# No Winning Moves: Calculated Casualties and Damages of a Nuclear Attack on the United States by Russia for First and Second Strike Scenarios

by

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Submitted to the Department of Nuclear Science and Engineering
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## Abstract

Simulations of nuclear attacks are a valuable assessment tool to analyze the capabilities of arsenals in order to inform policies and negotiations. Targeting strategies were developed for Russian first strike, Russian second strike with strategic warning, and Russian second strike without strategic warning scenarios utilizing the full Russian arsenal for the first strike and only the arsenal expected to survive a U.S. first strike with and without warning for the second strikes. The countervalue targets consisted of oil refineries and pipelines, shipping ports, and high voltage (HV) transformers in order to eliminate the U.S. supply of petroleum products and blackout the electrical grid. Beyond infrastructure damage, the blast fatalities and injuries were calculated using NUKEMAP, and the number of U.S. missile silos expected to survive an attack was calculated using a Monte Carlo simulation. The Russian first strike resulted in 49.73 million casualties and all oil refineries and major shipping ports and 2,809 HV transformers destroyed with 132—-225 surviving U.S. silos and 520 unused warheads. The Russian second strike with strategic warning resulted in 70.17 million casualties; all oil refineries, all major shipping ports, and 3,233 HV transformers destroyed with 783 or more unused warheads. The second strike without strategic warning resulted in 7.76 million casualties and 71 oil refineries, 27 major shipping ports, and 618 HV transformers destroyed. This study showed that deep arsenal reductions are possible while maintaining deterrence, the role of the U.S. ICBMs should be evaluated, and grid security and oil dependence should be addressed.

Thesis Supervisor: R. Scott Kemp
Title: Associate Professor

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Additionally, thank you to Alex Wellerstein for granting me unlimited access to NUKEMAP in order to run blast casualty calculations and to generate detonation maps for each attack scenario. I must also thank Pavel Podvig for providing insights and sources on the Russian arsenal and both Soviet and Russian nuclear strategy. Your feedback was instrumental in shaping the targeting strategies. I also want to thank Hans Kristensen for helping determine the composition of the Russian arsenal. I would also like to thank my mother, Amy Montoya, for proofreading this work.

Lastly, thank you to my computer for not dying during the course of this project. After 234 spreadsheets, it's finally finished.

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# Acronyms

**ALCM** air-launched cruise missile

**ALCS** airborne launch control system

**BMD** ballistic missile defense

**CEP** circular error probable

**DCS** digital control system

**DGZ** desired ground zero

**DOD** U.S. Department of Defense

**EMP** electromagnetic pulse

**EMT** equivalent megatonnage

**FERC** Federal Energy Regulatory Commission

**FEU** forty-foot equivalent unit

**GBI** ground-based missile interceptor

**GBSD** Ground-Based Strategic Deterrent

**GMD** Ground-Based Midcourse Defense

**HEMP** high-altitude electromagnetic pulse

**HV** high voltage

**ICBM** intercontinental ballistic missile

**INF** Treaty Intermediate-Range Nuclear Forces Treaty

**LCC** Launch Control Center

**LCSB** Launch Control Support Building

**LR** lethal radius

**MAF** Missile Alert Facility

**MIRV** multiple independently targeted reentry vehicles

**MMbpd** million barrels per day

**New START** New Strategic Arms Reduction Treaty

**NMCC** National Military Command Center

**NPT** Treaty on the Non-Proliferation of Nuclear Weapons

**$P_k$** probability of kill

**$P_k(n)$** multi-shot probability of kill

**PLC** programmable logic controller

**SALT** Strategic Arms Limitation Talks

**SCADA** Supervisory Control and Data Acquisition

**SLBM** submarine-launched ballistic missile

**SSBN** ballistic missile submarine

**$SSP_k$** single-shot probability of kill

**TEL** transporter erector launchers

**TEU** twenty-foot equivalent unit

**VLF** Very Low Frequency

**WTI** West Texas Intermediate

# Chapter 1

# Introduction

Nuclear weapons have not been used in war since their introduction in 1945, but the question of what would happen if they were employed remains ever-present. For both the United States and Russia, the primary role of nuclear forces has been deterrence, which has held for decades, but deterrence is predicated on the capacity to inflict damage in pursuit of objectives necessitates consideration of the possibility of nuclear war [14, 15]. Although the arsenals of the leading nuclear powers have been dramatically reduced since the Cold War, rising tensions and agreement terminations have prompted the Doomsday Clock to be moved to 100 seconds to midnight—the closest time in its history [16]. In such a climate, it continues to be worthwhile to assess the likely outcomes of a nuclear conflict in order to inform defense policy and treaty negotiations.

Since the Cold War, the United States and Russia have gradually reduced their nuclear arsenals through a series of bilateral agreements. In 1970, both nations ratified the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), which stipulates in Article VI that parties work to end arms races and move towards disarmament [17]. Starting with the Strategic Arms Limitation Talks (SALT I) in 1972, agreements have decreased the number of strategic warheads and delivery vehicles deployed by both countries while increasing verification measures and data exchanges [18]. However, cooperation has been declining. In 2019, the United States withdrew from the

Intermediate-Range Nuclear Forces (INF) Treaty[1] and the Open Skies Treaty,[2] citing Russian noncompliance [19, 20]. The current strategic arms control agreement, New Strategic Arms Reduction Treaty (New START) was extended for five years on February 3, 2021, just two days before it was set to expire; however, negotiations for a successor have not yet begun [19].

Meanwhile, Russia is in the midst of upgrading its nuclear forces, and the United States is planning to modernize its intercontinental ballistic missile (ICBM) force [21, 2]. On the American side, the proposal of replacing the Minuteman III ICBMs with the Ground-Based Strategic Deterrent (GBSD) missile is being hotly debated. Proponents for immediate replacement cite the reliability and survivability of ICBMs and express concern over maintaining the 50-year-old missiles when parts are no longer being manufactured [22, 23]. On the other hand, with the cost of the GBSD projected at nearly $100 billion, calls have been made to evaluate the feasibility of extending the lifetime of the Minuteman III missiles and/or reducing the size of the force [21, 23]. One role of the U.S. ICBM silos is to act as a "warhead sponge" by directing enemy fire away from cities and absorbing the brunt of the attack. In that capacity, the specifications of the missile matter little, thus a life-extended Minuteman III would be a cost effective means of maintaining deterrence.

Between impending negotiations on a new arms control treaty and decisions regarding the fate of the U.S. ICBM force, there is a need to analyze the current capabilities of the American and Russian nuclear forces, which can be accomplished through simulations of nuclear attacks. The deployed nuclear forces' abilities to survive attack and to inflict damage can be calculated and applied in evaluating policies regarding upgrades and changes in the composition of the arsenal. Conversely, assessing the ability of an adversary to inflict damage can reveal strategic weaknesses that should be addressed. Furthermore, the projected damages and surviving arsenals determined can indicate issues to be considered in future arms control negotiations, such as missile defenses, and can provide an estimate for how far arsenals can be

[1] The INF Treaty eliminated ground-launched ballistic and cruise missiles with a range between 500 and 5,000 km.

[2] The Open Skies Treaty permits aerial surveillance flights over participants' territory.

reduced while maintaining deterrence. This work aims to provide such information by simulating nuclear attacks on the United States by Russia in first strike, second strike with strategic warning, and second strike after a bolt-out-of-the-blue attack.

# Chapter 2

# Background

War gaming is by no means a new form of analysis, but previous work in the area has overlooked technical parameters and calculation methods, and the targeting strategies and metrics used have failed to consider critical outcomes. As further discussed in Sec. 4.1, the primary technical constraints in targeting are the yield and accuracy of the warheads and the configuration of the warheads on the missiles. With regard to targeting, the yield of a weapon—the explosive energy—determines the magnitude of the blast and thereby the radii of effects such as overpressure and thermal radiation; these radii also influence results by defining the areas in which to calculate casualties [24]. The accuracy of a missile is primarily a concern against counterforce targets, which require a detonation to be within a within a few hundred meters. Finally, missiles that carry multiple warheads in multiple independently targeted reentry vehicles (MIRVs) are subject to geographic constraints since the warheads carried by the same missile are limited in how far apart they can land. If these parameters are not accounted for in a simulation, then the modeled attack may not be achievable.

Along with the arsenal specifications considered, the calculation methods, targeting strategy, and analysis metrics used indicate the reliability and potential use of the results. The most commonly performed calculation is aggregating casualties, which can be estimated from the warhead and missile parameters and population of the target area or by simply scaling as a percent of the area's population (e.g., 80% of a given city's population would be considered casualties). Although easier to perform, scaling largely fails to account for the blast's spatial dependence on yield, leading to overestimation of fatalities, particularly in large metropolises. Other factors such as local fallout—which is dependent on the weather conditions at the time of the detonation—and long-term casualties from infrastructure damage increase the potential for error and subjectivity in aggregate casualty counts, which makes direct comparison between works using casualties as the metric difficult. Results could also be compared by the damage inflicted upon an adversary's arsenal and/or infrastructure, but those are not always considered, particularly if the strategies do not focus on similar targets. Some works emphasize counterforce targets—military sites—while others focus on countervalue targets—civilian targets—so the damages cannot be compared. It also bears considering whether the targeting strategy aligns with known Soviet or Russian nuclear policy and the rationale used to form it. Finally, no matter how well done an analysis may be, changes in arsenals, infrastructure, and populations eventually render results and conclusions out of date.

## 2.1 Cold War Era Analyses

Two complementary examples of nuclear war outcome analysis from the Cold War era are Sidney D. Drell and Frank von Hippel's "Limited Nuclear War," which considers counterforce attacks, and the MIT report "Nuclear Crash: The U.S. Economy After Small Nuclear Attacks" by M. Anjali Sastry, Joseph J. Romm, and Kosta Tsipis, which considers countervalue attacks [25, 26]. Drell and Von Hippel's analysis critiques the U.S. Department of Defense's (DOD) 1975 calculations by evaluating the fatality counts, fallout and sheltering assumptions, and reliability considerations and concludes that even the largest attack considered still leaves the United States with a large retaliatory arsenal and costs over 18 million American lives. As the authors note, the fatality counts reported by the DOD have potentially large errors since weather-dependent, near-term fallout deaths were included, 30-day long sheltering by civilians was assumed, and fratricide effects were excluded, the latter being a source of overestimation in the number of silos expected to survive. The total affected population also appears lower in the results since only fatalities, not injuries, are included. Furthermore, the study is obsolete since the U.S. now has 400 active silos, not 1,054; the yields and accuracies of the now-Russian arsenal have changed; and the population densities in impacted areas are markedly increased [25].

In contrast to Drell and Von Hippel's 1975 counterforce analysis, Sastry, Romm, and Tsipis's 1987 report only considers countervalue targets critical to the economy; in particular, petroleum refining, steel production, ports and airports, some manufacturing, etc. [26]. The goal of the work was to evaluate computer simulations of the economy following a strike and predict the impact and recovery time for various industrial sectors. While the economic analysis was well developed, the anticipated fatalities and injuries were approximated based on blast effects' radii, the area covered by the detonations, and the percent of the U.S. populations in those areas, so direct comparison of casualties between the publications would be futile. Although the consideration of bottleneck facilities such oil refineries and shipping ports is similar to this work, Sastry, Romm, and Tsipi's analysis does not include an attack on electrical grid beyond mentioning the possibility of an EMP detonation. The overall conclusions of their work demonstrated the clear vulnerability of the U.S. economy to even small attacks on critical industries [26]. Though the work is out of date in terms of the current and now-Russian arsenal, the targeting strategy used remains relevant.

## 2.2 Recent Analyses

A more recent and comprehensive analysis was performed by Matthew Kroenig and included in his 2018 book "The Logic of American Nuclear Strategy: Why Strategic Superiority Matters," but the calculation and targeting methods used as well as the disregard for the actual technical capabilities of the Russian arsenal render this scenario logistically impossible and its results appear to be vastly overestimated. First and foremost, rather than accounting for the varying yields of the warheads, Kroenig counted 100% of the population of the target cities as casualties citing long-term fallout effects and blast effects [27]. However, local fallout is only appreciable for surface bursts, which would be used against hardened targets such as silos, most of which are located in sparsely populated areas, and the fatalities and injuries from blast effects scale spatially with the warhead yield. For example, even for the highest yield warhead in the Russian arsenal, 800 kt, two detonations over the most densely populated part of the New York City metropolitan statistical area would cause approximately seven million short-term casualties while the population of the area is over 20 million [1, 28]. Kroenig also states that economic cost is not considered because "...there is not reliable, disaggregated data available on the GDP of all the metropolitan areas that are subject to attack in the following scenarios." On the contrary, that information is publicly available, disaggregated by metropolitan area, from the U.S. Bureau of Economic Analysis [27, 29].

Kroenig's first strike analysis is not technically possible because it ignores the distance limitations imposed by the MIRVed missiles and yield and accuracy considerations against hardened targets. In the first strike, three warheads were assigned to each of 440 silos, the two nuclear armed submarine bases, and three (sic) strategic air bases[1]; two warheads to each of 70 other military bases including Offut AFB (STRATCOM) and about 10 command and control targets; and two warheads each at the 131 most populous cities in the U.S. using up the full arsenal [27]. There are several issues with this plan, primarily that it treats all warheads as equal and independent. First, as described in Sec. 3.3 and Sec. 5.1.1, Russia does not have enough warheads with high enough yield and accuracy to target the silos 3-on-1—it does not even have enough to target all of the silos 2-on-1. Second, all of Russia's SLBMs and most of its ICBMs are MIRVed (see Tab. 4.1), so warheads cannot be arbitrarily divided into groups of two and three when the missiles carry four warheads that cannot separate by more than 100 km cross-range and 200 km down-range [30]. Third, when spatial effects of detonations and population density and/or GDP are considered, concentrating more warheads on the largest cities has a higher marginal damage than hitting more, smaller cities [31, 28, 1]. However, by taking the entire population

[1]there are actually five strategic air bases

of each target as the casualties, hitting more cities produces more casualties—this effectively produces the highest possible casualty counts with predictably massive over-estimations.

Interestingly, Kroenig does mention warhead yields and MIRVs when considering a Russian second strike even though they were absent from the first strike analysis. In spite of the acknowledgement, the second strike targeting strategy is also impossible because it includes targeting 15 cities with two warheads each while also stating that the surviving arsenal would be 9-800 kt ICBMs and 63-100 kt SLBMs in four warhead MIRVs, thus requiring the MIRVs to be split at distances that exceed technical limitations [27]. Furthermore, the study assumes the U.S ballistic missile defense system will destroy about a quarter of the incoming warheads, which by his own source may be an optimistic view of the system's capabilities considering the trajectory and speed of the target was known during the testing of the interceptors [32]. Kroenig only considers a bolt out of the blue first strike by the United States for the Russian second strike scenario; had strategic warning been assumed, far more Russian warheads would be expected to survive, thus leading to higher second strike casualties. Considering the results analysis, the casualty counting method for the first strike and the assumptions of no strategic warning and partially successful U.S. missile defenses for the second strike widen the gap in the results between the strikes, all of which directly support the other arguments in Kroenig's book [27].

Another Russian first strike analysis was done by Christopher Minson in 2019 entitled "Nuclear War Map: Simulating the Impact of a Nuclear Attack", but it has significant discrepancies between the stated targeting strategy and the animated map depicting the scenario; there are also major errors in the arsenal considerations and casualty calculations [33]. Minson's targeting strategy is based on the declassified document "Atomic Weapons Requirements Study for 1959" developed by the U.S. Strategic Air Command in 1956 [34]. Although an understandable basis, at the time it was developed, the United States had thousands more warheads than the Soviet Union—this is a different era with different arsenals and different priorities [35]. This also assumes that the Russian strategy mirrors the American strategy, which is unlikely considering the disparity between the arsenals as well as relevant writings from Soviet officers [36].

Regardless of the strategy, the targeting plan stated does not match the targeting plan used in the actual simulation. In the text, Minson lists, "...every significant military base in the United States is destroyed, as are the largest 100 cities and every state capital. Significant seaports, airports, oil infrastructure and hydroelectric facilities are also struck, per the goal of destroying economic infrastructure." [33]. Silo sites are also mentioned. However, his simulation only includes 388 targets using 1,069 warheads, which is not enough targets to include all described, and as in Kroenig's work, it is apparent that MIRV distance limits were not considered in targeting [37]. It is also clear from the map that either the silos were not targeted, or the specifications of the silos were not considered. On the map, around 20 warheads each hit F.E. Warren AFB and Malmstrom AFB and eight hit Minot AFB, but none were targeted at the actual missile fields, just the bases. Even if the detonations had occurred where the silos are located, 20 warheads is not enough to destroy 133 hardened silos that are spaced far enough apart to preclude destruction by a single warhead.

As for casualties, Minson considers 80% of each target's population as casualties based on a scaling of the Hiroshima data with a modern weapon yield [33]. There are several flaws with this method. First, it considers the Hiroshima casualty rate as a basis when both the number of casualties and the initial population of the city are highly uncertain [38]. Second, using Hiroshima as a basis is inaccurate because it presumes that all targets have a similar topography, geography, population density distribution, and building construction to Hiroshima in 1945 because otherwise, the casualty rate would not be the same [24]. Third, using a fixed yield-to-casualty rate assumes the yield of each warhead is proportional to the size of the blast effect, but the radius of blast effects scales non-linearly with yield. As Minson himself discussed, a 15 kt warhead does not have the same effects radius as a 500 kt or 5 Mt warhead [33].

There are other issues in Minson's analysis including attack duration, projected fallout, and the total Russian arsenal. The attack duration is shown as 120 minutes with military targets impacted first followed by countervalue targets in the second hour [33]. Even without regard to the ICBM and SLBM flight times, it would be impossible for the entire attack to be carried out in two hours because the Russian strategic bombers could not get within cruise missile range that quickly, especially when fully loaded [39, 40]. Although fallout is difficult to model and is not included in this work, Minson's scaling approximation is not applied to all surface bursts, so his work is not self-consistent. In cases of multiple warheads used against the same target, the fallout of only one of those warheads is displayed, which under-represents the fallout from those targets relative to targets hit with a single warhead. Heedless of dispersal, the amount of fallout is determined by the amount of fissionable material, which would increase with the number of warheads [33, 24]. Minson also states that the attack's 1,069 warheads is approximately 15% of "Russia's total nuclear capability," which calls into question what he used as the Russian arsenal since 1,069 is over half of the deployed strategic forces—including tactical and reserved weapons, even retired warheads, it would be a higher percentage [35]. As such, it is unclear what total arsenal and the specifications thereof were used.

Perhaps the most accurate modern analysis is PLAN A, which was developed by Princeton University's Science & Global Security Program in 2020. The simulation details a full nuclear war from limited use of tactical nuclear weapons in an escalation of a conventional conflict between Russia and NATO in Europe to full, strategic strikes by the U.S. and Russia [41]. As in this work, the casualty counts only consider immediate casualties and were calculated using data from NUKEMAP, which is based on the documented effects of nuclear weapons testing and ambient population data (see Sec. 3.2); as such, warhead and target specifications are accounted for, and the results can be compared both within the simulation and to other simulations such as this one that use the same or similar methods [41, 42].

That being said, PLAN A has notable issues in the targeting strategies used and further uncertainties since the arsenals and most of the targets are not disclosed. In the targeting strategy for the strategic phase after the war escalated beyond Europe, the United States launches a first strike, which Russia follows by launching on warning and targeting the U.S. silos, which brings up two issues [41]. First, although it is not known whether Russia has a launch-on-warning posture, literature indicates that the Soviet Union did not [36]. Furthermore, whether or not Russia would launch on warning, it does not make sense for Russia to target the U.S. silos knowing that they would be empty. In the final, countervalue phase of the war, PLAN A assumes the targets are the 30 most populous cities and economic centers of each side "using 5–10 warheads on each city depending on population size," all carried out by SLBMs [41]. However, beyond assuming that both countries follow the same attack plan, unless all of the American cities were hit with eight warheads each, this would once again require exceeding MIRV distance limitations since the Russian SLBM missiles each carry four warheads [6].

There is also the question of the strategic bombers. Aircraft were included in the tactical phase over Europe, but not in the strategic exchanges between Russia and the U.S. [41]. Even if it was assumed that Russia's strategic bombers were used in the tactical phase, the U.S. would logically have its bombers scramble when it launched its first strategic strike since the planes would otherwise presumably be destroyed in a retaliatory attack. Without further details, it is unclear why they were not included in the PLAN A simulation. The lack of detail adds further uncertainty since there is not enough information to determine whether missile accuracies and MIRV limitations were considered for the tactical and counterforce attacks.

## 2.3 Need for Updated, Modern Analysis

Considering these prior analyses on the outcomes of a nuclear attack on the United States by Russia, there arises a need for an analysis that is both up-to-date and technically possible as well as logical and self-consistent in targeting. This work seeks to address these shortcomings by considering missile and warhead specifications of the latest arsenal estimates in targeting and casualty counting and by developing strategies based on Russian capabilities and nuclear policy documents, historical Soviet stances, and modern infrastructure. This work also considers both counterforce and countervalue targets and analyzes not only immediate casualties but also expected infrastructure damage and surviving arsenals in order to gain a more comprehensive view of the outcomes. While immediate casualties are one metric of the severity of an attack, the surviving arsenal is also important in defining retaliatory capability, and damage to critical infrastructure is key in determining the impact on survivors, particularly in non-targeted areas, and whether widespread economic collapse is likely. In total, the aim of this work is to provide a contemporary comprehensive analysis of the outcomes of possible nuclear attacks on the United States by Russia in varying scenarios.

# Chapter 3

# Calculations

This chapter details the calculations used to account for missile accuracy, determine blast fatalities and injuries, estimate the number of silos that would survive an attack, and determine whether road-mobile missiles would survive an attack. The effects of fallout are not considered as it exceeds the scope of this project[1].

## 3.1 Distribution of Radial Error

Contrary to the saying "Close doesn't count except in horseshoes, hand grenades, and nuclear bombs," accuracy is critical in nuclear targeting, especially for hardened targets; therefore, error must be accounted for in order to estimate realistic damages rather than idealized ones. The prime example of this, as will be discussed in Section 3.3, is determining the survivability of silos. By performing random sampling assuming a normal distribution of detonation points about the desired ground zero (DGZ), over repeated trials, the average number of silos expected to survive a specified attack can be estimated. In turn, the number of silos expected to survive determines what forces are available for a retaliatory strike.

For each warhead, actual detonation coordinates can be calculated using the DGZ, the circular error probable (CEP) of the missile, and the direction of approach—the

[1] Accurate calculation of fallout requires classified information such as the fission fraction of the warhead and unknown data such as the weather at the time of detonation, which has high variability and cannot be predicted without knowing the day and time of the attack.

full derivation of the equations is detailed in Edmundson's work in "The Distribution of Radial Error and Its Statistical Application in War Gaming" [43]. In order to simplify the computation and increase the processing speed, the calculation was modified to use SI units and coded into Python, which allows for the calculation of an entire attack at once. Each warhead's detonation coordinates were found using the following method.

Because the circular error probable is the known measure of accuracy for the missiles being considered, the radial error is calculated in two-dimensions (rather than three-dimensions, which uses the spherical error probable). First, the standard deviation $\sigma$ is calculated as:

$$\sigma = \frac{CEP}{\sqrt{2\ln(2)}} \tag{3.1}$$

Wherein $CEP$ is the median radial error and $\sqrt{2\ln(2)} = 1.1774$ is a statistical constant for a circular Gaussian distribution [44]. The change in distance in each dimension is then calculated as:

$$d_x = \sigma r_x \tag{3.2}$$

$$d_y = \sigma r_y \tag{3.3}$$

Wherein $r_x$ and $r_y$ are Gaussian random numbers from a standard normal distribution, and $d_x$ and $d_y$ are the displacements in each dimension. The radial displacement $d$ and bearing $\theta$ are calculated using the Pythagorean theorem, and $\frac{\pi}{4}$ radians are added to the bearing in order to rotate the axis to align with the approximate direction of approach. The final detonation coordinates are calculated from the following equations [45]:

$$Lat_f = \arcsin(\sin(Lat_i)\cos\left(\frac{d}{R}\right) + \cos(Lat_i)\sin\left(\frac{d}{R}\right)\cos(\theta)) \tag{3.4}$$

$$Lng_f = Lng_i + \arctan\left(\frac{\sin(\theta)\sin(\frac{d}{R})\cos(Lat_i)}{\cos(\frac{d}{R}) - \sin(Lat_i)\sin(Lat_f)}\right) \tag{3.5}$$

Wherein $Lat_i$ and $Lng_i$ are the coordinates of the DGZ, $R$ is the radius of the

Earth[2], and $Lat_f$ and $Lng_f$ are the coordinates of the final detonation point. For the silo survivability application, the radial displacement $d$ is the result used in calculations; however, the final coordinates found are used for mapping applications.

## 3.2 Blast Casualties

The injuries and fatalities from blast effects were calculated using the NUKEMAP Bulk Casualty Calculator developed by Alex Wellerstein [46]. Wellerstein's program utilizes equations and data from "NUCLEAR BOMB EFFECTS COMPUTER (Including Slide-rule Design and Curve Fits for Weapons Effects)," by Fletcher, et al.; *The Effects of Nuclear Weapons*, 3rd edition by Glasstone and Dolan; and the 1979 Office of Technology Assessment report *The Effects of Nuclear War* to find the radii of the fireball and various overpressure and thermal radiation values which are then used to calculate projected injuries and casualties [42, 47, 24, 48]. The input population data is queried from the LandScan Global Population 2011 database developed by Oak Ridge National Laboratory and licensed by EastView, which details the ambient population[3] in each area [42].

Although NUKEMAP is the best available program for calculating short-term casualties, it is limited in that it only considers blast effects and neglects the effects of thermal radiation, building shielding, terrain, atmospheric properties, fires, and local fallout due to both the lack of data available and the computational intensity that such parameters would require [42]. However, the known sources of error are in competition as the absence of parameters such as terrain and shielding leads to overestimation while the absence of parameters such as thermal radiation, fires, EMPs, and local fallout leads to underestimation. Overall, NUKEMAP provides reasonable order of magnitude estimates of blast injuries and fatalities.

Due to the computational intensity of jointly calculating geographically overlap-

[2] $R = 6378.137$ km

[3] "Ambient population" corresponds to the average number of people physically in an area over a 24 hour period, not just the residential population, which accounts for commuters, tourists, visitors, etc.

ping detonations, overlaps were only accounted for in the second strike without strategic warning as it had few overlaps (see Sec. 5.3). For the first strike and second strike with strategic warning scenarios, overlaps were not considered, which is an unavoidable source of overestimation in the blast casualty results. However, the targeting was done so as to minimize overlaps, so the overall error is likely minor, especially since only immediate casualties are considered.

## 3.3 Silo Survivability

One of the most critical metrics of a missile silo is its survivability—how likely it is to survive an attack—which depends on the hardness of the silo and the specifications of the attack warhead and missile. Though difficult to calculate, the number of silos expected to survive an attack can serve as a measure of both the destructive capabilities of the attacking arsenal and the vulnerability of the targeted arsenal; it also provides an estimate of how many missiles would survive a first strike to be used in a retaliatory attack.

There are two key radial distances that determine survivability—the displacement and the lethal radius. As detailed in Sec. 3.1, the radial displacement of a warhead from the DGZ depends on the CEP of missile. The lethal radius (LR) is the distance from the detonation within which the target will be destroyed. The LR for a particular warhead and target can be calculated as:

$$LR = D_1 Y^{1/3} \tag{3.6}$$

Wherein $D_1$ is the characteristic silo hardness's overpressure radius[4] for a 1 kt surface burst and $Y$ is the yield of the attacking warhead in kilotons [24]. For a single detonation, if the displacement of the warhead from the DGZ is less than the LR, the target is destroyed.

Survivability is typically calculated with the probability of kill $P_k$, the probability

[4]e.g., for an attack on the U.S. silos, which are rated at a hardness of 2,000 psi, the 2,000 psi overpressure radius would be used

of destroying a silo; the single-shot probability of kill $SSP_k$, the probability of kill for a single warhead; and the multi-shot probability of kill $P_k(n)$, the probability of kill for multiple, independent warheads. The probability of kill can be calculated from one of the following equations [49, 44, 50]:

$$P_k = 1 - \exp\left(-\frac{LR^2}{2\sigma^2}\right) \tag{3.7}$$

$$P_k = 1 - \left(\frac{1}{2}\right)^{\left(\frac{LR}{CEP}\right)^2} \tag{3.8}$$

The $SSP_k$ factors in the reliability of the missile $R$ as:

$$SSP_k = RP_k \tag{3.9}$$

Eqs. 3.7, 3.8, and 3.9 give the probability of kill for a 1-on-1 attack. For n-on-1 attacks, $P_k(n)$ is calculated as:

$$P_k(n) = 1 - (1 - SSP_k)^n \tag{3.10}$$

However, these equations have limitations. First, they consider only one silo, not a strike on multiple silos, which would be the expected scenario in an attack. Second, the multi-shot probability assumes that each warhead attacking the silo has the same yield and CEP, which may not be the case if the warheads with the same specifications do not divide evenly. Most critically, the equation considers each warhead independently and ignores fratricide[5], which cannot be easily factored in because it has never been tested or observed, so there is no empirical data to determine the magnitude of the effects and how they scale with the time elapsed between waves [51, 52].

[5]Fratricide refers to the destructive effects the first detonated warhead exerts on subsequently arriving warheads that can divert or destroy the subsequent warhead(s); these effects include thermal and nuclear radiation, winds, and debris and vary with the time between waves. This presents a challenge to the attacker because the longer the time between waves, the lower the fratricide effects, but the longer wait also gives the attacked party time to fire the silo-based missiles in a retaliatory strike leading to strikes on empty silos [51].

In order to ameliorate the limitations of the theoretical calculation of silo survivability, this work determined silo survivability using a Monte Carlo simulation[6] coded in Python. Rather than evaluating the probability of a single silo surviving an attack, the program evaluates how many silos out of an entire ICBM force are expected to survive under a specified attack scenario. The input consists of entries for each warhead that includes the designation of the targeted silos, the detonation sequence (i.e., first, second, etc. warhead to hit that silo), the coordinates of the silo, the yield of the warhead, and the CEP of the missile. The detonation specifications are then used in multiple experiments of 10,000 trials in order to calculate the average number of silos that would survive the input attack.

For a single trial, the coordinates of the detonation point and the associated displacement from the DGZ due to missile inaccuracy of each warhead are found as detailed in Sec. 3.1. That displacement is then compared against the LR of the warhead as calculated in Eq. 3.6; if the displacement is less than the LR, the silo is counted as destroyed.

If the warhead is a subsequent detonation, fratricide is incorporated through random sampling by generating a random number in the range [0, 1); if the number is less than the fratricide rate, the subsequent warhead is assumed to miss its target, and the silo is marked as not destroyed. The process is repeated for all of the warheads in the attack. Next, the total number of silos that survive that trial are calculated and saved with each silo's designation used to prevent double-counting. Because there is no basis on which to determine the fratricide rate, repeated experiments were run at different fratricide rates in order to find both a range of surviving silos and the relation between the the fratricide rate and the number of silos that survive.

Each experiment consists of 10,000 trials, all at the same fratricide rate. After running all of the trials, the average number of surviving silos and the standard deviation are calculated, and, optionally, a histogram is generated to display the frequency of each number of silos surviving. The results of the experiments were then plotted with error bars representing the 95% confidence interval, as seen in Fig.

[6]A Monte Carlo simulation estimates a value through random sampling in repeated trials.

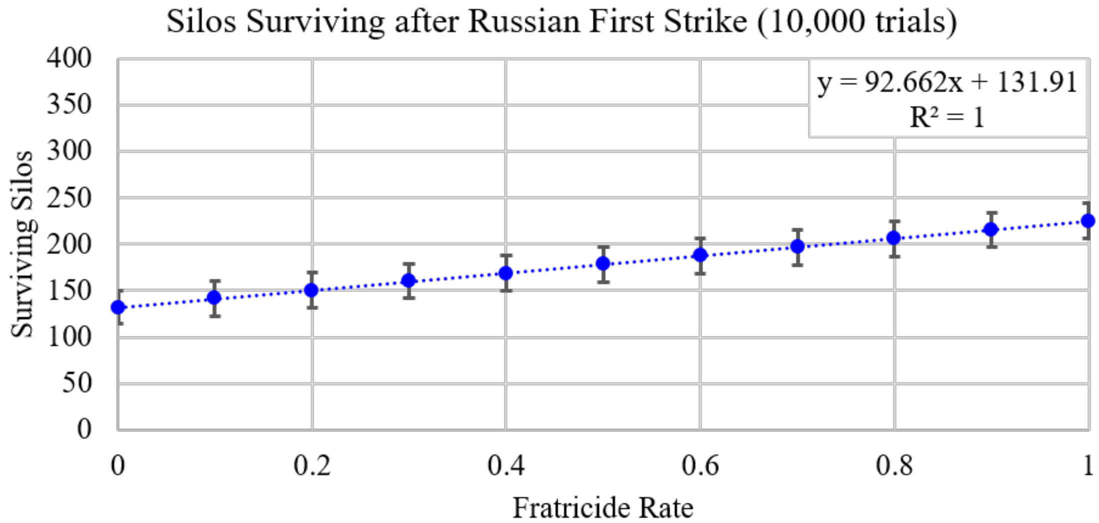


Figure 3-1: This plot depicts the number of U.S. ICBM silos out of the total 400 expected to survive the Russian first strike detailed in Sec. 5.1.1 over a range of fratricide rates. The data point at each rate indicates the experimental mean from 10,000 trials and the error bars indicate the 95% confidence interval. The minimum number of surviving silos is 131.9017 ± 17.9873 at a fratricide rate of 0%, and the maximum number of surviving silos is 224.6675 ± 18.8460 at a fratricide rate of 100%. The trendline shows that the relationship between the fratricide rate and the number of silos expected to survive is linear with $y = 92.662x + 131.91$ wherein $y$ is the number of surviving silos and $x$ is the fratricide rate.

3-1. The histograms of each experiment show a bounded Gaussian distribution, and the relation between the fratricide rate and the average number of surviving silos was found to be linear. This computation was used for both the Russian first strike outcomes in Chapter 6 to determine the inflicted damages on the U.S. arsenal and the Russian second strikes in Secs. 4.3 and 4.4 to determine how many silos are expected to survive a U.S. first strike.

## 3.4 TEL Survivability

While the primary defense of missile silos is their hardness, the primary defense of road-mobile ICBMs is their ability to leave their base and disperse—in Russia's case, into the surrounding forest. With sufficient warning time and insufficient satellite visibility for the attacking country to track the transporter erector launchers (TELs) carrying the missiles, the area that the TELs could be in would be too large to be strafed by the attacker's arsenal, thus ensuring the TELs would survive an attack. In this work, the necessary warning time was determined by using MATLAB to calculate and plot the number of W88 warheads needed to destroy the Russian TELs over a range of times and determining when the number of warheads needed exceeded the number deployed by the United States. W88 warheads were used because at 455 kt, they are the highest yield warhead currently deployed by the United States; furthermore, they are deployed on Trident II D5 SLBM missiles, which gives the fastest delivery time and accuracy [53].

For each base, the number of W88 warheads needed to cover the potential dispersal area was calculated assuming a TEL speed of 10 m/s and a hardness of 2 psi [54, 50]. First the maximum dispersal radius $R$ was found as the product of the speed and the time. The equivalent yield $Y$ in kilotons needed to achieve a large enough 2 psi overpressure radius was calculated as:

$$Y = \left(\frac{R}{D_1}\right)^3 \tag{3.11}$$

Wherein $D_1$ is the 2 psi overpressure radius for a 1 kt airburst. $Y$ was then converted to megatons[7] and used to determine the number of W88 warheads $n$ needed to cover the same area by equivalent megatonnage (EMT) as:

$$n = \left(\frac{Y}{0.455^{\frac{2}{3}}}\right) \tag{3.12}$$

As of October 2020, Russia's TELs are deployed at seven bases, so the number of warheads need per base $n$ is then multiplied by seven to find the total number of warheads needed to destroy the Russian road-mobile ICBMs at a specified warning time [2]. This calculation was performed over a range of times and then plotted as seen in Fig. 3-2. With 1 hour and 9 minutes of warning, the number of warheads needed exceeds the number of W88 warheads deployed by the United States, and with 1 hour and 50 minutes of warning, the number of warheads exceeds the number of warheads with a yield of 300 kt or greater deployed by the United States.

[7] 1 Mt = 1,000 kt

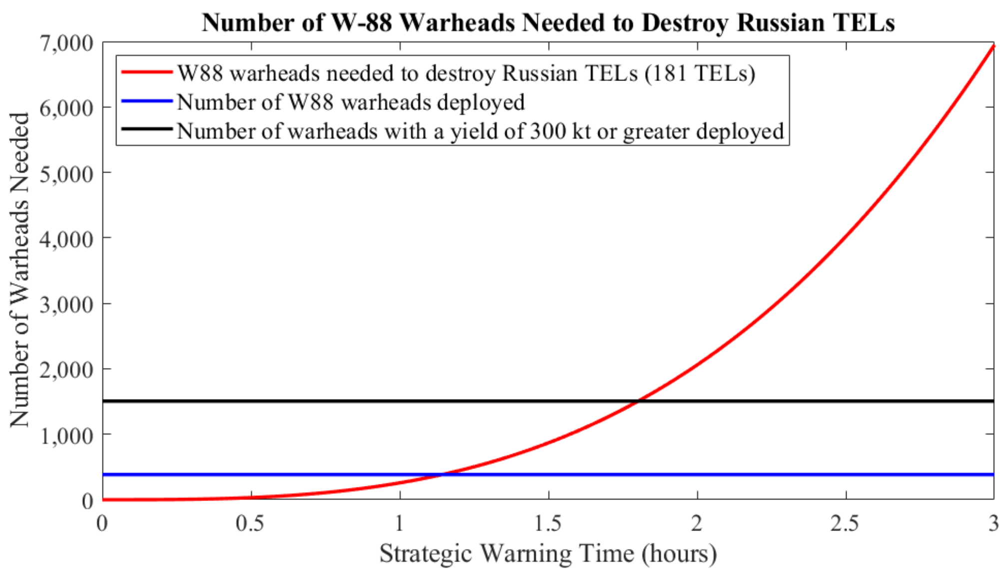


Figure 3-2: The red line indicates the number of W88 warheads needed to destroy all 181 of Russia's TELs with a given warning time. The blue line indicates the number of W88 warheads deployed by the United States, and the black line indicates the total number of warheads with a yield of 300 kt or greater deployed by the United States. The number of warheads needed exceeds the number of W88 warheads deployed at 1 hour and 9 minutes and exceeds the number of warheads with a yield of 300 kt or greater deployed at 1 hour and 50 minutes.

# Chapter 4

# Attack Scenarios

This chapter explains the Russian arsenal and attack scenarios used in this analysis. The arsenal specifications are based on the known status as of October 2020 as well as projections in light of ongoing modernization. The attack scenarios include a Russian first strike against the United States and two Russian second strikes launched after a U.S. first strike, one with strategic warning and one without strategic warning. Both second strike scenarios assume that Russia absorbs the U.S. first strike rather than launching on warning for two reasons. First, it is unlikely that Russia has a launch-on-warning posture because the Soviet Union did not and there have not been significant changes in the command and control system [36, 55]. Second, a strike launched on warning would follow the same targeting strategy detailed in the second strike with strategic warning scenario since the missiles that would be destroyed in a first strike are not necessary to meet all of the targeting objectives. As long as the U.S. ICBM silos are not targeted, launching on warning does not change the targeting enough to warrant developing and analyzing a separate scenario; at most, increased redundancy could be built in to account for potential losses, but that would have a minimal effect on the results, thus it was not included.

| ICBMs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Russian Name** | **NATO Name** | **Basing** | **Year** | **Range (km)** | **CEP (km)** | **Yield (kt)** | **Max Load** | **Launchers** | **Warheads** |
| RS-20V R-36M2 | SS-18 Satan | silo | 1988 | 1,500 | 0.22 | 800 | 10 | 46 | 77 |
| Avangard | SS-19 Mod 4 | silo | 2019 | 9,000 | 0.22 | HGV (550) | 1 | 2 | 2 |
| RS-12M | SS-25 Sickle | mobile | 1985 | 11,000 | 0.39 | 800 | 1 | 27 | 27 |
| RS-12M2 Torpol-M | SS-27 Mod 1 | silo | 1997 | 11,500 | 0.35 | 800 | 1 | 60 | 60 |
| RS12M1 Torpol-M | SS-27 Mod 1 | mobile | 2006 | 11,500 | 0.35 | 800 | 1 | 18 | 18 |
| RS-24 Yars | SS-27 Mod 2 | silo | 2014 | 10,500 | 0.35 | 550 | 4 | 18 | 72 |
| RS-24 Yars | SS-27 Mod 2 | mobile | 2010 | 10,500 | 0.35 | 550 | 4 | 135 | 540 |
| **Subtotal** | | | | | | | | **306** | **796** |
| **SLBMs** | | | | | | | | | |
| **Russian Name** | **NATO Name** | **Tubes/ SSBN** | **Year** | **Range (km)** | **CEP (km)** | **Yield (kt)** | **Max Load** | **Launchers** | **Warheads** |
| R-29R | SS-N-18 M1 Stingray | 16 | 1978 | 6,500 | 0.9 | 200 | 3 | 16 | 48 |
| R-29RM Sineva | SS-N-23 M1 | 16 | 2007 | 11,500+ | 0.5 | 100 | 4 | 80 | 320 |
| R-30 Bulava | SS-N-32 | 16 | 2014 | 8,000+ | 0.5 | 100 | 6 | 64 | 256 |
| **Subtotal** | | | | | | | | **160** | **624** |
| **Ballistic Subtotal** | | | | | | | | **466** | **1420** |
| **Strategic Bombers** | | | | | | | | | |
| **Russian Name** | **NATO Name** | **ALCM** | **Year** | **ALCM Range (km)** | **CEP (km)** | **Yield (kt)** | **Max Load** | **Launchers** | **Warheads** |
| Tu-95MS6 | Bear-H6 | AS-15A | 1984 | 2,500 | 0.25 | 250 | 6 | 14 | 84 |
| Tu-95MS16 | Bear-H16 | AS-23B | 1984 | 5,000 | 0.25 | 250 | 16 or 8 | 7 | 56 |
| Tu-95MSM | Bear-H Mod | AS-23B | 2015 | 5,000 | 0.25 | 250 | 14 | 18 | 252 |
| Tu-160 | Blackjack | AS-15A | 1987 | 2,500 | 0.25 | 250 | 12 | 11 | 132 |
| **Subtotal** | | | | | | | | **50** | **524** |
| **Total** | | | | | | | | **516** | **1944** |

Table 4.1: Estimated Russian Strategic Nuclear Forces as of Oct. 2020 [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13]

## 4.1 Russian Arsenal

The specifications of the Russian arsenal are critical parameters in developing strategies for targeting the United States and performing damage calculations because they define the technical capabilities and limitations of their force. As shown in Tab. 4.1, Russia's strategic nuclear forces currently include seven intercontinental ballistic missiles (ICBMs), three submarine-launched ballistic missiles (SLBMs), and four strategic bomber configurations, which differ in basing, range, accuracy, yield, and maximum load. Of those, the yield—the explosive energy measured as the equivalent mass of TNT that would produce the same amount of energy[1]—and the accuracy measured as the circular error probable (CEP)—the radial distance from the aiming point within which half of the warheads are expected to land [56, 57]—are of primary concern in calculating the blast effects, which will be covered more extensively in later sections. The basing determines the survivability of the missiles and, together with the range, the time of flight needed for the missile to reach its target(s). The maximum load denotes the number of warheads that an individual delivery system can carry. For bombers, that is simply how many air-launched cruise missiles (ALCMs) it can hold at full capacity. For ballistic missiles, the value corresponds to the maximum number of warheads that can be loaded on each missile that has multiple independently targeted reentry vehicles (MIRVs), though not all missiles are fully loaded. MIRVs must be taken into account when targeting because the warheads they carry are limited in how far apart they can travel[2], which imposes a geographic restriction.

Because official data on the composition of the Russian arsenal is not publicly available, the arsenal used in this work is based on the aggregate data from the September 2020 New START data exchange and assumptions made in light of ongoing modernization efforts [6, 2]. According to the September 2020 New START data exchange, Russia has 510 deployed ICBMs, SLBMs, and Heavy Bombers with 1,447 countable warheads [58]. Under New START, only one warhead is attributed to each

[1] 1 kt $= 4.184 \times 10^{12}$ J

[2] 100 km cross-range, 200 km down-range [30]

bomber in the aggregate count; therefore, the actual number of warheads is several hundred greater than stated [59]. In this work, all bombers are assumed to carry their maximum load with the newest compatible ALCMs.

The aggregate number of warheads does not correspond with the maximum loading of the ballistic missiles as it would exceed the limits set by the treaty, though which missiles are downloaded and by how much is unknown. For the SLBMs, the Bulevas and Sinevas are assumed to be loaded with four warheads. On account of the modernization of the arsenal, the newest ICBMs, the SS-27 Mod2s, are assumed to be fully loaded with the rest of the warhead inventory distributed among the older SS-18s, loaded at one or two warheads each.

Because of their differing characteristics, ICBMs, SLBMs, and strategic bombers are suited for different target types. In the Russian arsenal, the ICBMs have the highest yield warheads, which makes them the best to use against hardened targets, such as missile silos. SLBMs have the shortest time of flight out of the triad, so they are best for use against the most urgent targets such as command centers. However, as shown in Tab. 4.1, the SLBMs have the worst accuracy and the lowest yields, so redundancy is needed against hardened targets to increase the kill probability. Finally, because of their long time of flight relative to ballistic missiles, the ALCMs carried by the strategic bombers are best directed against countervalue targets since it is expected that the United States will have launched any surviving missiles in a retaliatory strike before Russia's ALCMs could reach them.

## 4.2 Russian First Strike

The first scenario considered is a first strike against the United States by Russia with the goals of damage limitation and economic devastation. Due to being a first strike, damage limitation is the primary goal because a retaliatory strike is to be expected. Following the plan outlined in Sec. 5.1, the counterforce targets include the U.S. ICBM silos and strategic forces' bases in order to minimize the return fire as much as possible. However, this a largely futile goal for Russia since the United States typically has 8–

10 nuclear-armed submarines patrolling at any time, thereby ensuring that at least 900–950 warheads would survive a Russian first strike [53]. Consequently, it would also make sense not to target the ICBMs and reallocate the high yield warheads to countervalue targets since Russia could expect an overwhelming response regardless. In this work, the targeting used for the Russian second strike with strategic warning could also be used as a first strike that does not target the missile silos.

The countervalue part of the attack is designed to inflict "unacceptable damage" as suggested by Russia's nuclear deterrence policy released in June 2020 [14]. The traditional definition of "unacceptable" damage in deterrence theory first promulgated by U.S. Secretary of Defense Robert McNamara is the loss of 20–25% of the population and 50–67% of industrial capacity [60]. Although the blast casualties from this scenario are expected to fall short of 20%, the inordinate damage to critical infrastructure would cause long-term fatalities that far exceed the unacceptable range. In order to inhibit industrial capabilities, the key choke points of the oil industry and the electrical grid are targeted (see Sec. 5.1) so as to interrupt manufacturing and any supply chains that depend on petrochemical products such as plastics. Shipping ports are also targeted in order to disrupt imports to replace damaged equipment or make up shortfalls.

Because it is a first strike, the full Russian arsenal as detailed in Tab. 4.1 is considered available for the attack although not all of it is used. 520 SLBM warheads were not used in the first strike because the targeting objectives could be fulfilled without them, and they are a survivable asset. The strategic bombers and silo-based ICBMs would be destroyed by a return strike, and the road-mobile ICBMs would be needed to target the U.S. silos, but submarines could disperse at sea, so the SLBMs were the missiles reserved. Given how many targets were hit, using those warheads would be overkill. Although 520 100-kt warheads would not deter the U.S. from retaliating, in terms of deterrence, they exceed the arsenals of the other nuclear-armed NATO nations—France and the United Kingdom—and in terms of a bilateral conflict, it leaves open the possibility of launching a third strike [35].

While a first strike would be a departure from Soviet policy and suicidal in the face of the expected U.S. retaliation force, Russia's 2020 nuclear deterrence policy release does include situations in which Russia would consider first use of nuclear weapons [36, 7, 14]. The explicitly listed scenarios include: ballistic missile attack or any use of nuclear weapons against an ally, use of other types of weapons of mass destruction (e.g., chemical or biological) against Russia or an ally, attack on a government or military site critical to the nuclear forces' response, and an overwhelming conventional attack that threatened the existence of Russia. That being said, nuclear first use could also be at a tactical rather than strategic range. Alternatively, it could also be a limited strike that does not necessarily escalate all the way to global nuclear war. For this scenario, it is assumed that Russia is making the first strike using intercontinental range weapons detonating on U.S. soil. Escalation, then, would be a ball in the United States' court—a study beyond the range of this work.

## 4.3 Russian Second Strike with Strategic Warning

The Russian second strike with strategic warning scenario details an attack on the United States by Russia following a first strike on Russia by the United States for which Russia has at least two hours of warning to go on high-alert. The U.S. first strike is assumed to have included a counterforce attack intended to reduce Russia's arsenal. As a second strike, economic destruction is the top priority with the same countervalue targeting priorities as the first strike. As a secondary objective, command centers and some strategic forces' bases are hit to destroy any warheads held in reserve and to impede the ability of the U.S. to wage war and to recover from the attack. The U.S. ICBM silos are not targeted because they are presumed to be empty after the first strike by the United States and thereby not a priority target.

The available Russian arsenal was determined to be the forces expected to survive a U.S. first strike with at least two hours of warning. The SLBMs are all expected to survive since the submarines could be dispersed. The bombers may or may not survive depending on how long it would take Russia to receive warning of an incoming attack and transmit the order to scramble; however, the cruise missiles carried by the bombers were not used in this scenario, thus their survival is not of paramount importance. Using the calculation detailed in Sec. 3.4, with two hours of warning, the number of warheads required to destroy the Russian road-mobile ICBMs exceeds the deployed U.S. forces (see Fig. 3-2); therefore, all of the road-mobile ICBMs are expected to survive.

For the silo-based ICBMs, the method described in Sec. 3.3 was used to calculate the number of Russian silos expected to survive a U.S. first strike in four potential attacks with all 126 Russian silos in use assumed to have a hardness of 1,500 psi [7]. The first options are an attack using the Minuteman III ICBMs (CEP = 0.12 km) with 200 335-kt warheads and 52 300-kt warheads for a 2-on-1 attack or 126 335-kt warheads for a 1-on-1 attack [61, 53]. The other options use the Trident II SLBMs (CEP = 0.09 km) carrying 455-kt W88 warheads for either a 2-on-1 or 1-on-1 attack [62, 53]. Based on the results listed in Tab. 4.3, for a 2-on-1 attack using ICBMs and either attack using SLBMs, none of the Russian ICBMs silos are expected to survive a U.S. first strike. As such, none of the silo-based Russian ICBMs were considered available for this strike.

| **Attack** | **Surviving Silos** |
|---|---|
| Minuteman III ICBMs (335 kt and 300 kt), 2-on-1 | $0.0417 \pm 0.4025$ |
| Minuteman III ICBMs (335 kt and 300 kt), 1-on-1 | $2.0700 \pm 2.7858$ |
| Trident II SLBMs (455 kt), 2-on-1 | $0.0 \pm 0.0$ |
| Trident II SLBMs (455 kt), 1-on-1 | $0.0151 \pm 0.2390$ |

Table 4.2: This table lists the number of Russian silos expected a U.S. first strike with specified attack plan with the 95% confidence interval. The 126 Russian silos are all assumed to have a hardness of 1,500 psi. The values were determined using a Monte Carlo simulation of 10,000 trials each as detailed in Sec. 3.3.

As in the first strike scenario, not all of the available arsenal was used in the attack as not all warheads were needed in order to achieve the targeting objectives. 18 800-kt ICBM warheads, 116 550-kt ICBM warheads (4×550-kt MIRVs), 580 100-kt SLBM warheads (4×100-kt MIRVs), and all surviving cruise missiles were held in reserve. These could be used in an additional exchange or held as a deterrent against a third strike by the U.S. or an attack by America's nuclear-armed NATO allies France and the United Kingdom. If this strategy was used as a first strike that did not target the

ICBM fields, then the remaining warheads would give Russia the ability to launch a third strike against the U.S.

## 4.4 Russian Second Strike after Bolt out of the Blue Attack

The final scenario considered is a Russian second strike against the United States following a surprise first strike on Russia by the United States that is assumed to have included a counterforce attack designed to reduce the available Russian arsenal as much as possible. With few missiles surviving, the goal of this attack is to inflict as much economic damage as possible using all surviving warheads. The only counterforce targets hit in this strike are the White House and the Pentagon in order to impede the coordination of recovery efforts. Because not enough warheads are available to hit all of the primary targets in the first strike scenario, the priority of the targets was determined based on their daily economic contribution as detailed in Sec. 5.3.

The available Russian arsenal was determined to be the forces expected to survive a U.S. first strike with 15-minute warning of an incoming attack but without prior warning that would lead Russia to put its forces on high-alert. As in the second strike with strategic warning scenario, none of the silo-based ICBMs are expected to survive (see Tab. 4.3). Without sufficient time to disperse, the road-mobile ICBMs (see Fig. 3-2), strategic bombers, and SLBMs on submarines in port are also not expected to survive. This leaves only SLBMs on patrolling submarines. Russia typically has 1–2 submarines out at any given time; for this work, it is assumed that one submarine carrying 16 Sineva SLBMs (4×100-kt MIRVs) from the Northern Fleet and one submarine carrying 16 Bulava SLBMs (4×100-kt MIRVs) from the Pacific Fleet survive for a total of 32 missiles carrying 128 warheads [6, 30]. All 128 warheads are used in the attack.

# Chapter 5

# Targeting

The targeting strategy for this work has two goals: damage limitation and economic devastation. Damage limitation is primarily applicable to the Russian first strike scenario, which assumes that the United States would launch a retaliatory strike, whereas the Russian second strike scenarios place higher emphasis on economic destruction. Neither the Russian first strike nor Russian second strike with strategic warning employ all of the available warheads as the full available arsenal was not necessary to achieve the objectives of the attack plans.

In every attack scenario, the number of targets exceeds the number of detonations because of clusters that enable the destruction of multiple targets with a single warhead[1]. The exact coordinates were used for all counterforce targets because of the need for accuracy against hardened targets, as was discussed in Sec. 3.1. For contervalue targets, the detonation coordinates were determined by manual and computational means in order to hit as many targets as possible with each warhead with all countervalue targets within the 5 psi overpressure radius of a detonation. Although the blast pressure alone may not be sufficient to destroy all targets, when combined with other effects of nuclear explosions including debris, the targets would be expected to sustain enough damage to render them inoperable [24]. For example, oil industry targets and oil-cooled transformers are particularly susceptible to fires,

[1] In this work, "target" refers to an objective to be destroyed while "detonation" refers to the blast caused by a single warhead. One detonation may be intended to destroy multiple targets.

which could lead to secondary explosions. In addition to direct targeting, Python scripts were written to identify countervalue targets that fell within the 5 psi overpressure radius of each other both to identify overlapping detonations within a single list of targets and to identify collateral damage in a list of potential targets based on a list of planned detonations. This allowed for the identification of lower priority targets that were destroyed even though they were not directly targeted.

## 5.1 Russian First Strike

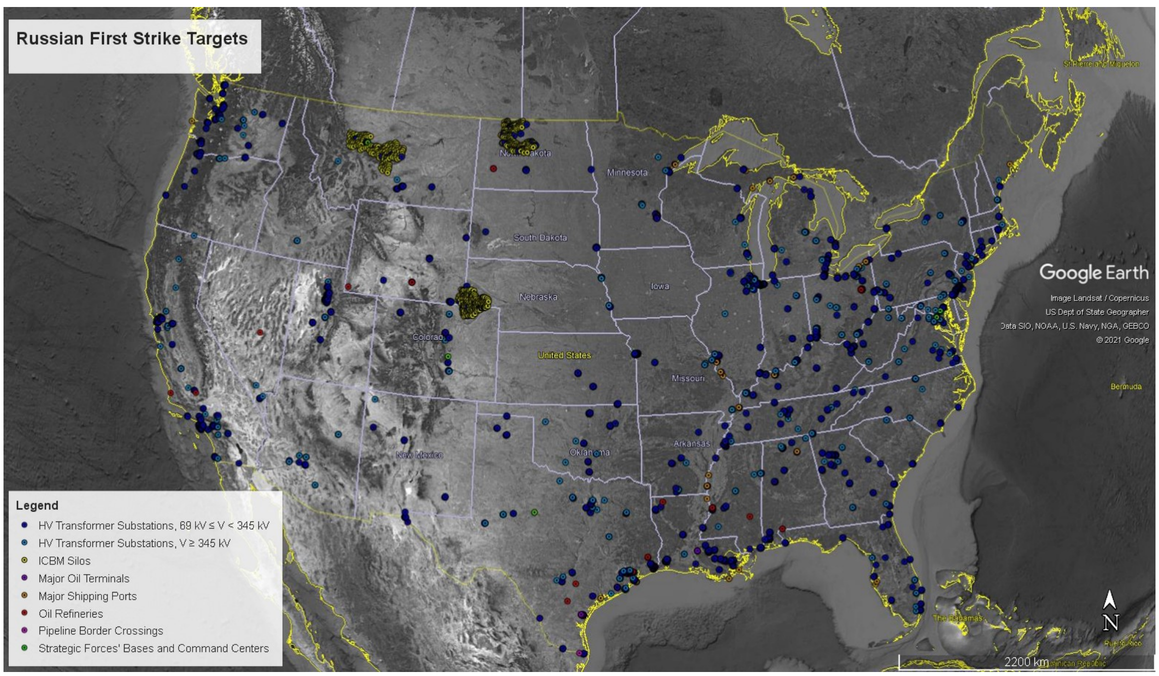


Figure 5-1: This map displays all of the targets in the contiguous United States hit in the Russian first strike scenario with the targets color-coded by category. Not all targets are visible due to marker overlaps. Mapping by Google Earth with map data from Image Landsat/Copernicus, US Dept. of State Geographer, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO, ©2021 Google.

In the case of a first strike by Russia, the top priority is to destroy as much of the American strategic forces as possible in order to minimize the retaliation and to destroy key command centers in order to impede the chain of command and disrupt launch orders. The second priority is a countervalue attack designed to destroy the U.S. economy and hamper recovery efforts, which is achieved here by disrupting the oil industry, the electrical grid, and shipping ports. This approach emphasizes long-term damage over blast casualties since the former would more effectively shift the balance of power in Russia's favor than the latter. The blast fatalities and immediate injuries would be much higher if major cities were targeted directly, but in the long run, the human cost of eliminating electricity and oil for years could be even higher.

This scenario does not exhaust the available arsenal as not all warheads were needed to hit all of the intended targets. All of the ICBMs are used because they are needed to attack the U.S. missile silos, and all of the cruise missiles carried by the strategic bombers are used because they would not survive a retaliatory strike. Nonetheless, 130 SLBM missiles carrying 520 warheads (4×100 kt MIRVs) are kept as a reserve deterrent. Although they are not expected to deter against a return strike by the United States, 520 warheads exceeds the nuclear warhead inventory of all other nations and is greater than the combined inventories of America's NATO allies of France and the United Kingdom [35].

### 5.1.1 ICBMs

The United States currently has 400 loaded ICBM silos and 50 empty silos that are kept warm[2] with 150 silos at each of three missile fields operated by missile wings at Minot AFB in North Dakota; Malmstrom AFB in Montana; and F.E. Warren AFB spanning Wyoming, Nebraska, and Colorado (see Fig. 5-2) [63]. Each missile wing is divided into three squadrons of 50 missiles, and each squadron is divided into five flights of 10 missiles. Each flight in the wing is designated by a letter of the alphabet, and each facility is designated by a number with the Missile Alert Facility (MAF)—comprised of the above ground Launch Control Support Building (LCSB) and the underground Launch Control Center (LCC)—designated as 01 and the ICBM silos as 02–11 [64, 65, 66]. For this work, it is assumed that Russia knows which 50 silos are empty due to sufficient satellite visibility of the removal process, thus only the 400 loaded silos are targeted [67]. While it is known that the 50 empty silos are distributed between the three wings, the exact silos are unknown to the author. For

[2] A silo in "warm" status is emptied of its missile but not destroyed and is capable of being reloaded.

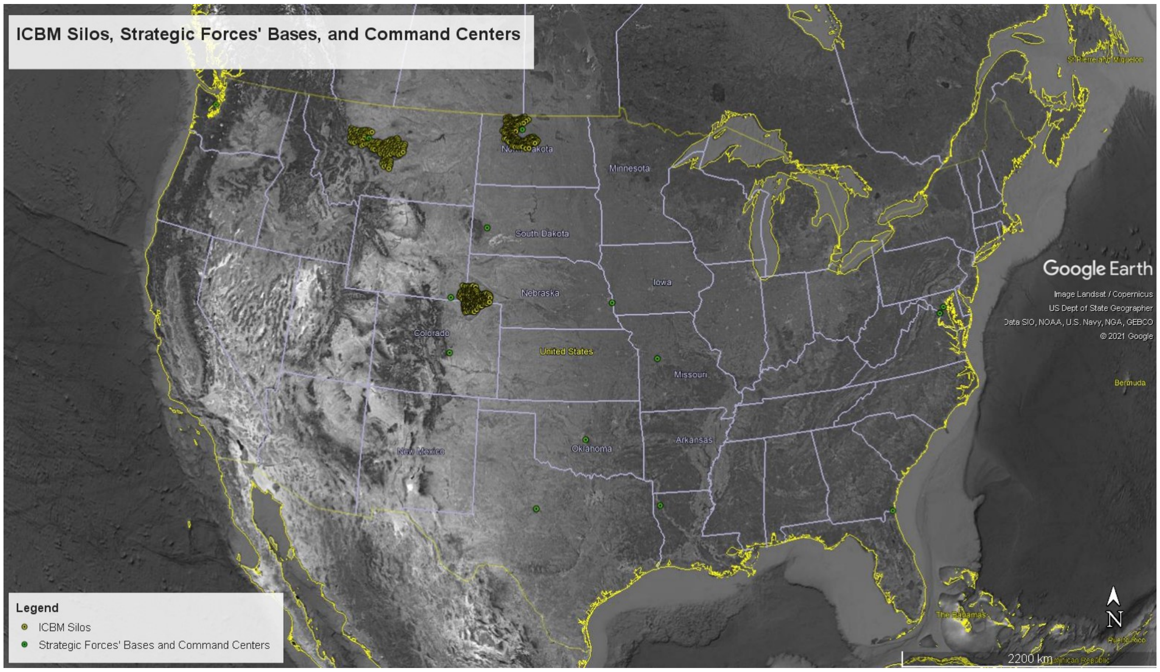


Figure 5-2: This map displays the U.S. ICBM silos and other counterforce targets hit in the contiguous United States in the Russian first strike scenario with the targets color-coded by category. Not all targets are visible due to marker overlaps. Mapping by Google Earth with map data from Image Landsat/Copernicus, US Dept. of State Geographer, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO, ©2021 Google.

this work, the silo designated as 11 was removed from each flight, A-02 was removed from each wing, and F-02 was removed from Minot AFB and Malmstrom AFB in order to achieve a relatively even distribution of the empty silos. Due the uniformly low human population density of the missile fields, the effect of this assumption on the blast casualties is negligible.

For this scenario, the U.S. ICBM silos are targeted with all but two missiles of Russian ICBM force and three SLBM missiles. 397 silos are targeted 2-on-1 with ICBM warheads, and three silos, one per wing, are targeted 4-on-1 with SLBM warheads due to the lower missile accuracy and warhead yield of the Russian SLBMs and the MIRV constraint of four warheads per missile. For each wing, the silo targeted with SLBM warheads is the westernmost silo in order to minimize fratricide effects on the ICBM warheads as the SLBMs will arrive first.

The LCCs are not targeted for two reasons: hardness and airborne backup. For comparison, each Minuteman III launch tube[3] extends about 80 feet below the surface and consists of 1/4 inch steel plate with reinforced bars and approximately 14 inches of reinforced concrete around with a foundation of 2 inch steel plate and 4 feet of concrete; the blast door on top is 3.5 feet thick reinforced concrete weighing over 90 tons, and the missile itself has a suspension system to minimize shock [68, 69, 64]. The estimated hardness of these silos is 2,000 psi [51]. In contrast, the LCCs are 32 feet underground and are constructed of 1/4 inch steel plate surrounded by 3-4 feet of reinforced concrete. Inside, the acoustical enclosure containing the launch control consoles is shock isolated with a suspension system allowing up to two feet of bouncing in any direction [64]. Furthermore, even the destruction of all 15 LCCs won't prevent the U.S. from launching a retaliatory strike—each E-6B Mercury aircraft carries an airborne launch control system (ALCS), which allows it to launch the U.S. ICBMs even if the LCCs are destroyed, and there is always at least one E-6 in the air [70, 71].

### 5.1.2 Other Counterforce

In addition to the ICBM silos, the United States' strategic bomber bases, ballistic missile submarine (SSBN) bases, and relevant command centers are targeted as part of the damage limitation strategy (see Fig. 5-2). These bases include SSBN bases Naval Submarine Base King's Bay in Georgia and Naval Base Kitsap - Bangor in Washington and the strategic bomber bases Barksdale AFB in Louisiana, Dyess AFB in Texas, Ellsworth AFB in South Dakota, Minot AFB in North Dakota, and Whiteman AFB in Missouri. Additionally, Malmstrom AFB in Montana and F.E. Warren AFB in Wyoming are targeted because they house the missile wings that operate the ICBM force, and Tinker AFB in Oklahoma is targeted because it houses the E-6 fleet, which serves as an airborne command post for the strategic forces and carries the ALCS and Very Low Frequency (VLF) transmitters to communicate with the SSBNs [72, 73, 70, 71]. For the command centers, the White House and the National Military Command Center (NMCC) in the Pentagon issue the nuclear launch orders, which

[3] "Launch tube" refers to only the part of the silo that contains the missile and excludes the surrounding equipment and maintenance rooms, which are shock isolated from the launch tube [64].

are then carried out by STRATCOM (Offut AFB in Nebraska), NORAD (Peterson AFB in Colorado), and Global Strike Command (Barksdale AFB in Louisiana), so those bases are targeted. As a precaution, CYBERCOM (Fort Meade in Maryland) is also targeted to prevent a retaliatory cyberattack [73, 74]. In the first-strike scenario, all of these bases and command centers are hit with SLBM warheads because they are the fastest, which is imperative in an attempt to impede the issuance of launch orders, and because all of the Russian ICBM warheads are needed to target the U.S. ICBM silos. Multiple warheads are assigned to each target due to the lower warhead yield and missile accuracy of the Russian SLBMs.

### 5.1.3 Oil

Transportation in the United States is overwhelmingly dependent on petroleum products, which makes oil a prime target for causing economic devastation. In 2019, transportation accounted for 28% of America's total energy use of which 91% was fueled by petroleum products [75]. Beyond transportation, petroleum products include asphalt, lubricants, and petrochemical feedstocks which are used in the production of plastics [76]. A large-scale disruption to petroleum production could quickly domino into global product shortages due to supply chain disruptions such as those that occurred in March 2021 due to petrochemical plants shutting down amid electricity shortages caused by a freeze in Texas [77].

Oil refineries serve as a choke point in the petroleum-production process as crude oil must be refined for most uses. There are 135 oil refineries in the United States[4] with a total capacity of about 19 million barrels per day (MMbpd) as of January 2020 [78]. In addition to domestic refining, the U.S. imports 2.3 MMbpd of non-crude petroleum liquids and refined petroleum products via petroleum ports and pipelines [79]. In order to cut off the United States' access to petroleum products, the 135 refineries, all petroleum ports within the states[5], and the six border crossings of

[4]excludes the Kingshill site in the U.S. Virgin Islands due to geographic separation

[5]excludes Ponce and San Juan, Puerto Rico due to geographic separation and the lack of refineries in Puerto Rico

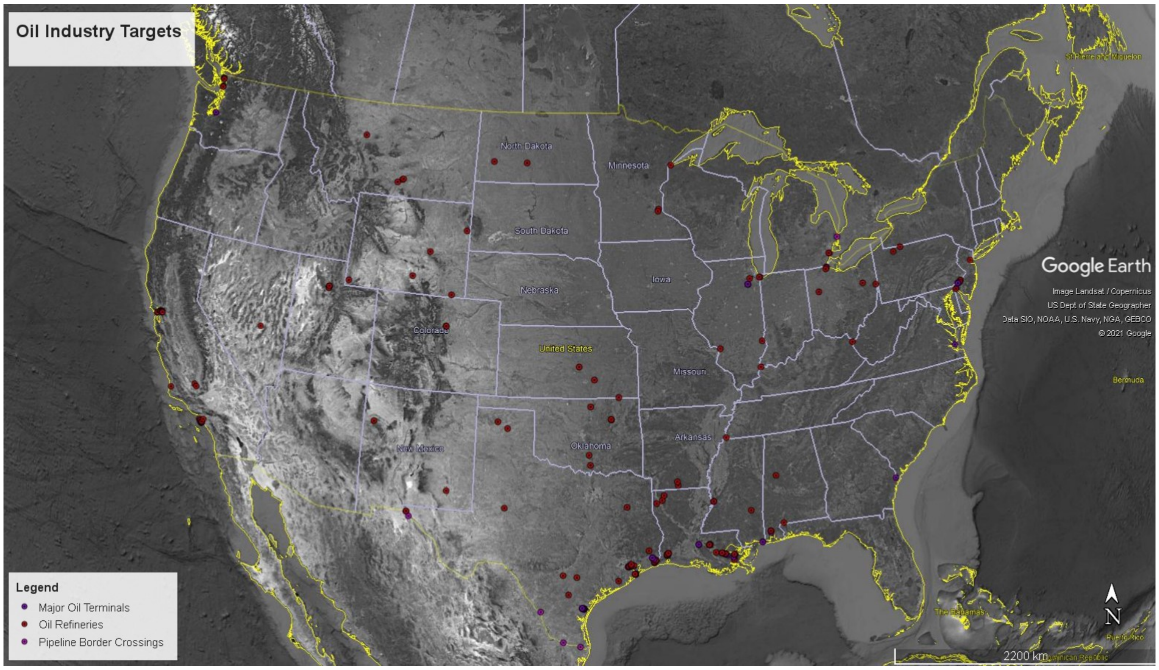


Figure 5-3: This map displays the oil industry targets in the continental United States hit in the Russian first strike scenario with the targets color-coded by category. For clarity, only major oil terminals are shown. Not all targets are visible due to marker overlaps. Mapping by Google Earth with map data from Image Landsat/Copernicus, US Dept. of State Geographer, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO, ©2021 Google.

pipelines carrying products[6] are targeted with ALCMs carried by Russian strategic bombers (see Fig. 5-3) [80]. The four strategic oil reserve sites are not targeted because they contain crude oil, not refined products [81].

### 5.1.4 Shipping

In order to impede commerce, recovery efforts, and the replacement of equipment (e.g., transformers), the 148 largest ports[7] by total tonnage, excluding those already targeted as petroleum ports, are attacked with ALCMs carried by Russian strategic bombers (see Fig. 5-4) [82, 83]. Total tonnage was used rather than foreign tonnage because it better serves as an indicator of port capacity since terminals and equipment could be used for imports rather than domestic freight in an emergency.

[6]These six pipelines are primarily used to export refined products from the United States to Mexico (five) and Canada (one), but they are targeted because the direction of the flow in a pipeline can be reversed.

[7]150 largest ports except Ponce and San Juan, Puerto Rico, which are excluded due to geographic separation

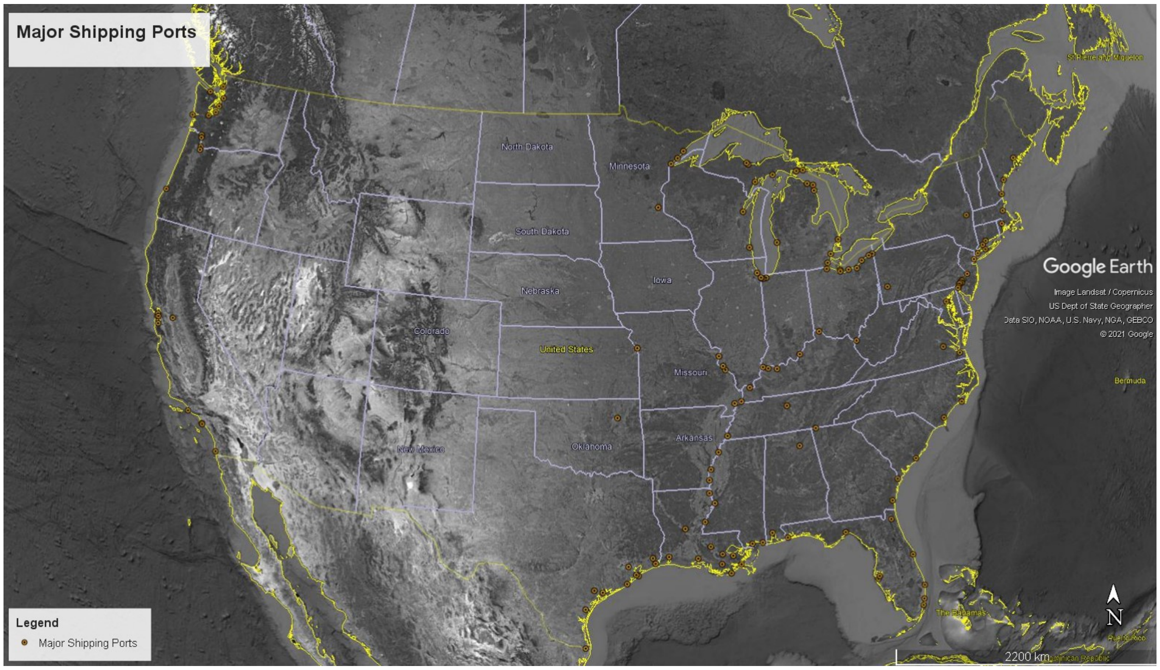


Figure 5-4: This map displays the major shipping ports in the contiguous United States hit in the Russian first strike scenario. Not all targets are fully visible due to marker overlaps. Mapping by Google Earth with map data from Image Landsat/Copernicus, US Dept. of State Geographer, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO, ©2021 Google.

### 5.1.5 Electricity

The final component of the countervalue attack is directed towards the electrical grid in order to cause a nationwide blackout that would likely take years to restore. Due to its critical role in the residential, industrial, and commercial sectors, electricity is an ideal target as its absence will devastate the country. The top residential uses of electricity include space heating, space cooling, water heating, refrigerators and freezers, and lighting; the top commercial uses include computers, refrigeration, space cooling, and ventilation; and the top industrial uses include machine drive, process and boiler heating, facility HVAC, electrochemical processes, and refrigeration [84]. Compounded with the devastation of the oil industries, even vital industries, such as hospitals, that have backup generators will lose power.

Perhaps the most critical use of electricity is the pumping and treatment of water and wastewater. Irrigation, thermoelectric power production, industrial production, livestock, mining, and the drinking water supply all depend on electricity, thus a prolonged nationwide blackout would lead to food and water shortages [85, 86]. Furthermore, 61.6% of water withdrawls come from freshwater surface sources; if surface sources become contaminated by fallout, ground sources will need to be used, and groundwater requires about 31% more electricity than surface water due to pumping requirements [85]. Without electricity and without oil, transportation, communication, heating, cooling, agriculture, and water will all be crippled. The long-term damage and loss of life is unfathomable.

The first part of the attack on the electrical grid consists of exo-atmospheric detonations of two 800-kt warheads from Russian ICBMs over the continental United States in order to produce electromagnetic pulses (EMPs) large enough to cover most of the country as well as parts of Mexico and Canada. The waveform of a high-altitude EMP (HEMP) consists of three pulses: E1 with a duration of about 100 ns, E2 with a duration of about 1 ms, and E3 with a duration of tens of seconds. E1 is primarily a danger to microelectronics including consumer electronics and control and communication systems such as SCADAs (Supervisory Control and Data Acquisition), DCSs (digital control systems), and PLCs (programmable logic controllers) [87]. Additionally, transformers could be affected by surges in sensor and control lines propagating to conduits and relays, and distribution systems may be disrupted by insulator failure, damage, or flashover [88]. E3 mainly affects long transmission lines by inducing currents on the order of 1,000 A, which could in turn cause irreparable damage to transformers left vulnerable after E1 and E2 weaken protection from relays. The full extent of the possible damages and blackouts is unknown as atmospheric nuclear testing was banned in 1963, shortly after the phenomena were observed in Hawaii from the U.S. Starfish test and in Kazakhstan from three Soviet tests, all in 1962. Simulations have not reached a consensus on the effects, but exo-atmospheric detonations are expected to impact electronics nationwide as the U.S. grid is not hardened to withstand EMPs [24, 87, 88].

The second part of the attack on the electrical grid targets high voltage (HV) transformer substations[8]. HV transformers serve to step up the voltage of transmit-

[8]One substation may have multiple HV transformers

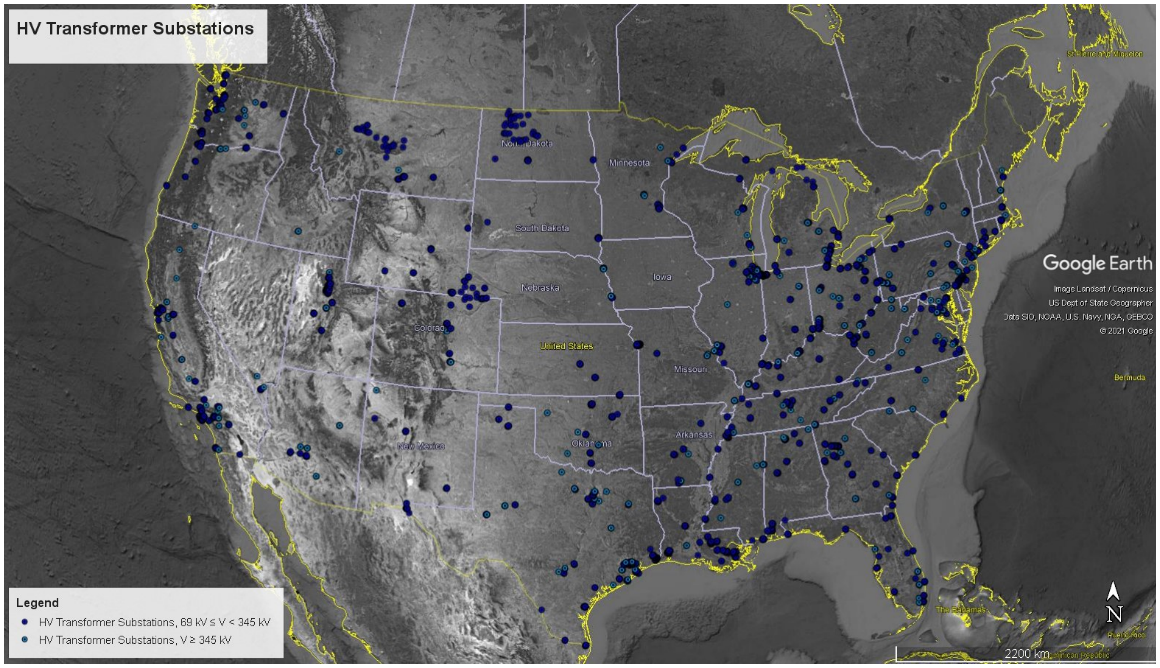


Figure 5-5: This map displays the high-voltage (HV) transformer substations in the continental United States hit in the Russian first strike scenario with the targets color-coded by maximum voltage $V$. Not all targets are visible due to marker overlaps. Mapping by Google Earth with map data from Image Landsat/Copernicus, US Dept. of State Geographer, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO, ©2021 Google.

ted electricity from the medium voltage (15–50 kV) output by power plants to high voltages (138–765 kV) in order to minimize power losses along transmission lines[9] [89]. Although HV transformers comprise less than 3% of U.S. transformers, they carry 60–70% of the country's electricity [90].

Despite their critical role, HV transformers are vulnerable to attack with recent examples including rifle attacks against a 500 kV substation in Metcalf, CA in April 2013 and against a substation in Florida in 2005 with the latter resulting in a local blackout [90]. To date, there have been no successful attacks against multiple HV transformer substations, but an unreleased study by the Federal Energy Regulatory Commission (FERC) reported by the Wall Street Journal concluded that a coordinated attack on just nine substations across the three grid interconnections[10] could cause a nationwide blackout lasting at least 18 months [91]. The long time frame

[9]By Ohm's Law, $P = RI^2$ and $V = IR$ where $P$ is power, $R$ is resistance, $I$ is current, and $V$ is voltage. Holding the resistance of the transmission line constant, increasing the voltage causes the current to decrease, which in turn causes the power loss to decrease.

[10]Eastern Interconnection, Western Interconnection, and Texas Interconnection

is due in large part to the replacement process as most HV transformers are custom built, and utilities have few, if any spares [89]. HV transformers take at least 6 to 12 months to manufacture, not including wait and transportation times, and usually cost between $2 million for a 230 kV unit to $15 million for a 765 kV unit. There are only five manufacturers in the United States, none of which build units of 500 kV or greater, so most units must be imported; without electricity or oil, all units would need to be imported. Transportation poses another obstacle as the size of the HV transformers necessitates the use of specialized, 36-axle railcars, but the United States has fewer than 20 of these. Although there are some flatbed trucks that can also transport them, capacity limits and route restrictions limit their use [91, 90, 89]. A nuclear attack against the most critical HV transformers would cause widespread blackouts and completely overwhelm the manufacturing capacity. Moreover, the attacks on the oil industry and major shipping ports detailed in the previous subsections would impede the import and transport of replacement transformers and prolong the outages. If it takes about a year to replace a single HV transformer, how long would it take to replace several hundred or even several thousand?

All of the ALCMs carried by the Russian strategic bombers remaining after targeting the oil industry and shipping sites are used up on HV transformer substations in the continental United States. Since the bombers would not survive a retaliatory strike, there is no value in holding them as a reserve deterrent. Without knowing the power ratings or line currents, the substations were ranked in order of importance by the product of the maximum voltage and the number of lines in an approximation of Ohm's Law[11] where the number of lines serves as a proxy value for current. The substations were then divided into two groups based on their maximum voltage: greater than or equal to 345 kV and between 69 kv (inclusive) and 345 kV [92]. The 323 highest ranked substations with a maximum voltage of 345 kV or greater were targeted directly; among those, 64 aim point coordinates were shifted in order to hit additional substations in the same group.

Due to their geographic location and separation from the contiguous states, all

[11] $P = IV$ where $P$ is power, $I$ is current, and $V$ is voltage

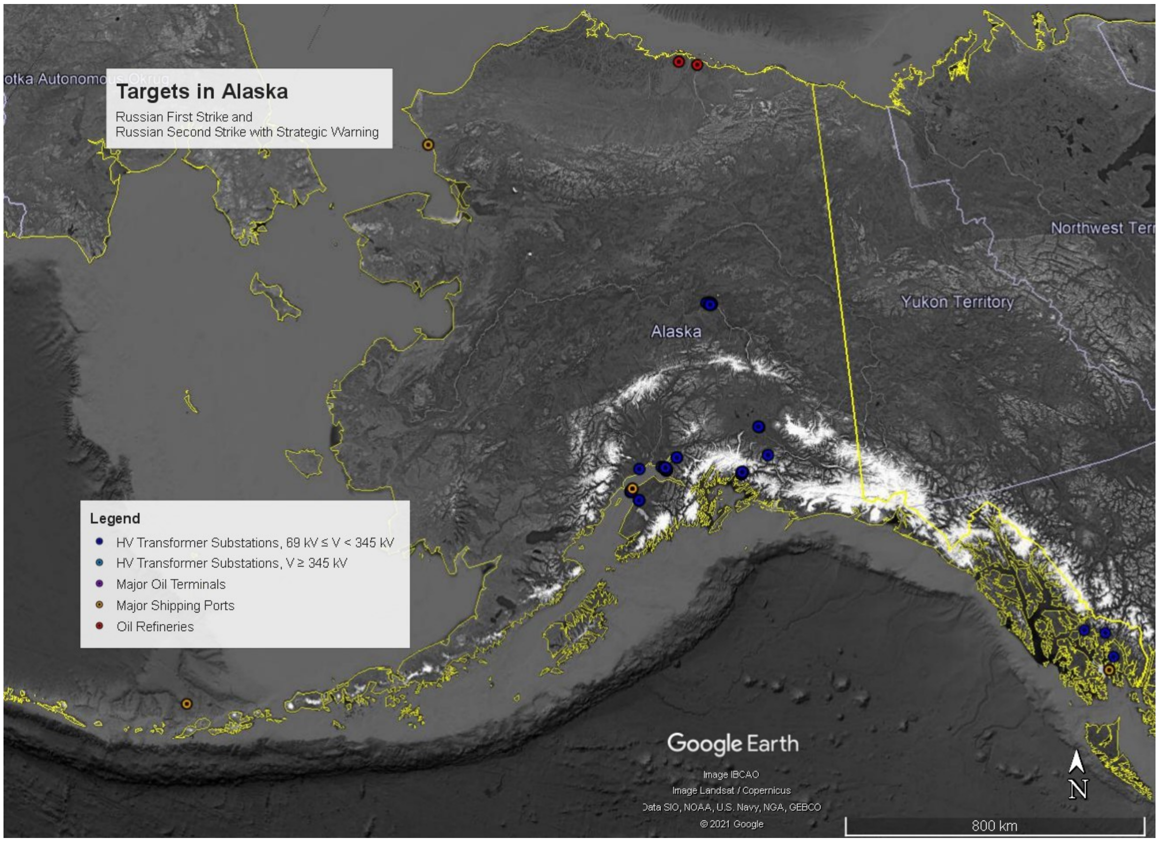


Figure 5-6: This map displays all of the targets in Alaska hit in the Russian first strike and the Russian second strike with strategic warning scenarios with the targets color-coded by category. Not all targets are visible due to marker overlaps. Mapping by Google Earth with map data from Image Landsat/Copernicus, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO, ©2021 Google.

of the targets in Alaska and Hawaii are hit with SLBM warheads from Bulava SSBNs stationed at Rybachiy [65, 3]. The Bulava's missiles are MIRVed; therefore, 20 HV transformers are targeted to use the excess warheads on the missiles targeting Alaska's and Hawaii's oil refineries, petroleum ports, and major shipping ports[12] (see Figs. 5-6 and 5-7). These targets include all of the substations with a maximum voltage of 230 kV, which are the highest voltage substations in those states. For each MIRV group, the substations were chosen by the highest ranking (maximum voltage multiplied by the number of lines) within range.

For all states, in addition to the substations deliberately targeted, substations within the 5 psi overpressure radius of a detonation were counted as collateral damage

[12]There are no high voltage transformers within MIRV range of Prudhoe Bay, AK; Kivilina, AK; and Unalaska Island, AK, so an entire MIRV was used on each of those sites

in order to better reflect the scope of the destruction. For the first strike scenario, in total, 485 substations with a maximum voltage of 345 kV or greater and 2,324 substations with a maximum voltage between 69 kv (inclusive) and 345 kV were damaged or destroyed (see Fig. 5-5).

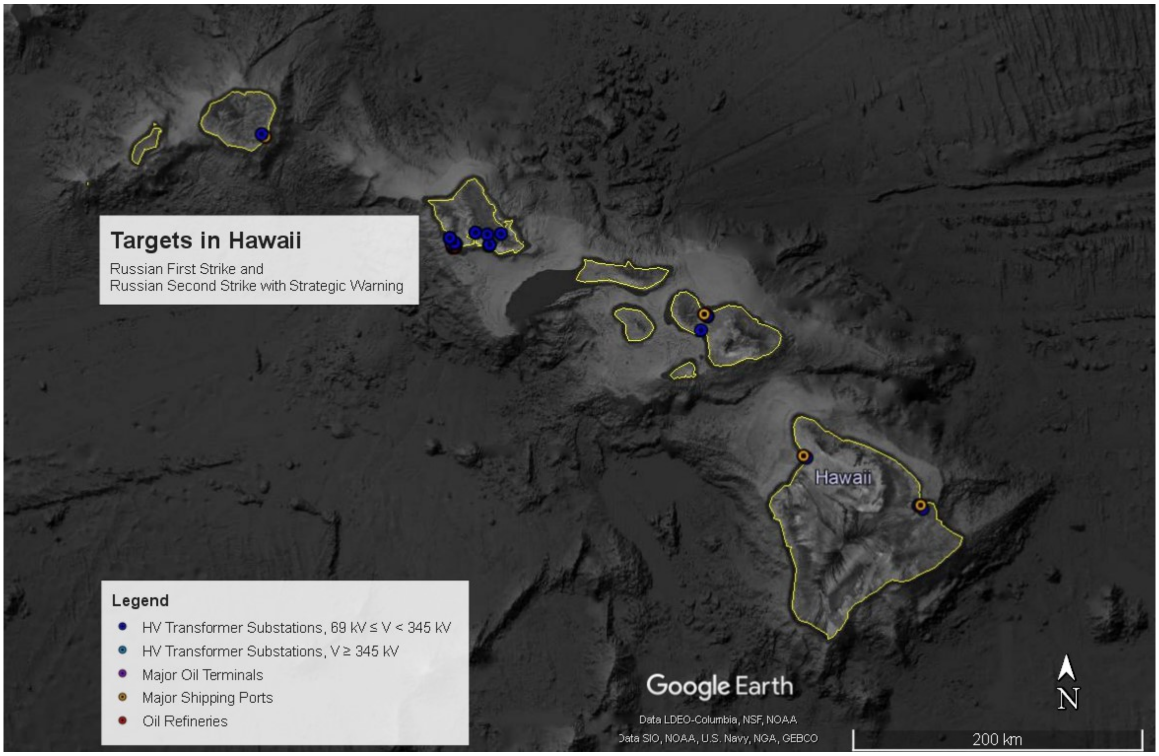


Figure 5-7: This map displays all of the targets in Hawaii hit in the Russian first strike and the Russian second strike with strategic warning scenarios with the targets color-coded by category. Not all targets are visible due to marker overlaps. Mapping by Google Earth with map data from Data LDEO-Columbia, NSF, NOAA, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO.

## 5.2 Russian Second Strike with Strategic Warning

For the case of a Russian second strike with strategic warning, the primary objective is a countervalue attack on the oil industry, electrical grid, and major shipping ports, as detailed in Sec. 5.1. As described in the scenario overview in Sec. 4.3, all of the Russian road-mobile ICBMs and SLBMs are expected to survive the first strike, and the bombers might survive albeit with lower payloads. However, the entire available arsenal was not used—18 800-kt ICBM warheads, 116 550-kt ICBM warheads (4×550-

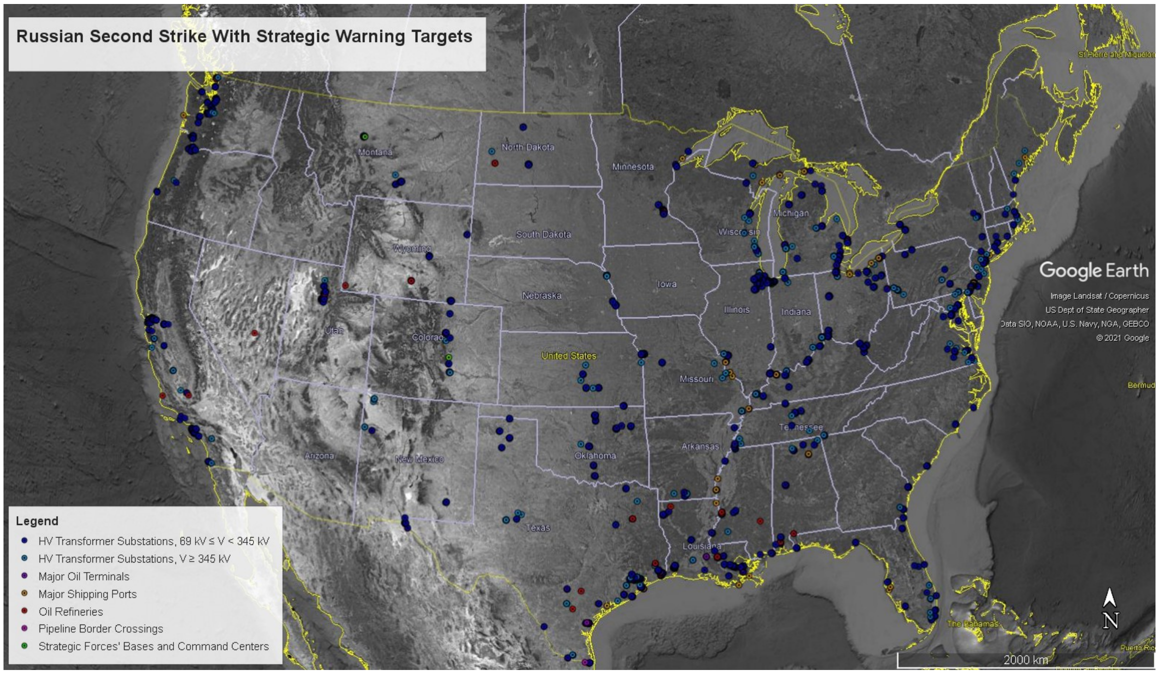


Figure 5-8: This map displays all of the targets in the contiguous United States hit in the Russian second strike with strategic warning scenario with the targets color-coded by category. Not all targets are visible due to marker overlaps. Mapping by Google Earth with map data from Image Landsat/Copernicus, US Dept. of State Geographer, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO, ©2021 Google.

kt MIRVs), 580 100-kt SLBM warheads (4×100-kt MIRVs), and all surviving cruise missiles were reserved. The main reason that less than half of the available warheads were utilized is that the U.S. silos are not targeted in this scenario since it is assumed the United States would use its ICBMs in the first strike, thus leaving the silos empty. Because the silos were not targeted, the surviving Russian ICBM warheads were available for use in the countervalue attack. Between clustered targets and higher warhead yields, fewer warheads were needed to fulfill the targeting objectives.

As in the first strike scenario, all oil refineries, petroleum ports, and major shipping ports within the the 50 states[13] and all international border crossings of pipelines carrying refined petroleum products were targeted with 550 kt and 800 kt warheads carried by Russian ICBMs as seen in Fig. 5-8. Because the 550 kt warheads are in MIRVs with four warheads per missile, aim points were found in groups of four that ensured all detonations would fall within the geographic constraints of the reentry

[13]sites in Puerto Rico and the U.S. Virgin Islands were excluded due to geographic separation

vehicles.[14] In order to use excess warheads from MIRVs directed towards oil and shipping targets, high voltage (HV) transformer substations were hit with priority towards higher ranked substations following the method in Sec. 5.1.5. In addition to those targeted, all substations within the 5 psi overpressure radius of a detonation were counted in order to accurately reflect the expected damages of the strike. In total, 3,233 HV transformer substations—317 substations with a maximum voltage of 345 kV or greater and 2,916 substations with a maximum voltage between 69 kV (inclusive) and 345 kV—were damaged or destroyed.

Although counterforce targets were not prioritized in this attack because it is a second strike and damage limitation is no longer necessary, all of the strategic forces bases and command centers listed in Sec. 5.1.2 except for Dyess AFB and Ellsworth AFB were hit in order to use up warheads in MIRVs. Oil and shipping targets without enough other targets within range to use an entire MIRV were hit with 800 kt warheads carried by the SS-27 Mod 1 missiles as those have only one warhead per missile. An additional two 800 kt warheads were detonated exo-atmospherically in order to generate EMPs, the same as in the first strike scenario in Sec. 5.1.5. The first strike targets were also used for Alaska and Hawaii, which were hit by SLBMs (see Sec. 5.1.5 and Figs. 5-6 and 5-7).

## 5.3 Russian Second Strike after Bolt out of the Blue Attack

The goal of the Russian second strike without strategic warning is to inflict as much economic destruction as possible. With only two submarines carrying 16 missiles each expected to survive (see Sec. 4.4), a maximum of 128 detonations in 32 regions are possible. Because the submarines carry 100 kt warheads, the overpressure radii from each detonation are smaller, thus fewer targets can be hit by each detonation. For counterforce targets, only the Pentagon and the White House were targeted in order to disrupt the national leadership and incite panic. To rank the potential

[14] 100 km cross-range, 200 km down-range

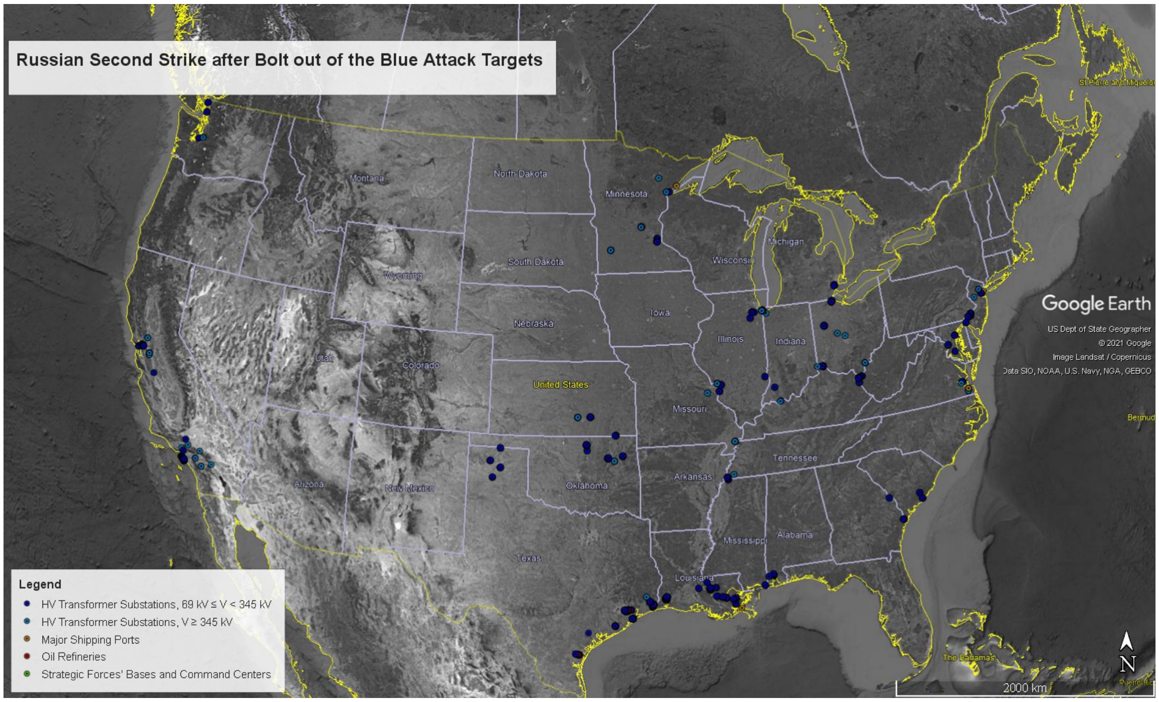


Figure 5-9: This map displays all of the targets in the contiguous United States hit in the Russian second strike without strategic warning scenario with the targets color-coded by category. Not all targets are visible due to marker overlaps. Mapping by Google Earth with map data from Image Landsat/Copernicus, US Dept. of State Geographer, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO, ©2021 Google.

countervalue targets in order of significance, the average economic impact of each oil refinery, shipping port, transnational petroleum product pipeline, and high voltage (HV) transformer substation was estimated in terms of 2019 USD handled per day. Because all petroleum ports are connected to a shipping port and/or oil refinery, they were not separately ranked. Due to a lack of data to quantify the expected damages, no warheads were used as high-altitude EMPs for this scenario.

For both oil refineries[15] and petroleum product pipelines, the daily economic impact was calculated from capacity in units of barrels per calendar day and the average of the West Texas Intermediate (WTI) and Brent crude oil prices for 2019[16] [93, 94, 95, 96, 97, 98]. The value for shipping ports was calculated from the the total annual tonnage and the 2014 average freight rate in USD[17] per 40-foot equivalent unit

[15] For this strike, only refineries with atmospheric distillation (133/135) were considered as others would be downstream.

[16] 2020 data was not used due to the oil market crash and resulting price volatility

[17] adjusted for inflation to 2019 USD [99]

(FEU)[18] for the trans-Pacific market from Shanghai to the United States West Coast or East Coast depending on each port's location [82, 101]. For HV transformer substations, the power was approximated using the known number of lines and maximum voltage along with an estimated current of 700 A, which is approximately two-thirds of the average HV transmission line capacity [102]. The economic value was then found for each substation using the estimated power and the 2019 average wholesale electricity price for the major trading hub serving the majority of the state in which the substation is located [103].

The estimated monetary values and relative rankings were then used to assign the 128 warheads to targets in 32 groups of four detonations each so as to maximize the economic impact while adhering to the geographic limitations of the MIRVs. In total, 27 major shipping ports, 69 oil refineries, 53 HV transformer substations, 0 pipeline border crossings, the White House, and the Pentagon were targeted as seen Fig. 5-9. Additionally, two oil refineries, 16 substations with a maximum voltage of 345 kV or greater, and 549 substations with a maximum voltage between 69 kV (inclusive) and 345 kV were within the 5 psi overpressure radius of a detonation.

[18] 1 FEU is equivalent to 24 tons [100]

# Chapter 6

# Results

In this chapter, the outcomes of the three simulated attack scenarios are described. The resulting blast fatalities, injuries, total casualties, and damages to critical infrastructure are detailed in Tab. 6.1. Additionally, the maps showing the detonations in each attack are Fig. 6-1 for the Russian first strike scenario, Fig. 6-2 for the Russian second strike with strategic warning, Fig. 6-3 for those two scenarios in Alaska and Hawaii, and Fig. 6-4 for the Russian second strike after a bolt-out-of-the-blue attack. For the Russian first-strike scenario—the only strike which targets the U.S. ICBM silos—the number of silos expected to survive is also discussed.

Of the three scenarios in this work, the Russian second strike with strategic warning yields the highest blast casualties, though the immediate casualties for all three scenarios pale in comparison to the likely long-term casualties. Even though the Russian second strike with strategic warning used approximately one-third the number of warheads the Russian first strike used; not targeting the ICBMs allowed for the reallocation of the highest yield Russian warheads to the countervalue targets, which led to an increase in both fatalities and injuries while meeting the same targeting objectives. That being said, the goal of the countervalue mission for both scenarios is economic destruction, not maximum casualties. If the goal was to maximize casualties, the 520 warheads held in reserve in the Russian first strike scenario and the 723 or more warheads held in reserve in the Russian second strike with strategic warning would have been used, no counterforce targets would be included, and city centers would

| | Russian First Strike | Russian Second Strike with Strategic Warning | Russian Second Strike without Strategic Warning |
|---|---|---|---|
| **Immediate Casualties** | | | |
| Blast Fatalities (million) | 11.65 | 16.70 | 1.57 |
| Blast Injuries (million) | 38.07 | 53.46 | 6.20 |
| Total Blast Casualties (million) | 49.73 | 70.17 | 7.76 |
| **Infrastructure Damaged or Destroyed** | | | |
| Oil Refineries | 135 | 135 | 71 |
| Major Shipping Ports | 148 | 148 | 27 |
| Petroleum Products Pipeline Border Crossings | 6 | 6 | 0 |
| HV Transformer Substations, $V \geq 345$ kV | 485 | 317 | 69 |
| HV Transformer Substations, $69 \text{ kV} \leq V < 345$ kV | 2,324 | 2,916 | 549 |

Table 6.1: This table enumerates the results of each strike scenario analyzed in this work. The first section lists the calculated blast fatalities, injuries, and total casualties in millions; some totals differ from the sum of the fatalities and injuries due to rounding. The second section tallies the critical infrastructure damaged or destroyed, which includes all installations within the 5 psi overpressure radius of a detonation. The total number of installations within the 50 states that could potentially be hit are 135 oil refineries, 148 major shipping ports, 6 petroleum products pipeline border crossings, 1,875 HV transformer substations with a maximum voltage $V$ of 345 kV or greater, and 50,027 HV transformer substations with a maximum voltage $V$ of greater than or equal to 69 kV and less than 345 kV.

have been targeted directly rather than aiming for critical infrastructure. Since no civilian populations were directly targeted, the total casualties are much lower than possible.

Furthermore, these numbers only cover the immediate casualties from blast effects, which exclude long-term illnesses and deaths from fallout, lack of medical care, and the consequences of the infrastructure damage. Without oil and electricity, the nation's food and water supplies, hospitals' capabilities, communications networks, transportation options, heating and cooling systems, and countless other support systems will be depleted and/or fail. Without operational ports, the import of oil and electrical equipment to restore power will be limited to land and air. Since the lack of oil and shipping is a national issue, and the grid blackout is expected to be nationwide, those in areas not within range of a detonation to experience blast effects will also be affected (see Sec. 5.1.5). Consequently, the long-term consequences could prove far more deadly than the actual blasts.

The loss of critical infrastructure is analogous for the Russian first strike and Russian second strike with strategic warning scenarios; the damage is less but still disastrous for the Russian second strike without strategic warning. In the first two scenarios, 19.24 million barrels per day (MMbpd) of oil refining capacity is destroyed, which is equal to 93.67% of the U.S. daily consumption in 2019, and in the third scenario, 16.18 MMbpd representing 78.68% of 2019 U.S. consumption is destroyed [79]. As for shipping, the ports damaged or destroyed in the first two scenarios handled

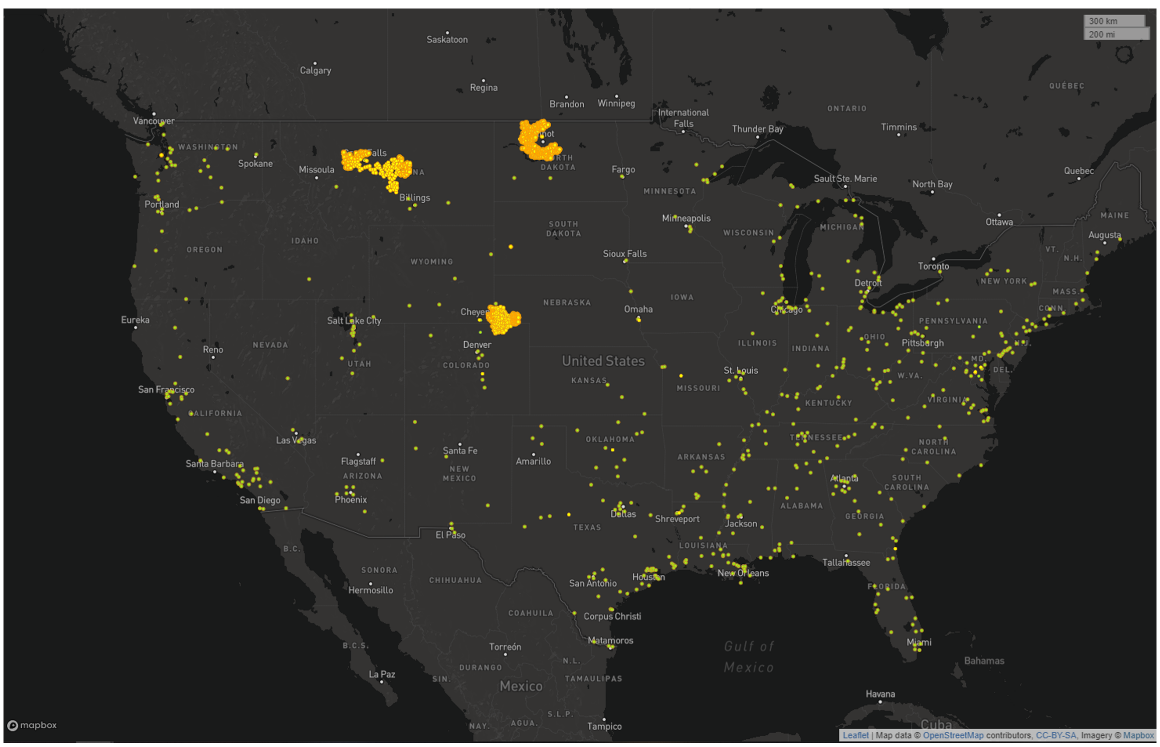


Figure 6-1: This map visualizes the 1,378 detonations for the Russian first strike scenario that hit the continental United States with each point representing a detonation to scale. The varying colors of the concentric circles represent the radii of blast phenomena with the innermost showing the fireball radius and the outermost showing the thermal radiation radius for 3rd degree burns. The three notably large clusters on the map—in North Dakota, Montana, and across Wyoming, Nebraska, and Colorado—show the ICBM fields with each silo hit by multiple warheads individually. The nuclear detonation data and display is from NUKEMAP by Alex Wellerstein (https://nuclearsecrecy.com/nukemap/), and the map data is from ©OpenStreetMap contributors, CC-BY-SA, Imagery ©Mapbox [1].

a total of 2.61 billion tons in 2017, and the ports damaged or destroyed in the third scenario handled a total of 1.86 billion tons in 2017. Both of those values exceed the U.S. total freight tonnage transported by water for 2017 (986 million tons) since that figure does not include freight transported by multiple modes; needless to say, losing those ports would eliminate the vast majority of the United States' waterborne transport capacity [104]. Based on prior research on cascading failures in the electrical grid, all three of the attack scenarios are likely to lead to a nationwide blackout due to grid failure [105, 91]. In the long-term, the replacement time and cost increases with the number of substations rendered inoperable, thus the Russian first strike causes the most damage followed by the Russian second strikes with and without strategic warning respectively [90].

For the Russian first strike scenario, another key metric is the number of U.S.

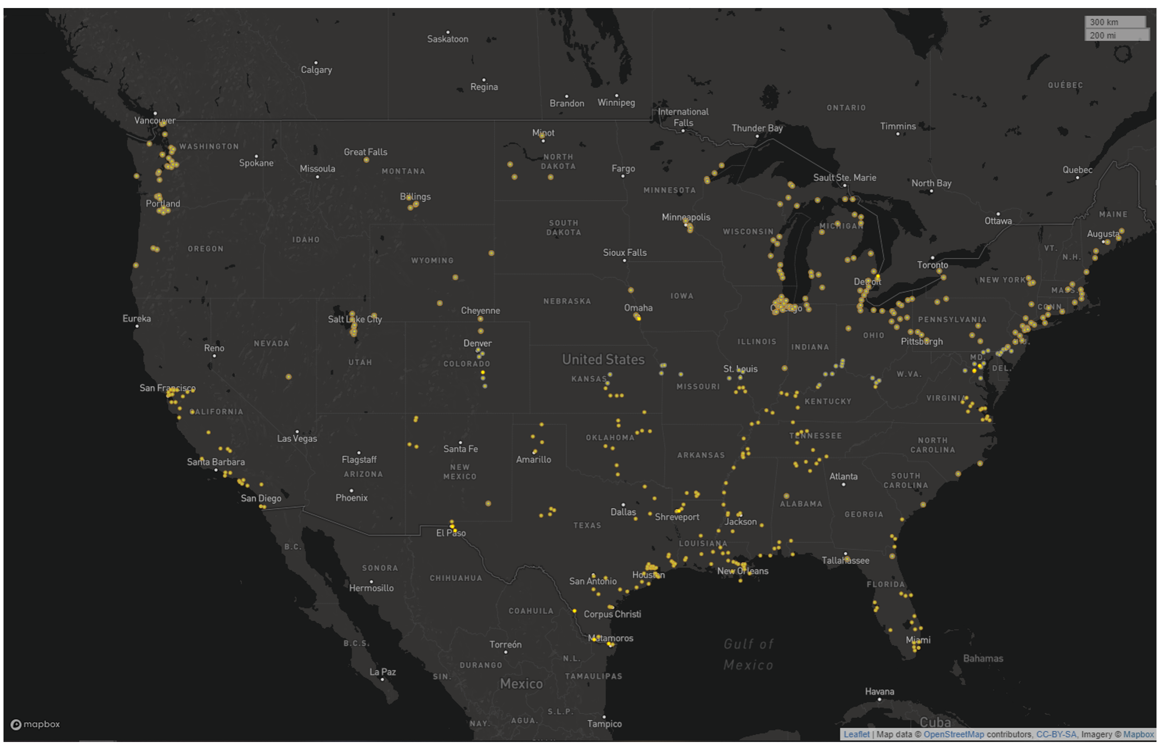


Figure 6-2: This map visualizes the 446 detonations for the Russian second strike with strategic warning scenario that hit the continental United States with each point representing a detonation to scale. The varying colors of the concentric circles represent the radii of blast phenomena with the innermost showing the fireball radius and the outermost showing the thermal radiation radius for 3rd degree burns. The nuclear detonation data and display is from NUKEMAP by Alex Wellerstein (https://nuclearsecrecy.com/nukemap/), and the map data is from ©OpenStreetMap contributors, CC-BY-SA, Imagery ©Mapbox [1].

ICBM silos expected to survive. As discussed in Sec. 3.3, the value can only be narrowed down to a range since there is no data on which to estimate the fratricide rate; in this work, the number of surviving silos was calculated using a Monte Carlo Simulation at 11 different fratricide rates ranging from 0% to 100% in 10% increments. As can be seen in Fig. 3-1, the minimum number expected to survive out of the 400 silos is 131.9017 ± 17.9873 (32.98%) at a fratricide rate of 0%, and the maximum number expected to survive is 224.6675 ± 18.8460 (56.17%) at a fratricide rate of 100% with 95% confidence. The trendline that was fit to the data shows that the fratricide rate $r$ and the number of silos expected to survive $S$ are linearly related by:

$$S = 92.662r + 131.91 \tag{6.1}$$

with an $R^2$ value of 1. Although the total number of U.S. Minuteman missile silos

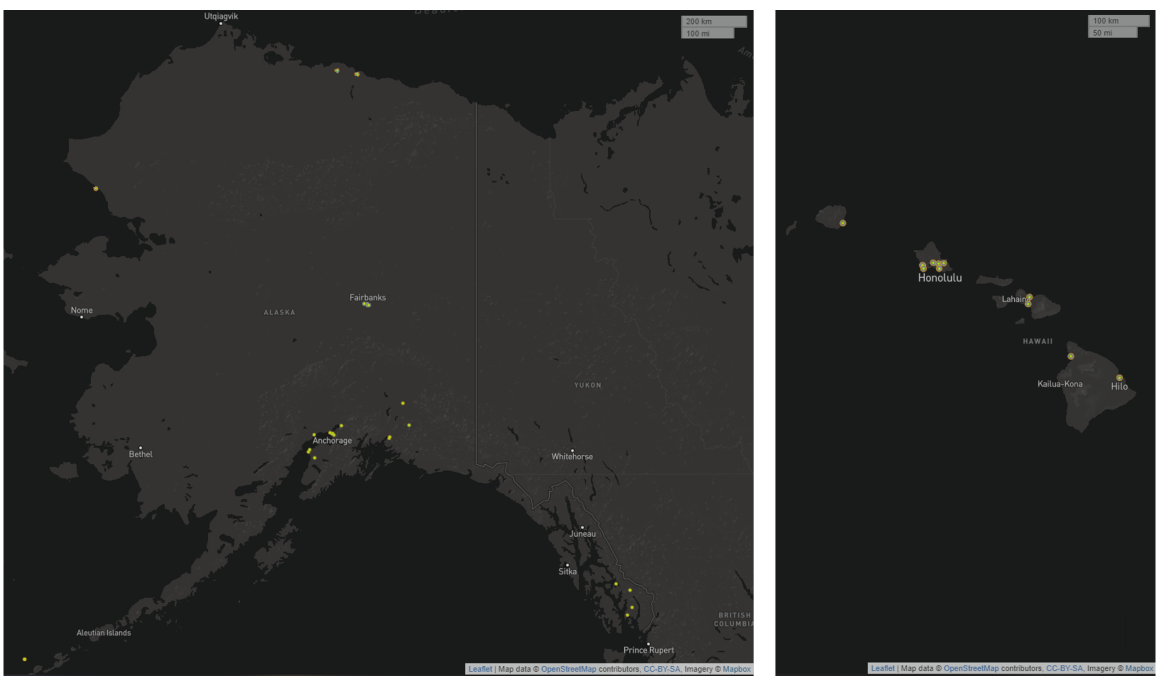


Figure 6-3: These maps visualize the 44 detonations for the Russian first strike and Russian second strike with strategic warning scenarios that hit Alaska (left) and Hawaii (right) with each point representing a detonation to scale. The varying colors of the concentric circles represent the radii of blast phenomena with the innermost showing the fireball radius and the outermost showing the thermal radiation radius for 3rd degree burns. The nuclear detonation data and display is from NUKEMAP by Alex Wellerstein (https://nuclearsecrecy.com/nukemap/), and the map data is from ©OpenStreetMap contributors, CC-BY-SA, Imagery ©Mapbox [1].

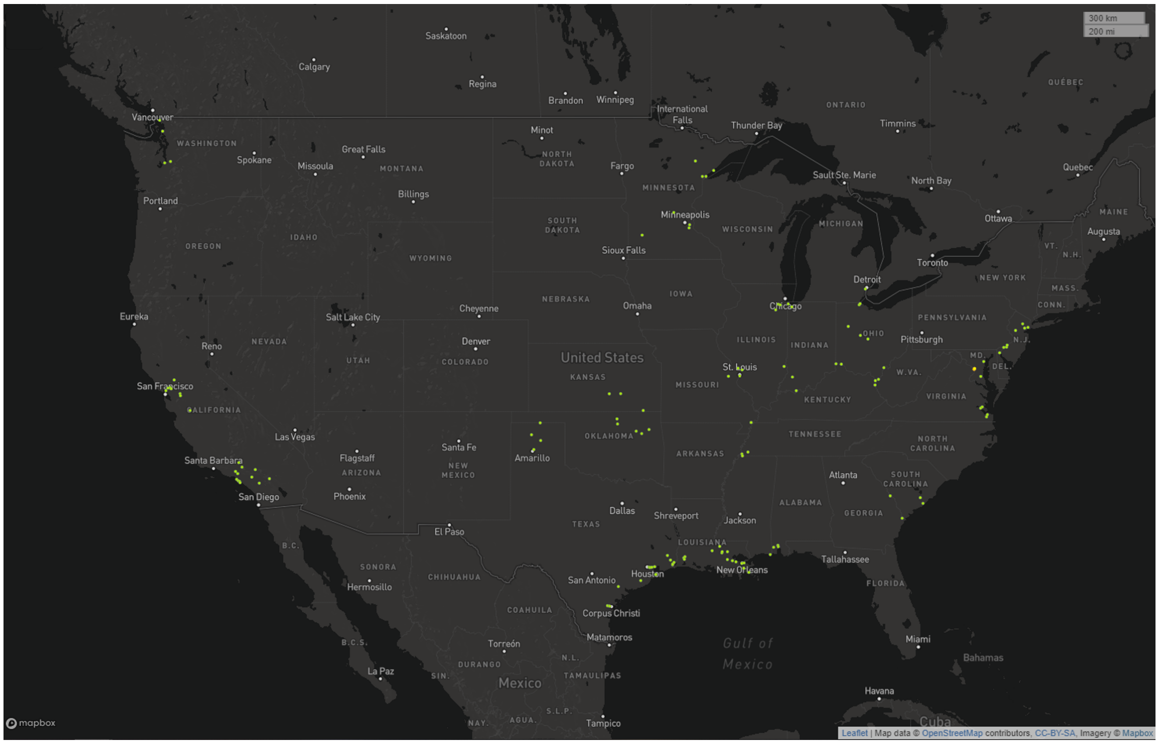


Figure 6-4: This map visualizes the 128 detonations for the Russian second strike after a bolt-out-of-the-blue attack with each point representing a detonation to scale. The varying colors of the concentric circles represent the radii of blast phenomena with the innermost showing the fireball radius and the outermost showing the thermal radiation radius for 3rd degree burns. The nuclear detonation data and display is from NUKEMAP by Alex Wellerstein (https://nuclearsecrecy.com/nukemap/), and the map data is from ©OpenStreetMap contributors, CC-BY-SA, Imagery ©Mapbox [1].

in operation has decreased from 1,000 during the Cold War to 400 at time of writing, the percentage of silos expected to survive a then-Soviet, now-Russian 2-on-1 attack has remained fairly constant with estimates from the 1980's of 42.7% of U.S. silos surviving and from 1990 of 32.4% surviving [7].

# Chapter 7

# Conclusions

The results of this study provide valuable insight on the capabilities of the U.S. and Russian arsenals and reveal issues to be addressed in policies and negotiations. First and foremost, the Russian first strike and Russian second strike with strategic warning scenarios showed that sizable arsenal reductions are possible without compromising deterrence. In both scenarios, unacceptable damage[1] was inflicted with over 500 warheads remaining. Even the Russian second strike without strategic warning scenario produced catastrophic results with only 128 warheads. On the American side, the simulation of an attack on the Russian ICBM silos in Sec. 4.3 showed that the United States could eliminate the Russian ICBMs entirely with a 1-on-1 attack using accurate SLBM warheads, rather than a 2-on-1 attack, thereby reserving more warheads to be used on other targets. While both nations work on modernizing their arsenals, downsizing should also be considered.

As for the fate of the U.S. Minuteman III missiles, replacement may be premature. The Trident II SLBMs are capable of eliminating the Russian missile silos and counterforce targets of a similar hardness; as such, the ICBMs could be allocated toward countervalue targets for which accuracy is less of a concern. Coupled with the potential for deep arsenal reductions, extending the lifetime of the current land-based missiles, at least until the next arms control treaty is negotiated, would be a prudent measure lest the newly created and deployed GBSD missiles be retired quickly. Even

[1]loss of 20–25% of the population and 50–67% of industrial capacity

if the Minuteman missiles must be replaced eventually, waiting to see whether the number of active silos is decreased could reduce the necessary budget for the program.

This study also raises the question of whether the ICBMs are an essential leg of the triad. With regard to the sponge argument, the blast casualties for the Russian first strike scenario, which targets U.S. ICBM silos, were lower than those of the Russian second strike without strategic warning, which did not target them, but the total damages and expected long-term casualties of both strikes were comparable. Furthermore, the Russian first-strike scenario showed that unacceptable damage could be inflicted in a countervalue attack while also conducting a 2-on-1 attack on the U.S. silos and leaving 520 warheads in reserve. The so-called sponge absorbed over half of the warheads used, but it did not absorb the economic destruction.

On the Russian side, there is cause for concern over American missile defenses. As detailed in Sec. 4.4, a surprise attack by the United States would leave Russia only 32 missiles with which to retaliate. Consequently, U.S. ground-based missile interceptors (GBIs) would only have to destroy 32 missiles in order to evade nuclear retaliation. The U.S. Ground-Based Midcourse Defense (GMD) system has already been tested against ICBMs with the Department of Defense stating they are capable of defending against a small number of incoming ICBMs. SLBMs would be more difficult targets for interceptors due to the possibility of using a depressed trajectory, but an asymmetrical nuclear war is already possible since a surprise attack would leave Russia with only 32 missiles but would leave the United States with over 1,000[2] [106]. Undoubtedly, ballistic missile defenses (BMDs) will feature prominently in future arms control negotiations.

The United States should also address the security of the electrical grid and dependence on oil. Though it may not be possible to harden high voltage (HV) transformers to protect against a nuclear strike, the damages could be ameliorated by reducing the risk of cascading failures through increased redundancy and inter-connectivity, more distributed generation with grid-islanding capabilities, and by making HV transformers easier to replace—be that through design standardization, the procurement of

[2] 900–950 SLBMs and 132–225 ICBMs, see Sec. 4.2 and Fig. 3-1

spares, or otherwise. That being said, making the grid more interconnected would increase the potential damage from a cyber attack, so grid security must be simultaneously evaluated at both the physical and digital level. Additionally, the United States' overwhelming dependence on oil for transportation constitutes a security risk as oil refineries and pipelines act as choke points, which magnify the consequences of a limited attack. For example, the May 2021 ransomware attack that shut down the Colonial Pipeline led to price spikes and fuel shortages along the U.S. East coast with Energy and Homeland Security Departments assessments concluding that the shut down had been days away from causing nationwide ramifications as the disruption to the petroleum product distribution system would cause diesel shortages and refinery shut downs [107]. If shutting down one pipeline for a week would disrupt transportation nationally, it may be reasonable to extrapolate that destroying multiple or even all of the oil refineries in the United States would be devastating.

This work showed that, should the unimaginable come to pass and a nuclear war is declared, there is no clear path to victory. Regardless of which side launches first, the loss of life would be staggering and the situation for the survivors would be apocalyptic. Even if there are quantitative differences, the outcomes are qualitatively equivalent. As the 1983 film *WarGames* concluded, "the only winning move is not to play," [108].

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