Strategic Defenses

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in Michael J. Mazarr and Alexander T. Lennon, eds.,
Toward a Nuclear Peace (New York: St. Martin's Press, 1994), pp. 69–86

In the wake of the Persian Gulf War and the collapse of the Soviet Union, the focus of the Strategic Defense Initiative (SDI) has shifted from defense against massive missile attacks to defense against much smaller attacks. In his 1991 State of the Union Address, President George Bush stated:

> Looking forward, I have directed that the SDI Program be refocused on providing protection from limited missile strikes, whatever their source. Let us pursue a SDI Program that can deal with any future threat to the United States, to our forces overseas, and to our friends and allies.

The Pentagon's Strategic Defense Initiative Organization (SDIO) quickly enshrined these goals in its "global protection against limited strikes" program, later renamed the Global Protection System (GPS). This system is intended to address two types of threats: the possibility of an accidental or unauthorized missile launch from the former Soviet Union and intentional attacks from Third World nations. The GPS and related proposals for limited missile defenses have received substantial support in Congress.[1] This, combined with the recent agreement between Presidents Bush and Yeltsin to explore the possibility of joint work on a global missile defense, has reinvigorated the debate over limited defenses.[2]

An important consideration in designing a limited defense is that it not upset strategic stability—a goal that is well recognized by Congress and the new Clinton administration.[3] The United States and Russia most likely will want to retain a nuclear deterrent for the foreseeable future; if they did not, the problem of accidental or unauthorized launches would be easy to solve.[4] A nuclear deterrent force requires a survivable and massively destructive retaliatory

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[1] For example, the Missile Defense Act of 1991 increased SDI funding by 34 percent, and called for development of the required technology to allow the deployment of a limited missile defense by 1996. Earlier in 1991, Senators Warner, Cohen, and Lugar proposed a limited defense system consisting of 700 to 1200 ground-based interceptors based at five to seven sites

[2] White House, Office of the Press Secretary, "Joint U.S.-Russian Statement on a Global Protection System," 17 June 1992.

[3] For background on defenses, see Paul L. Chrzanowski, "The Transition to a Deterrence Posture More Reliant on Strategic Defenses," in Dietrich Schroeer and David Hafemeister, eds., *Nuclear Arms Technologies in the 1990s* (New York: American Institute of Physics, 1988), pp. 220-243; Dean Wilkening and Kenneth Watman, "Strategic Defenses and First-Strike Stability," (Santa Monica, CA: RAND, R-3412-FF/RC, November 1986); Glenn A. Kent and David E. Thaler, "First-Strike Stability and Strategic Defenses," (Santa Monica, CA: RAND, R-3918-AF, October 1990); and William Kerby, "The Impact of Space Weapons on Strategic Stability and the Prospects for Disarmament: A Quantitative Analysis" (Hamburg: Institut fur Friedensforschung und Sicherheitspolitik, October 1986).

[4] If, for example, the two countries had no fears about each other, but wanted nevertheless to maintain (vastly smaller) nuclear arsenals as a deterrent to attacks by other nations, they could engage in a multitude of cooperative

capability, and this capability must not be threatened by a limited defense. If a limited defense even *appears* capable of nullifying an opponent's nuclear deterrent under some circumstances, it may hinder or even reverse the ongoing process of reducing strategic arsenals, thereby making us less rather than more secure. These critiques do not necessarily apply to tactical missile defenses, which seek only to defend deployed U.S. and allied military forces against local cruise or ballistic missile attack.

FUTURE DEFENSIVE FORCES

As expressed in the Missile Defense Act of 1991, the goal of a limited defense is to provide "a highly effective defense of the United States against limited ballistic missile threats, including accidental or unauthorized launches or Third World attacks, but below a threshold that would bring into question strategic stability." In addition, a limited defense system should "provide a highly effective theater missile defense to forward-deployed expeditionary elements of the Armed Forces of the United States and to friends and allies of the United States." The act was a bipartisan piece of legislation and, in theory, could help guide U.S. policy on strategic defenses even in a Clinton administration.

Limited Attacks

The design of a limited defense depends rather sensitively on the definition of "limited attack." Accidental attacks are usually thought to involve the launching of a single missile, but it is unclear why accidents, whose nature is entirely speculative, would not involve many more weapons. Unauthorized attacks are more readily defined as the launch of the maximum number of missiles under the direct command of a single individual.[5] In the case of Russia, this might be a regiment of ICBMs (e.g., nine SS-25s each armed with one warhead), or all of the missiles on a submarine (e.g., twenty SS-N-20s with five warheads each).[6]

Third World attacks are also highly speculative because so few nations have missiles capable of attacking the United States. Indeed, the only Third World nation with such forces is China, which has deployed four liquid-fuel ICBMs and 24 short-range SLBMs, each armed with a single

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measures to reduce the probability of unauthorized and accidental launches, such as joint attack warning, improved security and command and control, or the installation of destruct-after-launch systems. Such measures would be far more reliable and far less expensive than building a defensive system to guard against the launch of each other's missiles. See *Reducing the Dangers of Accidental and Unauthorized Nuclear Launch*: *Alternatives to a Ballistic Missile defense System* (Washington, D.C.: International Foundation for the Survival and Development of Humanity, January 1990).

[5] *Architecture Integration Study: Interim Report* (Washington, DC: Strategic Defense Initiative Organization, U.S. Department of Defense, April 1992), p. 9.

[6] We assume that Russia will meet the agreed limit on SLBM warheads by reducing the number of warheads carried by each SLBM, not by reducing the number of submarines (which, while saving the most money, would make the force more vulnerable to antisubmarine warfare), or by reducing the number of SLBMs on each submarine (which would make targeting more difficult). For example, the Typhoon, which now carries twenty missiles and 200 warheads, is assumed to carry the same number of missiles but half the number of warheads. If Russia instead reduces the number of submarines, the maximum number of missiles that could be launched in an unauthorized attack would remain the same but the number of warheads would double; if they reduce the number of missiles per submarine, the number of warheads would remain the same but the number of missiles would be halved.

warhead, and is in the process of modernizing these forces.[7] Israel and India have a latent ICBM capability, since both have orbited satellites using indigenous space launch vehicles, but neither has plans to develop an ICBM. The gradual diffusion of missile technology and expertise may increase the number of countries capable of fielding ICBMs or SLBMs in the future, but it is highly unlikely that any Third World nation would deploy a force significantly larger or more capable than China's.

Setting aside for the moment missile attacks on allies or U.S. forces overseas, which might involve much larger numbers of short-range missiles, *a reasonable goal for a limited defense would be to intercept up to ten ICBMs, carrying ten warheads, launched simultaneously from any point on land, and up to twenty SLBMs, carrying a total of 100 warheads, launched rapidly from any point in the oceans.* The defense should be "highly effective" against such attacks, meaning that it should provide "high confidence of extremely low or no leakage."[8] Here we will interpret "highly effective" to be an average overall effectiveness of 99 percent; that is, an average of only 1 out of 100 incoming warheads would penetrate the defense.

A less demanding measure of effectiveness, such as the ability to intercept just 90 percent of incoming warheads (or even 75 or 50 percent), would ease the burden on any defensive system and reduce the potential instability it might cause. A less capable system would need fewer interceptors and would therefore be less likely to disrupt a retaliatory strike. Yet the purposes of a very limited defense demand near-perfection for its truncated missions. A defense explicitly designed to safeguard U.S. cities against accidental, unauthorized, or Third World strikes that allowed the destruction of even one city would be counted as a failure. If a Russian submarine commander succeeded in launching 100 warheads at the United States, for example, a defense that destroyed 90 of them while allowing the rest to smash New York, Chicago, and Washington and kill millions of people would hardly justify either public confidence or the investment of tens of billions of dollars.

Possible Architectures

A wide range of limited-defense architectures have been proposed, ranging from the 100-interceptor, ground-based defense allowed by the 1972 Anti-Ballistic Missile Treaty (ABM Treaty) to a combination of thousands of space-based and ground-based interceptors and sensors. But as noted, an ABM Treaty-compliant system has no hope of meeting the goals outlined by Congress. One hundred interceptors simply could not be made be so effective that they could intercept 100 incoming warheads with anything approaching zero leakage. And in any case, even a perfect system based at the treaty-designated site at Grand Forks, North Dakota, would leave most of the U.S. population unprotected. Radars at Grand Forks would be unable to track a wide range of possible missile trajectories, including ICBM attacks by China or North Korea on San

[7] John Wilson Lewis and Hua Di, "China's Ballistic Missile Programs: Technologies, Strategies, and Goals," *International Security*, Vol. 17, No. 2 (Fall 1992), p. 19, 28. According to Lewis and Di, the current SLBMs will be replaced by a much longer-range and more accurate missile in the mid-to-late 1990s, and the ICBMs will be replaced by solid-fuel missiles by 2010.
[8] *Report to Congress: Conceptual and Burden Sharing Issues Related to Space-based Ballistic Missile Defense Interceptors* (Washington, DC: U.S. Department of Defense, March 1992), p. 7.

Francisco, or by Libya or Iran on Boston. Interceptors based Grand Forks would, moreover, have no hope of engaging SLBMs launched against coastal targets.[9]

Expanded ground-based systems involving three to seven sites and up to a thousand interceptors have also been proposed. While such systems offer the prospect of defending all U.S. territory, they are unlikely to meet the ambitious goals set for a limited defense. As argued by the U.S. Department of Defense,[10] a single-layer architecture is inherently vulnerable to catastrophic failure if the attack has unusual and unanticipated characteristics.[11] Even if enough interceptors are available for multiple independent shots at each warhead (which would *not* be possible for short-range SLBM launches), "high confidence of extremely low or no leakage" is unlikely.

Nor would ground-based systems protect friends and allies of the United States against surprise attack.[12] Theater defenses might be able to defend particular targets, but only if enough warning is available to deploy the defense. Indeed, reliance on ground-based systems could actually encourage surprise attacks on allies precisely for this reason.

To provide for a highly effective limited defense, SDIO has proposed a two-layer GPS consisting of space-based interceptors (SBIs) and ground-based interceptors (GBIs).[13] Current schemes envision about 1,000 SBIs or "brilliant pebbles" orbiting the Earth, ready to attack missiles soon after they are launched, and up to 1,000 GBIs based in the United States to destroy the warheads before they reenter the atmosphere. Defense of friends and allies would be accomplished by the same constellation of SBIs combined with rapidly deployable ground-based theatre defenses. The system apparently was designed to defend against a simultaneous attack by 200 warheads, which is the largest number of warheads now deployed on a single Russian submarine.

A system consisting of roughly 1,000 SBIs and 500 GBIs would be the smallest deployment capable of meeting the goals of limited defense. This projection is consistent with SDIO estimates.[14] Yet a defensive system of this size would, even at the low levels of strategic forces set forth in the Washington summit agreement, threaten the survivable retaliatory capability of both Russia and the United States and could prove destabilizing in several other ways.

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[9] Lisbeth Gronlund and David C. Wright, "Limits on the Coverage of a Treaty-compliant ABM System," *Physics and Society*, Vol. 21, No. 2 (April 1992), p. 6.

[10] See *Conceptual and Burden Sharing Issues,* p. 9, 18-21.

[11] For example, the attacker may employ countermeasures intentionally, such as decoys or chaff, or unintentionally as happened when Iraqi-launched Scuds tumbled and broke up in the atmosphere.

[12] Space-based defenses may also be incapable of destroying short-range missiles, especially if the trajectories are slightly depressed. See David C. Wright and Lisbeth Gronlund, "Underflying Brilliant Pebbles," *Nature*, Vol. 350 (25 April 1991), p. 663.

[13] To achieve a 99 percent kill probability with a two-layer system, each layer must have a statistically independent kill probability of 90 percent, which, while highly ambitious, is not obviously unachievable.

[14] The initial GPALS architecture called for 1,000 SBIs and 750 to 1,000 GBIs based at five to seven sites (depending on whether Alaska and Hawaii are defended). Since the maximum number of warheads aboard a submarine is likely to be cut in half for both the United States and Russia, the number of GBIs required should be reduced by a similar factor. The *Architecture Integration Study* (AIS) has suggested that as little as 500 SBIs and 200 GBIs based at three sites might be sufficient, but this ignores several stressing attack scenarios and depends on highly optimistic estimates of midcourse discrimination and interceptor lethality. Using more realistic assumption, the AIS concludes that 1000 SBI and 600 GBI are needed. See the appendix for more detail.

STRATEGIC STABILITY

To preserve deterrence, one must convince adversaries that one's nuclear forces can inflict unacceptable damage after withstanding an all-out first strike and after penetrating an adversary's defenses. If both sides are convinced that a first strike by either side would lead to the destruction of the attacker, and that the attacker would not be much better off than the victim, then there should be no incentive to strike first. The lack of incentives to strike first, even when the risk of nuclear war appears high, is known as "crisis stability." The insensitivity of the nuclear balance to changes in the number or character of weapons is known as "arms race stability." The most desirable state is when both sides believe that there are no incentives to strike first under any circumstances and when there is little hope (or worry) that the purchase of additional offensive or defensive weapons by either side would change this situation.

The survivability of nuclear forces is highly sensitive to their alert status, since virtually all non-alert forces can be destroyed by a first strike. Table 6.1, "Alert Rates in Peacetime and Crisis," gives optimistic but reasonable assumptions about the percentage of U.S. and Russian forces that might be on alert during normal peacetime operations and during a serious crisis. These alert rates are consistent with recent operational practices as well as recent agreements between the United States and Russia.[15]

Table 6.1

Alert rates in peacetime and crisis.

	United States		**Russia**	
	Peacetime	**Crisis**	**Peacetime**	**Crisis**
ICBMs	95%	95%	50%	80%
SSBNs	67%	83%	44%	67%
Bombers	0%	50%	0%	50%

Using the offensive force structures and alert rates given in tables 1.1 and 6.1, table 6.2, "Nuclear Weapons Surviving a First Strike," gives estimates of the U.S. and Russian forces that could be expected to survive a first strike by the other and be delivered in retaliation (see

[15] Russian road-mobile ICBMs are assumed to have a lower alert rate than U.S. silo-based ICBMs due to the necessity of maintaining crews ready to drive the missile launchers at a moment's notice (much like bombers). Twelve of the 18 U.S. SSBNs are assumed to be at sea at peacetime, surging to 15 during a crisis. During the Cold War, the alert rate of the (much larger) Soviet SSBN fleet was only about 20 percent (about 12 of 60 subs); I assume that Russia would maintain the same number of SSBNs at sea during peacetime (12 of 27), surging to 18 during a crisis. (According to press reports, however, the alert status of Russian SSBNs has been very low since the breakup of the Soviet Union.) Russian bombers have never been on quick-reaction alert, and the U.S. removed its bombers from peacetime alert in 1991. During a crisis, I assume that 50 percent of the bombers (both Russian and U.S.) would be ready to takeoff in a few minutes after warning of an attack is received.

Appendix 1 for details). A Russian first strike could destroy about 80 percent of U.S. ICBMs, all ballistic-missile submarines (SSBNs) in port, and all bombers on alert. A U.S. first strike could destroy all non-alert Russian mobile ICBMs, submarines, and bombers, and up to 20 percent of the alert mobile ICBMs. Thus, the outcome mostly depends on the alert status of the forces.

An attack when the alert status of opposing forces is low is often referred to a "surprise attack" or a "bolt-from-the-blue." Most analysts consider a bolt-from-the-blue first strike to be implausible, especially in view of the improved relations between the United States and Russia. They believe that a nuclear attack could come only after an extended crisis.

Table 6.2.

Nuclear Weapons Surviving a First Strike (assuming no strategic defenses are deployed)

Weapons	United States		Russia	
	Peacetime	**Crisis**	**Peacetime**	**Crisis**
ICBMs: warheads	110	110	140	220
EMT (equivalent megatons)	50	50	120	180
SLBMs: warheads	1000	1300	690	1000
EMT	310	390	150	220
Bombers Warheads	0	470	0	300
EMT	0	210	0	120
Total: warheads	**1100**	**1900**	**830**	**1600**
EMT	**370**	**660**	**260**	**530**

It is worth noting, however, that alert status might be kept low intentionally even during a crisis or that warning of an impending attack might be ignored. For example, Soviet leader Nikita Khrushchev did not raise the alert status of Soviet forces during the Cuban missile crisis, presumably because he believed that alerting forces would increase the risk of war. Stalin ignored warnings of attack by Germany because he feared that defensive preparations might anger Hitler and prompt an attack. The United States ignored indications of imminent attack by Japan on Pearl Harbor. Thus, many analysts, while admitting the low probability of a bolt-from-the-blue attack, consider it a reasonable basis for prudent defense planning.

Even after suffering a bolt-from-the-blue first strike, both nations could deliver a devastating retaliation equal to about 300 EMT.[16] A retaliatory strike of this magnitude could kill 60 to 100 million people in either country—a prospect that should be more than sufficient to deter a first

[16] The equivalent megatonnage of a warhead is the yield raised to the two-thirds power, since the area that can be destroyed by blast is proportional to the two-thirds power of the yield. (This scaling law does not apply, however, to the other destructive effects of nuclear weapons, such as fire.) The equivalent megatonnage referred to here is the sum of the EMT for all surviving, deliverable warheads and bombs.

strike.[17] A first strike when opposing forces are on crisis alert would lead to a retaliatory attack about twice as large, but not much more fearsome.[18] Thus, the nuclear balance is extremely stable at these force levels.

A limited defense can, however, cast doubt on this fearsome retaliatory capability, possibly undermining crisis and arms race stability. For example, a defensive system designed to intercept the missiles from a single submarine launched by an insane commander obviously could intercept the same missiles launched in retaliation. Indeed, because all SSBNs would not be clustered in one small area, and because the victim of a first strike could not fire its SLBMs precisely in unison, many more SLBMs could be engaged. Even if simultaneous, clustered SLBM launches are possible, reliance on such a strategy might lead to hasty retaliatory decisions that undermine efforts to end the war, as well as making SSBNs more vulnerable to antisubmarine warfare.[19]

It may seem counterintuitive to say that a defense designed to intercept 100 warheads would under different circumstances be capable of intercepting thousands, but there are three important differences between defending against a limited attack and defending against a large retaliatory strike: the spatial and temporal extent of the attack, and the probability of destroying an individual warhead.

In terms of *spatial extent*, a limited defense would be designed to engage up to twenty missiles launched from a single point on the Earth and up to 100 warheads targeted against any region in the United States. The same system could, however, destroy many more missiles if the launches were spread out over Russia and the oceans, because many more SBI could participate in the defense. For example, a defense designed to intercept a few ICBMs *or* SLBMs could destroy both at the same time, just as it could simultaneously destroy ICBMs launched from eastern *and* western Russia. In fact, about six times as many ICBMs can be engaged in the boost phase if the launches are distributed among current bases across Russia rather than at a single point.

A defense's effectiveness would also be affected by the *temporal extent* of attacks. A limited defense would be designed to engage up to ten ICBMs launched simultaneously, and up to twenty SLBMs launched rapidly. While first strikes and limited attacks could be synchronized precisely, it

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[17] Barbara G. Levi, Frank N. von Hippel and William H. Daugherty, "Civilian Casualties from 'Limited' Nuclear Attacks on the Soviet Union," *International Security*, Vol. 12, No. 3 (Winter 1987/88), p. 188; and Barbara G. Levi, Frank N. von Hippel and William H. Daugherty, "Civilian Casualties from 'Limited' Nuclear Attacks on the United States," *International Security*, Vol. 12, No. 3 (Winter 1987/88), p. 188. The authors give 90 to 140 million deaths for a 300-EMT attack on the Soviet Union; since Russia contains only 52 percent of the population of the former Soviet Union (but a higher percentage of its military and economic targets), it is reasonable to assume that casualties from a 300-EMT attack on Russia would be closer to the estimates given for the United States.

[18] The diminishing returns of increasingly large attacks is indicated by the fact that increasing the delivered EMT by 33 percent (to 400 EMT) increases the number of deaths by 5 to 12 percent.

[19] The victim of a first-strike could conceivably delay the bulk of the retaliatory strike, firing the missiles through the "hole" in the SBI defense created by a small initial retaliatory strike. But this strategy depends on the implausible assumptions that the victim's space-tracking capabilities survive the first-strike, that the aggressor cannot rapidly maneuver existing SBIs or deploy new SBIs to plug the gap in the defense, that the victim would wait days for the hole to appear above his forces (while vulnerable to bomber attack and antisubmarine warfare), or that SSBNs could quickly maneuver into position below the hole.

is unlikely that nations would have the same confidence in a retaliatory strike—especially one that took the victim somewhat by surprise. If all of the ICBMs or SLBMs in a given region do not fire in unison, additional SBI will orbit into view and will be able to participate in the defense. If, for example, a retaliatory launch of all the SLBMs from all the submarines in a typical patrol zone takes two to three times as long as a rapid launch of SLBMs from a single submarine, then four to five times as many missiles could be destroyed in the boost phase.[20] If the SSBNs are distributed among two to three such patrol zones, then the number of retaliatory missiles intercepted could be eight to sixteen times more than the number the system was designed to intercept in a limited attack.

All of the affects the system's *probability of kill*. A limited defense designed to engage 100 warheads with a 99-percent probability of kill could engage many more warheads with a somewhat lower kill probability, destroying considerably more than 100 warheads. For example, a two-layer defense in which each layer could engage 100 warheads with an independent kill probability of 90 percent could on average destroy almost twice as many warheads in a large retaliatory attack as in a limited attack (180 vs. 99). Moreover, if three interceptors (each with a kill probability of 54 percent) are required in each layer to achieve an overall kill probability of 90 percent, then nearly twice as many missiles or warheads could be destroyed (320 vs. 180).[21] Thus, in this simple example, one can see how a system designed to destroy 99 warheads (out of 100) would be capable of destroying as many as 320 (out of 600).

Table 6.3, "Warheads Surviving a Limited Defense," gives the number of U.S. and Russian warheads and equivalent megatonnage that would survive a counterforce first strike by the other and penetrate both layers of a GPS defense. As described above, the space-based layer is assumed to be capable of intercepting ten ICBMs launched simultaneously from a small area in the United States or Russia and up to twenty SLBMs launched rapidly from a single submarine anywhere in the oceans. The ground-based layer, which is assumed to be capable of intercepting up to 100 warheads targeted against a given region of the United States or Russia, is composed of 500 interceptors.[22] Both layers are assumed to have independent kill probabilities of 90 percent, for an overall kill probability of 99 percent.[23] Retaliatory ICBMs are assumed to be launched

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[20] See appendix 1 for details. Assumes SBI with a maximum speed of 6 km/s, an altitude of 460 km, and a reaction time of 60 s, and SLBMs with a burnout time of 170 s and a burnout altitude of 240 km, and that SSBN are spread over a million-square-kilometer patrol area.

[21] See appendix 1 for details. If p is the kill probability of an interceptor and n is the number of interceptors, then the probability of kill P after n independent shots is given by $P = 1 - (1-p)^n$. Thus, $p = 1 - (1-P)^{1/n}$; if $P = 0.9$ and $n = 3$, $p = 0.54$. The total number of incoming warheads that can be destroyed in one-on-one engagements is proportional to np.

[22] Although Russia is nearly twice as large as the United States, the northern regions of the country contain few cities, and it is unlikely that a negotiated agreement on defenses would allow Russia more GBI or GBI sites than the United States.

[23] As described in the appendix1, the SBI calculations are based on the scaling for boost-phase intercept. If midcourse intercepts are possible with high probability of kill (e.g., 90 percent), then a system designed to destroy ten ICBMs or twenty SLBMs would be less effective against a retaliatory strike than indicated here, but accurate estimates would require detailed orbital simulations. It is far more likely, however, that a high probability of kill will not be possible in midcourse; if several intercept attempts are required, this would increase the effectiveness against retaliatory strikes, as described above. Moreover, I assume that the system is designed to intercept 20 rather than 24 SLBMs, that a retaliatory SLBM strike is launched from just two bastions, that only one shot is required to

simultaneously from existing bases in the United States and Russia; SLBMs are assumed to be launched from two widely separated million-square-kilometer patrol zones;[24] both are assumed to be launched against targets spread across Russia or the United States.

Table 6.3.

Warheads Surviving a Limited Defense

Warheads	United States		Russia	
	Peacetime	**Crisis**	**Peacetime**	**Crisis**
Peacetime	3500	3500	3000	3000
After First Strike	1100	1900	800	1600
After SBI	600	1300	260	1000
After GBI	130	900	30	540
Results: EMT	**40**	**300**	**10**	**200**

Source: see appendix for details.

Note that if strategic forces are on crisis alert, Russia would be capable of delivering a retaliatory strike of roughly 200 EMT after suffering a first strike and penetrating U.S. defenses; under similar circumstances, the United States could deliver some what more. In both cases, limited missile defenses reduce the delivered megatonnage by more than a factor of two, with less than half being delivered by missiles (mostly SLBMs). Even so, retaliatory attacks of this magnitude could kill 50 to 100 million Americans or Russians,[25] and should therefore serve as a powerful deterrent. On the other hand, 200 EMT may be uncomfortably low for military planners who typically use "worst-case" assessments that significantly underestimate the performance of their own weaponry while overestimating that of an opponent.

If, however, a first strike is launched when forces are on peacetime alert, no bombers would survive and Russia would be able to deliver only about 10 EMT in a retaliatory strike—twenty times less than the amount that could be delivered without limited defenses. If targeted against the most densely populated U.S. cities, this would be enough to kill 5 to 10 million people. A U.S. retaliatory strike under similar circumstances would be limited to 40 EMT.

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achieve a 90 percent kill probability in both layers, and that the SBI constellation is perfectly matched against both threats (i.e., that a system designed to intercept twenty SLBMs would not be capable of intercepting more than ten ICBMs, and vice-versa). Thus, it is unlikely that the results given here overestimate the capability of a limited defense against a retaliatory strike.

[24] Russia reportedly keeps its SSBNs on patrol in the Barents Sea and the Sea of Okhotsk, while U.S. SSBNs roam the Atlantic and Pacific Oceans. One might assume, however, that the U.S. would cluster its SSBNs as a counter-measure to a limited defense without greatly increasing their vulnerability. The estimates given here assume that a fleet of SSBNs could not launch its missiles in less than twice the time required by a single SSBN, which seems reasonable after suffering a first strike.

[25] Levi, von Hippel, and Daugherty, "Civilian Casualties," p. 188.

Clearly, then, strategic defenses on the order contemplated in the GPS program would have devastating implications for strategic stability at a level of 500 to 1000 warheads. Table 6.3 explains, for example, that of the 1,100 warheads from a peacetime-alert U.S. deterrent forces surviving a first strike, only 130 would penetrate a GPS-like defense. For a similar Russian retaliation of 830 warheads, fewer than 30 would penetrate. If both nations had only 1,000 warheads in their whole force, with perhaps several hundred surviving a first strike, the number of warheads that would survive a first strike and a limited defense would be very small—at best a few dozen. At a level of 500 warheads, it is possible that a defense would wipe out the retaliation completely. In short, further reductions in offensive arms and limited strategic defenses are incompatible.

THE DANGERS OF DEFENSE

In addition to instability, another danger is that steps taken to reinforce deterrence could lead to a net loss in security. Russia could, for example, reverse its planned reductions in nuclear weapons and their peacetime alert status, or at least prevent deeper reductions from taking place. This would be detrimental to international security because such reductions play an important role in lowering the risk of accidental or unauthorized use of nuclear weapons. Increasing peacetime alert rates by putting bombers back on quick-reaction alert or increasing the number of SSBNs on patrol forces both sides into a more hair-trigger posture, increases opportunities for accidents and unauthorized use, and contributes to the possibility of misunderstanding and unintended escalation.

Even worse, a nation that believes that its retaliatory capability is threatened by defenses may resort to offensive countermeasures, such as decoys, maneuvering reentry vehicles, faster-burning boosters, and depressed-trajectory SLBM launches. This might in turn spawn improvements in the defense to maintain the desired effectiveness against limited attacks. The risk of such a new defense-offense arms race would certainly be reduced given the major-power trust and amity presumed in this report. Like large nuclear forces, however, strategic defenses are not appropriate to a world where no risk of war exists, and continued pursuit of them can therefore produce suspicion and mistrust.

In this connection, it is worth mentioning that effective SBIs necessarily would be highly capable antisatellite (ASAT) weapons, even against attack-warning and communications satellites in high orbits. These and other military satellites are crucial components of the U.S. nuclear deterrent, as well as being invaluable force-multipliers in conventional conflict, as shown in the Persian Gulf War.[26] For example, Russia might fear that its satellites would be destroyed in an attack by the United States, leaving it incapable of communicating with its retaliatory forces. Thus, the SBIs' inherent ASAT capability would only exacerbate instabilities in the nuclear balance created by limited defenses.

Another danger is that a nation possessing limited defenses might become enamored with the goal of becoming invulnerable to nuclear threats of all kinds. If effective limited defenses could be

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[26] See, for example, Steve Fetter, "Protecting Our Military Space Systems," in Edmund S. Muskie, ed., *The U.S. in Space: Issues and Policy Choices for a New Era*, (Washington, DC: Center for National Policy Press, 1988), pp. 1-25.

built while strategic arsenals are reduced, a nation might convince itself that a near-perfect missile defense was within reach. The temptation to expand "limited" missiles defenses and to complement them with an effective air defense might be irresistible.[27] If rival nations wanted to maintain mutual vulnerability, such a decision would almost certainly trigger an arms race.

Even if neither side is tempted to expand the defense, the possibility of rapid expansion will be an unavoidable characteristic of an effective limited defense. Once the necessary SBIs, GBIs, and tracking sensors are developed, tested, and deployed in large numbers, expanding the system simply would be a matter of producing more interceptors. Indeed, any limited defense would require a ready supply of spare interceptors to replace those that are used in tests or in battle or that fail with age. The "brilliant pebble" SBI is so small and light that 1,000 could be orbited with just a dozen or so Titan-IV rockets, making quick expansion of the system a real possibility.[28] Moreover, additional SBIs could be placed in orbits optimized for coverage of Russia, where they would be about twice as effective against Russian ICBMs and SLBMs in northern patrol areas as SBI in orbits chosen for uniform coverage of the Earth.[29]

U.S.-RUSSIAN COOPERATION?

It is often said that the dangers of limited defenses could be managed by close cooperation between the United States and Russia, but such cooperation is highly unlikely and even if it were possible would be irrelevant. Either the United States and Russia will want to maintain the other's vulnerability, or they will not. If either nation wants to maintain the vulnerability of the other, then cooperation on limited defenses would be self-defeating, since limited defenses substantially reduce that vulnerability.[30]

If, on the other hand, both the United States and Russia no longer wished to maintain the vulnerability of the other, then there would be much less expensive and much more effective ways of reducing the likelihood of accidental or unauthorized use. The two nations could, for example, cooperate on installing improved permissive action links, improved command, control, and communications facilities, or systems to destroy errant missiles after launch- provided that all

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[27] The United States lost interest in air defense after the Soviet Union deployed ICBMs, because a defense against aircraft would do little good without an accompanying defense against missiles. If effective missile defenses are deployed, however, this would be sure to reopen the debate over air defense. For a discussion of the potential of strategic air defense, see Arthur Charo, *Continental Air Defense: A Neglected Dimension of Strategic Defense* (Cambridge, MA: Center for Science and International Affairs, Harvard University, 1990).
[28] Assuming each brilliant pebble weighs 100 to 150 kg (including garage and station-keeping fuel), and that the Titan-IV, which has a payload capacity of 18 tonnes to low-earth orbit, could orbit 10 tonnes of brilliant pebbles.
[29] For a boost-phase defense. See Christopher T. Cunningham, "The Space-based Interceptor," in Dietrich Schroeer and David Hafemeister, eds., *Nuclear Arms Technologies in the 1990s* (New York: American Institute of Physics, 1988), p. 278.
[30] It would be logically possible for the United States and Russia to maintain a jointly operated defensive system to guard against unauthorized or accidental launches from either country, which could be disabled by either country during a period of potential conflict between the two countries. In addition to the enormous management problems such a system would create, a limited defense that was disabled during crises would not be very useful, since accidental, unauthorized, or limited attacks would be most likely at these times.

those measures are implemented with the proper safeguards and conditions.[31] In short, there is no role for cooperative defenses against accidental or unauthorized attacks: when cooperative defense is possible, it isn't necessary; when it could be useful, it isn't possible.

At the other end of the spectrum, maintenance of large nuclear arsenals and the development of strategic defenses is sometimes justified as a hedge against renewed conflict with Russia. But unless the United States is very careful, such actions are just as likely to generate suspicion and cause friction between the two countries—a self-fulfilling prophesy of renewed military competition. Moreover, if a new cold war erupts *and* defenses are deployed, an offense-defense arms race is likely, with both sides jockeying to maintain a nuclear deterrent in the face of increasingly sophisticated defenses.

EFFECTS ON OTHER NUCLEAR POWERS

One often-ignored but absolutely critical aspect of strategic defenses is their possible effect on the "middle" nuclear powers. United States allies in Europe, as well as China, are likely to object vehemently to any significant deployment of strategic defenses. Defenses could undermine the security of U.S. allies and spark costly and destabilizing new arms buildups in various regions.

China has opposed SDI since its inception, because even a limited defense would effectively nullify China's modest ICBM and SLBM force. If China decided that maintaining the vulnerability of the nuclear superpowers was vital to its security, it would have little choice but to engage in an expensive program to modernize its nuclear arsenal by building more ICBMs and SLBMs, developing multiple warheads and penetration aids for its missiles, or deploying weapons that are invulnerable to ballistic-missile defenses, such as bombers and cruise missiles. When the Soviet Union and the United States were developing first-generation ABM systems in the mid-1960s, China responded with programs to develop a larger ICBM, multiple warheads, penetration aids (electronic countermeasures and light exoatmospheric decoys), and a fractional orbital bombardment system.[32] If China responds to GPS in a similar manner, it could stimulate a wider nuclear arms race in South Asia involving India and Pakistan.

France and the United Kingdom would be in a similar position if Russia deployed a limited defense. As now planned, the survivable strategic forces of both nations are likely to consist of one or two SSBNs on patrol during peacetime. This is deemed a sufficient deterrent in the absence of defenses, but if Russia acquires even a limited nationwide defense, France and the United Kingdom would have little choice but to greatly expand their forces greatly or rely on the United States for deterrence.

CONCLUSIONS

A limited defense that provides a high degree of protection against unauthorized, accidental, or other small attacks, including the launch of all SLBMs from a single submarine, would also be

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[31] See Sherman Frankle, "Aborting Unauthorized Launches of Nuclear-armed Ballistic Missiles though Postlaunch Destruction," *Science and Global Security*, Vol. 2, No. 1 (1990), pp. 1-20, for a discussion on how this can be done in an absolutely secure manner.
[32] Lewis and Di, "China's Ballistic Missile Programs," p. 17, 21.

highly effective against a retaliatory strike. The ability to deliver a devastating blow in response to a first strike, which is the *sine qua non* of deterrence, would be substantially reduced. Indeed, a nation's retaliatory capability after absorbing a bolt-from-the-blue attack would fall well below the 200 EMT commonly assumed to represent a minimum deterrent. A potent retaliatory strike is possible only if the attack comes when nuclear forces are on alert, but most of this would be delivered by bombers, not by missiles, and could be subject to attrition by improved air defenses.

If the United States or Russia faced a limited GPS-type defense, it might well conclude that its nuclear deterrent capabilities were lacking. In response, the country might halt planned reductions in nuclear forces or deploy a variety of countermeasures to defeat the defense, inducing both nations to spend additional money without increasing their security. In the extreme case, limited defenses could trigger the kind of offense-defense arms race that the Anti-ballistic Missile Treaty was designed to prevent. Close U.S.-Russian cooperation could ameliorate the adverse side-effects of limited defenses, but if such close cooperation was possible, there would be easier, cheaper, and more effective ways to reduce the threat of unauthorized or accidental missile launches.

Limited defenses would also have a profound effect on the other nuclear powers, whose more modest strategic arsenals would be effectively nullified by a limited defense. Most worrisome would be the reaction of China, who, unlike France and the United Kingdom, could not count on extended deterrence from one of the nuclear superpowers. If, as in the past, China responds to the prospect of superpower defenses by initiating modernization programs to preserve its deterrent, it could trigger a wider nuclear arms race in South Asia.

Under reasonable assumptions about future force structures and the performance of offensive and defensive systems, therefore, limited defenses can threaten strategic stability. Given the very low probability of unauthorized or accidental launches, and the very small number of countries that will have the capacity to attack the United States with ballistic missiles in the foreseeable future, the benefits of limited strategic defenses are not worth the penalty of decreased stability. And while a more ambitious view of strategic defenses, as a hedge against rearmament in a world of tiny nuclear arsenals, might be attractive to some, this chapter suggests that there is no stable path to that nuclear end state.

Apart from extremely small territorial defenses, the one form of missile defense that does not threaten stability is tactical systems designed to protect military forces. The U.S. military certainly needs better tactical missile defenses, and it will develop and deploy them; indeed, given the risks of strategic defenses, the bulk of U.S. work on missile defenses should focus on tactical systems. The major challenge in the years ahead may be to prevent the effects of those efforts from spilling over into the strategic nuclear realm and creating unwanted instability.

APPENDIX 1

First-Strike Survivability and Defense Penetration

Steve Fetter

The analysis in chapter 6 is supported by estimates of the number of warheads that would survive a first strike and penetrate a two-layer limited defense. This appendix details the methods used to derive these estimates.

1. First-strike Survivability

1.1. *Silo-based ICBMs*. The probability that a silo-based ICBM would survive an attack by a single warhead to fire in retaliation is given by

$$P_s = R_1 \cdot A_1 \cdot (1 - P_k) \qquad \text{(A-1)}$$

where R_1 and A_1 are the reliability and alert rate of the ICBM and P_k is the probability that the attacking warhead would destroy the silo. P_k is given by

$$P_k = R_2 \cdot A_2 \cdot [1 - 2^{-(LR/CEP)}]^2 \qquad \text{(A-2)}$$

where R_2, A_2, and *CEP* are the reliability, alert rate, and accuracy of the attacking warhead, and *LR*, the lethal radius, is maximum distance at which the warhead would destroy the silo. For hardened silos, *LR* is given approximately by

$$LR \approx 470 \cdot (Y / H)^{1/3}\, meters \qquad \text{(A-3)}$$

where Y is the yield of the attacking warhead in kilotons and H is the hardness of the silo in psi. Here we assume that the 500 Russian SS-25s are used to attack the 500 U.S. Minuteman-III silos; in this case, $Y \approx 750$ kilotons, $H \approx 2000$ psi, and $CEP \approx 200$ meters.[1] Assuming that $A \approx 0.95$ and $R \approx 0.9$ for both missiles gives $P_s = 0.22$; therefore, only 110 of the 500 Minuteman-III missiles would survive to participate in a retaliatory strike.

The above analysis assumed that the SS-25 force does not suffer attrition from a possible limited U.S. missile defense. If such a system exists, the SBI layer would be saturated with little attrition (about 50 missiles—see next paragraph), and the GBI layer could be exhausted by SLBM warheads arriving in the region earlier. Moreover, surplus SLBM warheads or late-arriving bombers also could be used to attack the silos. Thus, the existence of a limited defense would not guarantee the survival of a substantially greater number of silos.

The above analysis also assumes that the Minuteman missiles ride out the attack. If the missiles were launched at first warning of an attack (assuming that it is physically possible to launch the missiles in 15 or 20 minutes), virtually all of the alert and reliable missiles could

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[1] The International Institute for Strategic Studies, *The Military Balance 1991-1992* (London: IISS, 1991), p. 225.

“survive” to retaliate. Fortunately, numerous statements by government officials have made it clear that “launch on warning” is not the policy of the United States. Launch on warning is not considered to be an acceptable solution to the problem of ICBM vulnerability because of the possibility that an attack might be ordered in response to a false warning. Even if the warning is accurate, the preprogrammed targets might be inappropriate, and the more-or-less automatic use of ICBMs would make a war more difficult to terminate.

1.2. *Road-mobile ICBMs*. If we assume that alert road-mobile ICBMs dash from their shelters upon warning of an attack (rather than randomly roaming a large deployment area), the probability of kill is given by

$$P_k = n \cdot R_2 \cdot A_2 \cdot (LR / RU)^2 \quad \text{(A-4)}$$

where n is the number of attacking warheads per shelter and RU, the maximum distance traveled until detonation of the attacking warheads, is given by

$$RU = v \cdot (t - t_r) \quad \text{(A-5)}$$

where v is the average launcher speed, t is the missile flight time, and t_r is the reaction time (i.e., the time to detect the missile launches, notify the missile bases, man the launchers, and scatter from the base). A reasonable speed for the SS-25 launcher is 50 kilometers per hour; missile flight times from close-in SSBNs would be 15 to 18 minutes; reaction times might be about 5 to 8 minutes. Inserting these values into equation A-5 gives a mean value for RU of about 8 kilometers. Assuming a launcher hardness of 5 psi and 100-kiloton attacking SLBM warheads detonated at optimum height of burst, $LR \approx 3.2$ kilometers. Assuming two attacking warheads per shelter, missile reliabilities of 0.9, and a peacetime alert rate of 0.5 gives a mean P_s of about 0.28; a crisis alert rate of 0.8 gives a mean P_s of about 0.45. Therefore, the mean number of surviving missiles is about 140 and 220, respectively.

1.3. *SLBMs and Bombers*. We assume that all alert SLBMs and bombers would survive an attack, so the fraction available for retaliation is simply equal to $R \cdot A$. Seventy-five percent of surviving bombers are assumed to function properly, penetrate air defenses, and deliver their weapons. Bomber fly-out patterns could in principle be barraged with SLBM warheads from close-in SSBNs, but a significant percentage of the bombers could be destroyed only if the bombers were based on the coast and depressed-trajectory SLBM launches were used, both of which are highly unlikely. The existence of limited defenses would not improve the survivability of submarines and bombers, since the number of warheads available for a first strike is much larger than the number of submarine and bomber bases or defensive interceptors.

2. SBI Boost-Phase Defense

I focus on boost-phase defense for two reasons. First, it is analytically simple. Because missiles do not travel far in boost phase, simple analytical approximations can be used. Second, intercepting missiles in the boost phase is probably much easier than intercepting warheads in the midcourse phase. It is much easier to detect, track, and destroy a large, hot, fragile booster than a small, cold, and hard reentry vehicle. Moreover, SLBMs will continue to carry more than one reentry vehicle per missile, and penetration aids (chaff, flares, decoys, and antisimulation techniques) will make it difficult to achieve a high probability of kill in midcourse. Thus, we can get a good idea of the effectiveness of limited defenses against retaliatory strikes simply by using boost-phase scaling.[2]

2.1. *Simultaneous, Point Launch*. The number of SBI required for boost-phase intercept of N_m missiles launched simultaneously from a single point on the Earth is approximately equal to

$$N_i \approx AR \cdot N_m \cdot n \tag{A-6}$$

where n is the number of SBI used per missile and AR, the "absentee ratio," is the total number of SBI divided by the number that can participate in the defensive engagement. The probability P_k of destroying a missile with n SBI, each of which has an independent probability of destroying the missile of p_k, is given by

$$P_k = 1 - (1 - p_k)^n \tag{A-7}$$

Assuming that the goal of the SBI defense is to achieve an overall kill probability of $P_k = 0.9$, table A-1 gives the relationship between the p_k of individual SBI and the number of SBI required per missile. Note that if more than one SBI per missile is required to achieve $P_k = 0.9$, then the system would be capable of destroying considerably more missiles in one-on-one engagements compared to systems using one highly effective SBI per missile. The number of missiles that can be destroyed in one-on-one engagements, which is important in evaluating the effectiveness of a defense against a massive strike, is proportional to $n \cdot p_k$.

The fraction of SBI that can participate in the defense is a function of the maximum range of the SBI and the distribution of the attack in space and time. The maximum range of a SBI during the boost phase is given by[3]

$$D = v_i \cdot (t_b - t_i) \tag{A-8}$$

where v_i is the maximum SBI velocity, t_b is the missile burn time, and t_i is the time it takes to detect the launch and fire the SBI plus half the time it takes to accelerate to the maximum

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[2] Strategic Defense Initiative Organization plans to intercept a substantial fraction of reentry vehicles in midcourse. Unfortunately, estimating the effectiveness of midcourse defenses requires detailed and complicated orbital simulations that are beyond the scope of this paper. As noted above, I believe that it will not prove possible to achieve a high single-shot probability of kill during midcourse. The use of boost-phase scaling may overestimate the effectiveness against retaliatory strikes somewhat, but several other assumptions in this analysis work in the opposite direction: a very high single-shot SBI kill probability in boost phase (0.9); the precise matching of capabilities against ICBM and SLBM threats (i.e., a SBI constellation designed to intercept ten ICBMs would be able to intercept no more than 20 SLBMs, and vice versa); and that alert SSBNs are clustered in just two patrol zones.

[3] Corrections for the rotation of the Earth or limitations imposed by the Earth's atmosphere can be neglected for boost-phase intercept. See Christopher T. Cunningham, "The Space-Based Interceptor," in Dietrich Schroeer and David Hafemeister, eds., *Nuclear Arms Technologies in the 1990s* (New York: American Institute of Physics, 1988), p. 269.

velocity. Brilliant pebbles are reportedly designed for $v_i \approx 6$ km/s,[4] and $t_i \approx 60$ s represents a reasonable value for attack warning and acceleration.

Table A-1.

The number of interceptors required to give an overall kill probability of 0.9 as a function of the p_k of the interceptor, and the relative number of missiles that can be destroyed in one-on-one engagements

Interceptor Kill Probability p_k	**Number of Interceptors Required n**	$\frac{n \cdot p_k}{0.9}$
0.90	1	1.0
0.68	2	1.5
0.54	3	1.8
0.44	4	1.9
0.37	5	2.0

If the missile launches occur simultaneously at a point anywhere on the Earth's surface, the absentee ratio would be given by

$$AR = \frac{4 \cdot p \cdot (R_e + h_o) \cdot (R_e + h_b)}{FP} \qquad \text{(A-9)}$$

where h_o is the SBI orbital altitude (about 460 km for brilliant pebbles), h_b is the burnout altitude of the missile, and R_e is the radius of the Earth (about 6,370 km). Each SBI can intercept missiles launched within a certain area on the surface of the Earth; this area is called the "footprint" (FP) of the interceptor:

$$FP = p \cdot d^2 \qquad \text{(A-10)}$$

where the radius d is given by

$$d = [D^2 - (h_o - h_b)^2]^{1/2} \qquad \text{(A-11)}$$

Table A-2 give values for t_b and h_b for the Trident II and Minuteman III missiles, and the corresponding values of D and FP given by equations A-8 and A-10.[5]

[4] Dr. Lowell Wood of Lawrence Livermore National Laboratory has stated that a brilliant pebble would have enough fuel to leave Earth orbit and go into orbit around Mars, which would require a total delta-v of 6.0 km/s.

[5] Assuming a uniform acceleration of 30g, 20 s would be required to accelerate the SBI to 6 km/s, during which time the average velocity would be 3 km/s, so the time lost to acceleration is roughly 10 s. In addition, at least 30 to

Table A-2.

The burn-out time (t_b) and altitude (h_b) of the Minuteman-III/SS-25 ICBMs and the Trident-II/SS-N-20 SLBMs, the maximum range at which a 6-km/s SBI could engage these missiles in the boost phase, and the corresponding SBI footprint.

Missile	t_b (s)	h_b (km)	D (km)	FP (10^6 km^2)
Trident-II/SS-N-20	170	240	660	1.22
Minuteman-III/SS-25	190	190	780	1.68

2.2. *Simultaneous, Distributed Launch*. To estimate the effectiveness of the defense against a retaliatory ICBM strike, we must first estimate the number of SBI that would be within range d of the launch sites. The number of SBI that can participate in a defense, and therefore the number of missiles that can be destroyed in the boost phase, is determined by the ratio of this area to the footprint. In other words, the number of missiles that can be engaged in a retaliatory strike, N_r, is approximately equal to

$$N_r \approx N_m \cdot \frac{DA}{FP} \qquad \text{(A-12)}$$

where N_m is the number that can be engaged if launched from a single point on the Earth (in this case, ten), and DA is the area within range d of the retaliatory launch sites.

An area of about $7.5 \cdot 10^6$ km^2 lies within 730 km of the seven SS-25 bases in Russia; adding a few more bases to accommodate a total of 500 SS-25s might increase this to about $9 \cdot 10^6$ km^2. Thus, an SBI defense designed to engage ten ICBMs launched from a single point on the Earth's surface would be able to engage 10·(9/1.68) = 54 simultaneously launched SS-25s, destroying about 50 of them.

Similarly, an area of about $4.3 \cdot 10^6$ km^2 lies within 730 km of the four Minuteman-III bases. Thus, a limited SBI defense could engage 10·(4.3/1.68) = 27 Minuteman-III missiles launched simultaneously from current bases, destroying about 25 of them.

2.3. *Rapid, Point Launch*. An SSBN can launch missiles rapidly but not simultaneously, because the hot rocket exhaust would damage adjacent missiles, and because one must wait for the yaw and pitch of the submarine to stabilize. During the launch sequence, additional SBI will orbit within range of the launch point, increasing the fraction of SBI that can participate in the defense.

Estimating the fraction of SBI that can participate in a extended launch from a single point on the Earth is rather complicated, since it depends on the details of the SBI orbits. The easiest case

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40 s would be required for the target missile to rise above the highest clouds at altitudes of 10-15 km, where the hot booster plume could be detected, and tens of seconds would be required to activate and target the SBI. General Abrahamson, former head of SDIO, stated in testimony before the Senate Defense Appropriations Subcommittee on 19 March 1987 that the response time would be 70 s.

to evaluate is when all SBI orbits intersect at the same point (e.g., polar orbits). The minimum SBI density would then be 90 degrees from the points of intersection, where the orbits would be approximately parallel. In this case, the "footprint" or area within which SBI could participate in a boost-phase defense is approximately

$$FP \approx p \cdot d^2 + 2 \cdot d \cdot v_o \cdot t_m \qquad \text{(A-13)}$$

where v_o is the orbital velocity of the SBIs (7.6 km/s) and t_m is time required to launch all 20 or 24 SLBMs. The first term in equation A-13 presents the instantaneous footprint of equation A-10; the second represents the area swept out by the motion of SBIs toward the launch site during the launch sequence.

Note that the total number of SBIs required for a SLBM boost-phase defense depends on the launch time. Unfortunately, estimates of t_m are rare in the unclassified literature. It is reported that early U.S. Polaris missiles could be fired at the rate of about one per minute.[6] Later estimates of Soviet capabilities give a rate of one every 15 seconds,[7] and there are reports that the Soviet Union fired two SS-N-20 missiles 20 seconds apart in 1982.[8] One source states that the Trident submarine can launch all of its missiles in six minutes.[9] Thus, a reasonable range of values for t_m is 5 to 20 minutes.

2.4. *Rapid, Distributed Launch*. Unlike an accidental or unauthorized launch, which would come from a single submarine, a retaliatory SLBM strike would be launched by all SSBNs on patrol. It seems reasonable to assume that the SSBNs will be uniformly distributed over patrol areas of at least a million square kilometers.[10] In addition, it is reasonable to assume that it would take longer for a fleet of SSBNs to launch their missiles in retaliation than for a single SSBN to launch its missiles. Thus, the effective footprint for a retaliatory SLBM strike would be given by

$$FP' \approx p \cdot (d + r)^2 + 2 \cdot (d + r) \cdot v_o \cdot t_m \qquad \text{(A-14)}$$

where r is the effective radius of the patrol area and t_m is the time period over which the retaliatory launches occur. The ratio of the footprint for launches uniformly distributed over a patrol area of radius r to that for launches from a single SSBN is given approximately by

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[6] Herbert Scoville, Jr., "Missile Submarines and National Security," *Scientific American* (June 1972).
[7] James W. Winnefeld and Carl H. Builder, "ASW—Now or Never," *United States Naval Institute Proceedings*, Vol. 97 (September 1971), p. 21, quoted in Alton H. Quanbeck and Archie L. Wood, *Modernizing the Strategic Bomber Force: Why and How* (Washington, DC: Brookings, 1976), p. 45; and *The START Treaty and Beyond* (Washington, DC: U.S. Congressional Budget Office, October 1991), p. 157.
[8] *Aviation Week and Space Technology* (25 November 1982), p. 82; quoted in Thomas B. Cochran, William M. Arkin, Robert S. Norris, and Jeffrey I. Sands, *Nuclear Weapons Databook, vol. IV: Soviet Nuclear Weapons* (Cambridge, MA: Ballinger, 1989), p. 150.
[9] D. Douglass Dalgleish and Larry Schweikart, *Trident* (Carbondale, IL: Southern Illinois University Press, 1984), p. 29.
[10] For example, two of Russia's patrol areas, the Sea of Okhotsk and the Barents Sea, each have areas of 1.4 to 1.6 million square kilometers.

$$\frac{FP'}{FP} = \frac{p \cdot (d+r)^2 + 2 \cdot (d+r) \cdot v_o \cdot t_m}{p \cdot d^2 + 2 \cdot d \cdot v_o \cdot t_m} \qquad \text{(A-15)}$$

Table A-3 gives the ratio *(FP'/FP)* for several values of t_m and (t_m/t_m). Note that the footprint ratio depends mostly on (t_m/t_m), and that it is relatively insensitive to t_m.

Table A-3.

The ratio of the footprint for SLBMs launches distributed over an area of 10^6 km^2 and time t_m, to that for SLBM launches from a single submarine over time t_m, for t_m = 5, 10, and 20 minutes, and for t_m/t_m = 1, 2, and 3

t_m/τ_m	t_m/t_m		
	1	2	3
5	2.4	3.8	5.1
10	2.2	3.8	5.4
20	2.1	3.8	5.5

It seems reasonable to assume that a retaliatory strike would take at least twice as long as the launch of all the missiles from a single submarine (t_m/t_m = 2), so I will assume that *(FP'/FP)* ≈ 3.8. Thus, a SBI defense sized to engage 20 SLBMs launched rapidly from a single SSBN would be able to engage 20·3.8 = 76 SLBMs launched from each patrol area over a time period twice as long. Assuming that alert SSBNs are deployed in two patrol zones, a total of 136 missiles could be destroyed.

3. GBI Defense

I assume that the GBI defense consists of 500 interceptors deployed at five sites in the United States or Russia, with each interceptor having a probability of kill of 0.9. In estimating the number of warheads destroyed by the defense, we assume that the warheads are evenly divided among the five sites; thus, a maximum of 450 incoming warheads could be destroyed. The offense could, of course, choose to concentrate its attack on one or two regions, thereby saturating the defenses in these regions with more incoming warheads than available interceptors, but it is unlikely that military planners would be comfortable with basing deterrence on such a strategy. Currently, deterrence is based on being able to destroy a broad range of geographically distributed targets.