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Abstract

The probability of nuclear war is a major factor in many important policy questions, but it has gotten little scholarly attention. This paper presents a model for calculating the total probability of nuclear war. The model is based on 14 interrelated scenarios for how nuclear war can break out, covering perhaps the entire range of nuclear war scenarios. Scenarios vary based on factors including whether a state intends to make a first strike attack, whether the nuclear attack is preceded by a conventional war or a non-war crisis, whether escalation is intentional or inadvertent, the presence of false alarms of various types, and the presence of non-war nuclear detonations such as nuclear terrorism. As a first step towards quantifying the probability of nuclear war using the model, the paper also includes a dataset of historical incidents that might have threatened to turn into nuclear war. 60 historical incidents are included, making it perhaps the largest such dataset currently available. The paper also includes background information about probabilistic analysis and modeling to help readers understand how to think about the probability of nuclear war, including new theory for the decision to initiate nuclear war.

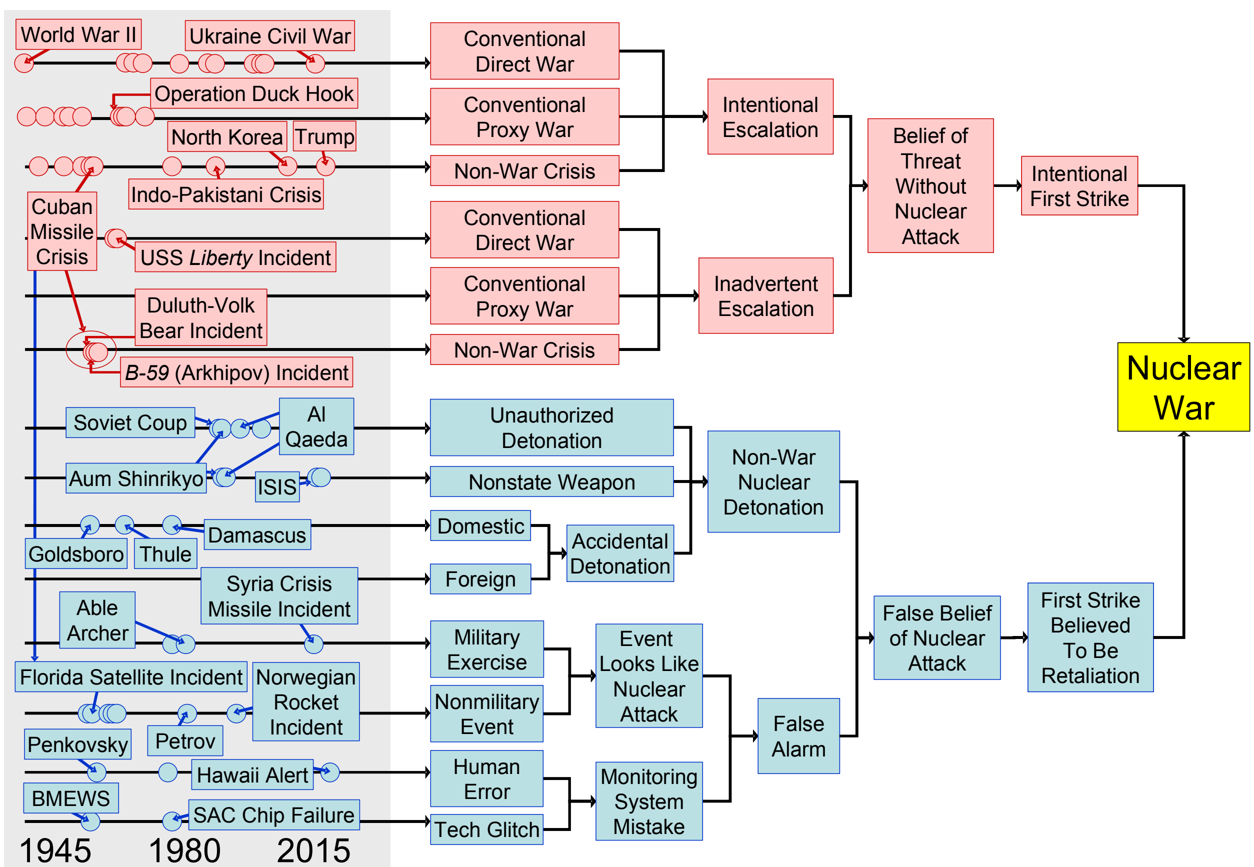

Figure 1. Summary of the paper. The shaded area graphs the historical incidents dataset, with select incidents labeled. The unshaded area shows the scenario model. Historical incidents point to their corresponding scenario. Red and blue coloring indicate the two main model branches.

1. Introduction

Nuclear weapons are important for a number of reasons, including their role in deterrence, national prestige, and military budgets. But underlying all this is the possibility that they could be used in war. Suffice to say, a nuclear war would be catastrophic. The targeted regions would lie in ruins. For a large enough nuclear war, the rest of the world could struggle to feed itself due to the global environmental phenomenon known as nuclear winter. Avoiding nuclear war is thus an important priority for the international community. But this begs the question: How likely is nuclear war?

This paper presents a model for calculating the total probability of nuclear war. Relative to prior work (which is reviewed below), this model features a wide range of nuclear war scenarios, i.e. the ways in which nuclear war can break out. To identify scenarios, we reviewed prior literature and compiled numerous historical incidents in which nuclear war threatened to occur. The model aims to include all important scenarios, finding a total of 14 interrelated scenarios. In case the included scenario set turns out to not be comprehensive, the model can readily be extended to accommodate any additional scenarios that are subsequently identified.

The model can be used to produce estimates for the probability of specific nuclear war scenarios and for the total probability of nuclear war across all scenarios. However, the paper stops short of attempting to estimate these probabilities. At this stage of the research, estimating the probabilities would require considerable guesswork and is likely to be quite mistaken. Rigorous quantification of the probabilities using this paper's modeling framework and/or other models is an important task for future research.

As a first step towards probability quantification, this paper also presents a detailed dataset of historical incidents that may have threatened to become nuclear war.[1] These historical incidents provide an empirical basis for assessing the probability of nuclear war. 60 events are included, making this perhaps the largest such dataset currently available. To derive probability estimates, one would need assessments of how close these events came to nuclear war. However, the "closeness" of the events is a matter of subtle historical interpretation, something that experts in the field disagree on.[2] Therefore, this paper does not attempt the assess the closeness of historical events to nuclear war, leaving this as another exercise for future research.

1.1 Motivations For This Research

In general, there are two reasons to model the probability of something: to produce probability estimates and to develop a better understanding of the underlying risk. Since this paper stops short of producing probability estimates, it is largely oriented towards an improved understanding of nuclear war risk. To that effect, the paper provides general background on nuclear war probability modeling in addition to its new model. Quantifying the probability should be an ongoing research project, in order to inform important policy questions such as:

How much should nuclear war be prioritized relative to other issues, including the threat of nuclear terrorism risk, or other global catastrophic risks? Policy makers have limited attention and a virtually unlimited range of issues they could focus on, as do concerned citizens and other relevant parties. The more likely nuclear war is to occur, the more it merits attention.

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[1] The dataset also includes the one actual nuclear war, World War II.

[2] Compare, for example, Lewis et al. (2014), arguing that many historical incidents came quite close to nuclear war, to Tertrais (2017), arguing that no incident since WWII has come close to nuclear war.

Which policies are most effective at reducing nuclear war risk? There are many policies that can reduce nuclear war risk.[3] Given whatever policy attention is allocated to nuclear war, policy makers should focus on the most effective policies, including policies most effective at reducing the probability of nuclear war.

How rapidly should states disarm nuclear weapons? The international community has broad consensus in favor of eventual nuclear disarmament. However, there is a major debate about how rapidly nuclear disarmament should proceed. The more likely nuclear war is to occur, the stronger the case may be for rapid disarmament.

What alert level should nuclear forces be placed on? Some nuclear-armed states keep their nuclear forces on a high state of alert, ready to launch on short notice. High alert is believed to strengthen nuclear deterrence, reducing the probability of attack from other nuclear-armed states. However, high alert also increases the probability of accidental nuclear weapons launch. Which alert level is best depends on the relative probabilities of these two types of nuclear war.

How aggressively should states pursue alternative weapons such as conventional prompt global strike? Some nuclear-armed states are developing new weapons technologies in order to reduce the role of nuclear weapons. One example is the United States' development of conventional prompt global strike, in which high-precision conventional weapons hit distant targets that previously only nuclear weapons could hit. These new weapons programs can be expensive. To the extent that these weapons reduce the probability of nuclear war, the more likely nuclear war is to occur without these new weapons, the more worthwhile investments in them are.

How aggressively should nuclear power be promoted in volatile places? Nuclear power can help reduce greenhouse gas emissions and advance economic development. However, it can also facilitate the proliferation of nuclear weapons. This tension is seen, for example, in debate over Iran's nuclear program. The more likely nuclear war is to occur, the more cautious the international community should be with nuclear power in places where nuclear weapons proliferation is a concern.

1.2 Prior Work

While nuclear war has been studied extensively since the beginning of the atomic age, there have been remarkably few efforts to model or quantify the probability of nuclear war. We conducted an extensive literature review and identified only the following studies. Bereanu (1983), Hellman (2008), Barrett et al. (2013), and Barrett (2016) model the probability of specific nuclear war scenarios. Lundgren (2013) estimates a probability for nuclear war occurring during previous decades. Avenhaus et al. (1989) present a theoretical model for the total probability of nuclear war based on an assumption that the probability will decline by a fixed amount each year. Intriligator and Brito (1981) and Brito and Intriligator (1996) model the effect of nuclear proliferation on the probability of nuclear war. Plous (1989) present a survey in which members of the public estimate the probability of nuclear war. There are also various studies that discuss the risk of nuclear war in qualitative terms without attempting to model or quantify the probability (e.g., Borrie 2014; Lewis et al. 2014; Baum 2015b). And there are various informal commentaries on the probability of nuclear war, such as Waltz's argument that deterrence makes the probability near-zero and Sagan's counterargument based on the possibility of accidents, false alarms, and inadvertent escalation (Sagan and Waltz 1995). And that, as far as we are able

[3] See Baum (2015a) for a survey of policies to reduce nuclear war risk.

to identify, is it. Seven decades of nuclear weapons has brought just this small handful of studies on the probability of nuclear war.

This paper's model is based on the scenario models of Hellman (2008), Barrett et al. (2013), and Barrett (2016), which we believe is a sound approach (though not necessarily the only sound approach). Whereas Hellman (2008), Barrett et al. (2013), and Barrett (2016) model specific scenarios or sets of scenarios, this paper's model attempts to cover the total probability across all scenarios. In that regard, this paper's model is similar to the nuclear terrorism model of Bunn (2006), which aims to model the full range of terrorist groups and their potential pathways to acquiring nuclear weapons.

2. Background

For purposes of this paper, we define nuclear war as an event in which one state attacks another state with nuclear weapons. This definition excludes nuclear terrorism and other attacks by nonstate actors, unauthorized detonations (which are made against the intentions of state authorities), and accidental nuclear detonations (which no one authorizes), unless these events cause interstate nuclear war (e.g., Ayson 2010).

2.1 Crossing The Threshold To Nuclear War

Most of the time, there is no nuclear war occurring. For any given nuclear-armed state, the default position is to not attack other states with nuclear weapons. For the state to launch a nuclear attack, its inclination to do so must cross its threshold for nuclear weapons use. By "inclination", we mean the degree to which a state (or specific individual(s) within the state) desires or prefers to launch a nuclear attack. In general, states are not inclined to use nuclear weapons—they only consider using them under certain circumstances, such as when they face (or perceive themselves to face) major threats.

A state's inclination to launch a nuclear attack and its threshold for carrying out an attack will in general change over time, due to changes in geopolitical circumstances, national policies, and the personnel involved in nuclear weapons attack decisions. For example, a state will tend to have a relatively low threshold for use during a hawkish presidency and a relatively high threshold during a dovish presidency. Nuclear war may likewise tend to have a lower probability during the dovish presidency, though this may not always hold. For example, the probability could be higher during the dovish presidency if a major foreign aggression or other geopolitical circumstance significantly increased the state's inclination to launch a nuclear attack.

Figure 2 shows one set of hypothetical inclination/threshold curves. These could correspond to the inclinations and thresholds for one state, or one individual within the state. Different states can have different inclinations and thresholds, which would give them different inclination and threshold curves—different versions of Figure 2. Different individuals within a state can also have different inclinations and thresholds. For the probability of nuclear war, the relevant individuals are those with the authority and capacity to launch nuclear weapons.

An example of inclination approaching the threshold may have occurred during the Cuban missile crisis. U.S. anti-submarine forces found a Soviet submarine and dropped depth charges on it to force it to the surface. Unbeknownst to the Americans, the submarine carried a nuclear torpedo. According to some accounts, the submarine's commanding officer, Valentin Savitsky, ordered the nuclear torpedo to be readied for launch. The launch may have been narrowly

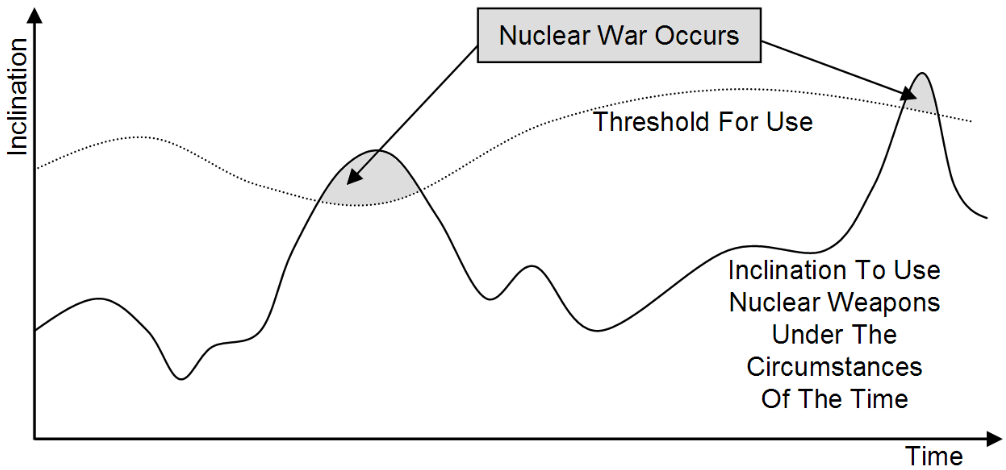

Figure 2. Illustrative sketch of a nuclear-armed state's inclination to use its nuclear weapons under the circumstances it faces at a particular time. Most of the time, the inclination to use (solid curve) is less than the threshold needed to use the nuclear weapons (dotted curve), in which case there is no nuclear war. Nuclear war occurs when the inclination to use crosses the threshold (shaded regions).

averted when Second Captain Vasili Arkhipov refused to permit the launch (Mozgovoi 2002). In this circumstance, Savitsky's inclination to use nuclear weapons crossed his threshold, but Arkhipov's inclination and thus the submarine's inclination did not, and nuclear war was avoided. However, other accounts of this incident state that while Arkhipov did help calm Savitsky down, Savitsky's inclination to use nuclear weapons did not cross his threshold, and the submarine was never close to launching its nuclear weapons (Savranskaya 2007). This example demonstrates both the concepts of inclination and threshold as well as the ambiguous nature of much of the historical data about nuclear weapons incidents.

A state's inclination to use nuclear weapons in an attack generally derives from a mix of geopolitical and internal factors. Perhaps the most important factor is the extent of tensions with other states. Nuclear weapons are most likely to be used when tensions are highest: during a major war or a severe crisis. Indeed, the only previous nuclear weapons attack came during a major war: World War II. Another important factor is the occurrence of various types of false alarms and other incidents that can lead a state to overestimate the severity of the threat it faces. Such incidents can create "one-sided tensions", in which one state feels tensions but the other does not.

A state's threshold for using nuclear weapons is its willingness to launch nuclear weapons in response to perceived tensions and other factors. It is the answer to the question "How inclined do you need to be in order to launch nuclear weapons?" The threshold is thus measured in units of inclination: a threshold at T units of inclination means one needs to be at least T inclined to use nuclear weapons in order to proceed with a nuclear attack. The level of the threshold depends on human factors like the attitudes of state leaders towards nuclear weapons and the strength of the international norm against nuclear weapons use. It also depends on technological factors like the availability of low-yield nuclear weapons (which may lower the threshold) and the availability of alternative weapons such as conventional prompt global strike (which may increase the threshold).[4]

[4] For a survey of weapons that may be used as alternatives to nuclear weapons, see Baum (2015c).

Figure 2 shows specific levels for a state's inclination and threshold at each point in time as if these levels are known. However, in general, one does not know a state's level of inclination or its threshold: both are uncertain. If such information was known, then it could be determined when (if ever) the state would enter nuclear war. Absent this information, one must think in terms of probabilities. At any given point in time, a state's level of inclination could be within some range, as could its threshold. Figure 3 shows probability distributions for the possible values of the inclination and threshold of one state at one point in time. The probability of that state entering nuclear war at that time is the probability of its inclination crossing its threshold during that time, which is the shaded region in Figure 3. Different states and different times will have different probability distributions: different versions of Figure 3. The probability of nuclear war thus varies from state to state and changes over time.

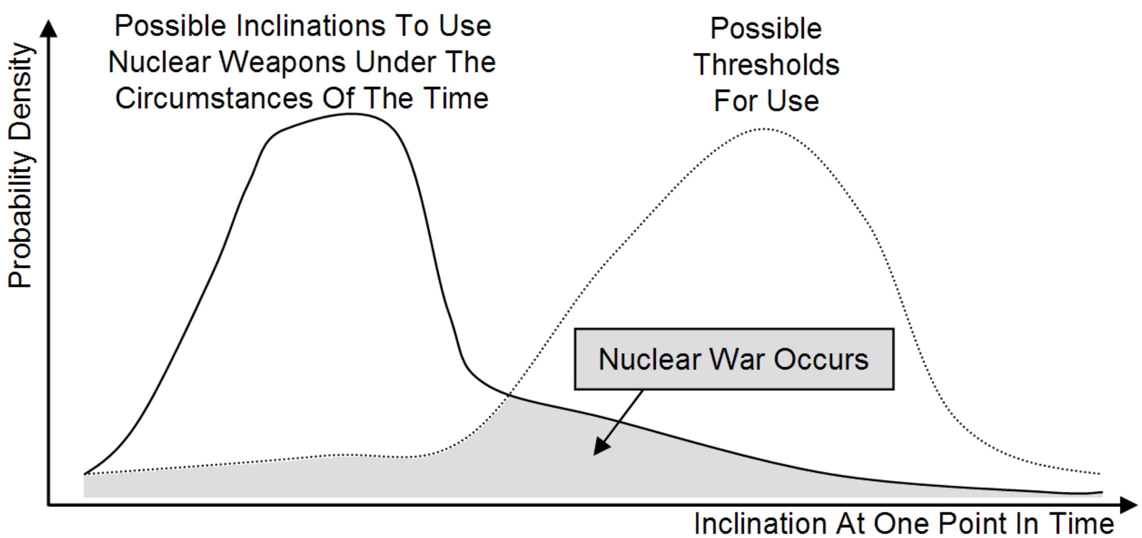

Figure 3. Illustrative sketch of probability distributions of possible levels of a nuclear-armed state's inclination and threshold at one point in time.

2.2 Probabilities, Rates, And Frequencies

A lot of different words can be used to describe uncertain possible events, such as probability, rate, frequency, likelihood, and possibility. These words are often used interchangeably in informal conversation. However, in formal technical analysis, they have precise and distinct meanings. This paper mainly uses three terms: probability, rate and frequency.

Probability is a measure of how likely an event is to occur. It is a number between 0 and 1 (0% and 100%). For a type of event that could happen at any time, such as nuclear war, the probability is commonly measured as the probability during some time period, such as the probability of nuclear war occurring during the next ten years.

Conditional probability is a measure of how likely an event is to occur given the condition that another event has already occurred.

Rate is a ratio of two quantities. The denominator is often but not necessarily a unit of time. It is a number greater than or equal to zero.

Frequency is the number of events of some type that occur during some period. The period is often but not necessarily a period of time. It is also a number greater than or equal to zero.

The terms rate and frequency can be used interchangeably when they both use the same units. This paper uses units of events per unit time for both rate and frequency. The two terms are used mainly in different contexts. Frequency is used mainly in the context of historical frequency, which is the number of events that occurred during some prior period of time. Rate is used mainly in the context of ongoing random processes, as denoted by the variable λ. However, it would not be incorrect to speak of historical rates or the frequency of events in random processes.

A simple way to distinguish between probability and rate/frequency is that probability is for the likelihood of a single event, whereas rate/frequency is for how often events of a certain type occur. For example, the World Series is a type of event, and the 2018 World Series is a single event of this type. At the time of this writing, oddsmakers give the Cleveland Indians a one-in-six (0.17, or 17%) chance of winning the 2018 World Series. This is a probability. Since the first World Series in 1903, the Indians have won two World Series, in 1920 and 1948. This is a historical frequency or rate of two per 114 years, or 0.018 per year. The historical frequency/rate suggests that on the average year, the Indians have a 0.018 (1.8%) probability of winning the World Series. Of course, the probability can change from year to year. This year, the Indians have a good team and a correspondingly higher probability. In general, the conditional probability of a team winning the World Series is high given the condition that the team is good.

The same logic applies to nuclear war. Nuclear war is a type of event, not a single event. It is thus straightforward to consider the rate or frequency at which nuclear wars occur. For the probability of nuclear war, one must be more specific: which nuclear war(s)? Instead of asking what the probability of nuclear war is, one should ask questions like: What is the probability that tensions between North Korea and the U.S. will lead to a nuclear war in 2018? (Here we assume that the North Korea-US tensions could only lead to at most one nuclear war in 2018, making it a single event and not a type of event.) What is the probability of at least one nuclear war occurring in the next 10 years? (Here the "event" is one or more nuclear wars. As long as at least one nuclear war occurs, then the event will have occurred.)

It is important to recognize that the probability of a nuclear war occurring increases over longer periods of time. The probability of nuclear war happening, say, next Wednesday afternoon is small relative to the probability of it happening sometime over the upcoming decade. To build up some intuition on this, Table 1 shows the number of nuclear wars expected over several periods of time. The left column is the annualized rate, which is equivalent to the average number expected over the course of one year. Assuming a constant rate, as the time period goes up by a factor of ten, the number of events expected also goes up by a factor of ten. For example, an event with a 0.1 (10%) annual probability will on average occur once per decade and ten times per century. This does not mean that one event will occur every decade. Some decades will have zero and some will have more than one. What it does mean is that the probability of a nuclear war goes up over time, even if the rate stays the same. In other words, the more time passes before all nuclear weapons are disarmed (at which point nuclear war becomes impossible, unless more nuclear weapons are built), the more likely a nuclear war is to occur. This point holds even if the rate changes, as long as it remains above zero.

Table 1 shows the possibility of multiple events happening in a given period. For example, an annualized rate of 0.1 corresponds to an average of ten events expected over the course of a century. However, for nuclear war, the more important number is often the probability of there being at least one. How many nuclear wars occur is of less interest. Indeed, if the first nuclear war is large enough, there might never be a second one. As Albert Einstein is quoted as saying,

Annualized Rate	Average Number Expected Per Year	Average Number Expected Per Decade	Average Number Expected Per Century
5	5	50	500
1	1	10	100
0.5	0.5	5	50
0.1	0.1	1	10
0.05	0.05	0.5	5
0.01	0.01	0.1	1

Table 1. Numbers of events expected per year, decade, and century under a constant annualized rate. Each row shows a different rate. All numbers shown here are strictly for illustration; they are not intended as actual nuclear war estimates.

"I know not with what weapons World War III will be fought, but World War IV will be fought with sticks and stones."

Table 2 shows the probability that at least one event will occur in one, ten, or one hundred years, for several different annualized rates. As with Table 1, the calculations assume that the rate stays the same over time.

Annualized Rate	Probability Of At Least One Event In A Year	Probability Of At Least One Event In A Decade	Probability Of At Least One Event In A Century
5	0.993	1.000	1.000
1	0.632	1.000	1.000
0.5	0.393	0.993	1.000
0.1	0.095	0.632	1.000
0.05	0.049	0.393	0.993
0.01	0.010	0.095	0.632

Table 2. Annualized rates and corresponding probabilities that at least one event will happen in a given time period. All numbers shown here are strictly for illustration; they are not intended as actual nuclear war estimates.

The numbers in columns 2-4 of Table 2 are calculated according to the formula

$$F_A(t) = 1 - \exp(-\lambda * t) \tag{1}$$

In Equation 1, $F_A(t)$ is the probability of at least one event of type A occurring during a time period of duration t, given that events occur at a constant rate λ. For example, if λ is an annualized rate of 0.1, then in one year, the probability of at least one event occurring is $1 - \exp(-0.1) = 0.095$. For further discussion of this formula, see Barrett et al. (2013).

In Table 2, the numbers still increase for larger time periods, but they go no higher than 1. They do not even go higher than 1 when the annualized rate is greater than 1. This is because the numbers are probabilities, which are never greater than 1. Some numbers in Table 2 appear to equal 1, but this is due to rounding error. All of the numbers approach but do not reach 1. For example, for an annualized rate of 0.1, the probability of at least one event in a century is 0.9999546. This is an extremely high probability, corresponding to a one-in-twenty-thousand chance of making it out of the next century without a nuclear war.

Table 2 also shows that when the annualized rate is low, it is approximately the same as the probability of at least one event in a year. It is commonly believed that the annualized rate of nuclear war is low, in which case the annualized rate is approximately the same as the annual probability: the probability of one nuclear war occurring in a year. For this reason, discussions of the probability of nuclear war often use the terms "annualized probability" or "annual probability" instead of "annualized rate" (e.g., Hellman 2008; Barrett et al. 2013; Barrett 2016). However, "annualized rate" is more precise and is thus used in this paper.

2.3 Historical Frequencies

The numbers in Tables 1 and 2 are purely illustrative. How would one go about coming up with numbers for the rate or probability of nuclear war? The traditional method for estimating probability is based on the historical frequency (or historical rate) at which a type of event is observed to occur. For example, the World Health Organization reports that road traffic crashes kill people at a rate of 1.25 million people per year worldwide (WHO 2018). With a global population of 7.6 billion, that means that the average person has about a one-in-6,000 annualized rate of dying in a road traffic crash.

The traditional method does not work for nuclear war. There has been one nuclear war in the 72-year history of nuclear weapons: World War II. The historical frequency therefore suggests an annualized rate of 1-in-72. However, the historical frequency of nuclear war does not give a good estimate of the ongoing rate or frequency. There are several reasons why:

(1) WWII was different. When the war broke out, nuclear weapons had not yet been invented. They were invented during the war, which is not something that can happen again. Additionally, nuclear deterrence did not yet exist: by the end of the war, only one country possessed nuclear weapons, so it could use its nuclear weapons without fear of nuclear retaliation. Other features of the international community have also changed since then, including the formation of the United Nations and the dissolution of the violent regimes that existed in Germany, Italy, and Japan. Because of these various differences, there may never be another war like WWII, and the historical data point it offers may offer limited insight to the ongoing rate of nuclear war.

(2) The probability of a nuclear war happening in any given year depends on the geopolitical circumstances prevailing during that year. For example, some experts believe that the probability of nuclear war between NATO and Russia increased during 2013-2015 due to the Ukraine crisis (e.g., Berls and Ratz 2015). The Ukraine crisis is a classic example of an event that can shift the annual probability of nuclear war. A 1-in-72 annualized rate estimate, made strictly by looking at the past, fails to account for present and future geopolitical circumstances. Careful historical analysis can give some indication of the frequency of relevant events like the Ukraine crisis, but the history should be interpreted in light of the fact that the future may be different.

(3) There have been several incidents in which nuclear war may have almost occurred. One such example is the submarine incident during the Cuban Missile Crisis described above. Additional examples are presented in the historical incidents dataset below. Had one or more of these incidents gone differently, there may have been more than one nuclear war in the last 72 years. This suggests an annualized rate higher than 1-in-72.

(4) If a second nuclear war had occurred, perceptions about the probability of nuclear war could be radically different. In the extreme case, if the war was large, humanity could be significantly diminished or even extinct. Most people alive today would not be around, including people who might read this paper. (This paper itself would presumably also not exist.) The fact that we can observe a historical absence of major nuclear war implies that none has ever

occurred. Factoring this in suggests a higher ongoing probability than our observations of historical frequencies would suggest (Ćirković et al. 2010). But even if a nuclear war was not so catastrophic, the conversation would still be very different, with different narratives and theories of international relations and different expectations for future events (Lebow 2015).

While historical frequencies do not give good probability estimates for nuclear war, historical data is nonetheless relevant. Historical incidents in which nuclear war might have occurred but did not teach us something about what it takes to get to nuclear war and how often precursor events occur. Such historical data is used extensively in the model below.

2.4 Scenario Modeling

A more sophisticated approach than simple historical frequencies is to model how nuclear war occurs: the steps needed to go from calm conditions to nuclear war for specific nuclear war scenarios. This approach is used by Hellman (2008), Barrett et al. (2013), and Barrett (2016) and is central to this paper's model.

Hellman (2008) models Russia-U.S. nuclear war caused by the escalation of a crisis like the Cuban missile crisis, using the following equation:

$$\lambda_{CMTC} = \lambda_{IE} * P_1 * P_2 * P_3 \tag{2}$$

In Equation 2, λ_{CMTC} is the annualized rate of a Cuban Missile-Type Crisis (CMTC) resulting in Russia-U.S. nuclear war; λ_{IE} is the annualized rate of an initiating event that could lead to a CMTC; P_1 is the conditional probability that an initiating event results in a CMTC (the "conditional" term means that P_1 is the probability of a CMTC given the condition that an initiating event has occurred); P_2 is the conditional probability that the CMTC leads to the use of a nuclear weapon (given the condition that a CMTC has occurred); and P_3 is the conditional probability that the nuclear weapon use escalates into a full-scale nuclear war (given the condition that a nuclear weapon has been used). The model thus has four steps that all must happen: the initiating event, the escalation into a crisis, the initial use of a nuclear weapon, and the escalation into a full-scale nuclear war. This model is depicted in Figure 4:

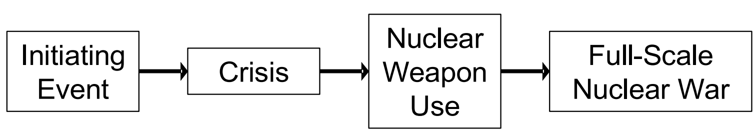

Figure 4. The Hellman (2008) model of nuclear war caused by a crisis like the Cuban Missile Crisis.

Figure 4 relates to Figure 2 in that Figure 4 shows a process through which the nuclear weapons use threshold can be crossed. Prior to an initiating event, a state would have a low inclination to use nuclear weapons. The initiating event and the subsequent crisis increase the participating state(s) inclination. The threshold is crossed when nuclear weapons are used. The threshold for nuclear weapons use was not crossed in the Cuban missile crisis, but there were several close calls (e.g., Hellman 2012).

The Hellman (2008) model has several attractive features. First, it enables more accurate rate and probability estimates by creating a way to bring in more historical data. If one only looks at historical data on nuclear war, the rate or probability of a nuclear war from a CMTC would appear to be zero because there has never been a nuclear war from a CMTC. However, the first two steps in the model—initiating event and crisis—have occurred. The historical frequency of the first two steps provides valuable information. Hellman (2008) uses the historical record to estimate $\lambda_{IE} = 0.06$ and $P_1 = 0.33$.

Second, the model helps people understand how this type of nuclear war works. Figure 4 provides a concise overview of CMTC nuclear war, which can be helpful for a whole range of discussions. For example, it gives people an understanding of what factors to look out for to see if some current event could lead to a CMTC nuclear war.

Third, the model points to a series of solutions. The risk of nuclear war from a CMTC can be reduced by reducing the rate of an initiating event, reducing the conditional probability that an initiating event escalates into a crisis, reducing the conditional probability that the crisis results in nuclear weapon use, and reducing the conditional probability that it escalates into nuclear war. Different solutions can be used for each step in the process. This insight is of great value to risk reduction policy, and it can be achieved without even calculating the rates and probabilities. If rates and probabilities are available, then one can quantify which solutions are most effective using Equation 2.

2.5 Ranges of Probabilities

Hellman (2008) uses the historical record for λ_{IE} and P_1, but there is no historical record available for P_2 and P_3. It is not known how often CMTCs escalate to nuclear weapons use and to nuclear war. Due to this uncertainty, Hellman (2008) considers a range of possible numbers for P_2 and P_3, using the range (0.1 to 0.5) for both P_2 and P_3. Such ranges of numbers offer a powerful analytical technique: they let us see how different numbers for certain model probabilities affect calculation of the total rate or probability. This is valuable when we are not sure which model rate and/or probability numbers we should use.

Arguably, Hellman (2008) should have used ranges of numbers for λ_{IE} and P_1 as well. While historical data is available for these parameters, the historical frequencies do not necessarily correspond to the ongoing rates and conditional probabilities. One reason is that the future may not resemble the past, due to shifts in geopolitics, technology, and other important factors. Another reason is that, in this instance, the historical data contains a small sample. Hellman (2008) cites just three possible initiating events: the Cuban Missile Crisis, Reagan's threat of a new naval blockade in Cuba, and the new NATO missile defense system in Eastern Europe. Had history gone slightly differently, there could have been one event or five (or zero or six or some other number), in which case the historical data would suggest a different ongoing rate.

Ranges of probabilities can be confusing to interpret. They depict different possible probabilities, which means they show uncertainty about uncertainty. One way to understand these ranges of numbers is to interpret the probabilities as rates or frequencies. For example, for P_3, this can be stated as: "We live in a world in which nuclear weapons use from a CMTC escalates to full-scale nuclear war somewhere between 10% of the time and 50% of the time." Another way to understand the ranges of numbers is to treat them as an exploration of possibilities. We might have a best guess for P_2 and P_3, but we could be curious what the final answer looks like for other values of P_2 and P_3. Sometimes, the final answer does not change much regardless of what number we use. In that case we do not need to worry much about which number we use. In other cases, the final answer changes a lot. This signals to us that the number in question is an important one to study more carefully.

2.6 Fault Tree Modeling for Sets of Scenarios

Barrett et al. (2013) and Barrett (2016) use a similar approach as Hellman (2008) but with an added degree of complexity: they model a set of related nuclear war scenarios. Barrett et al. (2013) and Barrett (2016) study inadvertent nuclear war between Russia and the U.S. Inadvertent nuclear war occurs when one side mistakes a false alarm for a real attack and launches nuclear weapons in what it believes is a counterattack but is in fact the first strike (more on this below). Adapting Hellman's notation, the core of the Barrett et al. (2013) model[5] can be written as:

$$\lambda_{In} = \lambda_{FA} * P_1 * P_2 * P_3 \tag{3}$$

In Equation 3, λ_{In} is the annualized rate of an inadvertent Russia-U.S. nuclear war; λ_{FA} is the annualized rate of a false alarm that could lead to inadvertent nuclear war; P_1 is the conditional probability that the false alarm is passed one step up the chain of command, from a Missile Display Conference (MDC, which is automatically called upon receiving an alarm) to a Threat Assessment Conference (TAC); P_2 is the conditional probability that the TAC passes the alarm the next step up the chain of command, to a Missile Attack Conference (MAC, which includes a briefing to the President and Secretary of Defense); and P_3 is the conditional probability that the MAC will result in a decision to launch nuclear weapons. The model is based on the U.S. chain of command; it is believed that Russia has a similar process.

Unlike Hellman (2008), the Barrett et al. (2013) model does not distinguish between the first launch of a nuclear weapon and the onset of full-scale nuclear war. This is because in inadvertent nuclear war, the initiating side believes that nuclear weapons have already been used. In other words, the false alarm plays the role of the initial nuclear weapon launch. It is conceivable that an inadvertent nuclear war would only see one or a small number of nuclear weapons used. However, this is an issue for the severity of nuclear war, which is beyond the scope of this paper.

Barrett et al. (2013) model four inadvertent nuclear war scenarios, based on two sets of conditions. First is whether the false alarm occurs during a crisis between the two countries (such as the Cuban Missile Crisis) or during a period of calm. It is believed that a false alarm that occurs during a crisis is more likely to be interpreted as a real attack. Second is the cause of the false alarm, in particular whether it is caused by a "usual" event like an equipment glitch or instead if it is caused by a nuclear terrorist attack that is mistaken as an attack by the other country (on the latter, see Ayson 2010). A nuclear terrorist attack could be harder to interpret because it involves an actual nuclear explosion.

Barrett et al. (2013) combine these four scenarios using a "fault tree" model. A fault tree model "branches out" to show different sequences of events that could be at fault for causing the final event. Figure 5 shows the Barrett et al. fault tree with four branches at left for the four inadvertent nuclear war scenarios. The mathematics of a fault tree can get complicated because it involves multiple scenarios. The model must use separate values of λ_{FA} for the "usual" alarms and for nuclear terrorism. It also must model the occurrence of crises. The details of the mathematics are beyond the scope of this paper but can be found in Barrett et al. (2013).

[5] The Barrett (2016) model is similar and is not described separately in this section.

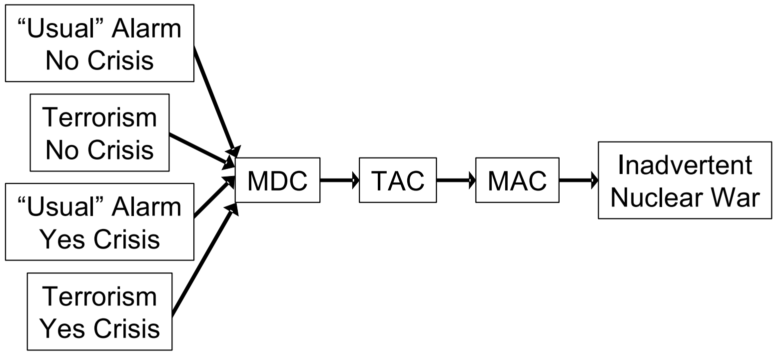

Figure 5. The Barrett et al. (2013) fault tree model of inadvertent nuclear war. The acronyms represent steps in the chain of command; they are defined in the main text.

3. The Model

The model in this paper has a similar fault tree structure as in Barrett et al. (2013). Whereas Barrett et al. (2013) models one set of nuclear war scenarios between Russia and the U.S., this paper seeks to model all important nuclear war scenarios between all relevant states. Because the model covers a broader range of scenarios, less detail on any one scenario is presented here. However, the model presented here can readily be expanded to include more detail as in Figures 4 and 5.

This model begins by distinguishing between two basic types of nuclear war. In the first type, a nuclear-armed state believes that it faces some major threat and that it is not under nuclear attack. The state intentionally launches a first-strike nuclear attack in order to begin nuclear war. For example, in World War II, the U.S. knew that it had the world's only nuclear weapons and knew that its attacks on Hiroshima and Nagasaki would make WWII a nuclear war. There were some uncertainties, such as whether the bombings would induce Japan's surrender. Indeed, historians still debate this question (e.g., Wilson 2013). But the U.S. did indeed know that it was the one making WWII a nuclear war—that much is not in debate.

In the second type of nuclear war, a nuclear-armed state mistakenly believes that it is already under nuclear attack and then launches nuclear weapons in what it believes is a retaliation but is in fact the first strike. This is known as accidental (Blair 1993) or inadvertent (Barrett et al. 2013) nuclear war. For example, the 1995 Norwegian rocket incident nearly saw Russia launch nuclear weapons in response to what appeared to be an incoming nuclear missile but turned out to be a scientific weather rocket. These scenarios are important because they show how nuclear war could occur even if both sides are deterred from making first strike attacks. The two types of nuclear war are shown in Figure 6 in the form of the two main branches of the model, shown in red and blue.

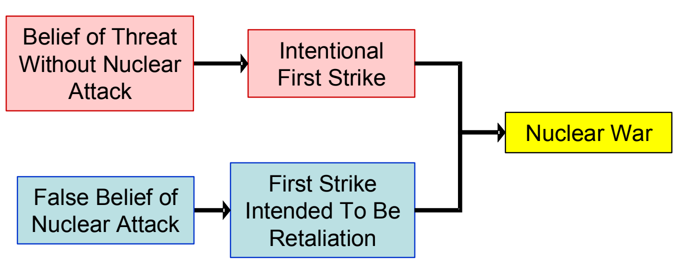

Figure 6. The two main model branches.

Following Figure 6, the total annualized rate of nuclear war can be quantified as follows.

$$\lambda_{NW} = \lambda_T * P_T + \lambda_F * P_F \tag{4}$$

In Equation 4, λ_{NW} is the annualized rate of nuclear war; λ_T is the annualized rate of events that could provoke intentional first strike; P_T is the conditional probability that one such event prompts an intentional first strike; λ_F is the annualized rate of a false belief of being under nuclear attack; and P_F is the conditional probability that the false threat prompts a first strike that is intended as retaliation.

In practice, the two types of nuclear war are not completely distinct. Threats that do not involve nuclear attacks can coincide with incidents creating false beliefs of nuclear attacks. For example, the Cuban missile crisis was rooted in the Soviet Union bringing nuclear weapons to Cuba. That could have led to an intentional first strike, for example if the U.S. invaded Cuba. During the crisis, there were also multiple false threats, such as a satellite that was mistaken for a nuclear missile heading for Florida. The model handles these situations by treating them as multiple nuclear war scenarios, some of which fit in the model's first branch and some of which fit in the second branch.

The fact that multiple nuclear war scenarios were approached during the Cuban missile crisis speaks to a broader point about the rate or probability of nuclear war: it is more likely to occur during times of high tensions. When tensions are high, wars and other crises are more likely to break out (meaning λ_T is larger) and those events are more likely to lead to an intentional first strike (P_T is larger). Also when tensions are high, certain types of false threats are more likely to occur (λ_F is larger) and any false threats are more likely to be perceived as real and acted upon (P_F is larger). This is one important reason why the annualized rate of nuclear war changes over time. In terms of Figure 2, crises increase a state's inclination to use nuclear weapons, which makes nuclear war more likely from each of several different scenarios.

3.1 Intentional First Strike

Figure 7 shows full detail for the first branch of the model, nuclear war based on a belief of a threat that does not involve a nuclear attack. Figure 7 is an extension of Figure 6. The two figures show different portions of the same model; they can be fused together to create one larger figure. The same also holds for Figures 8 and 9, showing the second branch of the model.

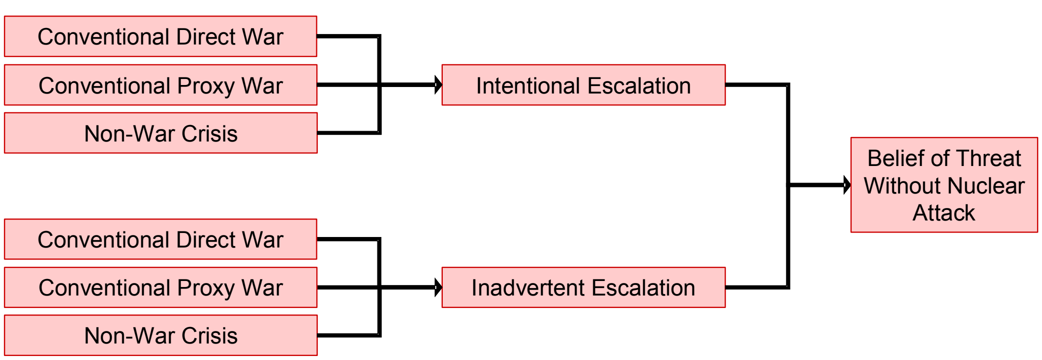

Figure 7. Full model detail for nuclear war based on a belief of a threat not involving a nuclear attack. This is the upper half of the model in Figure 6.

The first branch contains six scenarios corresponding to a 3x2 grid. Three types of initiating events are modeled: (1) Conventional direct war is war in which one or more of the main belligerents is a nuclear-armed state. For example, the 1999 Kargil War was fought between India and Pakistan, both of whom had nuclear weapons at the time. (2) Conventional proxy war is war in which one or more nuclear-armed states participate, but only in support of non-nuclear-armed states. For example, the Korean War was mainly between North and South Korea, but nuclear-armed U.S. and Soviet Union also played roles. (China and North Korea did not acquire nuclear weapons until later.) (3) A crisis is a high-tension event that could lead to nuclear war without conventional war occurring first. An example is the portion of the Cuban missile crisis that could have led to intentional first strike.

A particular incident can have elements of multiple types of initiating events. For example, the ongoing Ukrainian civil war is mainly a proxy war for Russia and perhaps also a direct war, whereas it is mainly a crisis for the U.S., and perhaps also a proxy war. The Ukrainian civil war is a good example of the fuzzy boundaries between these three types of initiating events. Despite these fuzzy boundaries, there are important differences between these three types of initiating events. Proxy wars are relatively unlikely to escalate because the security of the participating nuclear-armed state(s) is not directly threatened. The rate of each type of initiating event also varies from state to state. The U.S. and the Soviet Union/Russia have a longstanding tendency for proxy wars, from the Korean War to (arguably) the ongoing Syrian and Ukrainian civil wars. In contrast, India and Pakistan have more of a tendency for direct conventional war, especially over Kashmir. Both sets of states have also had periodic crises, such as the Cuban missile crisis and the 2008 Mumbai terrorist attacks.

The second dimension of the grid covers two ways in which initiating events can escalate: intentionally and inadvertently. Escalation occurs when one or both sides become more inclined to use nuclear weapons. In intentional escalation, states wish to escalate and act accordingly, such as by mobilizing their nuclear forces or making nuclear threats. In inadvertent escalation, states did not wish to escalate yet it happens anyway, such as when conventional war inadvertently threatens the other side's nuclear forces.

Inadvertent escalation is important because it means that crises and conventional conflicts can lead to nuclear war even when neither side wishes it. For any given initiating event, the conditional probability of intentional and inadvertent escalation can be different. The conditional probability of intentional escalation depends on the preferences of state leadership and their perceptions of threats. The conditional probability of inadvertent escalation depends on conventional war strategies, miscommunications, and a range of factors chalked up to the fog of war.

Inadvertent escalation is mainly associated with conventional war, but it can also occur during crises. For example, the Cuban missile crisis came close to inadvertent escalation on multiple occasions (Hellman 2012). In one occasion, a launch alarm was mistakenly sounded when an intruder alarm was supposed to go off instead. That said, conventional wars may be even more likely to escalate inadvertently. As Posen (1982, p.34) writes, "Civilians retaining the image of direct communication and control in the Cuban Missile Crisis or the Iran rescue mission may be shocked at how hard it is to follow, much less manage, a global war." Posen (1982; 1991) also describes how combat activities could inadvertently escalate. For example, if NATO and the Soviet Union had fought a conventional war, NATO anti-submarine forces in the Norwegian and Barents Seas may have inadvertently threatened Soviet nuclear forces based on the Kola Peninsula. Feeling their nuclear forces to be at risk, the Soviet Union could be tempted to use them.

3.2 First Strike Intended As Retaliation: Non-War Nuclear Detonation

The second branch of the model covers scenarios in which a nuclear-armed state mistakenly believes it is under nuclear attack by another state and launches nuclear weapons in what it believes is a retaliation but is in fact the first strike. The second branch contains two sub-branches, the first of which is shown in Figure 8. In the first sub-branch, there is a nuclear detonation that is not an act of war. One or more nuclear-armed states incorrectly believe that the detonation is an act of war. They then launch their nuclear weapons at whichever other state they believe is responsible.

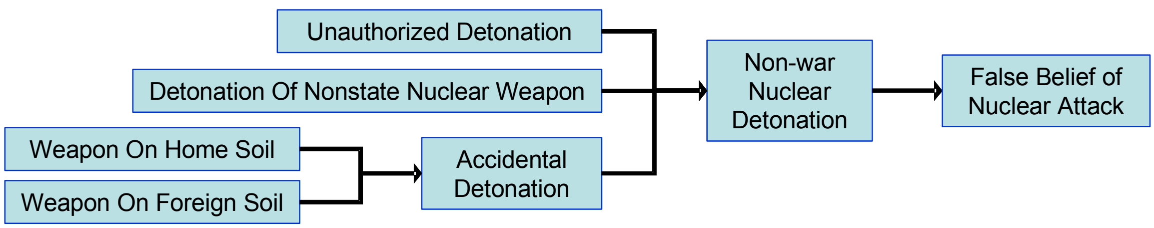

Figure 8. Full model detail for nuclear war based on a non-war nuclear detonation, in which a nuclear-armed state falsely believes a nuclear detonation is a nuclear attack by another state.

There are three types of non-war nuclear detonations. The first type is unauthorized detonation. This occurs when a nuclear weapon from the arsenal of a nuclear-armed state is detonated by some party that knowingly lacks authorization to do so. The unauthorized party could be a rogue faction of the state's military or an outside group such as a terrorist organization. The party could detonate the nuclear weapon(s) from within the state's military infrastructure, or it could steal the weapon and detonate it with its own infrastructure. Rogue military factions may be more likely to use the state's infrastructure, whereas outsider groups may be more likely to steal the weapon. This distinction is important because it points to different factors for estimating the probability and different policies for reducing it.

Unauthorized detonation sits in a grey area between the two main branches of the model. A nuclear attack on another state by a rogue faction of the perpetrator state's military is arguably an act of war. If it is considered an act of war, then it would be considered an inadvertent escalation. For example, during the Cuban missile crisis, U.S. forces threatened a Soviet submarine without realizing that it carried nuclear weapons. Submarine officers may have then almost launched the nuclear weapons despite not having orders to do so, though this account is disputed. If they had launched, this could have been considered an act of war, in which case it would be classified as crisis/inadvertent escalation in the first branch of the model.

Other potential unauthorized launch events are less likely to be considered an act of war. Such events include launches by nuclear weapons operators during times of peace, or theft of nuclear weapons and detonation from outside the state infrastructure. The latter scenario is closely associated with nuclear terrorism, for example in Bunn (2006), which models the probability of terrorists steeling or otherwise acquiring a state's nuclear weapon and then detonating it in an attack. Bunn (2006) estimates an annualized rate of nuclear terrorism of 0.034, though this number is intended as one possible reasonable estimate and is not to be considered definitive.

The second type of non-war nuclear detonation is the detonation of a nonstate nuclear weapon, by which we specifically mean the detonation of nuclear weapons that are built by nonstate actors. Building a nuclear weapon is a difficult technical and organizational challenge, especially for a group that lacks a state's resources and control of territory. However, it may be possible for nonstate groups to build their own nuclear weapons (Bunn and Wier 2006). Over the years, nonstate groups such as Al Qaeda and Aum Shinrikyo have attempted to acquire nuclear weapons from states and to build their own.

The third type of non-war nuclear detonation is accidental detonation. To date, no nuclear weapon has detonated by accident, but there have been several incidents that may have come close to accidental detonation (Schlosser 2013). The model distinguishes between accidental detonations that occur on home soil, in which a nuclear-armed state accidentally bombs itself, and those that occur on foreign soil, in which the state accidentally bombs another state. This distinction is important because accidental detonations are more likely to occur on home soil, but ones on foreign soil are especially likely to be perceived as an intentional attack. Indeed, the victim state may be unable to discern accident from intentional attack.

All three types of non-war nuclear detonations share similar dynamics for going from detonation to nuclear war. A nuclear-armed state must believe some other nuclear-armed state is responsible and must decide to conduct a nuclear attack in what it believes is retaliation. The nuclear-armed state that makes the "retaliation" attack could be, but does not need to be, the state that is the victim of the initial detonation. The following discussion refers to the various parties as the victim state, the attacker state (which could be the victim state), the blamed state, and the perpetrators (if the detonation was not an accident).

Ayson (2010) describes the dynamics in detail in the context of nuclear terrorism. The attacker state could blame another state because, for example, it believes that the blamed state: (1) conducted the attack on its own; (2) conducted the attack in collaboration with the terrorist perpetrators, perhaps in hope of dodging blame; or (3) did not conduct the attack, but should have prevented it, such as by shutting down the terrorist group or preventing it from acquiring the nuclear weapon(s). The first possibility is especially likely if the real perpetrators cannot readily be identified. The second and third possibilities are especially likely if the real perpetrators are identified and they have ties to the blamed state. Domestic pressure to act, confusion in the aftermath of the attack, fears of additional attacks, and preexisting tensions with the blamed state could make the attacker state further inclined to launch its nuclear weapons. On the other hand, the ability to identify the perpetrators and defeat them with non-nuclear force and concerns about breaking the taboo against states using nuclear weapons could make the attacker state less inclined to launch.

The attacker state's ability to correctly identify the perpetrator is not guaranteed. Some information can be obtained via technical analysis of physical properties of the detonated bomb, a process known as nuclear forensics. However, current U.S. nuclear forensic capabilities are limited (NRC 2010), and other states' capabilities are likely even more limited. Nuclear forensics would also only identify the origin of the bomb, not who delivered it. Other information may be more productive. Conventional terrorist attacks—especially large ones—are frequently attributed to their terrorist perpetrators and in turn any state sponsors; this suggests that attribution of nuclear terrorism is likely to succeed even without technical forensics (Lieber and Press 2013).

The question then would be whether attribution can occur fast enough to inform attacker state decision-making.

Even if the perpetrator is identified, the attacker state could still launch a nuclear attack. The ensuing nuclear war could be classified under either of the two main model branches, depending on whether the attacker state correctly assess the role of other states. If it identifies the perpetrator and mistakenly believes another state is complicit, then the nuclear war would be classified under the second branch. If the perpetrator has close ties to the blamed state, then it may be difficult to believe that the state played no role. This is especially true if the perpetrator is a rogue faction of the blamed state's military, or if the detonation was an accidental detonation on foreign soil in a state with poor relations with the blamed state. Rogue elements of a state's military could further leave the attacker state especially inclined to "retaliate" because the initial attack could seem close to an act of war and because additional attacks could be imminent. Relative to an outside (e.g., terrorist) group, it could be relatively easy for military insiders to acquire and detonate multiple weapons. The attacker state could legitimately wonder if the blamed state still had control of its own nuclear forces.

3.3 First Strike Intended As Retaliation: False Alarms

The second sub-branch of the second branch of the model (Figure 9) is for false alarm scenarios. In these scenarios, a state perceives an incoming nuclear attack when something else is happening. One type of false alarm occurs when some real-world event looks like a nuclear attack. Two types of events are modeled: (1) military exercises that look like preparations for an actual nuclear attack, such as the 1983 NATO Able Archer exercise that raised alarms in the Soviet Union, and (2) nonmilitary events that look like nuclear attacks, such as the 1995 Norwegian rocket incident or the Florida satellite incident that occurred during the Cuban missile crisis.

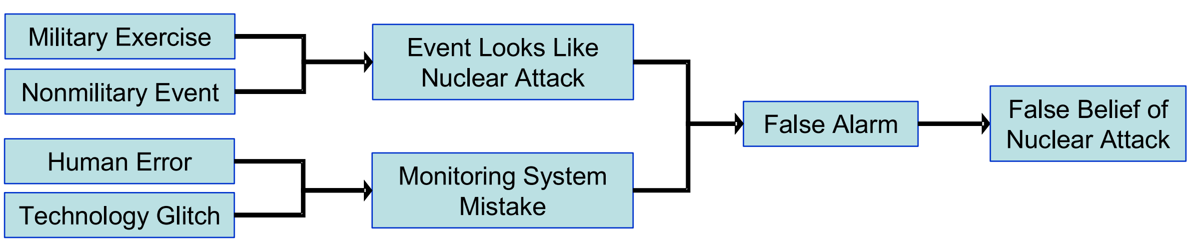

Figure 9. Full model detail for nuclear war based on a false alarm, in which a nuclear-armed state falsely believes a nuclear attack to already be occurring.

The distinction between military exercises and nonmilitary events is important because they have different probabilities and different risk reduction strategies. Military exercises often occur at a higher rate when tensions are high. Tensions were unusually high immediately prior to the Able Archer exercise. The recent Ukraine crisis has also prompted several military exercises by NATO and Russia (Frear et al. 2014; 2015). In contrast, nonmilitary events happen at roughly the same rate at all times. For risk reduction, the probability of false alarms from nuclear war from military exercises can be reduced by avoiding provocative exercises during periods of high tensions, by maintaining good communication so that all sides know that the activity is an exercise, and by improving monitoring capability to discern exercise from real attack. In contrast, the conditional probability of false alarms from nonmilitary events can only be reduced by improving monitoring capability.

The other type of false alarm occurs when there is no real-world event but attack alarms go off anyway. This is caused by one of two types of mistake in the systems that monitor for incoming nuclear attacks: (1) human error, in which monitoring system personnel accidentally set off an alarm, such as the 1979 incident in which a NORAD technician mistakenly loaded a training tape containing an attack scenario into an operation computer (Shulman 1979), and (2) technology glitch, in which monitoring system technology produces a false alarm despite personnel acting correctly, such as the 1980 U.S. Strategic Air Command incident in which a faulty computer chip triggered alerts, causing bomber crews to get ready for takeoff (CGUS 1981).

Human error and technology glitches also have different probabilities and risk reduction strategies. The probability of human error is related to such factors as training programs and morale, whereas the probability of technology glitch is related to factors like procurement decisions. Risk reduction likewise requires attention to the corresponding factors. The probability of technology glitches can also change significantly over time as the available technology changes. Assuming wise procurement decisions are made, the probability of nuclear war from technology glitches should decline over time. Despite these differences, human error and technology glitches can be closely related, for example via personnel responsible for keeping technology in working order.

3.4 The Full Model

The full model is shown in Figure 10. This shows how Figures 6-9 fit together.

4. Historical Incidents

In order to use the model to calculate the total rate of nuclear war, rates and conditional probabilities are needed for each step of each scenario. As discussed above, the historical frequency of nuclear wars is an unreliable indicator for the ongoing rate. Historical data on incidents from each scenario is nonetheless a valuable source of information for estimating the ongoing probability. Historical incidents show when a nuclear war scenario was initiated and how close it got to ending up in nuclear war.

Historical incident data provide some indication of the ongoing probability of the onset of the nuclear war scenarios, even when the incident does not end in nuclear war. Since historical incidents that do not end in nuclear war are more common than actual nuclear wars, more such data are available. Trends in historical frequency of historical incidents can suggest how high the ongoing probability is and whether it is increasing or decreasing. To be sure, trends can change, and geopolitical trends can be especially difficult to predict. That said, historical incident data nonetheless offer a valuable starting point.

Historical incident data do not show the frequency at which initial events escalate all the way to nuclear war. However, even there the data can provide some insights, especially when details of specific incidents are examined. What factors prevented the incidents from escalating further? How reliable might those be for future incidents? Answering these questions can help inform the estimates for the ongoing probabilities of escalation. More generally, qualitative analysis of

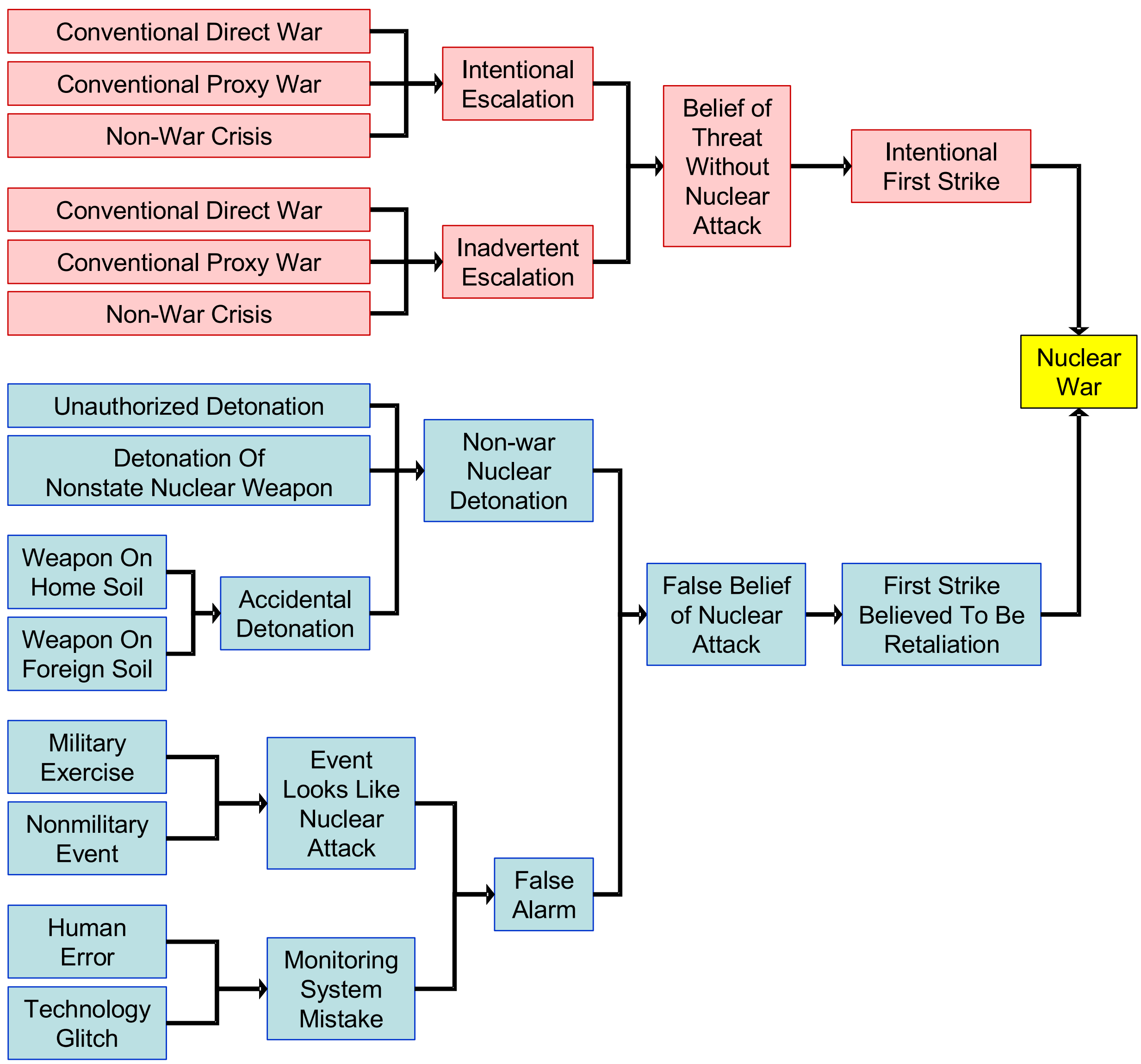

Figure 10. The entire model.

historical incidents can offer a richer understanding of the nuclear war scenarios and what factors affect their rates and conditional probabilities at each step from onset to nuclear war.

This section presents a compilation of historical incidents. It includes 60 historical incidents, making it the largest dataset of nuclear war historical incidents that we are aware of, though it is likely not comprehensive. In preparing this compilation, we have benefited from several prior surveys, including Sagan (1993), Yengst et al. (1996), Forden et al. (2000), Mowatt-Larssen (2010), Hellman (2012), Lewis et al. (2014), Frear et al. (2015), UCS (2015), Tertrais (2017), and Philips (undated). We also acknowledge several relevant databases of historical international conflicts and other incidents, each of which could be worthy resources for future research: the Uppsala Conflict Data Program,[6] the Stockholm International Peace Research Institute

[6] http://www.pcr.uu.se/research/ucdp/program_overview/about_ucdp

databases,[7] the Correlates of War Project,[8] and the International Atomic Energy Agency Incident and Trafficking Database.[9]

The careful reader may notice that some historical incidents do not fit neatly into the scenario classification scheme of this paper's model. For example, the Cuban missile crisis includes both intentional escalation events and inadvertent escalation events. The Ukrainian civil war could be interpreted as either a conventional direct war or a crisis. That is an inevitable consequence of this sort of scenario-based modeling approach. Any attempts to estimate rates and conditional probabilities from historical incidents should take this into account.

Finally, the number of incidents listed for each scenario is somewhat indicative of the frequency of incidents for that scenario, but with limitations. We made no attempt to comprehensively identify all scenarios, and our attempt was more thorough for some scenarios than for others. For example, we expect that we identified a relatively large portion of conventional war incidents and a relatively small portion of incidents related to nuclear terrorism. We also expect that we identified a relatively large portion of incidents involving the U.S., which is relatively transparent and well-researched.

Figure 11 summarizes the historical incidents dataset.

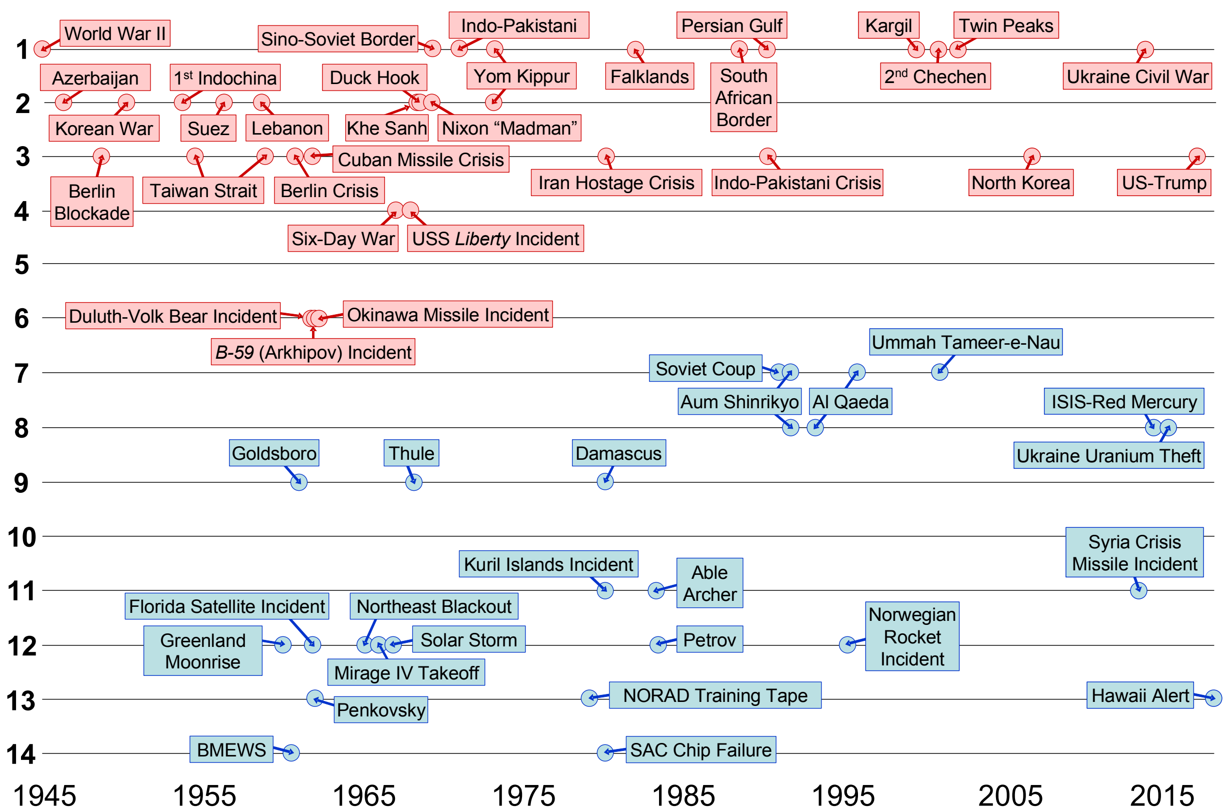

Figure 11. Summary of historical incidents dataset. Numbers 1-14 correspond to the 14 nuclear war scenarios in the order they appear in this section. A mapping from historical incidents to scenarios also appears in Figure 1.

[7] http://www.sipri.org/databases
[8] http://www.correlatesofwar.org
[9] http://www-ns.iaea.org/security/itdb.asp

4.1 Conventional Direct War, Intentional Escalation

- 1945, WORLD WAR II. The atomic bombings of Hiroshima and Nagasaki were primarily justified as being necessary to avoid U.S. invasion of Japan (Operation Downfall), which was expected to be much deadlier than the bombings. However, some scholars propose that Japan's surrender was induced not by the bombings, but instead by the Soviet Union's declaration of war on Japan (e.g., Wilson 2013). Another alleged motivation for the bombings is American desire to establish post-war superiority over the Soviet Union. Regardless, WWII remains the only historical incidence of nuclear war.
- 1969, THE SINO-SOVIET BORDER CONFLICT. The conflict occurred in two areas: first on the eastern border, along the Ussuri River north of North Korea, especially Zhenbao Island, and later on the western border, in the mountains north of the Himalaya. Total casualties were not much over 100. Nuclear threats were made by both sides, with the Soviets going as far as to instruct their embassy in Washington to gauge how the U.S. would react to a Soviet nuclear attack (Kuisong 2000, p.31-34).
- 1971, INDO-PAKISTANI WAR. The Soviet Union dispatched a flotilla that included what was probably a nuclear-powered submarine to confront the U.S. Seventh Fleet in the Bay of Bengal and to prevent the U.S. from intervening in the conflict between India and Pakistan over what is now Bangladesh (Kruglyakov 1975). Later reports that the Soviet submarine was armed with nuclear weapons seem to be the result of confusion about the meaning of the term "nuclear submarine".
- 1973, THE "YOM KIPPUR" ARAB-ISRAELI WAR, ISRAELI ACTIONS. After the war, there were reports that Israeli Prime Minister Golda Meir authorized the assembly of 13 20-kiloton tactical nuclear weapons for use against Syrian and Egyptian targets, possibly in order to get the U.S. to take action on Israel's behalf (Hersh 1993). More recent eyewitness testimony claims that Israeli Defense Minister Moshe Dayan proposed to demonstrate Israel's nuclear weapons capability on an unoccupied site, but that Meir rejected Dayan's plan (Cohen 2013).
- 1982, THE FALKLANDS WAR. In April 1982, the UK deployed two aircraft carriers armed with nuclear depth charges as part of the task force that engaged Argentina. The British War Cabinet considered removing the weapons from the carriers, but decided removing them would delay the deployment of the task force too long. After the UK lost several ships in combat, it decided to return the depth charges to England. The *New Statesman* alleged in 1984 that classified government telegrams showed that the U.K. also deployed a nuclear-armed submarine to the South Atlantic and was considering a "threatened or demonstration nuclear attack" on the city of Córdoba. The existence of these telegrams has never been independently confirmed (Freedman 2005, pp. 48-50).
- 1988, THE SOUTH AFRICAN BORDER WAR. In 1988, a Soviet-backed Cuban offensive in Angola threatened South African forces in Namibia. Shortly after a ceasefire was signed, South Africa announced that it had the "capacity to make" a nuclear weapon and began to prepare its Kalahari test site for a nuclear test. South African President F.W de Klerk later said that if South Africa was attacked, it planned to detonate a bomb as a demonstration of its capability, and threatened to use a bomb unless the U.S. intervened on its behalf (Pabian 1995, Liberman 2001).
- 1990, PERSIAN GULF WAR. U.S. Defense Secretary Dick Cheney commissioned a study of the feasibility of using nuclear weapons against the Iraqi Army. Cheney said that he was not

seriously considering using nuclear weapons but was curious about the U.S. options. The study was destroyed after Cheney reviewed it (Schwartz 1998, p. 111).

- 1999, THE KARGIL WAR. After Pakistani troops entered the India-controlled part of Kashmir, India responded by bombing Pakistani bases along the Line of Control (LOC). Pakistan moved its nuclear weapons from storage and Pakistan's foreign secretary Shamshad Ahmad said that Pakistan would "not hesitate to use any weapon in its arsenal to protect its territorial integrity (Lewis et al. 2014). General Pervez Musharraf later wrote in his memoir that Pakistan's nuclear delivery system was not in operation during the Kargil War (Musharraf 2006, p. 97).
- EARLY 2000S, THE SECOND CHECHEN WAR. There are reports that Russia would have threatened to use nuclear weapons if the U.S. had intervened on behalf of the Chechen opposition (Sokov 2014).
- 2002, TWIN PEAKS CRISIS (also known as the *2001-2002 India-Pakistan standoff* or *Operation Parakram*). Ongoing tension between India and Pakistan worsened when 31 people were killed were killed by Pakistani militants in a terrorist attack near the town of Kaluchak. Pakistan responded to the increase in tensions by conducting a series of ballistic missile tests. Several Pakistani officials also reiterated warnings that Pakistan might use nuclear weapons if its existence were threatened (Nayak and Krepon 2006, p. 33-34).
- 2013-2015, THE UKRAINIAN CIVIL WAR. The crisis and civil war that broke out in Ukraine in 2013 raised fears of nuclear war with Russia that had been largely dormant since the end of the Cold War. Russia made nuclear threats, like Vladimir Putin's March 2015 statement that Russia was ready to put nuclear weapons on alert in order to protect its "historic territory" in Crimea (MacFarquhar 2015). There has been general concern that the crisis could lead to NATO-Russia nuclear war (e.g., Berls and Ratz 2015). Depending on one's perspective, this incident could be classified as a Russia-Ukraine direct war, a NATO-Russia crisis, or potentially in other ways as well.

4.2 Conventional Proxy War, Intentional Escalation

- 1946, AZERBAIJAN CRISIS. Allied forces invaded and occupied Iran during WWII. After the war, the Soviet Union initially refused to leave. Iranian military efforts and American diplomatic pressure eventually prompted the Soviet Union to leave. After the crisis—in 1952—US President Harry Truman claimed that he compelled Joseph Stalin to withdraw Soviet troops from Iranian Azerbaijan by issuing an "ultimatum" involving a threat to use nuclear weapons (Mueller 1988). However, while the U.S. did send the Soviet Union a note calling for its withdrawal, research on the incident did not identify any evidence that Truman ever issued an ultimatum, much less threatened nuclear force (Thorpe 1978).
- 1950-1951, THE KOREAN WAR. In November 1950, after China joined the war, U.S. President Harry Truman told reporters the U.S. would consider using "every weapon that we have" against Chinese forces, including the atomic bomb. Then in 1951, the U.S. Joint Chiefs of Staff drafted an order authorizing the use of nuclear weapons in Manchuria if the Chinese launched airstrikes from there against U.S. forces in Korea (James 1985, p. 591) and the U.S. began sending B-29 bombers on nuclear attack training runs over North Korea. Although the U.S. signaled its willingness to use nuclear weapons, it never deployed any bombs for use in Korea (Dingman 1988).

- 1954, THE FIRST INDOCHINA WAR. In 1954, towards the end of the war, French soldiers were trapped at Điện Biên Phủ in northwestern Vietnam. The U.S. military was helping them. For this effort, the U.S. considered using nuclear weapons as part of a plan known as Operation Vulture. The threat was sufficiently serious that the French expected that the U.S. would use nuclear weapons (Grant 2004), though ultimately the U.S. decided against it.
- 1956, THE SUEZ CRISIS. In response to the invasion of Egypt by Israel, France, and the U.K., Soviet Premier Nikolai Bulganin sent letters to those countries plus the U.S., saying that the Soviet Union was "fully determined to crush the aggressors by the use of force and to restore peace in the East" and suggesting that the conflict could lead to a "third world war" (Gaddis 1997, p. 236).
- 1958, LEBANON CRISIS. A Lebanese civil war prompted the U.S. to intervene on behalf of the pro-West faction and against the pro-Soviet faction. The U.S. put its strategic air forces on alert and sent ships carrying nuclear ordnance to Lebanon (Quandt 1978, p. 256; Yengst et al. 1996, p. 125-29). President Eisenhower ordered the Chair of the Joint Chiefs of Staff to be prepared to use "whatever means might become necessary to prevent any unfriendly forces from moving into Kuwait" (Eisenhower 1965, p. 276).
- 1968, BATTLE OF KHE SANH. U.S. commanders in Vietnam studied the possibility of using tactical nuclear weapons to defend the U.S. military base at Khe Sanh (Yengst et al. 1996, p. 215-18). But Secretary of Defense Robert McNamara told President Johnson that "because of terrain and other conditions peculiar to our operations in South Vietnam, it is inconceivable that the use of nuclear weapons would be recommended there against either Viet Cong or North Vietnamese forces" (McNamara 1968).
- 1968, OPERATION DUCK HOOK. U.S. National Security Advisor Henry Kissinger developed contingency plans under the code name "Duck Hook" for a massive strike against North Vietnam. A memorandum Kissinger sent to President Johnson describing the state of planning of Duck Hook says that an important open question was whether the U.S. should be "prepared to use nuclear weapons" (Kissinger 1969).
- 1969, NIXON'S "MADMAN" EPISODE. In October 1969, U.S. President Richard Nixon put U.S. nuclear forces on high alert. The move was apparently intended to signal to Moscow that Nixon was unstable in hopes that this would motivate Moscow to act in ways that Washington considered more favorable. Exactly which Soviet actions were targeted is a matter of debate. Some observers have proposed that Nixon did this to signal opposition to the Soviet proposal to attack China with nuclear weapons in the Sino-Soviet border conflict, which was ongoing at the time. However, Sagan and Suri (2003) argue that Nixon was not focused on the Sino-Soviet border conflict, and instead acted in hopes of ending the Vietnam war in favorable terms.
- 1973, THE "YOM KIPPUR" ARAB-ISRAELI WAR, AMERICAN ACTIONS. Towards the end of the war, the Soviet Union threatened to send troops to Egypt. In response, the U.S. raised its alert status to DefCon 3. The U.S. had no intent to use nuclear weapons. Instead, the intent was to deter the Soviet threat. Additionally, only one minor incident of inadvertent escalation during this episode has been identified, which was quickly resolved (Sagan 1993, p.212-216).

4.3 Crisis, Intentional Escalation

- 1948-1949, BERLIN BLOCKADE. The U.S. deployed several groups of B-29 bombers to England, including a few "Silverplate" specification bombers that were outfitted to deliver nuclear weapons, potentially signaling to the Soviet Union a willingness to use those weapons (Young 2007).

- 1954-1955, THE FIRST TAIWAN STRAIT CRISIS. The crisis was fought principally between the People's Republic of China and the Republic of China, with the PRC attacking ROC-held islands near mainland China. The U.S. quickly moved in defense of the ROC. In September 1954, Chairman of the U.S. Joint Chiefs of Staff Arthur Radford recommended nuclear weapons be used if PRC's attack intensified, on grounds that the conflict was an important fight in the war against communism. In March 1954, U.S. Secretary of State John Foster Dulles also spoke of potential nuclear weapons use, "to make up for deficiency in conventional forces". Soon after, President Eisenhower said he saw no reason why smaller tactical nuclear weapons "shouldn't be used just exactly as you would use a bullet or anything else". Conventional and nuclear war plans were made, and war seemed imminent until April 1954, when PRC leadership abruptly committed to negotiating a ceasefire with the U.S. Whether the U.S. would have used nuclear weapons if the conflict continued remains unclear (Chang 1988).
- 1958, SECOND TAIWAN STRAIT CRISIS. The U.S. Joint Chiefs of Staff developed plans to defend Taiwan that called for nuclear strikes against China (Betts 1987). Records show that President Eisenhower considered using nuclear weapons, but only as a last resort (Chang 1988).
- 1961, THE BERLIN CRISIS. In June 1961, the Soviet Union demanded that American, British, and French forces leave West Berlin. That October, U.S. President John F. Kennedy considered a first strike against the Soviet Union. The Joint Chiefs of Staff had concluded that it would be impossible to defend West Berlin with just conventional weapons. Recent intelligence had shown that, contrary to what had widely been believed, the U.S. nuclear arsenal was much larger than the Soviet Union's. A group of White House and Pentagon officials produced a detailed plan to destroy the Soviet Union's second-strike capability by attacking 1,077 "military and urban industrial targets" in the "Sino-Soviet Bloc". Instead of launching an attack, Kennedy had Deputy Secretary of Defense Roswell Gilpatric give a speech revealing how many nuclear weapons the U.S. had relative to the Soviet Union. Soviet leader Nikita Khrushchev responded by conducting a test of a thirty-megaton bomb, the most powerful weapon that had been tested at that time (Kaplan 2001).
- 1962, THE CUBAN MISSILE CRISIS. The crisis began when President Kennedy learned of Soviet missiles being installed in Cuba. Intentional escalations occurred, for example, when the U.S. imposed a naval blockade and when the U.S. raised its alert to DefCon 2. The crisis also saw several incidents of inadvertent escalation, discussed below.
- 1980 IRANIAN HOSTAGE CRISIS. The U.S. reportedly developed contingency plans for a Soviet intervention in Iran that included the use of nuclear force (Halloran 1986; Schemmer 1986, p.124).
- 1990, THE INDO-PAKISTANI CRISIS. In the midst of escalating tensions with India over Kashmir, Pakistan became concerned that India was planning to attack. Pakistan signaled through diplomatic communications, public statements, and military movements that it would strike against India if it were attacked. Pakistan had apparently already developed a prototype nuclear device, but it is not clear whether it could have been effectively used against India at the time (Khan 2012, pp. 230-33).
- 2006-PRESENT, NORTH KOREA THREATS. Since its first nuclear weapon test in 2006, North Korea has repeatedly made extreme threats against South Korea and the U.S. For example, in

February 2011, North Korea threatened to turn the Blue House (where South Korea's President lives and works) into a "sea of fire" if South Korea and the U.S. went ahead with plans to conduct large-scale joint military exercises (CNN Wire Staff 2011). In April 2013, the North Korean army said it had "final approval" to launch nuclear attacks on the U.S. and said that war could break out "today or tomorrow (Boghani 2013). In February 2016, it threatened a "pre-emptive attack" that would turn both South Korea and the U.S. into a "sea of fire" if there were any attempt to overthrow the North Korean government (YNA 2016). Although North Korea did not seem to be preparing for an attack in any of these episodes and appears not to have the ability to launch attacks against the U.S., the U.S. and South Korea nonetheless take the threats seriously.
- 2017-PRESENT, AMERICAN THREATS. U.S. President Donald Trump has repeatedly made nuclear threats, primarily against North Korea. For example, in August 2017, Trump threatened North Korea with "fire and fury" (Myers and Sang-Hun 2017). In January 2018, Trump warned North Korea about his "nuclear button" (Baker and Tackett 2018).

4.4 Conventional Direct War, Inadvertent Escalation

- 1967, THE "SIX-DAY" ARAB-ISRAELI WAR. In 1967, Israel's nuclear program was close to the point where it could test a bomb if it chose to do so. When Egypt began to mobilize its forces on the Sinai Peninsula, Israeli teams assembled its nuclear bomb components into makeshift weapons, apparently without specific orders from military or political leadership to do so. They also drew up plans for a possible nuclear demonstration on an unpopulated site (Cohen 2007).
- 1968, USS *LIBERTY* INCIDENT. During the "Six-Day" War, Israeli fighters and torpedo boats attacked the USS *Liberty*, a research ship in international waters they had mistaken for an Egyptian destroyer. Because no conventionally-armed planes were in ready status, the U.S. responded to the *Liberty's* distress call by scrambling four nuclear-armed F4-B fighter-bombers. Secretary of Defense Robert McNamara recalled the planes within minutes and ordered a second, conventionally-armed response (Yengst et al. 1996, p.181-183).

4.5 Conventional Proxy War, Inadvertent Escalation

Our research did not identify any historical incidents.

4.6 Crisis, Inadvertent Escalation

- 1962, THE DULUTH-VOLK BEAR INCIDENT. On 25 October 1962, during the Cuban Missile Crisis, at Volk Field Air National Guard Base in Wisconsin, a klaxon launch alarm was mistakenly sounded when an intruder alarm was supposed to go off instead. Nuclear bombers made for the runway and nearly took off before the mistake was resolved. The intruder alarm was itself a false alarm. It originated at the Duluth Air Defense Sector in Minnesota. The "intruder" at Duluth turned out to be a bear (Sagan 1993).[10]

[10] While the intruding bear was presumably American, we note that the bear happens to be a symbol of Russia and the Soviet Union.

- 1962, *B-59* SUBMARINE INCIDENT. On or around 27 October,[11] during the Cuban Missile Crisis, the U.S. Navy tried to force the nuclear-armed Soviet submarine *B-59* to surface near Cuba using low-yield practice depth charges. The *B-59* had not been able to surface in order to communicate with Moscow for two days and was not sure whether hostilities between the U.S. and the Soviet Union had started. When the depth charges began to explode the submarine captain ordered his crew to prepare the submarine's nuclear torpedo. Then, after consultation with his second captain and his political officer, the captain ordered the submarine to surface (Mozgovoi 2002). The second captain, Vassily Arkhipov, has been credited with having vetoed the decision to launch the torpedo over the objections of the two other officers (Lloyd 2002). Sources conflict on whether the submarine crew had the authority to launch the torpedo without direct orders from Moscow. The submarine's communications officer later said in an interview that Arkhipov did play an important role in calming the captain down, but that while there was a danger of an accident or equipment malfunction, they were never close to intentionally launching the nuclear torpedo (Savranskaya 2007).
- 1962, THE OKINAWA MISSILE INCIDENT. Information about the incident comes from John Bordne, a nuclear missile operator for the U.S. in Okinawa in 1962 (Tovish 2015). Bordne reports that on 28 October, during the Cuban Missile Crisis, he and others in Okinawa were ordered to launch 32 nuclear missiles. However, the order did not include instructions to go from DEFCON 2 to DEFCON 1, as would ordinarily occur for launch. In order to confirm the launch order, the suspicious Okinawa crew asked if they should switch to DEFCON 1, at which point the launch order was quickly rescinded—the people on the other end of the line never intended to give the launch order, and instead there was some sort of communication failure. However, Bordne's account of the incident is disputed, and it is possible that the launch order never occurred (Tovish 2015).

4.7 Unauthorized Detonation

- 1991 SOVIET COUP. In August 1991, with the Soviet Union in crisis, a coup attempt was made against Soviet President Mikhail Gorbachev. During the coup attempt, command and control of the Soviet nuclear arsenal was in flux. Gorbachev's "nuclear briefcase" used to control the arsenal was disabled. Other briefcases existed, and control possibly went to Chief of General Staff Mikhail Moiseev (Tsypkin 2004).
- 1992, AUM SHINRIKYO IN RUSSIA. Aum Shinrikyo met with Russian officials in hopes of purchasing nuclear weapons. However, the Russian officials refused, apparently because they were not as corrupt as some in the West have feared (Daly et al. 2005).
- 1996, AL QAEDA IN RUSSIA. Al Qaeda leader Ayman Zawahiri was detained in Russia in 1996 and is suspected to have been there seeking nuclear weapons or materials (Mowatt-Larssen 2010).
- 2001, UMMAH TAMEER-E-NAU. In 2001, Pakistani nuclear scientists founded an NGO Ummah Tameer-e-Nau, which would subsequently offer to help al Qaeda acquire nuclear weapons (Mowatt-Larssen 2010).

[11] 27 October appears to be the correct date, though sources often list other dates.

4.8 Detonation Of A Nonstate Nuclear Weapon

- 1992, AUM SHINRIKYO IN AUSTRALIA. Aum Shinrikyo purchased a ranch in Australia with the intent of mining uranium to make their own nuclear weapon (Daly et al. 2005).
- 1993-1994, AL QAEDA IN SUDAN. Osama bin Laden and his associates had recently relocated to Sudan. While there, they attempted to acquire uranium (Mowatt-Larssen 2010).
- 2014, ISLAMIC STATE PURSUES RED MERCURY. The Islamic State attempted to acquire the fictional nuclear material “red mercury” in hopes of constructing a nuclear weapon (Chivers 2015).
- 2015, UKRAINE URANIUM THEFT. In August 2015, a criminal plot to steal uranium in western Ukraine was foiled by Ukraine’s State Security Service (AFP 2015). Note that this incident may not be particularly unusual. The IAEA’s Incident and Trafficking Database contains at least 714 incidents of theft or loss (IAEA 2015).

4.9 Accidental Detonation On Home Soil

- 1961, THE GOLDSBORO INCIDENT. On 24 January 1961, two nuclear bombs dropped to the ground near Goldsboro, North Carolina when a bomber lost a wing. The parachute on one of the bombs failed and broke apart on impact. The other bomb stayed largely intact, but five of its six failsafe devices failed during the crash. Defense Secretary Robert McNamara said in a report after the incident that “by the slightest margin of chance, literally the failure of two wires to cross, a nuclear explosion was averted” (CDI 1981; McNamara et al. 1963, p.2).
- 1968, THE THULE ACCIDENT. On 21 January 1968, a nuclear-armed B-52 bomber caught fire and crashed near the BMEWS early warning radar in Thule, Greenland. The nuclear weapons did not detonate, but they did spread radiation around the area. Had the BMEWS alarm system malfunctioned, it could have reported a nuclear explosion even if the weapons did not detonate. If the weapon detonated or if the alarm system malfunctioned, the incident could have appeared to be a Soviet attack (Sagan 1993, chapter 4).
- 1980, THE DAMASCUS EXPLOSION. On 19 September 1980, a nuclear-armed Titan II missile exploded at Little Rock Air Force Base in Damascus, Arkansas after an airman conducting maintenance on the missile had dropped a 25 lb socket wrench 80 feet above the rocket’s fuel tank, causing a leak. The warhead was propelled 200 yards from the explosion, but its safety features kept radioactive material from escaping. One airman was killed and several others were injured (Schlosser 2013).

4.10 Accidental Detonation On Foreign Soil

Our research did not identify any historical incidents.

4.11 Military Exercise, False Alarm

- 1980, THE KURIL ISLANDS INCIDENT. On 15 March 1980, the Soviet Union launched four submarine-based missiles as part of a training exercise. One of the launches appeared to a U.S. early warning sensor to be heading toward the U.S. U.S. officials convened a threat assessment conference (CGUS 1981).

- 1983, ABLE ARCHER. In November 1983, NATO conducted a military exercise in western Europe simulating a nuclear attack, codenamed Able Archer 83. The exercise occurred during a time of heightened tensions between NATO and the Soviet Union, with Soviet leadership fearing a U.S. first strike attack. Soviet intelligence monitored the exercise closely, trying to determine whether it might actually be the prelude to a real attack. Soviet forces made some responses, including moving leadership to a bunker and putting nuclear bomber planes on runway alert. Exactly how concerned the Soviets were and how close they were to launching their own attack is unclear and is a matter of ongoing inquiry (Manchanda 2009; Mastny 2009; Adamsky 2013).
- 2013, THE SYRIA CRISIS MISSILE INCIDENT. In August 2013, a chemical weapons attack in Ghouta, Syria sparked international concern. The U.S. was considering military intervention in Syria against the ruling Assad regime. Russia meanwhile supported Assad. In September 2013, Russian radar detected two missiles launched from the Mediterranean towards Syria. Russia initially suspected it to be the start of military action. Israel quickly spoke up to explain that it launched the missiles towards its own territory as part of a pre-scheduled ballistic missile defense test. The situation was resolved without any indication of nuclear weapons activity by any party (Williams and Gutterman 2013).

4.12 Nonmilitary Event, False Alarm

- 1960, GREENLAND MOONRISE INCIDENT. The new Ballistic Missile Early Warning System (BMEWS) interpreted, with "99.9 percent certainty", the moonrise as being the launch of long-range Soviet missiles. BMEWS passed on the warning to NORAD headquarters in Colorado. Because there was no other evidence of an attack—and because it seemed unlikely the Soviets would launch a first strike while Soviet Premier Nikita Khrushchev was visiting the U.N. in New York—NORAD determined it was a false alarm caused by the new system (Schlosser 2013, pp. 253-54).
- 1962, THE FLORIDA SATELLITE INCIDENT. On 28 October 1962, at the end of the Cuban Missile Crisis, radar operators in New Jersey reported that a nuclear missile would hit Florida shortly after 9:00 a.m. When there was no detonation at the expected time, radar operators discovered they had been confused by the unexpected appearance of a satellite at the same time as a test tape simulating an attack was being run. They had not been informed about the passage of the satellite because the facility that should have informed them had been assigned to other tasks during the crisis. In addition, radar systems that could have been used to confirm the attack were not operating at the time (Sagan 1993, pp. 130-31).
- 1965, NORTHEAST BLACKOUT. When power went out across the northeastern US, the Office of Emergency Planning went on full alert after the bomb alarm display lit up with twenty-two yellow lights indicating that communications with bomb sensor sites had been cut off and two red lights indicating—incorrectly—that nuclear weapons had been detonated near Salt Lake City, Utah and Charlotte, North Carolina. The false nuclear weapon detonation reports turned out to have been caused by defects in the bomb alarm console circuitry (Sagan 1993, p. 183).
- 1966, MIRAGE IV TAKEOFF. A French Mirage IV took off carrying a nuclear weapon in spite of French policy not to conduct flights with live nuclear weapons. The bomber launched after a short circuit in a display screen caused it to show a message indicating that planes should launch immediately for battle (Merchet 2015).

- 1967, Solar Storm. On 23 May, interference at Ballistic Missile Early Warning System (BMEWS) sites in Alaska, in Thule, Greenland, and in Yorkshire, England caused by a solar storm raised the alert level at NORAD on concerns at NORAD that the Soviets might be jamming the radar systems in preparation for an attack (Knipp 2016).
- 1983, The Stanislav Petrov Incident. On 26 September 1983, a Soviet satellite indicated a missile heading from the U.S. to the Soviet Union. The officer on duty, Stanislav Petrov, declined to report the matter to his superiors, believing it to be a false alarm. Petrov was correct: the satellite instead detected sunlight reflected off clouds that were in an unusual position relative to the satellite (Hoffman 1999).
- 1995, The Norwegian Rocket Incident. On 25 January 1995, Russian early warning radar picked up the launch of a rocket off the northern coast of Norway. The rocket had flight characteristics similar to a submarine-launched ballistic missile intended for a high-altitude nuclear attack that could blind Russian radar with an electromagnetic pulse. Russian nuclear forces went on full alert and prepared to retaliate if the missile was the beginning of a larger attack. Russian President Boris Yeltsin said the next day that he had activated the nuclear weapons command suitcase used to authorize a nuclear launch. When Russian early warning satellites failed to detect any more launches, the incident was declared a false alarm. Indeed, the rocket was a scientific weather rocket. Norway had notified Russia of the launch in advance, but the information was not passed on to the radar technicians (Schlosser 2013, p. 478).

4.13 Monitoring System Human Error, False Alarm

- 1962, The Penkovsky False Warning. Oleg Penkovsky was a Soviet intelligence officer and a spy for the U.K. and U.S. The U.K. and U.S. had given Penkovsky a secret procedure for him to alert them of impending Soviet attack. On 2 November 1962, just after the Cuban missile crisis, the alert sounded. A U.S. C.I.A. officer following up on the alert was taken for interrogation by the K.G.B. Because the alert came after the crisis and because the K.G.B. was there, the U.S. concluded—correctly—that Penkovsky had been compromised and that the alert was a false alarm (Sagan 1993).
- 1979, NORAD Training Tape Incident. On 9 November 1979, NORAD computers indicated that a major Soviet attack on the U.S. had begun after a training tape containing an attack scenario was mistakenly loaded into an operation computer by a technician. U.S. missile crews were put on high alert and nuclear bombers prepared to take off. Because early warning radar and satellites showed no signs of an attack the threat assessment conference was terminated after six minutes and no action was taken. In a declassified memo, a State Department official said that "false alerts of this kind are not a rare occurrence" but that there is "complacency about handling them that disturbs me" (Shulman 1979; see also Sagan 1993).
- 2018, Hawaii Missile Alert. On 13 January 2018, the Hawaii Emergency Management Agency (HI-EMA) sent a text using the Federal Emergency Alert System to people across Hawaii that read "BALLISTIC MISSILE THREAT INBOUND TO HAWAII. SEEK IMMEDIATE SHELTER. THIS IS NOT A DRILL." There was no inbound missile; instead, a HI-EMA employee had sent out the alert when he failed to hear the word "exercise" repeated at the beginning of a drill and mistook the drill for an actually missile warning (Berman and Fung 2018). Because HI-EMA didn't have a message canceling a missile alert

prepared in advance, it took 38 minutes for the agency to send a text indicating the alert had been sent in error. Earlier reports noted that it would have been easy to accidentally select an actual alert instead of a system test from the user interface's confusing dropdown of nearly identical alert options (Wang 2018).

4.14 Monitoring System Technology Glitch, False Alarm

- 1961, BMEWS COMMUNICATION FAILURE. On November 24, 1961, U.S. Strategic Air Command (SAC) lost contact with Ballistic Missile Early Warning System (BMEWS) early warning radar in Thule, Greenland. When SAC tried to call NORAD headquarters the line was dead. The fact that both lines of communication down at the same time raised concerns that an attack was underway and SAC's alert force was ordered to prepare for takeoff. The alert was called off after a U.S. bomber over Greenland was able to make contact with the radar facility. Subsequent investigation showed that a single AT&T switch at a microwave tower in Colorado had failed, which shut down communications between SAC and NORAD and communications with the early warning radar system. AT&T was supposed to build redundant circuits but had failed to do so (Schlosser 2013, p. 286).
- 1980, COMPUTER CHIP FAILURE. In June 1980, U.S. early warning systems at its Strategic Air Command repeatedly triggered alerts, which caused bomber crews to get ready for takeoff. The alerts were suspended when other missile attack warning systems showed no sign of an attack. An investigation blamed the false alerts on the failure of a single faulty computer chip (CGUS 1981; see also Sagan 1993).

5. Conclusions

For as long as some states possess nuclear weapons, there will be some chance that these weapons will be used in war. How high of a chance this is—the ongoing rate of nuclear war, or its probability over some time period—is an important factor in several major policy issues. However, there have been few attempts to model or quantify this probability. This paper presents a detailed model of nuclear war that can be used to understand and quantify the probability of nuclear war. This paper stops short of quantifying the probability because that would require more detailed analysis than one paper can provide. However, some important conclusions are nonetheless obtainable.

First and foremost, the probability of nuclear war can be modeled and quantified. Attempting to do so is not doomed to hopeless guesswork. This paper presents one approach to doing so, drawing on prior studies by Hellman (2008), Barrett et al. (2013), and Barrett (2016). The approach is based on identifying and modeling nuclear war scenarios, i.e. the range of ways that nuclear war can occur. Scenario modeling is attractive because it breaks the probability of nuclear war into smaller, more manageable parts, many of which can be informed by historical incidents. Scenario modeling is valuable both for quantifying the probability and for helping people understand how nuclear war is likely to occur. Scenario modeling provides quantitative and qualitative insights that are valuable for crafting policies to efficiently and effectively reduce the probability of nuclear war.

This paper models fourteen different nuclear war scenarios. Six scenarios occur when a nuclear-armed state intentionally makes a first-strike nuclear attack: three involving intentional escalation and three involving inadvertent escalation. Eight scenarios occur when a nuclear-armed state falsely believes that a nuclear attack has already occurred and makes what it believes is a retaliatory nuclear attack.

The three intentional escalation scenarios are the traditional focus of nuclear weapons debates. These are the scenarios for which nuclear deterrence should be most effective. The other eleven scenarios all involve some sort of mistake, either in inadvertent escalation or in the false perception of a threat. The preponderance of inadvertent and false-belief scenarios raises questions about the reliability of nuclear deterrence. Exactly how reliable nuclear deterrence is requires quantification of the probabilities of the various scenarios, which is beyond the scope of this paper.

Several factors cut across all fourteen scenarios. One is the severity of geopolitical tensions felt by nuclear-armed states. Higher tensions make states more inclined to use nuclear weapons. Wars and crises are more likely to commence and to escalate. Non-war nuclear detonations are more likely to be blamed on other states. False alarms are more likely to be mistaken as real attacks. Reducing tensions and improving relations with nuclear-armed states is a clear means of reducing the probability of nuclear war, and it could be an especially effective one.

Another cross-cutting factor is the strength of the norm against nuclear weapons use. This norm appears to have played a role in the avoidance of nuclear war since WWII (e.g., Tannenwald 1999). It works by raising the threshold required for states to decide to use nuclear weapons. The higher the threshold, the less likely some incident will cross it. This holds for incidents across all fourteen scenarios, though it may hold to a lesser extent for the four scenarios involving non-war nuclear detonations, because in these scenarios, the norm has already been broken. Efforts that strengthen the norm against nuclear weapons use, such as the recent humanitarian initiative to stigmatize nuclear weapons (e.g., Borrie and Caughley 2013), could be another effective means of reducing the probability of nuclear war. Strengthening the norm against nuclear weapons use may be an underappreciated benefit of the humanitarian initiative.

A third cross-cutting factor is the reliability of nuclear weapons systems. This includes the weapons themselves and the technologies and people who use them. It also includes everything from systems for monitoring for incoming attacks to systems for launching and detonating the weapons. The more reliable they are, the less probable nuclear war is, especially for the eight false-belief scenarios.

5.1 A Research And Policy Agenda

Because this paper stops short of quantifying nuclear war probabilities, it cannot comment on which policies would be most effective at reducing the probability of nuclear war. Furthermore, because the paper only addresses the probability of nuclear war, it cannot comment on which policies are most worth pursuing. Reducing the probability of nuclear war is an important policy goal, but it is not the only one. Reducing the severity of nuclear war is also important, as is reducing other risks. Furthermore, there are limited resources available for policy measures. The policies most worth pursuing will be those that reduce risks (and achieve any other policy aims) most efficiently and effectively. A research agenda should support policy making by quantifying the probability of nuclear war along with other risks and factors, with emphasis on the aspects that are most relevant to policy decisions.

With that in mind, here are some steps for future research that would make progress towards an understanding and quantification of the probability of nuclear war:

- Further refine the concept of inclination to launch nuclear weapons (Figure 2) and the factors that influence it.
- Expand the scenario models to include more steps in the pathway to nuclear war. For example, the Hellman (2008) and Barrett et al. (2013) models both include steps not included in this paper's model. Include details that are specific to certain nuclear-armed states, such as the U.S.-specific decision procedure modeled in Barrett et al. (2013; see Figure 5 above).
- Expand the historical incidents database. The current database is extensive but not comprehensive. Existing military conflicts databases are among the resources that could be readily tapped.
- Quantify historical incidents in terms of how far they went in their respective nuclear war scenarios. How inclined were the participating states to use nuclear weapons? What were the main factors? Which nuclear-armed states were more inclined to use nuclear weapons? This work can use the expanded scenario models and can also be used to refine the models.
- Compile historical indicators of thresholds for nuclear weapons use. The historical incidents database in this paper contains some relevant information, but it is mainly about states' inclinations to use nuclear weapons. Dedicated research on the history of norms, attitudes, and other factors relevant to thresholds would bring an improved understanding of thresholds.
- Quantify the effect of geopolitical tensions, norms, and other factors not already built into the scenario models.
- Project future geopolitical tensions, norms, and other factors as they relate to each nuclear-armed state's inclination to use nuclear weapons and threshold for use.
- Project future nuclear disarmament and proliferation as it changes in which states are nuclear-armed.
- Quantify all model parameters using historical incidents databases, expert judgment, and any other relevant information.
- Adjust probability estimates to account for observer selection effects (Ćirković et al. 2010) and counterfactual contingencies (Lebow 2015).

Here are some additional lines of future research that are important for nuclear war policy:

- Model and quantify the severity of nuclear war.
- Integrate analysis of nuclear war probability and severity to generate complete risk analysis of nuclear war.
- Quantify other relevant risks such as global warming (as it relates to nuclear power policy decisions).
- Model and quantify the effectiveness and costs of nuclear weapons policies and other risk reduction options.

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References

AFP (2015). Ukraine reports seizing nuclear material in western region. *AFP/Economic Times of India*, 6 August. http://economictimes.indiatimes.com/articleshow/48367704.cms

Avenhaus, R., Fichtner, J., Brams, S. J., & Kilgour, D. M. (1989). The probability of nuclear war. *Journal of Peace Research*, 26(1), 91-99.

Ayson, R. (2010). After a terrorist nuclear attack: Envisaging catalytic effects. *Studies in Conflict & Terrorism*, 33(7), 571-593.

Baker, P., & Tackett, M. (2018). Trump says his 'nuclear button' is 'much bigger' than North Korea's. *The New York Times*, 2 January.

Barrett, A. M. (2016). False alarms, true dangers? RAND Corporation document PE-191-TSF, DOI 10.7249/PE191.

Barrett, A. M., Baum, S. D., & Hostetler, K. (2013). Analyzing and reducing the risks of inadvertent nuclear war between the United States and Russia. *Science & Global Security*, 21(2), 106-133.

Baum, S. D. (2015a). Confronting the threat of nuclear winter. *Futures*, 72, 69-79.

Baum, S. (2015b). Breaking down the risk of nuclear deterrence failure. *Bulletin of the Atomic Scientists*, 27 July. http://thebulletin.org/breaking-down-risk-nuclear-deterrence-failure8562

Baum, S. D. (2015c). Winter-safe deterrence: The risk of nuclear winter and its challenge to deterrence. *Contemporary Security Policy*, 36(1), 123-148.

Bereanu, B. (1983). Self-activation of the world nuclear weapons system. *Journal of Peace Research*, *20*(1), 49-57.

Berls, R. E. Jr., & Ratz, L. (2015). Rising Nuclear Dangers: Assessing the Risk of Nuclear Use in the Euro-Atlantic Region. Published by the Nuclear Threat Initiative.

Berman, M. & Fung, B. (2018). Hawaii's false missile alert sent by troubled worker who thought an attack was imminent, officials say. *The Washington Post*, 30 January.

Betts, R.K. (1987). *Nuclear Blackmail and Nuclear Balance*. The Brookings Institution.

Blair, B. G. (1993). *The Logic of Accidental Nuclear War*. Brookings Institution Press.

Boghani, P. (2013). North Korean army claims it has final approval for nuclear strike on US. *CNBC*, April 4. Retrieved from http://www.cnbc.com/id/100615424

Borrie, J., (2014). A limit to safety: Risk, 'normal accidents', and nuclear weapons. ILPI-UNIDIR Vienna Conference Series, paper 3.

Borrie, J., & Caughley, T. (Eds.). (2013). *Viewing Nuclear Weapons Through a Humanitarian Lens*. Geneva: United Nations Institute for Disarmament Research.

Brito, D. L., & Intriligator, M. D. (1996). Proliferation and the probability of war: A cardinality theorem. *Journal of Conflict Resolution*, 206-214.

Bunn, M. (2006). A mathematical model of the risk of nuclear terrorism. *The Annals of the American Academy of Political and Social Science*, 607(1), 103-120.

Bunn, M., & Wier, A. (2006). Terrorist nuclear weapon construction: How difficult? *The Annals of the American Academy of Political and Social Science*, 607(1), 133-149.

CDI (1981). U.S. nuclear weapons accidents: Danger in our midst. Center for Defense Information, *The Defense Monitor*, X(5).

CGUS (1981). NORAD's missile warning system: What went wrong? Report to the Chairman. Comptroller General of the United States, Committee on Government Operations, House of Representatives.
Chang, G. H. (1988). To the nuclear brink: Eisenhower, Dulles, and the Quemoy-Matsu crisis. *International Security*, 12(4), 96-123.
Chivers, C. J. (2015). The doomsday scam. *New York Times Sunday Magazine*, 22 November, p.MM35. http://www.nytimes.com/2015/11/22/magazine/the-doomsday-scam.html
Ćirković, M. M., Sandberg, A., & Bostrom, N. (2010). Anthropic shadow: Observation selection effects and human extinction risks. *Risk Analysis*, 30(10), 1495-1506.
CNN Wire Staff (2011). North Korea threatens 'a sea of fire' upon South Korea. CNN, November 25. Retrieved from http://www.cnn.com/2011/11/24/world/asia/north-korea-sea-of-fire/
Cohen, A. (2013). When Israel stepped back from the brink. *The New York Times*. October 3.
Daly, S., Parachini, J., & Rosenau, W. (2005). Aum Shinrikyo, Al Qaeda, and the Kinshasa reactor: Implications of three case studies for combating nuclear terrorism. RAND Corporation document DB-458-AF.
Dingman, R. (1988). Atomic diplomacy during the Korean War. *International Security*, 13(3), 50–91.
Eisenhower, D.D.E. (1965). *The White House Years: Waging Peace 1956-1961*. Doubleday.
Forden, G., Podvig, P., & Postol, T. A. (2000). False alarm, nuclear danger. *IEEE Spectrum*, *37*(3), 31-39.
Frear, T., Kulesa, Ł., & Kearns, I. (2014). Dangerous brinkmanship: Close military encounters between Russia and the West in 2014. European Leadership Network.
Frear, T., Kearns, I., & Kulesa, Ł. (2015). Preparing for the worst: Are Russian and NATO military exercises making war in Europe more likely? European Leadership Network.
Freedman, L. (2005). *The Official History of the Falklands Campaign, Vol. 2: War and Diplomacy*. Routledge.
Gaddis, J. L. (1997). *We Now Know: Rethinking Cold War History*. Oxford University Press.
Grant, R. (2004). Dien Bien Phu. *Air Force Magazine*, 87(8), 78-84. http://www.airforcemag.com/MagazineArchive/Pages/2004/August%202004/0804dien.aspx
Hallorhan, R. (1986). Washington talk; how leaders think the unthinkable. *The New York Times*, 2 September.
Hellman, M. (2008). Risk analysis of nuclear deterrence. *The Bent of Tau Beta Pi*, 99(2), 14.
Hellman, M. (2012). Fifty Years After the Cuban Missile Crisis: Time to Stop Bluffing at Nuclear Poker. Published by Nuclear Age Peace Foundation and Federation of American Scientists.
Hersh, S. M. (1993). *The Samson Option: Israel, America and the Bomb*. Faber.
Hoffman, D., (1999). 'I had a funny feeling in my gut'. *Washington Post*, 10 February, A19.
IAEA (2015). Incident and Trafficking Database 2015 Fact Sheet. International Atomic Energy Agency. http://www-ns.iaea.org/downloads/security/itdb-fact-sheet.pdf
Intriligator, M. D., & Brito, D. L. (1981). Nuclear proliferation and the probability of nuclear war. *Public Choice*, 37(2), 247-260.
James, D. C. (1985). *The Years of MacArthur: Triumph and Disaster 1945-1965*. Houghton Mifflin.
Kaplan, F. (2001) JFK's first-strike plan. *The Atlantic*. October.
Khan, F. (2012). *Eating Grass: The Making of the Pakistani Bomb*. Stanford University Press.

Kissinger, H. (1969). Memorandum for the President. 2 October.
Knipp, D. J. (2016). The May 1967 great storm and radio disruption event: Extreme space weather and extraordinary responses." *Space Weather* 14(9), 614-633.
Kruglyakov, V. (1975). Interview with *Strike Force*. Retrieved from: https://www.youtube.com/watch?v=Er2E_PpVUYw
Kuisong, Y. (2000). The Sino-Soviet border clash of 1969: From Zhenbao Island to Sino-American rapprochement. *Cold War History*, 1(1), 21-52.
Lebow, R. N. (2015) Counterfactuals and security studies, Security Studies, 24:3, 403-412.
Lewis, P., Williams, H., Pelopidas, B., & Aghlani, S. (2014). Too Close for Comfort: Cases of Near Nuclear Use and Options for Policy. Chatham House.
Liberman, P. (2001). The rise and fall of the South African bomb. *International Security* 26(2), 45-86. The MIT Press.
Lieber, K. A., & Press, D. G. (2013). Why states won't give nuclear weapons to terrorists. *International Security*, 38(1), 80-104.
Lloyd, M. (2002). Soviets close to using A-bomb in 1962 crisis, forum is told. *The Boston Globe*, 13 October.
Lundgren, C. (2013). What are the odds? Assessing the probability of a nuclear war. *The Nonproliferation Review*, 20(2), 361-374.
MacFarquhar, N. (2015). Putin says he weighed nuclear alert over Crimea. *The New York Times*. March 15.
McNamara, R. S. (1968). Memorandum for the President. 19 February.
McNamara, R. S., et al. (1963). State-Defense Meeting on Group I, II, and IV papers memorandum of conversation (uncleared), January 26.
Merchet, J. D. (2015). Le jour où un Mirage IV décolla avec une vraie bombe nucléaire. *L'Opinion*, 8 June.
Mowatt-Larssen, R. (2010). Al Qaeda weapons of mass destruction threat: Hype or reality? Belfer Center for Science and International Affairs, Harvard University.
Mozgovoi, A. (2002). The Cuban samba of the quartet of foxtrots: Soviet submarines in the Caribbean crisis of 1962. *Military Parade*. Translated by Svetlana Savranskaya, National Security Archive. http://nsarchive.gwu.edu/NSAEBB/NSAEBB75/asw-II-16.pdf
Mueller, J. (1988). The essential irrelevance of nuclear weapons: Stability in the postwar world. *International Security*, 13(2), 55-79.
Musharraf, P. (2006). *In the Line of Fire: A Memoir*. Simon and Schuster.
Myers, S. L., & Sang-Hun, C. (2017). Trump's 'fire and fury' threat raises alarm in Asia. *The New York Times*, 9 August.
Nayak, P. & Krepon, M. (2006). *US Crisis Management in South Asia's Twin Peaks Crisis*. Stimson Center Report 57.
NRC (2010). *Nuclear Forensics: A Capability at Risk*. National Research Council.
Pabian, F. V. (1995). South Africa's nuclear weapon program: Lessons for US nonproliferation policy. *The Nonproliferation Review*, 3(1), 1-19.
Philips, A. F. (undated). 20 mishaps that might have started accidental nuclear war. Nuclear Age Peace Foundation. http://www.nuclearfiles.org/menu/key-issues/nuclear-weapons/issues/accidents/20-mishaps-maybe-caused-nuclear-war.htm
Plous, S. (1989). Thinking the unthinkable: The effects of anchoring on likelihood estimates of nuclear war1. *Journal of Applied Social Psychology*, 19(1), 67-91.

Posen, B. R. (1982). Inadvertent nuclear war?: Escalation and NATO's northern flank. *International Security*, 7(2), 28-54.
Posen, B. R. (1991). *Inadvertent Escalation: Conventional War and Nuclear Risks*. Cornell University Press.
Quandt, W. B. (1978). Lebanon, 1958, and Jordan, 1970. In Blechman, B. M. & Kaplan, S. S. (Eds.), *Force Without War: US Armed Forces as a Political Instrument*. Washington, DC: Brookings, pp. 222-257.
Sagan, S. D. (1993). *Limits of Safety: Organizations, Accidents, and Nuclear Weapons*. Princeton University Press.
Sagan, S. D., & Suri, J. (2003). The madman nuclear alert: Secrecy, signaling, and safety in October 1969. *International Security*, 27(4), 150-183.
Sagan, S. D., & Waltz, K. N. (1995). *The Spread of Nuclear Weapons: A Debate*. WW Norton.
Savranskaya, S. V. (2007). New sources on the role of Soviet submarines in the Cuban Missile Crisis. *Journal of Strategic Studies*, 28(2), 233-59.
Schlosser, E. (2013). *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety*. Penguin.
Schemmer, B. F. (1986). Was the US ready to resort to the use of nuclear weapons for the Persian Gulf in 1980? *Armed Forces Journal International* 124, September.
Schwartz, R. A. (1998). *Encyclopedia of the Persian Gulf War*. Jefferson, NC: McFarland & Co.
Shulman, M. (1979). Memo to Secretary of State Cyrus Vance, November 16. Washington, DC: U.S. Department of State.
Sokov, N. N. (2014). Why Russia calls a limited nuclear strike "de-escalation". *Bulletin of the Atomic Scientists*, 13 March. http://thebulletin.org/why-russia-calls-limited-nuclear-strike-de-escalation
Tannenwald, N. (1999). The nuclear taboo: The United States and the normative basis of nuclear non-use. *International Organization*, 53(03), 433-468.
Tertrais, B. (2017). "On the brink"—really? Revisiting nuclear close calls since 1945. *The Washington Quarterly*, 40(2), 51-66.
Thorpe, J. A. (1978). Truman's ultimatum to Stalin on the 1946 Azerbaijan Crisis: The making of a myth. *Journal of Politics*, 40(1), 188-195.
Tovish, A. (2015). The Okinawa missiles of October. *Bulletin of the Atomic Scientists*, 25 October. http://thebulletin.org/okinawa-missiles-october8826.
Tsypkin, M. (2004). Adventures of the "nuclear briefcase": A Russian document analysis. *Strategic Insights* 3(9).
UCS (2015). Close calls with nuclear weapons. Union of Concerned Scientists. http://www.ucsusa.org/sites/default/files/attach/2015/01/nuclear%20weapons%20close%20calls.pdf
Wang, A. B. (2018). Hawaii missile alert: How one employee 'pushed the wrong button' and caused a wave of panic. *The Washington Post*, 14 January.
WHO, 2015. Road traffic injuries. World Health Organization, Fact sheet number 358, updated October 2015. http://www.who.int/mediacentre/factsheets/fs358/en/
Williams, D. & Gutterman, S. (2013). Unannounced Israel-U.S. missile test fuels jitters over Syria. *Reuters*, 3 September. http://www.reuters.com/article/us-syria-crisis-russia-defence-idUSBRE9820AC20130903
Wilson, W. (2013). *Five Myths About Nuclear Weapons*. Houghton Mifflin Harcourt.

Yengst, W., Lukasik, S. & Jensen, M. (1996). *Nuclear Weapons That Went to War (NWTWTW)*. Science Applications International Corp. Report DNA-TR-96-25 to the U.S. Defense Special Weapons Agency.

YNA (2016). North Korea threatens to turn Seoul, Washington into 'sea of fire'. *Yonhap News Agency*. 25 February. http://english.yonhapnews.co.kr/northkorea/2016/02/25/93/0401000000AEN20160225006151315F.html

Young, K. (2007). US 'atomic capability' and the British forward bases in the early Cold War. *Journal of Contemporary History*, 42(1), 117-136.