RETHINK PRIORITIES

Would US and Russian nuclear forces survive a first strike?

Luisa Rodriguez | June 2019 | Rethink Priorities

Summary

The degree to which a nuclear war between the US and Russia could escalate depends on how many of their nuclear weapons would survive a first strike. For decades, both the US and Russia have been able to maintain a secure second strike by hiding their nuclear weapons on submarines, armored trucks, and aircraft. If improvements in technology allowed either country to reliably locate and destroy those targets, they would be able to eliminate the others' secure second strike, thereby limiting the degree to which a nuclear war could escalate.

But, at least for now though, technological progress has not advanced to the point of threatening the subset of the nuclear warheads that are deployed on mobile systems: sea-launched ballistic missiles, air-based strategic bombers, and road-mobile ICBMs. The problem of reliably locating a mobile target like a submarine or a plane equipped with advanced stealth technology is still unsolved. As a result, I expect both the US and Russia would be able to mount a massive second strike following a first strike by the other. Specifically, I expect somewhere between ~990 and ~1,500 of the US's nuclear warheads would survive a first strike. While I believe Russia's nuclear forces would fare slightly worse, I expect at least ~450 warheads and as many as ~1,240 warheads would survive.

Project Overview

This is the second post in Rethink Priorities' series on nuclear risks. In the first post, I look into which plausible nuclear exchange scenarios should worry us most, ranking them based on their potential to cause harm. In this post, I explore the make-up and survivability of the US and Russian nuclear arsenals. In the third post, I estimate the number of people that would die as a direct result of a nuclear exchange between NATO states and Russia. In the fourth post, I estimate the severity of the nuclear famine we might expect to result from a NATO-Russia nuclear war. In the fifth post, I get a rough sense of the probability of nuclear war by looking at historical evidence, the views of experts, and predictions made by forecasters. Future work will explore scenarios for India and Pakistan, scenarios for China, the contradictory research around nuclear winter, the impact of several nuclear arms control treaties, and the case for and against funding particular organizations working on reducing nuclear risks.

The Nuclear Triad

Both the US and Russia bolster their nuclear deterrence by maintaining a so-called nuclear triad, whereby each country splits its nuclear warheads across three forms of deployment: land-based intercontinental ballistic missiles (ICBMs), sea-launched ballistic missiles

(SLBMs), and air-based strategic bombers.[1,2,3]

Each leg of the triad has unique strengths that, together, make a country's nuclear forces responsive, survivable, and flexible. The benefit I'm most interested in here is survivability — the degree to which a country's nuclear forces would survive a first strike. If the US or Russia could completely eliminate the other's nuclear weapons, they wouldn't have what's called a secure second strike, which refers to the ability to execute a retaliatory strike even after an enemy has tried to eliminate one's nuclear forces. The secure second strike is paramount to the credibility of a country's deterrence policy. If a country can't credibly threaten that any nuclear attack will face a devastating nuclear counterattack in response, the disincentive against a first strike is much smaller.

To ensure the survivability of their nuclear forces, both the US and Russia have invested heavily in hiding and mobilizing their nuclear weapons, putting them on stealth bombers, submarines, and even the backs of giant armed trucks and trains that are hard to find and track.[4] They also keep them underground, in steel-reinforced concrete silos that are extremely difficult to penetrate.

But as technology improves, the secure second strike may be threatened. This might have two important effects: First, the probability of a nuclear exchange would likely go up, as deterrence would be severely weakened. Second, the risk that a limited nuclear exchange between the US and Russia could escalate to a full-scale nuclear exchange might go down, as whichever country was hit first would have many fewer nuclear weapons to retaliate with. And whether a nuclear exchange between the US and Russia would escalate to a full-scale war has a very large bearing on whether it poses a real extinction risk.

With this in mind, I look into exactly how secure the Russian and US nuclear forces are. I explore the strengths of each leg of the triad, how technology has influenced that leg's survivability, and what proportion of the US's and Russia's nuclear forces we should expect to survive a first strike today.

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[1] NTI defines deterrence as "The actions of a state or group of states to dissuade a potential adversary from initiating an attack or conflict through the credible threat of retaliation. To be effective, a deterrence strategy should demonstrate to an adversary that the costs of an attack would outweigh any potential gains. See entries for extended deterrence and nuclear deterrence."

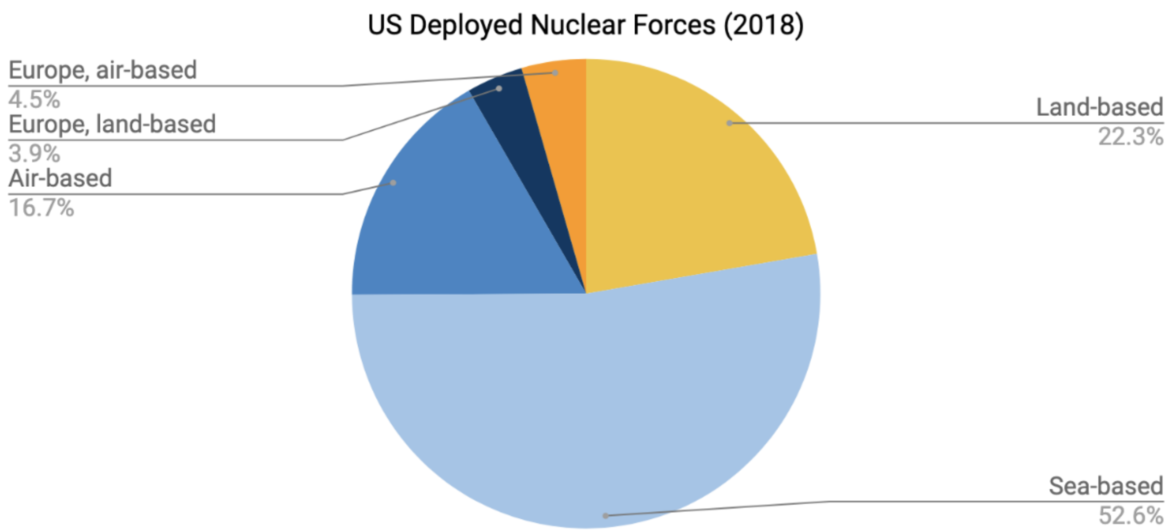
[2] See for example the NTI Glossary or (Woolf, A., 2018).

[3] NTI defines a ballistic missile as "A delivery vehicle powered by a liquid or solid fueled rocket that primarily travels in a ballistic (free-fall) trajectory. The flight of a ballistic missile includes three phases: 1) boost phase, where the rocket generates thrust to launch the missile into flight; 2) midcourse phase, where the missile coasts in an arc under the influence of gravity; and 3) terminal phase, in which the missile descends towards its target. Ballistic missiles can be characterized by three key parameters - range, payload, and Circular Error Probable (CEP), or targeting precision. Ballistic missiles are primarily intended for use against ground targets."

[4] Russia no longer uses rail-mobile missiles (Starchak, 2017).

The survivability of the US nuclear triad[5]

As of 2018, the total inventory of the US nuclear forces includes about 6,550 warheads, with about 1,800 nuclear warheads deployed (ready to launch at a moment's notice) (Kristensen & Norris, 2018).[6] Of these, about 400 are land-based, 300 are air-based, 945 are sea-based, and another 150 non-strategic weapons (short-range nuclear weapons intended for use in battle) are deployed in Europe (half air-based, and half land-based) (Kristensen & Norris, 2018).



The US's submarine-launched ballistic missiles (SLBMs)

US submarine-launched ballistic missiles (SLBMs), housed on its strategic nuclear submarines (SSBNs[7]), are considered the most survivable leg of the nuclear triad. This is because they are extremely hard to detect. Historically, submarines could only be detected using radar and acoustic technologies, like sonar (Deutsche Welle, 2017). Satellites can't see SSBNs through the ocean, nor can they be heard using acoustic technologies if they're quiet enough. Besides reducing light and sound that travels through water, the salinity, temperature, and pressure of the ocean also bend sound waves, reducing the accuracy of sonar (Holmes, 2016, p. 228). Further, US submarine countermeasures are among the best in the world. Its submarines' surfaces are covered in plastic, which disperses radar signals instead of reflecting them. They are also quieter than any other country's subs (Clark, 2015, p. 1).

[5] For simplicity, I ignore the UK's and France's nuclear forces in this discussion. Including them wouldn't affect my conclusions much if at all.
[6] Of the remaining warheads, 2,200 are in reserve and 2,550 are "retired and awaiting dismantlement" (Kristensen & Norris, 2018, Table 1).
[7] The SS indicates "submarine" (or, rather, submersible ship), the B indicates "ballistic missile," and the N denotes indicates that the submarine is nuclear powered.

But technological developments may finally be catching up to stealth technologies. Crucially, the US relies on being able to successfully conceal its SSBNs, but increasingly, the survivability of its SLBMs is threatened by trends in technology that make it easier to track SSBNs down. One area where things are evolving rapidly is remote sensing (Lieber & Press, 2017a, p. 32).

New analytic techniques are making remote sensing increasingly accurate. For example, new sensors can now pick up fainter signals than before, and they can more successfully distinguish between signals from the target and ambient noise in the ocean (Lieber & Press 2017a). Additionally, new acoustic techniques, improved signal processing techniques, and advancements in machine learning detection algorithms make it easier to detect a submarine by enabling a comparison between the expected ocean noise (for example waves and marine life) to the 'noise fields' that are actually being measured (Clark 2015). Better computer modeling can enhance information about a target, not unlike the techniques used today to enhance photographic images (Lieber & Press 2017a; Clark 2015). New detection techniques that are non-acoustic (such as lasers and light emitting diodes (LEDs)) could potentially provide more accurate intelligence and are expected to become more prominent in the coming years (Clark 2015).

Further, sensor platforms have become more diverse, and they can increasingly provide continuous intelligence and information about their targets (Lieber & Press, 2017a). This makes the SSBNs more vulnerable because their movement can be tracked over time, making it possible for an adversary to identify patterns in their routes. The older sensor platforms (satellites, submarines, and piloted aircraft) are supplemented by new, less vulnerable sensor platforms. For example, unmanned aircraft that are piloted from a distance and drones that go underwater decrease the survivability of SLBMs while posing minimal risk to the security 'seeker' (Lieber & Press 2017a).

Finally, intelligence data can be transmitted almost instantaneously, making it possible for the 'seeker' to make timely and informed decisions based on up-to-date information about the whereabouts of the SSBNs (Lieber & Press 2017a), making the SLBMs more vulnerable than ever before.

If Russia beat the US to incorporating these technologies into its intelligence gathering systems, it could gain a decisive advantage. According to Lieber & Press (2017a), the US would be hard-pressed to develop countermeasures quickly and effectively. Thus, the assumption that the sea-based leg of the triad is inherently invulnerable might not hold much longer.

But while the emerging technologies could eventually be game-changing, it has not yet become easy to track down submarines. Until that changes, I expect basically all of the US's SSBNs and their nuclear cargo would survive a counterforce first strike.

The US's air-based strategic bombers

Like SSBNs, strategic bombers are considered relatively survivable, albeit somewhat less so than submarines. There are three points at which bombers would be particularly vulnerable: 1) before takeoff, 2) during a retaliatory strike, when the bombers would have to fly over enemy territory, and 3) when refueling becomes inevitably necessary.

While many strategic bombers are concentrated at air bases and aircraft carriers, making them potentially convenient to target, early warning systems would likely give US pilots enough time to take off before the nuclear warheads arrived at their targets and detonated. Any bombers that didn't manage to take off in time would be caught at the air base and severely damaged. As machine learning techniques are built into earning warning systems, the advanced notice pilots have will get even longer (Boulanin eds., 2019).

Once in the sky, the sheer amount of dispersion strategic bombers can achieve makes them really hard to find and destroy. Compounding that is stealth technology similar to that used by submarines. That said, even stealthy aircraft risk revealing themselves if directed to detonate nuclear weapons over enemy territory, at which point tail engine smoke and other vulnerabilities could alert the enemy to their position. Further, many of the improvements that are shaping submarine warfare — things like improvements in radar and surveillance, among others — will increasingly pose a threat to the survivability of the US's air-based nuclear forces (Lieber & Press, 2017a).

Finally, nuclear weapons launched at air bases — either during the initial first strike or later on by enemy bombers — would have a chance of catching US aircraft as they eventually had to land to refuel or repair damage.

It's not clear exactly how many US bombers might be successfully destroyed during a counterforce first strike, though my impression is that many or even most would likely survive. My best guess is that the US would be left with somewhere between 60% and 100% of its air-based nuclear warheads: 180–300 US-based warheads and 50–80 US warheads deployed in Europe.

The US's intercontinental ballistic missiles (ICBMs)

Silo-based ICBMs are somewhat vulnerable to attack as their locations can generally be ascertained by their enemies — at least roughly — and they can't be moved (McKinzie, eds. 2001; Arms Control Association, 2019). The main challenge in targeting them is bombing them forcefully enough to penetrate the silos, which are deep underground and built with thick concrete and reinforced with steel (McKinzie, eds. 2001).

Over the course of the Cold War, the US and Russia got better and better at building super hardened silos — silos that were increasingly hard to damage (McKinzie, eds. 2001). For example, a 335 kiloton nuclear bomb — this is close to the median-sized bomb in the US arsenal — aimed at a Russian missile silo built around 1966 would have a 66% chance of "severely damaging" the silo (McKinzie, eds. 2001). By contrast, the same nuclear bomb aimed at the nuclear silos being built around 1975 would only have a 39% chance of severely damaging the silo (McKinzie, eds. 2001). Aiming two 335kt bombs at the same silos would increase the chances a bit, to 63%, and three bombs would increase the chances of severe damage a little bit more, to 77% (McKinzie, eds. 2001).

Despite this, both the US and Russia have nuclear weapons that are numerous, powerful and accurate enough to damage a large proportion of the others' missile silos. For example, in the counterforce scenario using 1,289 warheads modeled by [McKinzie et al.] (https://www.nrdc.org/sites/default/files/us-nuclear-war-plan-report.pdf) in 2001, the authors found that an attack using 500x 300kt warheads plus 220x 455kt warheads would severely damage all but 24 of Russia's then 360 missile silos (2001).

However, achieving 100% kill against Russia's silo-based missiles would be exceedingly difficult. According to the same analysis by McKinzie et al., another 360x 300kt warheads allocated to the then 360 Russian silos would only increase the number of severely damaged silos by seven (2001). Similarly, as of 2017, it would take 900 of Russia's 1600 deployed nuclear warheads to destroy all 450 of the US's silo-based ICBMs, leaving just 700 for attacks against the US SSBNs and air-based strategic bombers, along with all nuclear arsenals of NATO allies: France and the UK (Burg, 2017).

This also points to a general theme in counterforce targeting: there are rapidly diminishing returns to larger nuclear attacks, and it's really hard to get 100% success rate.

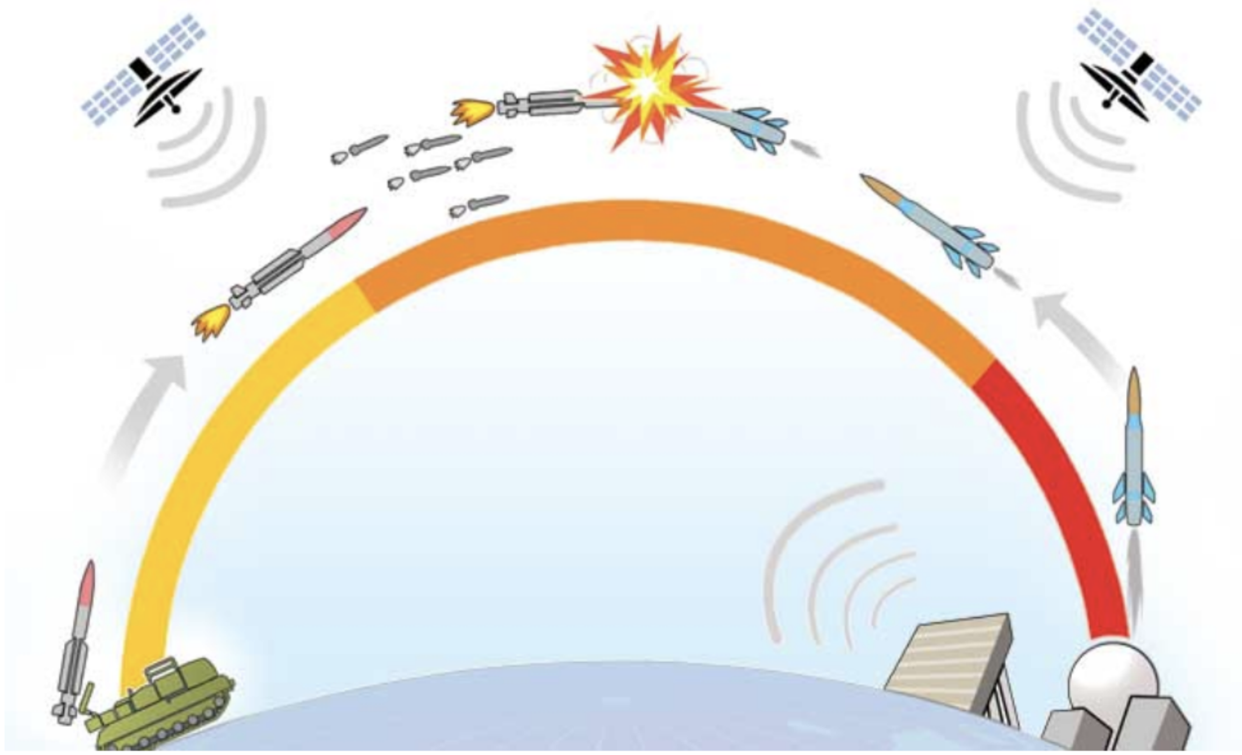
While Lieber and Press (2017a) point out that further improvements in accuracy will bring both the US and Russia closer to being able to take out 100% of each others' silo-based nuclear weapons, at least for now, I expect that even in the case of massive counterforce targeting, there would be at least a few surviving land-based nuclear warheads.[8]

This in mind, I expect that — if the US didn't pre-emptively launch a second strike following warnings that a first strike was on its way (launch on warning) — a first strike against the US would likely take out most of its ICBMs, though not all of them. My guess is that 1% to 25% of the US's nuclear forces would survive a Russian first strike — or, about 4–100 US-based warheads and 1–20 US warheads hosted by various European countries.

The US's Missile Defense Systems

According to the Nuclear Threat Initiative, the US has the world's most well-developed missile defense program, spending over $200 billion on the program since 1985 (Arms Control Association, 2019). But whether these missile defense systems would make a huge difference during a counterforce attack is unclear.

[8] Figure 1 also suggests, however, that despite vast improvements in missile accuracy, the weapons still are not effective enough to be employed individually against hardened targets. Even modern ballistic missiles are expected to miss or fail 20–30 percent of the time. The simple solution to that problem, striking each target multiple times, has never been a feasible option because of the problem of fratricide: the danger that incoming weapons might destroy or de°ect each other.32 The accuracy revolution, however, also offers a solution to the fratricide problem, opening the door to assigning multiple warheads against a single target, and thus paving the way to disarming counterforce strikes" (Lieber & Press, 2017a, p. 21).



Missile-defense systems rely on a very simple concept: shoot a big enough projectile at an incoming missile, and the missile will be destroyed on impact when the two crash into each other. This is known as hit-to-kill technology. But actually doing this successfully is really difficult, mainly because it's hard to actually locate and collide with a missile in midair. The US has only ever successfully destroyed a long-range missile in real life one time (McLaughlin & Martinez, 2017). The US has had some success destroying short-range missiles, hitting nine out of seventeen short-range missiles during missile defense tests since 1999 (Nuclear Threat Initiative, n.d.; McLaughlin & Martinez, 2017). But not only is a 53% success rate not particularly inspiring, this rate doesn't account for the fact that the tests themselves are sometimes delayed or canceled for bad weather or malfunctioning equipment — which likely bias the success rate upwards (Samson, 2008).

What's more, hitting long-range missiles is much harder than hitting short-range missiles. There are a bunch of different reasons for this. The first phase of a missile's trajectory is called the "boost phase" (Nuclear Threat Initiative, n.d.). A missile is vulnerable during the boost phase because it hasn't had time to pick up speed, and its engine gets really hot as it burns a lot of fuel to accelerate, making it easier for heat-seeking sensors to track and target. But the boost phase doesn't last long, and the missile defense systems usually can't get within range of the missile in time to be deployed.

The longest part of a missile's journey — the period when the country being attacked is most likely to deploy its missile defense system — is done in a re-entry vehicle, which is small, incredibly fast, and doesn't produce much heat. The low heat makes it hard for defense systems to track the target, and the high speeds and small size mean that tracking has to be really precise to actually connect. The Nuclear Threat Initiative has compared it to hitting a bullet in mid-air with another bullet. To make things even harder, Russia has countermeasures like decoys that the projectile, also called an interceptor, is likely to confuse with the real missile.

The so-called terminal phase of the missile's trajectory offers only a very short window for hit-to-kill defenses, and even a successful collision might have dangerous consequences as it's likely to happen over US territory.

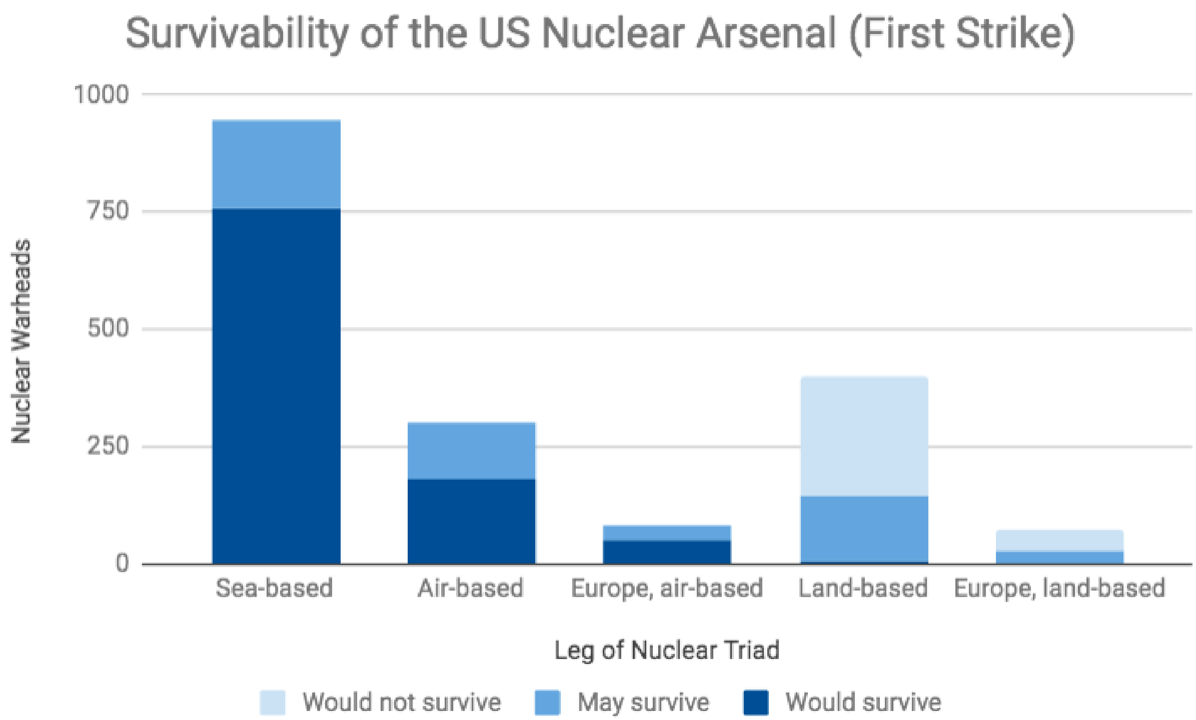
Given these challenges, I expect the US's missile defense systems wouldn't have much of an impact on the survivability of its nuclear forces.[9] At best, I expect that the US's missile defense systems might increase the number of surviving warheads by around 15%. At worst, they might have no impact at all.

Surviving a Russian first strike

From this, I draw the following conclusions about the survivability of the US nuclear triad. All told, unless Russia has made huge improvements in its technologies in recent years that we don't know about, of the three legs of the nuclear triad I would expect only the ICBM count to be reduced meaningfully during a first strike. Russia has not demonstrated the ability to track US submarines, and the advanced notice given by early warning systems should give strategic bombers enough time to leave air bases before a strike hit. Once in flight, most would likely avoid detection.

Given this, I expect that somewhere between 990 and 1,500 US nuclear warheads would survive a first strike.

[9] This is not to say that they're not valuable. Missile defense systems, and even the uncertainty around their effectiveness, may play an important role in deterrence. Uncertainty about the effectiveness of missile defense systems disincentivizes launching a first strike by reducing the enemy's overall confidence in its ability to succeed. Moreover, if an enemy *did* decide to launch a first strike despite that uncertainty, the enemy would have to guess at how large a first strike would have to be to ensure success. To make sure they didn't underestimate the requisite size — which would make the first strike a huge failure — they'd likely plan a conservatively large first strike to be sure they wouldn't fail. This would be expensive, thereby contributing to the disincentive to launch a first strike at all.

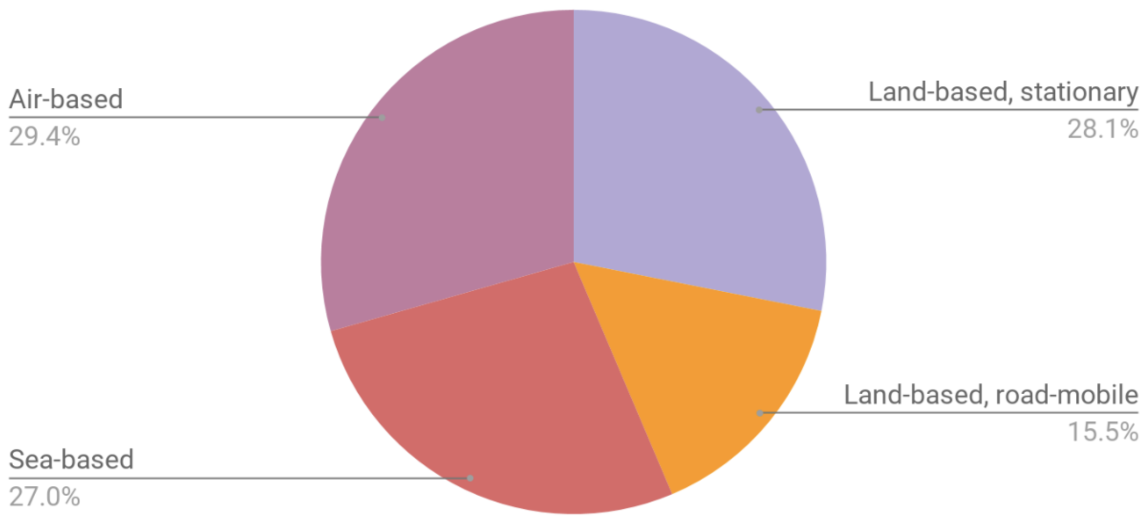


There are a few other very speculative factors that I haven't taken into account, but that could impact the number of US warheads that would survive a first strike. If the US or Russia were being deceptive about the size or make up of its nuclear arsenal, the quality of its missile defense systems, or any other capabilities related to the survivability of its nuclear arsenal, my conclusions could be way off. For example, if Russia has developed a way to track US submarines without anyone knowing, a first strike could end up being much more devastating. Similarly, it's possible that Russia would mount a cyberattack alongside a first strike — for example, tampering with the US's early warning systems (Blaire, 2017). If either of these elements were at play, the survivability of the US arsenal could actually end up being quite a bit higher or lower.

The survivability of the Russian nuclear triad

Currently, the total number of nuclear warheads in Russia's nuclear arsenal is estimated at 6,490, with ~1,600 deployed (Kristensen & Korda, 2019). While I'm most interested in understanding the distribution systems of deployed warheads as I did in the case of the US arsenal, the breakdown of deployed Russian warheads is more poorly understood; the US releases declassified reports on its arsenal while Russia doesn't. Given that, I can only assess the distribution of nuclear warheads in the air-based, sea-based, and land-based legs of the triad for the strategic nuclear forces — comprised of high-yield nuclear weapons that can be delivered over long distances.[10] I focus on the strategic forces as those are the weapons that would be used to target military facilities, industrial areas, and cities, while shorter-range tactical nuclear weapons are intended for use in battle (Kristensen & Korda, 2019). Of the approximately 2,670 strategic forces inventory, 1,165 nuclear warheads are land-based — 414 of those are road-mobile — 786 are air-based, and 720 are sea-based (Kristensen & Korda, 2019).

Russia's Strategic Nuclear Forces (2019)



Russia's submarine-launched ballistic missiles (SLBMs)

Again, locating enemy submarines is extremely difficult, making counterforce targeting against Russia's SSBNs very challenging. However, unlike the US, Russia's submarine fleet has a history of extremely poor "operational readiness" (McKinzie, eds. 2001, p.66).[11,12] Moreover, while the Russian navy has drastically improved in the past couple of decades, its submarines could be vulnerable during a first strike if only a few submarines were actually on patrol, or if they were positioned near their own naval bases, which the US would easily be able to target, as they have done in the recent past (Kristensen, 2013).[13]

[10] NTI defines strategic nuclear weapons as "A high-yield nuclear warhead placed on a long-range delivery system, such as a land-based intercontinental ballistic missile (ICBMs), a submarine-launched ballistic missile (SLBMs), or a strategic bomber." This is in contrast to tactical nuclear weapons, which are defined as "Short-range nuclear weapons, such as artillery shells, bombs, and short-range missiles, deployed for use in battlefield operations." It's worth noting that improved accuracy and other improvements will likely lead increasingly to low-yield nuclear weapons also being considered useful as strategic weapons (Lieber & Press, 2017b).
[11] "A recent article in Jane's Defense Weekly reports that the Russian Navy's operational readiness might be as low as 10 percent. With respect to the Pacific Fleet, for example, the following selected events from the year 2000 reveal the pervasive problems confronting the Russian navy today" (McKinzie, eds. 2001, p.66).
[12] Find details of Russia's navy's history of dangerous accidents, corruption, incompetence, on pages 67-68 (McKinzie, eds. 2001, p.67-68).
[13] "The recent decline contrasts with the Russian Navy's declaration last year that it would resume

As is the case with US SSBNs, new technologies in remote sensing make Russian SSBNs increasingly vulnerable. At the same time, countermeasures are difficult and extremely costly and time-consuming to develop (Lieber & Press, 2017a, pp. 46-48). Given that the US is believed to have a bigger nuclear modernization budget, Russia may be at a considerable disadvantage when it comes to the survivability of their SLBMs (Lieber & Press, 2017a; Tian et al., 2019; Kofman, 2019).[14]

Given all of this, I have a lot of uncertainty about whether or what proportion of the Russian SLBMs would survive a first strike. I can imagine it could be as few as 10% or as many as 100% of Russia's SLBMs (between 40 and 430).

Russia's air-based strategic bombers

Unlike the US, Russia does not have stealthy strategic bombers (for now). Instead, it has air-launched cruise missiles (ALCMs), shorter-range missiles, and nuclear gravity bombs

continuous deterrent patrols from mid-2012. Assuming the five patrols occurred throughout the year and not just in the last six months, the fleet would have had a hard time maintaining a continuous at-sea presence with only five patrols. Theoretically, it could be done if each patrol lasted an average of 73 days. That is how long a U.S. SSBN deploys on a good day. But Russian SSBNs are thought to do shorter patrols, probably 40-60 days each, in which case most of the five patrols would have had to occur between July and December to maintain continuous patrol from mid-2012. Even if the navy were able to squeeze a more or less continuous at-sea presence out of the five patrols, it would at best have consisted of a single SSBN – not much for a fleet of nine submarines or demonstrating a convincing secure retaliatory capability. Perhaps more significantly, the five deterrent patrols conducted in 2012 are not enough for each SSBN in the fleet to be able to conduct even one patrol a year. The five patrols by nine SSBNs indicate that only five or less submarines are active. That means that submarine crews do not get much hands-on training in how to operate the SSBNs so they actually have a chance to survive and provide a secure retaliatory strike capability in a crisis. Crews probably compensate for this by practicing alert operations at pier-side at their bases. Unlike U.S. SSBNs, which can patrol essentially with impunity in the open oceans, Russian deterrent patrols are thought to take place in "strategic bastions" relatively close to Russia where the SSBNs can be protected by the Russian navy against the U.S. and British attack submarines that probably occasionally monitor their potential targets" (Kristensen, 2013).

[14] Just how much larger the US modernization budget is is unclear. Russian nuclear spending has been underestimated in the past, and current comparisons of US and Russian defense spending may be misleading. Kofman writes: "ask yourself: Do we really know how much our adversaries spend on their military, and what they are getting for their money? Russia, for example, presents a glaring problem for academic and policy circles alike. Most comparisons are done in current U.S. dollars based on prevailing exchange rates, making Russia's economy seem the size of South Korea's. This approach is useless for comparing defense spending, or the country's purchasing power. Yet, it is used frequently to argue that despite a large military modernization program, and a sizable conventional and nuclear deterrent, Moscow is a paper tiger. As a consequence, the debate on relative military power and expectations of the future military balance is terribly warped by a low-information environment. The best example of this problem is a recent announcement by the Stockholm International Peace and Research Institute that Russian military spending has fallen to the sixth highest in the world in 2018, at $61.4 billion. Rest assured, or perhaps discomforted: Russian defense spending is several times higher than $61.4 billion, and the Russian defense budget remains the third largest in the world, dwarfing the military expenditures of most European states combined. In reality Russia's effective military expenditure, based on purchasing power parity (Moscow buys from Russian defense manufacturers in rubles), is more in the range of $150-180 billion per year, with a much higher percentage dedicated to procurement, research and development than Western defense budgets" (Kofman, 2019).

that would be launched from heavy bombers.[15] While they lack stealth technology, Russia's heavy bombers maintain their survivability by being able to launch cruise missiles from really far away (thousands of kilometers), shielding them from US air defense systems and fighter aircraft (Military Watch, 2018). So, my sense is that Russia's heavy bombers have comparable survivability to the US's stealthy strategic bombers. Like the US air-based nuclear forces, Russia is vulnerable at a few 'choke points' — before take off, mid-attack, and during refueling and repair — but is overall very survivable. While, as I described above, radar and other technologies are improving, Russia's heavy bombers will likely remain relatively survivable for the time being.

This in mind, I expect some fraction of Russian heavy bombers to be destroyed during a counterforce attack, but I believe many or most would remain unscathed. I guess that somewhere between 60% and 100% (280 and 470) of Russia air-based nuclear warheads would survive a first strike.[16]

Russia's intercontinental ballistic missiles (ICBMs)

Within the ICBM leg of the triad, deployed ICBMs can be further broken down into: silo-based ICBMs, which both the US and Russia have, and "road-mobile" ICBMs, which only Russia has.

Like the US's land-based nuclear forces, Russia's silo-based ICBMs would be vulnerable to attack. Also, like the US's land-based forces, super-hardened silos would make the destruction of 100% of Russia's silo-based nuclear weapons extremely costly, but improvements in US technology mean the US could get reasonably close (Lieber & Press, 2017a; McKinzie, eds. 2001). For example, the accuracy of US long-range ballistic missiles has improved dramatically since the end of the Cold War as a result of substantial progress in submarine geolocation and missile guidance systems. Whereas in 1985 US SLBMs had only a 9% chance of effectively destroying a hardened silo, today that chance has increased to 90% (Lieber & Press, 2017b, p. 3).

Russia's road-mobile land-based ICBMs have the additional tactical challenge of being 'relocatable.' Through bilateral arms control treaties, Russia has shared the coordinates of locations associated with a number of mobile ICBMs (associated garrisons, parking sites, etc.) (McKinzie, eds. 2001). The US also has intelligence on the dispersal patterns of road-mobile ICBMs, satellite imaging that's high-resolution enough to see road-mobile ICBMs (as long as they aren't in underground tunnels), and the ability to monitor

[15] A cruise missile is defined as "an unmanned self-propelled guided vehicle that sustains flight through aerodynamic lift for most of its flight path. There are subsonic and supersonic cruise missiles currently deployed in conventional and nuclear arsenals, while conventional hypersonic cruise missiles are currently in development. These can be launched from the air, submarines, or the ground. Although they carry smaller payloads, travel at slower speeds, and cover lesser ranges than ballistic missiles, cruise missiles can be programmed to travel along customized flight paths and to evade missile defense systems.

[16] Because the cruise missiles launched from Russia's heavy bombers are less stealthy than the US's air-based ballistic missiles, its cruise missiles would be more vulnerable to countermeasures once deployed. This means Russia's air-based nuclear forces would likely be less effective during a second strike relative to the US's air-based nuclear forces.

communications between road-mobile missiles (McKinzie, eds. 2001; Lieber & Press, 2017a).

According to McKinzie et al., road-mobile missiles are kept stationary at garrisons and parking sites periodically (2001). Many of them would only 'disperse' after a first strike early warning. Any road-mobile missiles still in the garrisons by the time a first strike arrived would be destroyed with relative ease. One to two 300kt nuclear warheads allocated per garrison known to be sheltering road-mobile ICBMs would yield a high probability of successfully destroying the missile systems positioned there (McKinzie et al., 2001).

What's more, the launch sites that would be used by Russia's mobile missiles are both relatively easy to identify and easy to target, meaning the US would have some success destroying road-mobile missiles even after they'd dispersed (McKinzie et al., 2001).

But road-mobile missiles that have been mobilized and aren't positioned at a launch site would be much harder to target, and in fact, used to be considered "inherently survivable" (see a discussion of the general consensus about this in Long & Green, 2014; McKinzie, eds. 2001, 54). According to Long and Green, "In particular, mobile nuclear weapons — 'relocatable targets' in the common parlance — are now generally viewed as untargetable in a first strike. A secure second strike has therefore become almost synonymous with a state possessing significant numbers of [SLBMs] and/or mobile intercontinental ballistic missiles (ICBMs)" (2014, p. 40).

Once located, road-mobile missiles are easier to destroy, even while moving, as they have weaker defenses than silo-based missile systems (Long & Green, 2014; Acton, 2010). In fact, a nuclear bomb wouldn't have to detonate particularly close to a road-mobile target to it to destroy it. For example, a 100kt ICBM detonated in the air would damage a road-mobile missile system anywhere within an area of 26 square kilometers (McKinzie, eds. 2001). And if the bomb detonated is big enough, the road-mobile missile system wouldn't be able to drive outside the radius of the detonation quickly enough to escape the blast, even with early warnings.

According to Long and Green (2014), improvements in technology, in particular by the US, is getting closer to being able to locate road-mobile ICBMs.[17] Modern sensors now take advantage of techniques like spectroscopy and interferometry, among others, allowing them to, for example, detect vapors that leak out of missile silos and trucks from a distance (Lieber & Press, 2017). Similarly, remotely piloted vehicles like drones will be able to monitor the movement of mobile-ICBMs, allowing the US to finally track mobile-ICBMs

[17] "The most notable improvement in US capability was revealed in 2009 when the existence of the RQ-170 stealth UAV became publicly known… Moreover, the United States is alleged to be already hard at work on an even more capable successor stealthy UAV. This new model, dubbed the RQ-180, is intended to be larger yet stealthier and have longer range than its predecessor" (Long & Green, 2014, p.61-62) "The implications of the RQ-170 for the ability of the United States to track mobile missiles are striking. At least in countries with limited air defenses (e.g. Pakistan, Syria, North Korea, and Iran) the United States can potentially track mobile missiles on patrol with real time video imagery and SIGINT. Mapping deployments and field launching sites would therefore be extraordinarily effective over time. Even in countries with more advanced air defense (Russia and China) the RQ-170 can potentially be routed to avoid air defense concentrations." (Long & Green, 2014, p.61-62)

over time after they've been identified (Lieber & Press, 2017).

But according to James Acton, co-director of the Nuclear Policy Program and a senior fellow at the Carnegie Endowment for International Peace, "locating mobile ballistic missiles is exceptionally hard," and even taking improvements in US technology into account, "it is still fiendishly difficult to locate mobile missiles hidden by a well-prepared enemy" (Acton, 2010). We're just not at the point where we can reliably detect and track road-mobile nuclear forces.

Taken together, I expect that — assuming Russia didn't launch on warning — between 75% and 99% (340–440) of Russia's silo-based ICBMs and between 10% and 50%, or (30–120) of its road-mobile ICBMs would be destroyed in a US first strike.

Russia's Missile Defense Systems

According to CSIS Missile Defense Project, "Russia now possesses some of the most advanced air and missile defense systems in the world" with missile defense systems across the country, and 68 nuclear-armed interceptors are located surrounding Moscow (2018; Secretary of Defense, 2019). To date, the defense systems have been limited to destroying aircraft, drones, cruise missiles, and short- to intermediate-range ballistic missiles, but the arrival of Russia's newest surface-to-air missile (the S-500) in 2020 may allow it to target US ICBMs (Ritzen, 2018; CSIS).[18]

But my impression is that these systems are intended to protect the capitol — not necessarily to protect Russia's nuclear arsenal. I therefore don't expect them to have any meaningful impact on the survivability of its nuclear arsenal.

Surviving a US first strike

Taken together, I expect that Russia's nuclear forces would likely fare a bit worse than the US's during a first strike. If we assume that Russia's deployed nuclear forces are distributed across the three legs of its triad in proportion to the distribution of its strategic warheads, Russia could be left with up to 1,240 nuclear warheads after a first strike. Realistically though, I expect it would be far fewer — perhaps as few as 450. In either case, Russia would still be able to mount a formidable second strike.[19]

[18] Also see ("Стало известно, когда появится опытный образец новейшей системы С-500," 2017)
[19] According to Lieber and Press (2018), "even a 90% effective strike against an enemy's arsenal would be a failure, since the surviving weapons could inflict a devastating counterattack."

Like above, my conclusions could be quite different if it turned out either the US or Russia were being deceptive about the size, composition, and capabilities of their nuclear arsenals or missile defense systems. While I think it's relatively less likely that the US would execute a cyberattack to augment a first strike against Russia, cyberattacks and other unknowns add to my uncertainty.

Conclusion

For now, it seems like neither the US nor Russia would likely be able to execute a 'perfect' counterforce strike, making it unlikely for either to put an immediate end to the nuclear exchange. Uncertainties about deception, cyberattacks, and other unknowns, I expect that between ~990 and ~1,500 of the US's deployed nuclear warheads and between ~450 and~1,240 of Russia's deployed nuclear warheads would survive a first strike. However, improvements in technology could substantially threaten the survivability of deployment systems that have been considered 'inherently survivable' for decades.

Rich countries have a considerable advantage in this regard. Conversely, countries with affluent opponents will increasingly struggle to conceal their nuclear arsenal (Lieber & Press, 2017a). In this regard, the US has a strategic advantage, as their defense budget is somewhat higher than that of its opponents, including Russia. While Russia's military spending was somewhere between $150-180 billion in 2018 (after adjusting for purchasing power), the US's was 3-4 times that, at a whopping $649 billion (Tian et al., 2019; Kofman, 2019).[20]

[20] Additionally, in the last decade, Russia allocated about $32.6 billion for modernization of its nuclear forces taking place between 2011 and 2020 (Cooper, 2018). Compare this to the modernization plan the US has implementing: the US will be spending around $50 billion *per year* in the coming decade,

Corrections and other revisions

July 14 2019 — In an earlier version of this post, I predicted that the US missile defense system might avert the destruction of about 15% of warheads that would otherwise be destroyed. I erroneously accounted for this by adding 15% of the total arsenal to my estimate of the surviving warheads rather than negating 15% of the would-be destroyed warheads. When I corrected for this mistake, I found that as many as ~1,500 of the US's nuclear weapons might survive a first strike (assuming the US didn't launch on warning) — not 1,660, as I originally concluded.

Credits

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for a total of $494 billion between 2019 and 2028 (Congressional Budget Office, 2019). However, these are absolute figures. The difference between the US and Russian nuclear modernization expenditures would be less extreme if adjusted for purchasing power.

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