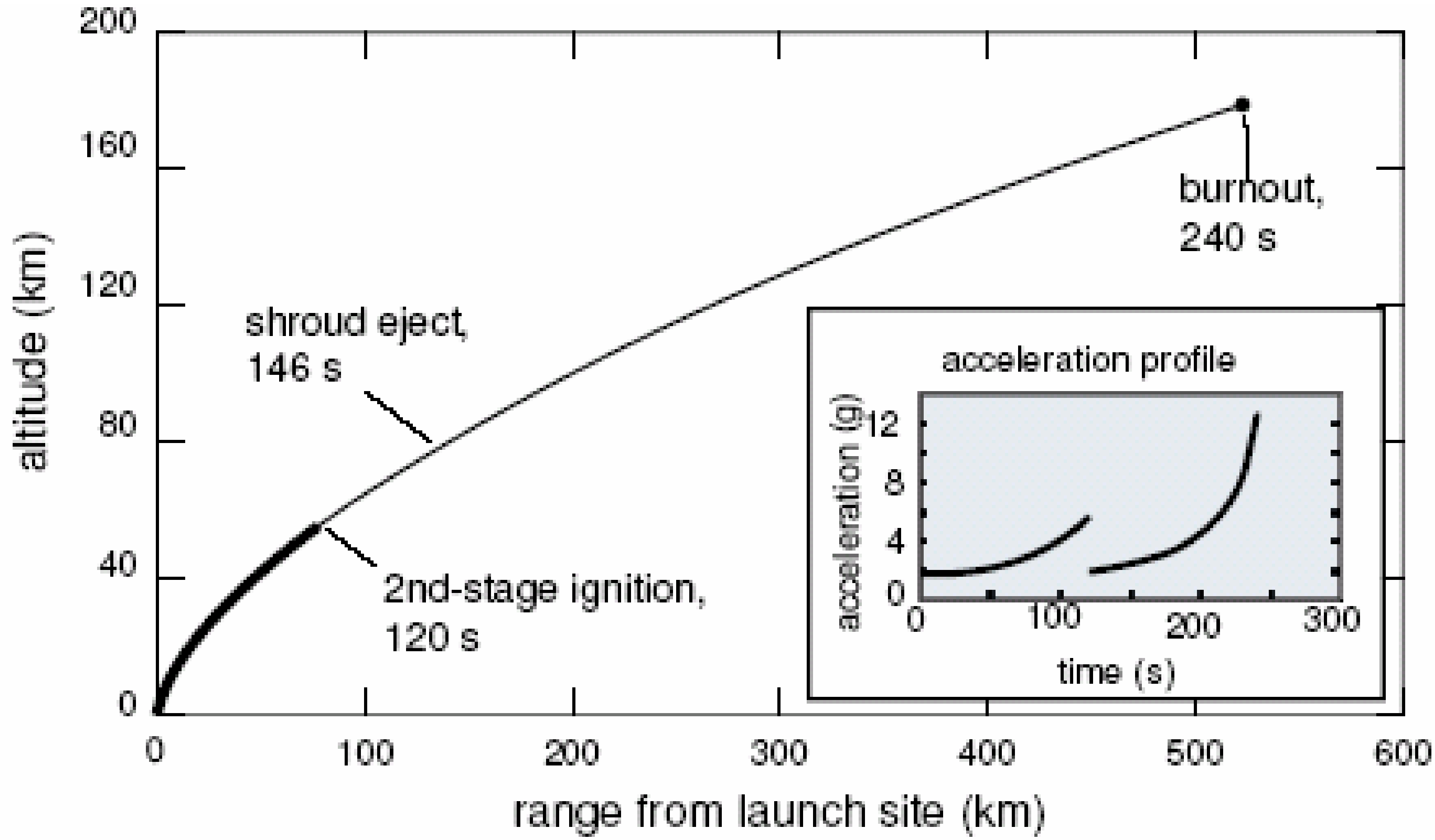


Figure 4.1. Liquid-propellant ICBM model L maximum-range boost-phase trajectory in the altitude-range plane. The first- and second-stage boost-phase trajectories are shown respectively by the heavy and light lines. Inset: Acceleration profiles of the two stages. The acceleration of the second stage reaches 12 g before it burns out.

(APS Study Group))

In 2003 the American Physical Society Study Group on Boost-Phase Intercept published its highly substantive study.(4) This confirmed that no land or sea-based BPI was feasible against China and Russia, given their vast land areas available for deployment, but, to my mind it reinforced its feasibility against North Korea and even against Iran. It did spell out the analysis that showed that with current interceptor kill-vehicle technology, the interceptor itself would have to be in the range of the 14-ton rocket that I advocated in my 1999 presentation, and not in the 1.4-ton range that is adapted to the vertical launch system on existing Navy ships. The APS Group detailed the countermeasures that might be used against BPI—primarily maneuvering of the ICBM booster—and scoped the •V required of the kill vehicle, leading to the large mass ratio that demands the 14-ton interceptor launch mass. Another critical parameter is the time required for a decision to launch the interceptor(s) after DSP detects the booster in flight—typically some 30 seconds after launch.

I still believe that the U.S. mid-course intercept program should be terminated, and the effort placed on rapid acquisition of a BPI system that would not only have some prospect of working against North Korean ICBMs before they had a chance to bring a payload of BW bomblets up to speed that would carry them to the United States, but by its nature would also deter the acquisition of such capabilities by North Korea and Iran.

Still, the problems remain-- of performance of the defense against ICBMs and, worse, the greater threat of delivery against U.S. coastal cities by short-range missiles. It is not worthwhile to defend against the ICBM threat (barricade the back door) when the simpler and more effective option is available to an adversary state, of short-range missile attack (an open front door).

In any case, we will need to depend on deterrence and preemption for our security against armed states. A greater threat, outside the scope of this talk, is terrorist delivery of nuclear or biological weapon, about which I have written for a long time. Here deterrence does not work, and defense against smuggling is difficult. The first line of defense against terrorist nuclear explosions in the United States lies in securing the world's nuclear weapons and weapon-usable materials-- plutonium and highly enriched uranium-- and in mounting a public health defense against terrorist induced disease-- especially smallpox. But that is another talk.

I would be delighted to entertain questions or comments on this presentation.

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1 "Countermeasures, A Technical Evaluation of the Operational Effectiveness of the Planned U.S. National Missile Defense System," UCS-MIT Study, A.M. Sessler (Chair of the Study Group), J.M. Cornwall, R. Dietz, S.A. Fetter, S. Frankel, R.L. Garwin, K. Gottfried, L. Gronlund, G.N. Lewis, T.A. Postol, and D.C. Wright, April 2000. Available online at *http://www.ucsusa.org/publications/report.cfm?publicationID=308*

2 "Midgetman Needs Anti-Simulation Decoys," paper by E. Teller on p. 44 of Armed Forces Journal International, March 1987.

3 "Cooperative Ballistic Missile Defense," by Richard L. Garwin November 17, 1999 Available online at *www.fas.org/RLG*.

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