The Nukes We Need

Preserving the American Deterrent

Keir A. Lieber and Daryl G. Press

THE SUCCESS of nuclear deterrence may turn out to be its own undoing. Nuclear weapons helped keep the peace in Europe throughout the Cold War, preventing the bitter dispute from engulfing the continent in another catastrophic conflict. But after nearly 65 years without a major war or a nuclear attack, many prominent statesmen, scholars, and analysts have begun to take deterrence for granted. They are now calling for a major drawdown of the U.S. nuclear arsenal and a new commitment to pursue a world without these weapons.

Unfortunately, deterrence in the twenty-first century may be far more difficult for the United States than it was in the past, and having the right mix of nuclear capabilities to deal with the new challenges will be crucial. The United States leads a global network of alliances, a position that commits Washington to protecting countries all over the world. Many of its potential adversaries have acquired, or appear to be seeking, nuclear weapons. Unless the world's major disputes are resolved—for example, on the Korean Peninsula, across the Taiwan Strait, and around the Persian Gulf—or the U.S. military pulls back from these regions, the United States will sooner or later find itself embroiled in conventional wars with nuclear-armed adversaries.

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Preventing escalation in those circumstances will be far more difficult than peacetime deterrence during the Cold War. In a conventional war, U.S. adversaries would have powerful incentives to brandish or use nuclear weapons because their lives, their families, and the survival of their regimes would be at stake. Therefore, as the United States considers the future of its nuclear arsenal, it should judge its force not against the relatively easy mission of peacetime deterrence but against the demanding mission of deterring escalation during a conventional conflict, when U.S. enemies are fighting for their lives.

Debating the future of the U.S. nuclear arsenal is critical now because the Obama administration has pledged to pursue steep cuts in the force and has launched a major review of U.S. nuclear policy. (The results will be reported to Congress in February 2010.) The administration's desire to shrink the U.S. arsenal is understandable. Although the force is only one-fourth the size it was when the Cold War ended, it still includes roughly 2,200 operational strategic warheads—more than enough to retaliate against any conceivable nuclear attack. Furthermore, as we previously argued in these pages ("The Rise of U.S. Nuclear Primacy," March/April 2006), the current U.S. arsenal is vastly more capable than its Cold War predecessor, particularly in the area of "counterforce"—the ability to destroy an adversary's nuclear weapons before they can be used.

Simply counting U.S. warheads or measuring Washington's counterforce capabilities will not, however, reveal what type of arsenal is needed for deterrence in the twenty-first century. The only way to determine that is to work through the grim logic of deterrence: to consider what actions will need to be deterred, what threats will need to be issued, and what capabilities will be needed to back up those threats.

The Obama administration is right that the United States can safely cut its nuclear arsenal, but it must pay careful attention to the capabilities it retains. During a war, if a desperate adversary were to use its nuclear force to try to coerce the United States—for example, by threatening a U.S. ally or even by launching nuclear strikes against U.S. overseas bases—an arsenal comprised solely of high-yield weapons would leave U.S. leaders with terrible retaliatory options. Destroying Pyongyang or Tehran in response to a limited strike would be vastly

disproportionate, and doing so might trigger further nuclear attacks in return. A deterrent posture based on such a dubious threat would lack credibility.

Instead, a credible deterrent should give U.S. leaders a range of retaliatory options, including the ability to respond to nuclear attacks with either conventional or nuclear strikes, to retaliate with strikes against an enemy's nuclear forces rather than its cities, and to minimize casualties. The foundation for this flexible deterrent exists. The current U.S. arsenal includes a mix of accurate high- and low-yield warheads, offering a wide range of retaliatory options—including the ability to launch precise, very low-casualty nuclear counterforce strikes. The United States must preserve that mix of capabilities—especially the low-yield weapons—as it cuts the size of its nuclear force.

DETERRENCE IN DARK TIMES

THE PRIMARY purpose of U.S. nuclear forces is to deter nuclear attacks on the United States and its allies. During peacetime, this is not a demanding mission. The chance that leaders in Beijing, Moscow, or even Pyongyang will launch a surprise nuclear attack tomorrow is vanishingly small. But peacetime deterrence is not the proper yardstick for measuring the adequacy of U.S. nuclear forces. Rather, the United States' arsenal should be designed to provide robust deterrence in the most difficult of plausible circumstances: during a conventional war against a nuclear-armed adversary.

In the coming decades, the United States may find itself facing nuclear-armed states on the battlefield. U.S. alliances span the globe, and the United States is frequently drawn into regional conflicts. Washington has launched six major military operations since the fall of the Berlin Wall: in Panama, Somalia, Kosovo, Afghanistan, and twice in Iraq. Furthermore, most of the United States' potential adversaries have developed—or seem to be developing—nuclear weapons. Aside from terrorism, the threats that dominate U.S. military planning come from China, North Korea, and Iran: two members of the nuclear club, and one intent on joining it.

The central problem for U.S. deterrence in the future is that even rational adversaries will have powerful incentives to introduce nuclear

weapons—that is, threaten to use them, put them on alert, test them, or even use them—during a conventional war against the United States. If U.S. military forces begin to prevail on the battlefield, U.S. adversaries may use nuclear threats to compel a cease-fire or deny the United States access to allied military bases. Such threats might succeed in pressuring the United States to settle the conflict short of a decisive victory.

Such escalatory strategies are rational. Losing a conventional war to the United States would be a disastrous outcome for any leader, and it would be worth taking great risks to force a cease-fire and avert total defeat. The fate of recent U.S. adversaries is revealing. The ex-dictator of Panama, Manuel Noriega, remains in a Miami prison. The former Bosnian Serb leader, Radovan Karadzic, awaits trial in The Hague, where Yugoslav President Slobodan Milosevic died in detention three years ago. Saddam Hussein's punishment for losing the 2003 war was total: his government was toppled, his sons were killed, and he was hanged on a dimly lit gallows, surrounded by enemies. Even those leaders who have eluded the United States—such as the Somali warlord Muhammad Farah Aidid and Osama bin Laden—have done so despite intense U.S. efforts to capture or kill them. The United States' overseas conflicts are limited wars only from the U.S. perspective; to adversaries, they are existential. It should not be surprising if they use every weapon at their disposal to stave off total defeat.

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Coercive nuclear escalation may sound like a far-fetched strategy, but it was NATO's policy during much of the Cold War. The Western allies felt that they were hopelessly outgunned in Europe at the conventional level by the Warsaw Pact. Even though NATO harbored little hope of prevailing in a nuclear war, it planned to initiate a series of escalating nuclear operations at the outbreak of war—alerts, tactical nuclear strikes, and wider nuclear attacks—to force the Soviets to accept a cease-fire. The United States' future adversaries face the same basic problem today: vast conventional military inferiority. They may adopt the same solution. Leaders in Beijing may choose gradual,

coercive escalation if they face imminent military defeat in the Taiwan Strait—a loss that could weaken the Chinese Communist Party's grip on power. And if U.S. military forces were advancing toward Pyongyang, there is no reason to expect that North Korean leaders would keep their nuclear weapons on the sidelines.

Layered on top of these challenges are two additional ones. First, U.S. conventional military doctrine is inherently escalatory. The new American way of war involves launching simultaneous air and ground attacks throughout the theater to blind, confuse, and overwhelm the enemy. Even if the United States decided to leave the adversary's leaders in power (stopping short of regime change so as to prevent the confrontation from escalating), how would Washington credibly convey the assurance that it was not seeking regime change once its adversary was blinded by attacks on its radar and communication systems and command bunkers? A central strategic puzzle of modern war is that the tactics best suited to dominating the conventional battlefield are the same ones most likely to trigger nuclear escalation.

Furthermore, managing complex military operations to prevent escalation is always difficult. In 1991, in the lead-up to the Persian Gulf War, U.S. Secretary of State James Baker assured Iraq's foreign minister, Tariq Aziz, that the United States would leave Saddam's regime in power as long as Iraq did not use its chemical or biological weapons. But despite Baker's assurance, the U.S. military unleashed a major bombing campaign targeting Iraq's leaders, which on at least one occasion nearly killed Saddam. The political intent to control escalation was not reflected in the military operations, which nearly achieved a regime change.

In future confrontations with nuclear-armed adversaries, the United States will undoubtedly want to prevent nuclear escalation. But the leaders of U.S. adversaries will face life-and-death incentives to use their nuclear arsenals to force a cease-fire and remain in power.

THE CASE FOR COUNTERFORCE

IF THE United States hopes to deter nuclear attacks during conventional wars, it must figure out how it might respond to such attacks, and it must retain the nuclear forces to do so. The most horrific

retaliatory threat that the United States might issue—to destroy cities if enemy leaders brandish or use nuclear weapons—is a poor foundation for deterrence. First, this threat lacks credibility. Destroying cities would be a vastly disproportionate response if an enemy used nuclear weapons against a purely military target, such as a U.S. carrier group at sea or even a U.S. base located away from a major city (such as the U.S. airfields on Guam or Okinawa). During recent wars, the United States has labored to minimize enemy civilian casualties. It is hard to believe that Washington would reverse course and intentionally slaughter hundreds of thousands of civilians, especially if no U.S. or allied city has been destroyed.

Moreover, a retaliatory strike on an enemy city would not even achieve critical military objectives, so the horrendous consequences would be inflicted for little purpose. If an enemy used nuclear weapons, the most pressing U.S. objective would be to prevent further nuclear attacks. Destroying one of the enemy's cities—even its capital—would neither eliminate its nuclear forces nor even necessarily kill its leaders. Nor could the United States respond to an enemy's limited nuclear strike simply by marching to its capital city to capture and hang its leaders; that would leave time for more strikes on allies' cities. In such a crisis, the United States would need to stop the enemy's nuclear attacks immediately.

> If not backed by the capability and the credibility to execute threats, deterrence is a dangerous bluff.

Of course, no one knows how a U.S. president would respond in such dark circumstances. It is possible that the United States would retaliate by attacking enemy cities—fear or anger might prevail over reason. But that mere possibility is a perilous foundation for deterrence. A credible deterrent must give U.S. leaders acceptable options in the event an enemy were to use nuclear weapons. An arsenal that can only destroy cities fails that test.

The least bad option in the face of explicit nuclear threats or after a limited nuclear strike may be a counterforce attack to prevent further nuclear use. A counterforce strike could be conducted with either conventional or nuclear weapons, or a mix of the two. The

attack could be limited to the enemy's nuclear delivery systems—for example, its bombers and missile silos—or a wider range of sites related to its nuclear program. Ideally, a U.S. counterforce strike would completely destroy the enemy's nuclear forces. But if an adversary had already launched a nuclear attack against the United States or its allies, a response that greatly reduced the adversary's nuclear force could save countless lives, and it could open the door to decisive military actions (such as conquest and regime change) to punish the enemy's leadership for using nuclear weapons.

During the last decades of the Cold War, the nuclear arsenals of the United States and the Soviet Union were too big to be completely destroyed in a disarming strike, and, in any case, their nuclear delivery systems were not accurate enough to destroy large numbers of hardened targets. But the world has changed. Washington's potential adversaries field much smaller arsenals. Meanwhile, U.S. delivery systems have grown vastly more accurate.

MODELING THE UNTHINKABLE

To ILLUSTRATE the growth in U.S. counterforce capabilities, we applied a set of simple formulas that analysts have used for decades to estimate the effectiveness of counterforce attacks. We modeled a U.S. strike on a small target set: 20 intercontinental ballistic missiles (ICBMs) in hardened silos, the approximate size of China's current long-range, silo-based missile force. The analysis compared the capabilities of a 1985 Minuteman ICBM to those of a modern Trident II submarine-launched ballistic missile.[1]

In 1985, a single U.S. ICBM warhead had less than a 60 percent chance of destroying a typical silo. Even if four or five additional warheads were used, the cumulative odds of destroying the silo would never exceed 90 percent because of the problem of "fratricide," whereby incoming warheads destroy each other. Beyond five warheads, adding more does no good. A probability of 90 percent might sound high, but it falls far short if the goal is to completely disarm an enemy: with

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[1]The technical details of the analysis presented in this essay are available online at www.dartmouth.edu/~dpress.

a 90 percent chance of destroying each target, the odds of destroying all 20 are roughly 12 percent. In 1985, then, a U.S. ICBM attack had little chance of destroying even a small enemy nuclear arsenal.

Today, a multiple-warhead attack on a single silo using a Trident II missile would have a roughly 99 percent chance of destroying it, and the probability that a barrage would destroy all 20 targets is well above 95 percent. Given the accuracy of the U.S. military's current delivery systems, the only question is target identification: silos that can be found can be destroyed. During the Cold War, the United States worked hard to pinpoint Soviet nuclear forces, with great success. Locating potential adversaries' small nuclear arsenals is undoubtedly a top priority for U.S. intelligence today.

The revolution in accuracy is producing an even more momentous change: it is becoming possible for the United States to conduct low-yield nuclear counterforce strikes that inflict relatively few casualties. A U.S. Department of Defense computer model, called the Hazard Prediction and Assessment Capability (HPAC), estimates the dispersion of deadly radioactive fallout in a given region after a nuclear detonation. The software uses the warhead's explosive power, the height of the burst, and data about local weather and demographics to estimate how much fallout would be generated, where it would blow, and how many people it would injure or kill.

> It is becoming possible for the United States to conduct nuclear strikes that inflict relatively few casualties.

HPAC results can be chilling. In 2006, a team of nuclear weapons analysts from the Federation of American Scientists (FAS) and the Natural Resources Defense Council (NRDC) used HPAC to estimate the consequences of a U.S. nuclear attack using high-yield warheads against China's ICBM field. Even though China's silos are located in the countryside, the model predicted that the fallout would blow over a large area, killing 3–4 million people. U.S. counterforce capabilities were useless, the study implied, because even a limited strike would kill an unconscionable number of civilians.

But the United States can already conduct nuclear counterforce strikes at a tiny fraction of the human devastation that the FAS/NRDC study predicted, and small additional improvements to the U.S. force

could dramatically reduce the potential collateral damage even further. The United States' nuclear weapons are now so accurate that it can conduct successful counterforce attacks using the smallest-yield warheads in the arsenal, rather than the huge warheads that the FAS/NRDC simulation modeled. And to further reduce the fallout, the weapons can be set to detonate as airbursts, which would allow most of the radiation to dissipate in the upper atmosphere. We ran multiple HPAC scenarios against the identical target set used in the FAS/NRDC study but modeled low-yield airbursts rather than high-yield groundbursts. The fatality estimates plunged from 3–4 million to less than 700—a figure comparable to the number of civilians reportedly killed since 2006 in Pakistan by U.S. drone strikes.

One should be skeptical about the results of any model that depends on unpredictable factors, such as wind speed and direction. But in the scenarios we modeled, the area of lethal fallout was so small that very few civilians would have become ill or died, regardless of which way the wind blew.

Critics may cringe at this analysis. Many of them, understandably, say that nuclear weapons are—and should remain—unusable. But if the United States is to retain these weapons for the purpose of deterring nuclear attacks, it needs a force that gives U.S. leaders retaliatory options they might actually employ. If the only retaliatory option entails killing millions of civilians, then the U.S. deterrent will lack credibility. Giving U.S. leaders alternatives that do not target civilians is both wise and just.

A counterforce attack—whether using conventional munitions or low- or high-yield nuclear weapons—would be fraught with peril. Even a small possibility of a single enemy warhead's surviving such a strike would undoubtedly give any U.S. leader great pause. But in the midst of a conventional war, if an enemy were using nuclear threats or limited nuclear attacks to try to coerce the United States or its allies, these would be the capabilities that would give a U.S. president real options.

GOOD THINGS IN SMALL PACKAGES

As THE United States restructures its nuclear arsenal and overall strategic posture, it should ensure that it has three distinct capabilities. First, it still needs some high-yield nuclear weapons (such as those

deployed on land-based missiles and in submarines), although fewer than it currently possesses. If the U.S. military had to destroy an enemy's nuclear force in circumstances so dire that collateral damage was not a major concern, these weapons would provide the best odds of success. They maximize the odds of getting the target, albeit at the cost of enormous collateral damage.

The United States also needs conventional counterforce weapons. The U.S. military already fields precision nonnuclear weapons that can destroy nuclear targets, and the Pentagon has wisely made conventional capabilities a key element of its "global strike" mission, which seeks the capacity to hit any target anywhere in the world in less than an hour. Conventional weapons permit the United States to conduct a counterforce strike without crossing the nuclear threshold, and without killing millions.

> Without working through the macabre realities of deterrence, the United States risks creating a nuclear force that gives a president no acceptable choices.

To illustrate the promise of conventional counterforce, we modeled an attack on 20 land-based silos using B-2 bombers and bombs guided by GPS. If GPS signals were not jammed, an attack would destroy most of the silos and have about a 50–50 chance of destroying them all. The problem with conventional counterforce weapons is that, lacking the destructive power of nuclear weapons, they depend on pinpoint accuracy. If an enemy can jam GPS signals near the target, the odds of destroying all 20 silos with current bombs are essentially nil. In short, conventional weapons offer the ability to destroy an enemy's nuclear forces with minimal collateral damage, although with only a fair chance of success.

For the third leg of the U.S. strategic force, the United States should retain the lowest-yield warheads in its nuclear arsenal and (if it has not already done so) enhance their accuracy. If the low-yield nuclear bombs and cruise missiles, which reportedly use inertial guidance systems, were even half as accurate as their conventional, GPS-guided cousins, they could match the effectiveness of high-yield nuclear weapons while inflicting casualties more akin to those caused by conventional bombs.

Improving the accuracy of the United States' low-yield nuclear bombs and cruise missiles may not be as simple as attaching GPS

guidance systems. The Pentagon has been reluctant to use GPS on nuclear weapons because adversaries might conduct intense GPS jamming near their high-value targets or disrupt GPS transmissions with high-altitude nuclear detonations. But GPS may still have a role. The United States has overcome local GPS jamming in the past. More important, the enhanced accuracy gained by having GPS guidance during even half of a weapon's flight time—before the signal is lost— would be enough in many circumstances to permit a highly effective, low-casualty counterforce strike. Whether the slight accuracy improvements come from GPS, next-generation inertial guidance, or other technologies, high-accuracy delivery systems with low-yield weapons should form the backbone of the U.S. nuclear deterrent.

CONFRONTING NUCLEAR REALITIES

CRITICS MAY object to such calculations on the grounds that this approach evaluates the U.S. nuclear arsenal by measuring its capability to carry out nuclear strikes when the real purpose of the arsenal should be to deter wars, not fight them. According to this criticism, whether U.S. nuclear forces can destroy Chinese, North Korean, or (in the future) Iranian nuclear targets during a war is irrelevant, and planning for such contingencies is macabre.

But this criticism is incoherent. Deterrence depends on the capacity to carry out threats. Retaining that capacity is not a sign that the United States has moved beyond deterrence to a war-fighting posture for its nuclear arsenal; rather, the capacity to execute threats is the very foundation of deterrence.

Of course, a deterrent threat also needs to be credible—that is, an adversary needs to be convinced that a retaliatory threat will actually be executed. If not backed by the capability and the credibility to execute threats, deterrence is merely a dangerous bluff. A deterrent force should therefore provide decision-makers with options they would conceivably execute if their redlines were crossed. Otherwise, allies will question U.S. assurances, adversaries will doubt U.S. threats, and a U.S. president may confront an escalating crisis without any acceptable options.

More broadly, any analyst or policymaker who proposes a nuclear posture for the United States must answer four fundamental questions:

What enemy actions are to be deterred? Under what circumstances might those actions be taken? What threats would a U.S. president wish to issue? And does the proposed arsenal give the president the ability to carry out those threats? Without working through the grim realities of deterrence, the United States risks creating a force that gives the president no acceptable choices and therefore will not reliably deter U.S. enemies.

A second criticism of the argument for retaining and improving certain counterforce capabilities is that the cure could be worse than the disease. Counterforce capabilities may mitigate escalation during a conflict—for example, by dissuading adversaries from nuclear saber rattling, by reassuring allies that the United States can defend them, and, if necessary, by giving the United States the ability to pursue regime change if adversaries brandish or use nuclear weapons. But they may also exacerbate the problem of controlling escalation if an adversary feels so threatened that it adopts a hair-trigger nuclear doctrine. Specifically, the United States' ability to launch a disarming strike without killing millions of civilians might increase the escalatory pressures that already exist because of the nature of the U.S. military's standard wartime strategy. Conventional air strikes on radar systems, communication links, and leadership bunkers may look even more like the precursors of a preemptive disarming strike if adversaries know that the United States possesses a well-honed nuclear counterforce capability.

This second criticism has merit. Nevertheless, the benefits of maintaining effective counterforce capabilities trump the costs. Strong counterforce capabilities should make adversaries expect that escalating a conventional war will lead to a disarming attack, not a cease-fire. Beyond deterrence, these capabilities will provide a more humane means of protecting allies who are threatened by nuclear attack and give U.S. leaders the ability to pursue regime change if an adversary acts in a truly egregious fashion. Moreover, some danger of escalation is unavoidable because the style of U.S. conventional operations will inevitably blind, rattle, and confuse U.S. adversaries. If the United States has powerful counterforce tools, these may dissuade its enemies from escalating in desperate times, and U.S. leaders would have a much more acceptable option if deterrence fails.

The nuclear forces the United States builds today must be able to act as a reliable deterrent, even in much darker times. Many of those who recommend a much smaller U.S. nuclear arsenal—and assign little importance to a nuclear counterforce option—fail to consider the great difficulties of maintaining deterrence during conventional wars. The U.S. nuclear arsenal should retain sufficient counterforce capabilities to make adversaries think very carefully before threatening to use, putting on alert, or actually using a nuclear weapon. Any nuclear arsenal should also give U.S. leaders options they can stomach employing in these high-risk crises. Without credible and effective options for responding to attacks on allies or U.S. forces, the United States will have difficulty deterring such attacks. Unless the United States maintains potent counterforce capabilities, U.S. adversaries may conclude—perhaps correctly—that the United States' strategic position abroad rests largely on a bluff.☯

The Nukes We Need:
Preserving the American Deterrent
Technical Appendix[1]

This appendix explains the analysis that underpins arguments in "The Nukes We Need:
Preserving the American Deterrent," *Foreign Affairs* (November/December 2009), pp.
39-51.

Questions and comments are welcome. Please direct them to Daryl Press
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The Leap in U.S. Nuclear Counterforce: 1985 to the Present.[2]
The leap in U.S. counterforce capabilities over the past twenty-five years can be
illustrated by comparing the effectiveness of the most potent counterforce weapon in the
U.S. arsenal in 1985 (the Minuteman III ICBM, armed with a W78 warhead) to that in
the current force (the Trident II SLBM, armed with a W88 warhead).[3] We model a U.S.
strike on an arsenal of twenty missiles deployed in silos hardened to withstand up to
3,000 psi of overpressure. This target set is similar to China's current silo-based ICBM
force.

Analysts typically assume that an attack on hardened silos would utilize ground bursts –
meaning detonations at or near ground level – because ground bursts maximize the area
that is subjected to extremely high levels of overpressure. For ground bursts, the lethal
radius (LR) of a given warhead against a given target can be estimated by:

(1) $LR = 2.62 * Y^{(1/3)} / H^{(1/3)}$

where Y is the warhead's yield in megatons, H is the silo's hardness in psi, and LR is
expressed in nautical miles (nm). The odds that a given delivery system (e.g., a missile)
will deliver the warhead within the LR, the so-called "single shot probability of kill" or
SSPK, is:

(2) $SSPK = 1 - 0.5^{(LR/CEP)^2}$

where CEP is the delivery system's accuracy.[4]

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[1] We thank Eric Hundman and Austin Grant Long for helpful discussions about conventional counterforce,
and Jonathan Chipman for assistance with LandScan.
[2] This section describes the analysis that underpins the arguments on pp. 45-46 about the leap in U.S.
counterforce capabilities.
[3] We selected 1985 as the comparison year because Peacekeeper missiles – the first of the current
generation of highly-accurate ICBMs – were initially deployed in 1986.
[4] CEP stands for "circular error probable" and is the median miss-distance. In other words, half the
warheads land closer to the target than the CEP and half land further away.

The odds of destroying the target must also take into account the reliability (R) of the weapon system. The variable R is a crude estimation of the probability that the delivery system and warhead function correctly. The variable "terminal kill probability" (TKP) incorporates SSPK and R, where:

(3) $TKP = R * SSPK$.

If multiple warheads are sent to destroy a single target, then the target only survives if all the warheads fail. Therefore the odds of destroying the target with n-shots, $p(kill)_n$, is 1 minus the likelihood that every warhead misses, or

(4) $p(kill)_n = 1 - (1 - TKP)^n$

When multiple warheads are assigned to destroy a single target, if they are timed to arrive within a short period of time (e.g., to destroy a silo before its missile can be fired), there is a significant danger of fratricide: the possibility that one incoming warhead will interfere with the others. The biggest fratricide risk stems from the problem of the near miss: that a warhead might detonate near the intended target but just outside the LR, creating a dust cloud that shields the target from other incoming warheads. Because reentry vehicles are travelling at great speeds (in excess of Mach 10), even small dust particles might destroy or deflect an incoming reentry vehicle.

It is important to note that when nuclear delivery systems suffer a system failure (e.g., a booster doesn't fire, or a missile's guidance system malfunctions), it does not generally create fratricide risks, because the warheads on the malfunctioning delivery vehicle will not detonate near their targets – if they detonate at all. Therefore, fratricide is only a problem when three conditions are met: (1) the first-arriving warhead and the delivery system carrying it function correctly (i.e., there is no "reliability" failure); (2) the first warhead nevertheless misses the target; *and* (3) the first warhead detonates along the flight path of the other incoming systems. To make a rough estimate of the likelihood of the third condition, we assume that a target is shielded if the first warhead detonates short of the target[5] and without substantial lateral inaccuracy.[6]

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[5] Misses that hit "long" of the target do not generally create fratricide risks for warheads approaching nearby silos because planners are assumed to strike target sets in a back-to-front pattern. It is also worth noting that planners can strike a target with ballistic missiles approaching from multiple trajectories – e.g., with a warhead from an ICBM launched from the continental United States and warheads fired by submarines at different locations. This would further reduce the fratricide problem.

[6] Unless there is bias in the distribution of "near misses," half of the misses will fall short of the target (the other half falling long). We assume that half of those short misses will land close enough to the desired impact point in a lateral direction to put a dust cloud in line with other incoming warheads. We also conducted sensitivity analysis to establish the upper bound for the fratricide problem by assuming that all misses that fall short of the target create a shielding dust cloud. That change increases the fratricide problem, and therefore *increases* the relative advantage of the modern Trident II over the 1985 Minuteman III, because a higher fraction of the Minuteman misses are "near misses," whereas virtually all of the Trident misses are system reliability failures. (Trident II is so accurate that if the weapon system functions, the target is destroyed.)

Unclassified sources suggest that a W78 warhead has a 335-kiloton yield, and a 1985 vintage Minuteman III missile with a Mk-12a reentry vehicle had an accuracy of approximately 180 meters CEP. We assume reliability (R) of 85%. Against a 3,000 psi silo, a single W78 has an SSPK of 69%, and a TKP of 59%. A 4-on-1 attack on a single silo would have roughly a 89% of destroying it; adding two more warheads would only increase the odds slightly, to 90%. Even at 90%, the odds of destroying 20 out of 20 silos are less than 12%.

By contrast, a W88 with a 455-kiloton yield on a 90 meter CEP Trident II missile (R=85%) would have an SSPK of essentially 1.0, and a TKP of 85%. A 4-on-1 attack on a single silo would have in excess of 99% probability of destroying it, and the odds of a 4-on-1 attack destroying all 20 targets would be 97%.

Figure 1 illustrates the probability of destroying a single 3,000 psi silo using various numbers of W78 and W88 warheads (launched by the Minuteman III and Trident II missiles, respectively). **Figure 2** reveals the strategic implications of this leap in counterforce capability by showing the probability of destroying a 20-silo target set. Today, the odds of a disarming strike on a small target set with a multi-warhead attack would depend almost exclusively on target intelligence. If the targets can be found, they can be destroyed.[7]

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[7] Several sources claim that China has deployed decoy silos to complicate an attack on its missile force. There is no evidence at the unclassified level that would allow these claims to be confirmed; nor is there a way to estimate the number of decoys China may have built. However, if these reports are correct, and even if the United States has had no success differentiating decoys from actual silos, the existence of decoy silos would increase the number of warheads required for an attack, but not the likelihood of the attack succeeding – assuming the United States has enough warheads to allocate to real and decoy targets. Attacking large numbers of decoys would, however, increase fatalities in China from an attack. Differentiating real and decoy silos is undoubtedly a high priority for U.S. technical- and human-intelligence.

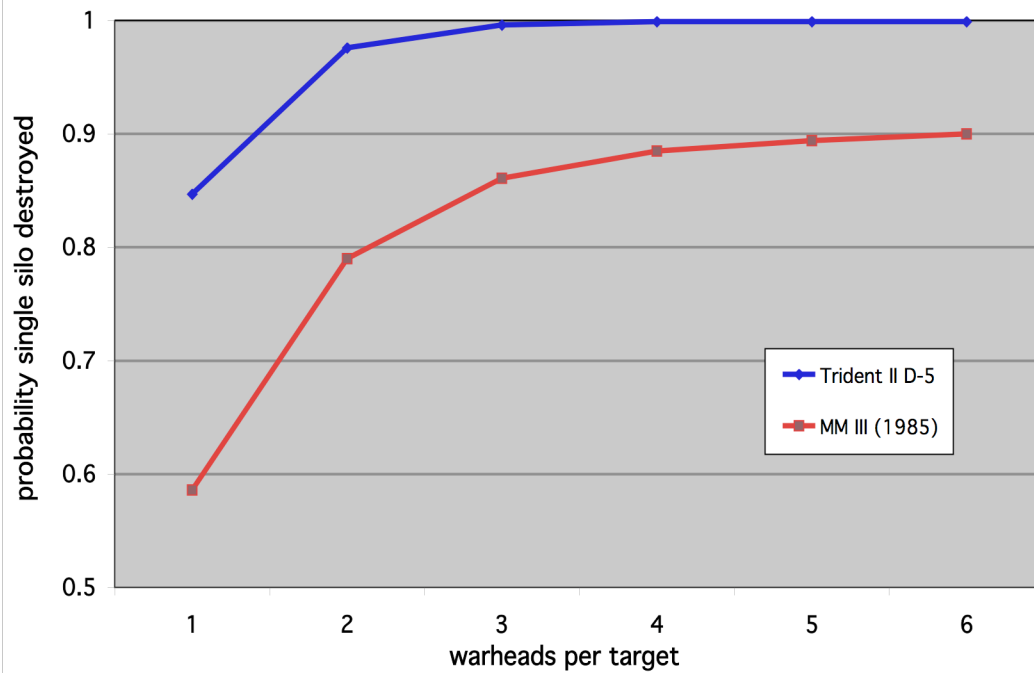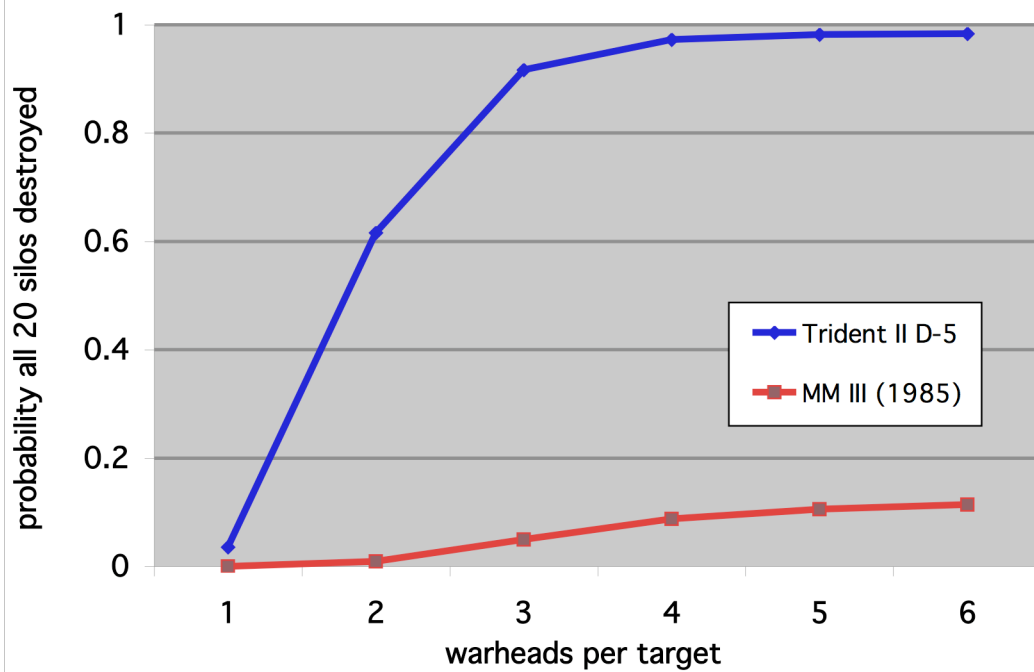Figure 1: Counterforce capabilities vs. single silo

Trident II D-5
MM III (1985)

probability single silo destroyed

warheads per target

Figure 2: Counterforce capabilities vs. twenty silos

Trident II D-5
MM III (1985)

probability all 20 silos destroyed

warheads per target

Modeling Fatalities from Nuclear Strikes on 20 ICBMs[8]

We illustrate the potential for low-casualty nuclear counterforce strikes by comparing the expected fatalities from a nuclear strike with high-yield weapons on a small target set to those of a low-yield attack on the same targets. As an example, we target 20 Chinese ICBMs.[9] The precise location of China's silo-based ICBM force is not available at the unclassified level; in fact, whether or not the United States has identified each of China's silos is a very closely guarded secret. A previous study by the Federation of American Scientists and the Natural Resources Defense Council, which modeled a high-yield counterforce strike on China's ICBM silos, hypothetically placed the silo targets in a mountainous region east of Xian, near the city of Luoning, in Henan Province.[10] This is a plausible assumption given the reported basing location of the Second Artillery Corps brigade responsible for the long-range missiles, as well as the strategic value of placing silos in mountainous regions to shield them from some incoming missile trajectories.

In short, we use the same assumed target location as the FAS/NRDC study in order to permit a direct comparison of results: Whereas that study modeled the effect of using high-yield warheads set for ground bursts; we modeled a counterforce strike using low-yield warheads set for airbursts (details below).

Nuclear Effects and Air Bursts

Nuclear detonations cause a series of "prompt" lethal effects (principally from blast and fire) as well as radioactive fallout. Fallout is created after a nuclear detonation occurs near the ground, when debris from the ground is sucked into the hot, ascending air, and mixes with the residual radioactive material from the warhead. As the debris falls back to earth, it spreads lethal radiation.

Targeters have long sought ways to use nuclear weapons to destroy hardened military targets, such as missile silos, without causing massive civilian casualties – for example by detonating the weapons at sufficiently high altitude to prevent fallout – but their efforts have been largely futile. **Figure 3** illustrates the problem. The green line (on the top) indicates the minimum altitude of a detonation to prevent fallout – that is, to prevent ground material from being sucked up into the fireball. The red line (on the bottom) is the maximum altitude of a detonation that can still create 3,000 psi on the ground. The

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[8] This section explains the analysis on pp. 46-47, particularly the casualty estimates.

[9] According to unclassified sources, China has approximately 20 silo-based long-range missiles, plus roughly a dozen mobile ICBMs. Beijing is also working on a submarine-based ballistic missile force, but none of the submarine-based weapons have been deployed. Attacking a small, deployed force of mobile missiles is also possible, but the key factors that would determine success and failure are the quality of real-time intelligence on missile launcher locations, and the time delay between target identification and warhead arrival. Therefore, formulas 1-3 from the previous section are useful for estimating effectiveness against fixed ICBMs, but are not useful for estimating effectiveness against attacks on mobile targets. Estimating the effectiveness of those attacks would require a different conceptual model. If located, mobile missile launchers are far easier to destroy than hardened silos. The analysis later in this appendix that suggests that hardened targets can be destroyed with minimal collateral damage is likely even more true for mobile launchers.

[10] Hans M. Kristensen, Robert S. Norris, and Matthew G. McKinzie, Chinese Nuclear Forces and U.S. Nuclear War Planning (Washington, DC: Federation of American Scientists and Natural Resources Defense Council, November 2006).

problem is clear: for the warhead yields displayed in the figure, there are *no altitudes* that create sufficient destructive effect on the ground without causing fallout – one cannot choose a height of burst that is simultaneously above the green line and below the red one.

But **Figure 4** offers a solution: for very small-yield warheads, there are altitudes that achieve the desired destructive effect on the ground, yet which create virtually no fallout.[11] The problem with using such low-yield warheads, however, is that they require high levels of accuracy.

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[11] The fallout threshold does not create a binary outcome. Above the threshold virtually no fallout occurs, but slightly below the threshold there is little fallout. Figures 3 and 4 are derived from equations in Glasstone and Dolan, The Effects of Nuclear Weapons, U.S. Department of Defense, (Washington, DC: Government Printing Office, 1977).

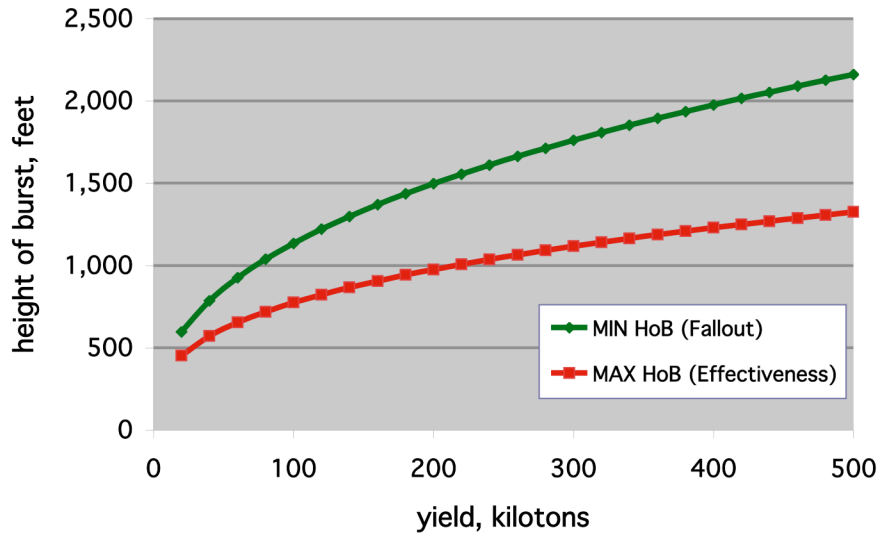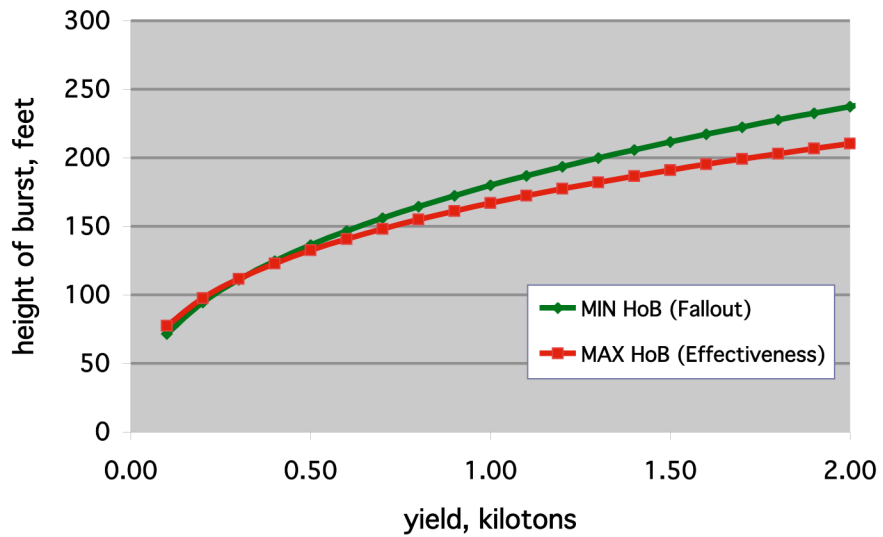Fig 3: The Impossibility of High-yield Low-casualty Counterforce

MIN HoB (Fallout)
MAX HoB (Effectiveness)

Fig 4: The Low-yield Window for Low Casualty Strikes

MIN HoB (Fallout)
MAX HoB (Effectiveness)

Accuracy and Height of Burst

To estimate fatalities resulting from a set of low-yield nuclear strikes we need to specify warhead yields and choose heights of burst (HoBs) for the detonations. For yields, we use 0.3 kilotons, 1.5 kilotons, and 5.0 kilotons, which correspond to open-source descriptions of the lowest yield options on the B61 bomb and the W80 warhead for cruise missiles.

If the goal were to reduce fatalities on the ground, targeters would wish to maximize height of burst.[12] There is a limit to how high they can go: above the red line on **Figures 3 and 4**, the warheads will not produce 3,000 psi on the ground. In fact, as the HoB increases toward the line, the LR on the ground shrinks. How high HoB can be raised, therefore, depends on how accurate the delivery system is (more accurate permits smaller LR), and how many warheads will be assigned to each target (more warheads permits smaller LR, because each warhead can produce a lower TKP and still achieve the desired likelihood of mission success).

We examine the tradeoffs that targeters would face between (a) warhead yield, (b) accuracy, (c) number of warheads per target, and (d) height of burst as the first step to estimate the fatalities on the ground from *operationally realistic* nuclear counterforce strikes. This requires a five-step process.

First, we define the mission goal as: achieve 95% probability of destroying all 20 targets. Second, for each targeting strategy (i.e., 4-on-1, 5-on-1, etc.), we calculate what TKP is required per warhead to achieve a 95% probability of destroying all 20 silos.[13] Third, we calculate what LR is required, as a function of CEP, to achieve the required level of TKP (for a 4-on-1, 5-on-1, or 6-on-1 attack).[14] Fourth, for each warhead yield and targeting strategy, we calculate how high the HoB can be and still produce the required LR.[15] Finally, for those HoBs, we calculate the prompt fatalities as well as the fallout fatalities (calculations described below).

What this method produces is a set of targeting options using different combinations of warhead yields, heights of burst, and warhead numbers. For any level of CEP, this method indicates the number of fatalities that would be produced using any combination of warheads, numbers, and HoBs – holding constant the 95% requirement of destroying all 20 targets. In other words, this method illustrates the range of options available for achieving a 95% "pk-all" against the target set, and the fatalities on the ground associated with each option.

Modeling Prompt Effects of Nuclear Detonations

During the Cold War, analysts used two principal models to estimate the prompt effects of nuclear detonations on nearby civilians: a blast overpressure model and a conflagration

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[12] Increasing HoB reduces fallout. It also slightly increases fatalities from prompt effects. But for these yields and range of HoB, the net effect of increasing HoB generally saves lives.

[13] These calculations can be done by manipulating Formula (4).

[14] This can be done by manipulating Formulas (2) and (3).

[15] We base our estimates on Figures 3.73 in Glasstone and Dolan, Effects of Nuclear Weapons.

model.[16] The overpressure model – which is the standard model – assumes that the percentage of people killed in an area depends primarily on the amount of overpressure to which they're exposed. Intense overpressure crushes structures and turns loose objects into lethal projectiles.   Conflagration models are designed to capture the potential consequences of mass fires. For large yield weapons, the thermal effects of nuclear detonations may extend far beyond the range of significant overpressure.[17] Because our analysis focuses on very small yield warheads, the overpressure model is more appropriate for this analysis.

Overpressure models often estimate the relationship between overpressure and fatality rates by extrapolating from the casualty data from Hiroshima. They estimate how much peak overpressure various parts of the city received from the detonation, and compare those "overpressure zones" to the fatality rates on the ground. By doing so, analysts generate a relationship between the overpressure the people in a zone were exposed to and the fatality rate in that zone.[18]

Estimating fatalities using the overpressure model, therefore, only requires four simple steps: (1) estimating the size of each "overpressure zone"; (2) estimating the number of people located in each zone; (3) multiplying the fatality rate by the number of people; and (4) accounting for the cumulative effects of multiple warhead detonations. The size of each overpressure zone can be estimated using Figure 3.73 from the seminal book by Samuel Glasstone and Philip Dolan, The Effects of Nuclear Weapons.[19] Population densities for the mountainous parts around Luoning are available, in 1-km "cells," from LandScan. Approximately 54 people live in every square kilometer in the region in question.[20]

To estimate the consequences of multiple warheads detonating at a single target, we treat each arriving warhead as an independent event. For example, we estimate that a four warhead strike on a given target would kill roughly 95% of the people located in the 5-10

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[16] William Daugherty, Barbara Levi, and Frank von Hippel, "Consequences of 'Limited' Nuclear Attacks on the United States," International Security, Vol. 10, No. 4 (Spring 1986), pp. 3-45.

[17] Theodore Postol, "Possible Fatalities from Superfires following Nuclear Attacks in or Near Urban Areas," Frederic Solomon and Robert Q. Marston, eds., The Medical Implications of Nuclear War (Washington, D.C.: National Academy Press, 1986; see also, Lynn Eden, Whole World on Fire: Organizations, Knowledge, and Nuclear Weapons Devastation (Ithaca, NY: Cornell University Press, 2003).

[18] Daugherty, Levi, and von Hippel, "Consequences," p. 11. In Hiroshima, roughly 95% of the people exposed to 20 psi or more of overpressure were killed. 75% of those exposed to between 10 and 20 psi died. Those exposed to 5-10 psi had a 53% mortality rate, and 12% of those exposed to 2-5 psi died.

[19] Samuel Glasstone and Philip J. Dolan, The Effects of Nuclear Weapons, 3rd edition, U.S. Department of Defense and Energy Research and Development Administration (Washington, D.C.: U.S. Government Printing Office, 1977), pp. 110-15. The figure shows the relationship between height-of-burst and overpressure for 1-kiloton bombs. The range for any given overpressure can then be scaled for the desired warhead yield; the scaling rules are in Glasstone and Dolan on the same pages indicated above.

[20] We calculated the average population density for two zones which cover the mountains near Luoning. The zones include all twenty hypothesized targets from the FAS/NRDC study, as well as most of the mountainous area around Luoning. According to LandScan data, the average population density is 54 people per square kilometer. We thank Jonathan Chipman at Dartmouth's Applied Spatial Analysis Library for his help with the LandScan analysis.

psi zone, because the odds of surviving each detonation is 47%, and the odds of surviving all four would be 47% to the 4th power. Treating each detonation as an independent event leads us to *significantly overstate* the number of fatalities from the strike, because (a) the people who survived the first detonation are probably those (on average) who are further from the detonation point or in some other favorable protective position, which makes it more likely they would survive subsequent attacks, and because (b) prompt fatalities make up the vast majority of the fatalities in all these strikes. The low casualty estimates we generate may therefore significantly overstate how many Chinese civilians would be killed in such a strike.

For an example, the prompt effects of a 4-on-1 attack on a single silo in the mountains near Luoning, using 0.3 kiloton weapons and 90 feet HoB, would kill virtually everyone within 1,000 feet of the target, and 40% of the people located between 1,000 feet and 1900 feet. Those numbers total 33 expected deaths; attacking 20 similar silos puts the fatalities in the range of 660.[21]
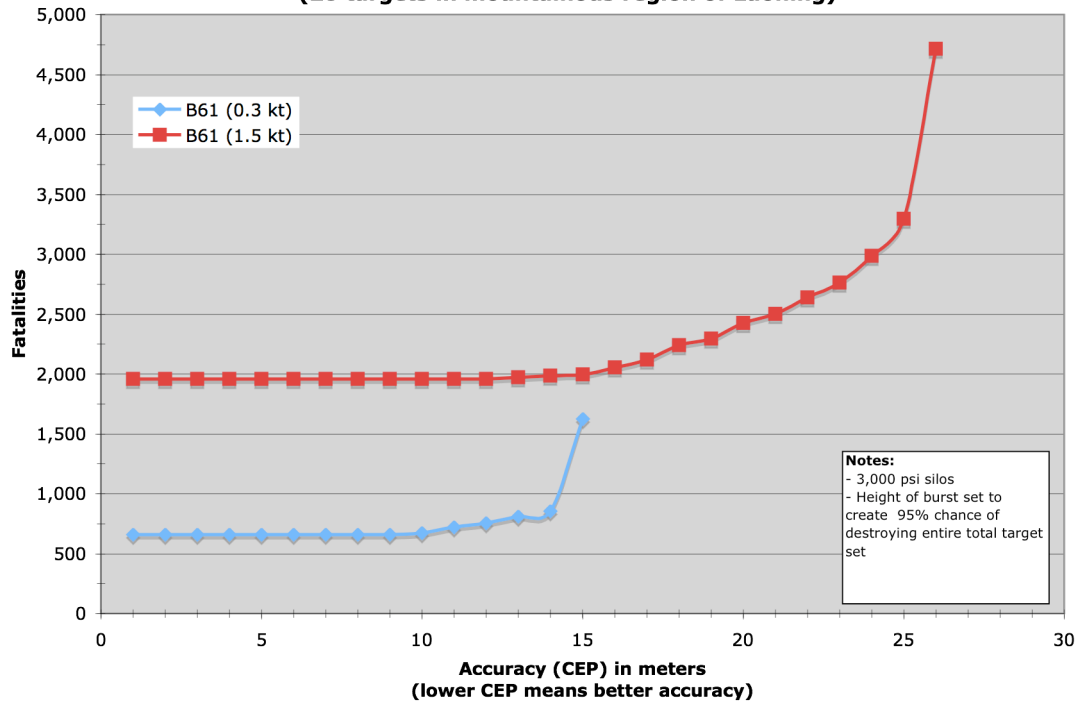
<u>Modeling Fallout.</u>
We use HPAC version 3.2.1 to model fallout fatalities for each combination of warhead yield, number of warheads, and the plausible range of HoBs.[22] For each value of CEP, we seek to identify the targeting strategy that minimizes casualties: we tradeoff HoB vs. number of warheads per target to find the combination that produces the lowest level of fatalities, which we report, as a function of CEP in **Figure 5**.

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[21] HPAC, the computer program we use to model fallout, also estimates fatalities from prompt effects. Strangely, HPAC – which uses the same LandScan population data that we use – estimates prompt fatalities at roughly 4 times the rate we estimate. This is particularly surprising because we intentionally *overestimate* fatalities on the ground from prompt effects (to make our analysis conservative) by assuming that each warhead has an independent effect on the nearby population (as described above). For the HPAC calculations of prompt fatalities to be correct, the detonations would have to be 100% lethal out to 1 psi – which is implausible. HPAC's problem may stem from the way it calculates population density: it may be using a less fine-grained subset of Luoning, and may have sampled an area outside the mountains, which has 4 times the population density of the mountainous region. Given that all the targets in this analysis are within the mountains, population density calculations should not include the villages and urban areas outside the zone. Note that this apparent problem with HPAC may cause us to overstate the fallout casualty estimates, for which we rely on HPAC – if the software is using questionable data for population density.

[22] HPAC calculates fallout fatalities for two different assumptions – (1) the population remains indoors for 48 hours after the detonations, and (2) the population remains outside. We assume that the population seeks shelter, so we report fatality numbers as a weighted average of indoors (75%) and outside (25%).

Fig 5: Chinese Fatalities from a U.S. Nuclear Counterforce Strike (20 targets in mountainous region of Luoning)

Legend:
- B61 (0.3 kt)
- B61 (1.5 kt)

Y-axis: Fatalities (0 to 5,000)

X-axis: Accuracy (CEP) in meters
(lower CEP means better accuracy)

Notes:
- 3,000 psi silos
- Height of burst set to create 95% chance of destroying entire total target set

Comparing Conventional and Low-yield Nuclear Counterforce[23]

We use formulas (2), (3), and (4) to estimate the effectiveness of conventional counterforce strikes against hardened silos. The main obstacle to such an analysis is that formula (1), which calculates lethal radius (LR) of a nuclear warhead of a given yield against a given target hardness, is not appropriate for conventional explosives. The key questions one must address when estimating LR for a conventional bomb against a silo are: (a) will directly striking the silo cap with a bomb destroy or sufficiently damage the silo to make the missile unusable?, and (b) can a bomb of a given explosive power miss the silo cap by any distance and still disable the silo/missile? If so, what is the maximum distance?

There appears to be considerable innovation occurring in the area of penetrators for conventional bombs, aimed to increase their ability to penetrate hard and buried targets. Because some of these innovations may not be reported in the open-source literature, we model a conventional strike in a manner that gives the benefit of the doubt to conventional weapons. This also has the benefit of pushing against the general thrust of our argument, which emphasizes the unique capabilities of low-yield nuclear warheads.

The main 2,000-lb GPS-guided bomb in the U.S. arsenal is the GBU-32, armed with a BLU-109 penetrator. The BLU-109 carries 535 lbs of advanced explosives, which have more explosive power per unit of mass than TNT. One of the first such explosives, Tritonal, is reported to have about 18% increased explosive power relative to TNT. Newer explosives are reported to have up to 50% more.

In estimating LR, the first question is whether a bomb will damage or destroy the silo or missile if it directly strikes the silo cap. One way to assess this is to estimate how much overpressure the bomb creates when it explodes. We use a formula from Gilbert Kinney and Kenneth Graham's book Explosive Shocks in Air[24] to estimate the maximum overpressure created by a GBU-32/BLU-109, as well as the dissipation of overpressure as a function of distance from the detonation.[25] If the bomb carries 535 lbs of advanced explosive, which has the explosive equivalent of between 630 and 800 lbs of TNT (depending on whether one assume 18% or 50% better explosive power than TNT), then the warhead's detonation will create in excess of 11,000 psi of overpressure at the point of detonation (i.e., out to about a tenth of a meter), and will exceed 3,000 psi out to 1 meter (or 1.1 meters if the explosive is 50% more powerful than TNT). A direct hit of the silo cap will, therefore, expose between 3 and 4.5 square meters of silo cap to greater than 3,000 psi and should damage or destroy the silo.

The calculations above also suggest that a bomb might damage the silo if it misses the target by a meter. In fact, this probably underestimates the lethal range of a penetrating

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[23] This section explains the analysis on p. 48 of "The Nukes We Need."

[24] Gilbert F. Kinney and Kenneth J. E. Graham, Explosive Shocks in Air (New York: Springer, 1985)

[25] A BLU-109 has 535 lbs of explosive – or 243 kg. If it is 18% more explosive than TNT, it releases the explosive energy of 287 kg of TNT. Using that figure, we can model overpressure as a function of distance from detonation by using the formulas in Kiney and Graham, Explosive Shocks in Air, 1985, vol. 2. We thank Eric Hundman and Austin Long for helpful discussions about modeling conventional counterforce strikes.

bomb, which is designed to delay detonation until it has penetrated several meters into the concrete or dirt. By delaying detonation until the bomb has penetrated the ground, more of the energy of the explosion is harnessed. To give the conventional bombs the benefit of the doubt, we assume that the bomb can damage the silo if it falls within 1.5 meters of the edge of the silo.

Many large ballistic missiles appear to have silo doors that are slightly more than twice the diameter of the missiles they shield. China's silo-based DF-5 missiles are 3.35 meters in diameter, so we estimate the silo caps being 7 meters across. If the center of the silo cap is the aimpoint, the bomb can miss the target by 3.5 meters and still strike the door. If, for reasons discussed above, the bomb can miss by 1.5 meters and still damage the silo, then LR of the bomb against the silo is roughly 5 meters.

We modeled a conventional strike on the target set of 20 3,000 psi silos using B-2 stealth bombers armed with 2,000-lb GPS-guided bombs. The United States has 20 B-2 bombers. The strike we envision uses roughly a third of the force, or 7-8 aircraft.[26] Each B-2 can carry 16 2,000-lb bombs, so using 7-8 aircraft permits approximately 120 bombs, or 6 per target. GPS-guided bombs can attain an accuracy of about 5 meters (CEP); if GPS is effectively jammed and only inertial guidance is functioning, then we assume that accuracy falls significantly – to 30 meters CEP or greater.[27]

If LR is 5 meters, and CEP is 5 meters, then from Formula (2) SSPK is 50%. Assuming a reliability for U.S. bombs of 90%, TKP = 45% per bomb per silo. A 6-on-1 attack has a 97% chance of destroying each silo, but only (approximately) a 57% chance of destroying all 20. Roughly speaking, there is about a 50% chance of destroying all 20 silos. If GPS is jammed near the targets and CEP falls to 30 meters, the odds of destroying each silo is only 2%, and the odds of destroying them all is virtually zero.

For low-yield nuclear weapons, as we explain in the previous section, we identify combinations of yield, warheads per target, and height of burst to achieve 95% pk-all against the 20 silos. A higher probability of success could be achieved, by lowering HoB, but at the cost of more fatalities.

An important implication of Figure 5 is that while conventional weapons require GPS-like accuracy to achieve good results against hardened silos, low-yield nuclear warheads can achieve 95% pk-all against a 20 silo target set *while minimizing fatalities*, even if the delivery systems cannot achieve pinpoint accuracy. If B-61 bombs were given GPS/INS systems (like those on JDAMs), plus terminal seekers, and GPS was functioning and unjammed during a strike, the bombs could achieve 5 meters CEP and would be expected to inflict fewer than 700 fatalities. If GPS were jammed half way to the target and,

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[26] It is widely reported that B-2s require significant maintenance on a frequent basis to retain their stealthy qualities. Therefore we assume that at most 70% of the force is available for missions at any given time (14 aircraft) and that half of them are tasked with this mission – i.e., 7-8 bombers.

[27] Some analysts report a 30-meter CEP if the bomb's GPS guidance system is jammed, but the bomber can still use GPS. If the bomber and bomb both lose GPS, then accuracy will degrade further. However, as we illustrate below, even 30 meters CEP is too inaccurate for the mission described here.

relying on INS and the terminal seeker, the bombs could "only" achieve 10 meters CEP, fatalities would be in the ballpark of 750. If the United States can develop redundant guidance systems, it should easily be able to achieve less than 15 meters CEP in almost any operational environment – a figure that is low enough to produce small numbers of casualties in strikes like we modeled.