Analyzing and Reducing the Risks of Inadvertent Nuclear War Between the United States and Russia

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ABSTRACT

This paper develops a mathematical modeling framework using fault trees and Poisson processes for analyzing the risks of inadvertent nuclear war from U.S. or Russian misinterpretation of false alarms in early warning systems, and for assessing the potential value of options to reduce the risks of inadvertent nuclear war. The model also uses publicly available information on early-warning systems, near-miss incidents, and other factors to estimate probabilities of a U.S.-Russia crisis, the rates of false alarms, and the probabilities that leaders will launch missiles in response to a false alarm. The paper discusses results, uncertainties, limitations, and policy implications.

INTRODUCTION

War involving significant fractions of the U.S. and Russian nuclear arsenals, which are by far the largest of any nations, could have globally catastrophic effects such as severely reducing food production for years,[1] potentially leading to collapse of modern civilization worldwide and even the extinction of humanity.[2] Nuclear war between the United States and Russia could occur by various routes, including accidental or unauthorized launch; deliberate first attack by one nation; and inadvertent attack. In an *accidental* or *unauthorized* launch or detonation, system safeguards or procedures to maintain control over nuclear weapons fail in such a way that a nuclear weapon or missile launches or explodes without direction from leaders. In a *deliberate* first attack, the attacking nation decides to attack based on accurate information about the state of affairs. In an *inadvertent* attack, the attacking nation mistakenly concludes that it is under attack and launches nuclear weapons in what it believes is a counterattack.[3] (Brinkmanship strategies incorporate elements of all of the above, in that they involve intentional manipulation of risks from otherwise accidental or inadvertent launches.[4])

Over the years, nuclear strategy was aimed primarily at minimizing risks of intentional attack through development of deterrence capabilities, though numerous measures were also taken to reduce probabilities of accidents, unauthorized attack, and inadvertent war. For purposes of deterrence, both U.S. and Soviet/Russian forces have maintained significant capabilities to have some forces survive a first attack by the other side and to launch a subsequent counter-attack. However, concerns about the extreme disruptions that a first attack would cause in the other side's forces and command-and-control capabilities led to both sides' development of capabilities to detect a first attack and launch a counter-attack before suffering damage from the first attack.[5]

Many people believe that with the end of the Cold War and with improved relations between the United States and Russia, the risk of East-West nuclear war was significantly reduced.[6] However, it has also been argued that inadvertent nuclear war between the United States and Russia has continued to present a substantial risk.[7] While the United States and Russia are not actively threatening each other with war, they have remained ready to launch nuclear missiles in response to indications of attack.[8]

False indicators of nuclear attack could be caused in several ways. First, a wide range of events have already been mistakenly interpreted as indicators of attack, including weather phenomena, a faulty computer chip, wild animal activity, and control-room training tapes loaded at the wrong time.[9] Second, terrorist groups or other actors might cause attacks on either the United States or Russia that resemble some kind of nuclear attack by the other nation by actions such as exploding a stolen or improvised nuclear bomb,[10] especially if such an event occurs during a crisis between the United States and Russia.[11] A variety of nuclear terrorism scenarios are possible.[12] Al Qaeda has sought to obtain or construct nuclear weapons and to use them against the United States.[13] Other methods could involve attempts to circumvent nuclear weapon launch control safeguards or exploit holes in their security.[14]

It has long been argued that the probability of inadvertent nuclear war is significantly higher during U.S.-Russian crisis conditions,[15] with the Cuban Missile Crisis being a prime historical example. It is possible that U.S.-Russian relations will significantly deteriorate in the future, increasing nuclear tensions. There are a variety of ways for a third party to raise tensions between the United States and Russia, making one or both nations more likely to misinterpret events as attacks.[16]

Although many deterrence system failure modes have been identified, additional research could be valuable in identifying residual hazards, quantifying their relative risks, and informing policies.[17] Many analysts have recommended that analysis be performed of risks of inadvertent nuclear war. Hellman[18] suggested employing probabilistic risk analysis (PRA) methods, such as those used in assessing risks at nuclear power plants. These can assess overall system failure probabilities using fault trees to define relationships between failure-initiating events and enabling conditions. The methods also incorporate information on system component failure rates and interactions, with statistical estimation of system component failure rates and other risk model parameters using available empirical data.[19] Complete characterization of all relevant nuclear weapons system component failure rates and interactions would require significantly more information than is publicly available, though such interactions also may be impossible to fully predict because of the complexity of relevant systems and their interactions.[20] However, useful characterization of at least some potential failure modes is provided in the literature on inadvertent nuclear war hazards, and relatively limited amounts of such information have yielded important insights in previous estimates of probabilities of specific nuclear inadvertent nuclear war or other war scenarios.[21] This paper incorporates and builds on that work.

This paper uses mathematical modeling to estimate the annual probability of inadvertent nuclear war between the United States and Russia, as well as estimating how much that probability could be reduced with specific risk-reduction strategies. Assessing the risks in those terms could be useful in comparing options for reducing the risks of inadvertent nuclear war. It also facilitates comparison of the risks of nuclear war to other types of global catastrophic risks such as asteroids or pandemics, which often can be characterized in terms of annual probability of a catastrophic event, i.e. one with impacts above some threshold chosen to distinguish a truly catastrophic event from less-consequential events.[22]

Some previous work has been done to estimate the annual probability of nuclear war. Hellman[23] provided a rough estimate of the overall annual probability of nuclear war between the United States and Russia. This paper makes use of some of Hellman's analysis, e.g. regarding the probability of a U.S.-Russia crisis, though this paper uses other sources and approaches for other components of its risk model, partly in order to assess relative risks of various types of inadvertent nuclear war scenarios and to assess potential value of risk-reduction strategies. Wallace et al.[24] estimated the conditional probability of unresolved serious false alarms arising in U.S. or Russian early-warning systems during a crisis, under which conditions a leader might face great pressure to launch missiles in response to indications of attack. However, Wallace et al. did not estimate the probability of a crisis, nor did they assess the probabilities of other scenarios that could provide indications of an attack.

This paper goes beyond previous nuclear war probability assessments in two main ways: First, it applies risk analysis methods using fault trees and mathematical modeling to assess relative risks of multiple inadvertent nuclear war scenarios previously identified in the literature. Second, it combines the fault tree based risk models with parameter estimates based on the literature, characterizing uncertainties in the form of probability distributions, with propagation of uncertainties in the fault tree using Monte Carlo simulation methods. This paper also performs sensitivity analyses to identify dominant risks under various assumptions.

SCOPE AND APPROACH

Modeled Systems and Scenarios

The analysis considers characteristics of U.S. and Russian nuclear arsenals, doctrines, systems for early warning of attack from the other nation, and systems for command, control, communications and intelligence (C3I). The model is based primarily on a synthesis of statements regarding the U.S. and Soviet/Russian nuclear arsenals, doctrines, and systems for early warning and C3I, which were made by analysts that used unclassified information and interviews to construct their own models in the 1980s and 1990s, such as Marsh and Wallace et al.[25] It presumes that the assumptions of its model continue to apply to the United States and Russia, which seems roughly consistent with descriptions of both U.S. and Russian forces over the past two decades.[26] It is also assumed that at the level of analysis presented here, Soviet/Russian early-warning systems and response procedures can be reasonably approximated as being functionally equivalent to those of the United States[27] despite some known differences (e.g. as succinctly summarized by Mian et al.[28]).

Both the United States and Russia have systems designed to provide indications of missile attack underway, including satellites to detect hot plume gases from a missile launch and radar to detect missiles in flight. As with any sensor, both satellite and radar systems are susceptible to false positives, so in general the early-warning systems are looking for events that resemble missile launches on multiple detector systems, e.g. on both satellite and radar systems, at the same time. If indications of an attack seem sufficiently convincing, leaders are contacted and briefed on the situation, and must decide whether to launch their own missiles in response to the indications of attack.

Figure 1 shows the basic attack indicator and response decision steps in the U.S. system run by the North American Aerospace Defense Command (NORAD). A first indication of a possible attack from one sensor system prompts a Missile Display Conference (MDC) and system operators investigate the information. If that information is found to be a false indication of an attack, then nothing further occurs. If the information is corroborated by a second sensor system, then a Threat Assessment Conference (TAC) is called. Depending on available information and the number of confirmatory attack indications from separate sensor systems, NORAD will issue either high or low confidence in its attack threat assessment. With a high confidence assessment, NORAD will call a Missile Attack Conference (MAC), including a brief to the President and Secretary of Defense, who then decide whether to launch missiles in response before the use-it-or-lose-it point after which an incoming nuclear attack could prevent a coordinated counter attack.[29] (Terms such as "TAC-level" and "MAC-level" events refer to Soviet/Russian decision procedure steps that are assumed to be roughly analogous to U.S. steps.)

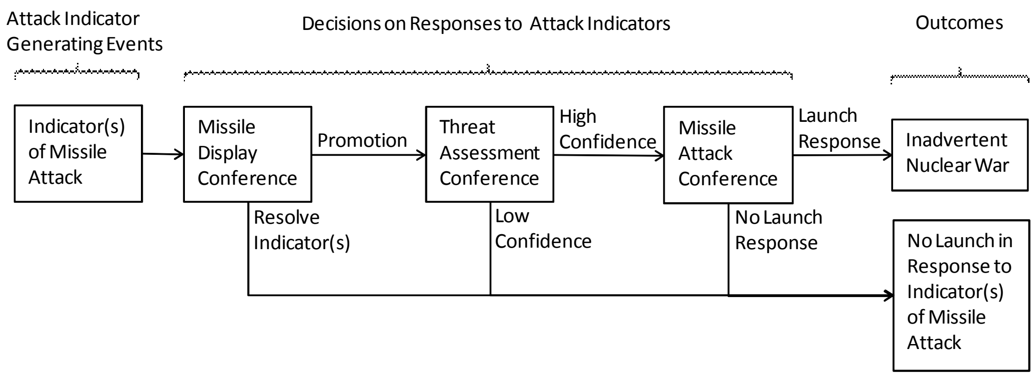

Figure 1. Basic steps in responses to false indicators of missile attack

Attack indicators may or may not be resolved (identified as a false alarm) before passage of the decision time, i.e. the time available for leaders to decide whether to launch missiles in response to indicators of an attack before the use-it-or-lose-it point.[30] If attack indicators remain unresolved before elapse of the decision time, then leaders must decide whether to launch a counter-attack despite uncertainty. Depending on the warning system used and the apparent location of the attack indicated, decision times can range from up to a half an hour for an intercontinental ballistic missile (in an "optimistic" case) down to effectively zero time between confirmed detection of a submarine-launched ballistic missile (or an equivalent attack launched very near that nation's borders) and the time when the order for a coordinated counter-attack would need to be given.[31]

It is assumed that the United States and Russia use a combination of Launch Under Attack (LUA) and Launch On Warning (LOW) capabilities and postures,[32] along with decisions by leaders on whether to actually launch in response to early warning attack indicators or to ride out the indicated incoming attack instead. Both LUA and LOW postures are designed to allow a missile launch in response to a perceived attack once attack indicators are provided by early warning systems and before the perceived attack is expected to impact or disable command and communication capabilities (neither the LUA nor LOW postures rely on "riding out" an attack before launching a counter-attack). The primary difference between the LUA and LOW postures is in the level of early warning system evidence of impending attack required to pass the attack indication signal detection threshold (at which point "decision time" begins), and the amount of time required to obtain that level of evidence. With LOW, indications of an attack with only one "family of sensors", i.e. either satellite or radar, would be sufficient evidence to decide whether or not to give the launch order; with LUA, attack indications from two separate families of sensors, i.e. both satellite and radar, are required.[33] Launch Under Attack takes more time to collect evidence than Launch On Warning (i.e. LUA provides less decision time than LOW, therefore LUA is more susceptible to disruptions from short flight time attacks. However, LUA is more effective at ruling out false alarms because it collects more early-warning data than LOW. It is assumed here that the United States and Russia use the less responsive and less false-positive prone LUA posture during periods of normal or low tension and the more-responsive but more error-prone LOW posture during periods of high tensions or crisis.[34] There is some uncertainty and debate about whether and when the United States and the USSR/Russia employed or employ LUA/LOW postures.[35] At least some of this uncertainty is may be intentional and cultivated by defense planners to complicate the adversaries' planning efforts.[36] This uncertainty is addressed implicitly in the model by assuming that both nations use LUA/LOW capabilities and postures but by also including model parameters representing the probability that leaders would launch a counterattack in response to attack indicators. It assumes that there is some probability that leaders would choose to ride out the apparent incoming attack and rely on second-strike capabilities, for example, instead of launching a counter-attack before the use-it-or-lose-it point). The analysis adapts the launch decision time and event duration time model of Marsh and Wallace et al. Assumptions are made about the distribution of decision times, based on decision time parameter values given by Wallace et al. In cases where a MAC is due to an unresolved MDC during a U.S.-Russia crisis, this paper assumes that neither the United States nor Russia will launch an attack in response to the unresolved MDC before the decision time elapses.

The appendix contains additional information on modeled early warning systems, response procedures, and scenarios.

Qualitative Modeling Assumptions

Synthesizing available information as given above and in the Appendix, the following are the base-case assumptions about the combinations of circumstances and false alarms assumed to be regarded as sufficient evidence to produce a MAC. Under low U.S.-Russia tensions, some fraction of TACs from typical false positive events could be considered serious enough to be promoted to a MAC. Under high U.S.-Russia tensions, some fraction of TACs from typical false positives, or one unresolved MDC, could be considered serious enough to be promoted to a MAC. In addition, regardless of tension level, the analysis assumes that some fraction of possible nuclear terrorist attacks could produce indications of nuclear attack from the other nation.

The preceding describes the base-case or "Danger Calm" case set of assumptions used in this paper. For sensitivity analysis, this paper also considers a "Safe Calm" case where it is assumed that launch of missiles by the United States or Russia in response to mistaken indicators of attack during low U.S.-Russia tensions is essentially impossible, i.e. that U.S. and Russian leadership would only believe early warning system indications of attack during a U.S.-Russia crisis. The Safe Calm case is roughly consistent with the implicit assumptions of Wallace et al., Hellman and other analysts that focus on the risk of an inadvertent launch due to false alarms during crises, though some analysts also consider cases where U.S. or Russian leaders would have some probability of believing false alarms of attack during low U.S.-Russia tensions.[37] The analysis assumes that in the Danger Calm base case, the annual rate of launch of U.S. or Russian missiles in response to mistaken indicators of nuclear attack is the sum of the rates of such launches during both low U.S.-Russia tensions and during U.S.-Russia crisis periods. In the Safe Calm sensitivity case, the annual rate of inadvertent nuclear war is simply equal to the rate of inadvertent launches during U.S.-Russia crisis periods.

The probability that there is a U.S.-Russia crisis at any particular point in time is treated as an independent or exogenous variable in the model. Although some real-world crisis probability factors could be affected by U.S. and Russian decisions, such as escalation or de-escalation strategies employed in a crisis, such factors are not addressed in the current model. Furthermore, the probability of a crisis has several factors that are exogenous to U.S. and Russian decisions, such as probabilities of conflicts affecting Russian interests in the Baltic states.[38]

This paper considers two basic types of events that could cause serious mistaken indications of attack by the other nation. First is a generic category of usual false alarm events defined to include the kinds of events that caused historical false-alarms, in order to incorporate publicly available empirical data on frequencies of false alarm indications in U.S. systems between 1977 and 1983.[39] The second category of event is nuclear terrorist attacks, some of which could be perceived by the United States or Russia as an indication of an attack from the other nation. Such scenarios could include overcoming one nation's security measures and launching one or more of their missiles at the other nation[40] or potentially other means. Estimates of probabilities of nuclear terrorist attack were given by national security experts surveyed by Lugar;[41] a roughly consistent range of estimates resulted from the mathematical modeling of Bunn[42] and from the estimates of Allison[43] and Garwin.[44] Presumably, there would be a number of factors used to determine the resemblance of a nuclear terrorist attack to an attack from other nations, including decision time. Those factors are not specifically addressed, partly because of paucity of data and partly to avoid assisting terrorists. Instead, at the risk of inaccuracy, the model makes simple assumptions to derive the associated parameter estimate ranges.

Fault Tree Representation of Inadvertent Nuclear War Scenarios

Figure 2 is a compact graphical representation of the inadvertent nuclear war pathways. The figure is a simple fault tree constructed to analyze the probability of inadvertent nuclear war between the United States and Russia (the "top event", in fault tree terminology) as a function of the probabilities of various conditions and events (which are below the top event in the fault tree). The relationship between the conditions and events is expressed in all-caps Boolean terms, including "AND", "OR", and "NOT". For example, the inadvertent launch of U.S. missiles in response to mistaken indicators of nuclear attack occurs if a TAC-level false-alarm event occurs in combination with two specific failure conditions: if the false alarm is promoted to the level of a MAC, and if a decision to launch is made in response to the MAC-level false indicators of attack. The Boolean algebra is then used in event rate and failure condition probability calculations, described in the next section. The fault tree shows this paper's two main categories of false alarms, the "usual" false alarms and nuclear terrorist attacks. The fault tree also shows two U.S.-Russia tension levels, low tension and crisis.

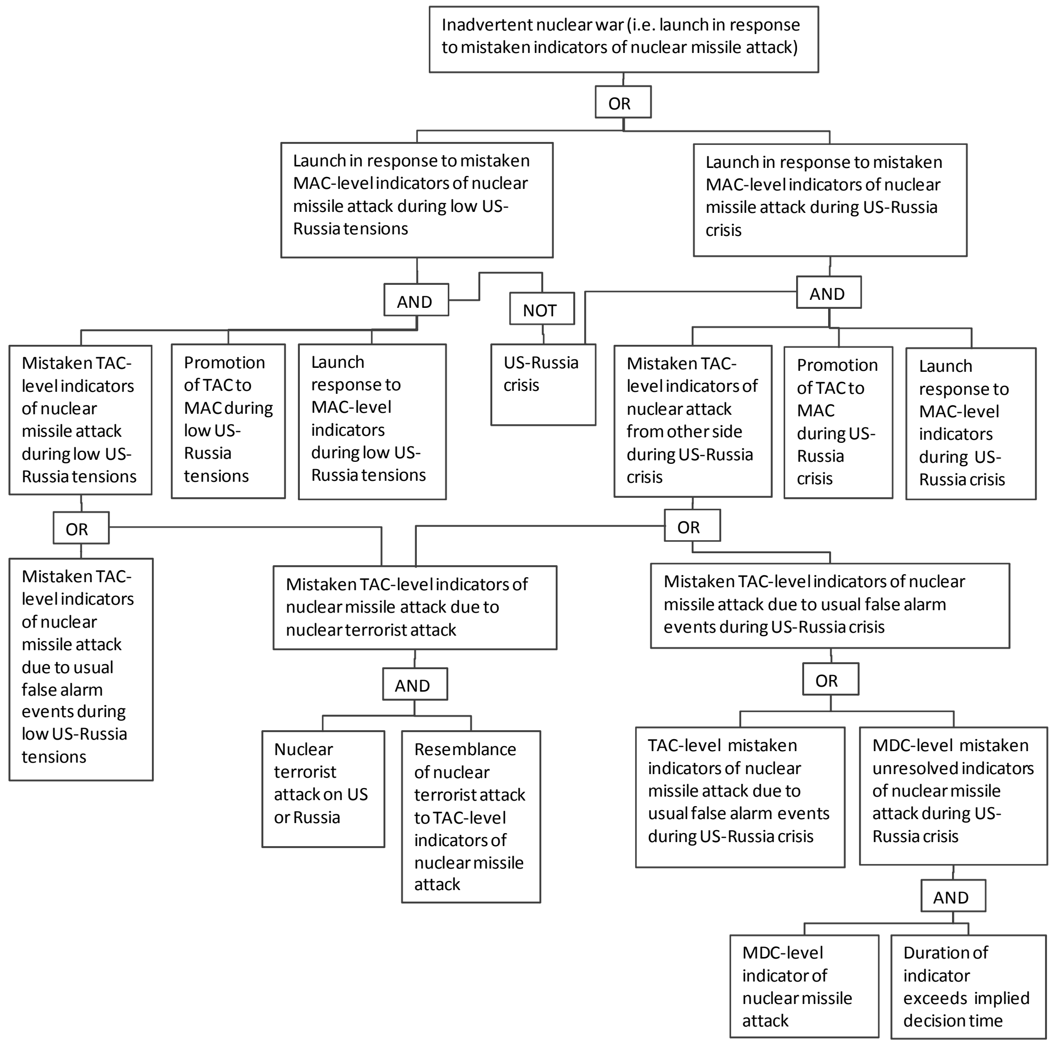

Figure 2. Simple fault tree of inadvertent nuclear war pathways and conditions

Mathematical Modeling of Event Rates and Probabilities

Given the large uncertainties in critical model forms and parameters, the analysis does not seek single best-estimate model parameter values, but rather seeks credible input parameter ranges to produce a range of model output estimates.[45] Exploratory, sensitivity and uncertainty analyses are performed to identify which input uncertainties have the greatest influence on the uncertainty of the results and to assess the robustness of conclusions given model limitations and uncertainties.

Following the example of several earlier probabilistic models of inadvertent nuclear war,[46] it is assumed that the occurrence of mistaken attack indicators are independent random events with constant occurrence rates, which this paper models as Poisson arrival processes.[47] There are several types of mistaken attack indicators, each of which occur at their own rates, as in a merging of Poisson processes. There is also some probability that any particular mistaken attack indicator will be part of a combination of other events that produce inadvertent nuclear war, as in a splitting or thinning of Poisson processes. These ideas are developed more formally in the following description.

Let the arrival rate of a type of event A (e.g. a false indication of an attack from the other nation) be the expected or average number of events per year x. In a Poisson process, the probability of an event A occurring during a period of time t is then given by the cumulative distribution function $F_A(t)$ of the exponential lifetime distribution:[48]

$$F_A(t) = 1 - \exp(-xt) \tag{Eq. 1}$$

For any given type of event A, suppose there are sets of subtypes of events A_i, any of which would be considered an instance of event type A. Let x_i be the arrival rate of event type A_i. Note that event types A_i are linked by OR gates to event types A in the fault tree, meaning that an instance of event A will have occurred if there is an occurrence of event type A_1, or type A_2, or A_3, etc. Equivalently, consider the Poisson process producing event A to represent a merging or aggregation of the Poisson processes producing events A_i so that the arrival rate x equals the sum over i of x_i. As indicated in the fault tree in Figure 2, the model assumes there are three types of false attack indicators (i.e. A_1 denotes Threat Assessment Conference level attack indicators, A_2 denotes Missile Display Conference level attack indicators that normally would not be treated as TACs but might be if not quickly resolved during a crisis, and A_3 denotes nuclear terrorist attacks).

Furthermore, suppose that for a particular type of event A_i, conditions C_{ij} are necessary for a specific event of type A_i to be considered an occurrence of event type A. Let p_{ij} be the probability of condition C_{ij}. For example, the model assumes that one condition for the occurrence of inadvertent nuclear war is that given a false indication of attack, there is also a failure to prevent a launch of missiles in response to the mistaken indications of attack. Note that conditions C_{ij} are linked by AND gates to events A_i in the fault tree, meaning e.g. that an instance of inadvertent nuclear war only occurs if there is a false indication of attack, and there is a launch of missiles in response to the mistaken indications of attack. Equivalently, consider the Poisson processes producing events A_i under conditions C_{ij} to represent a splitting, disaggregation, or thinning of those Poisson processes so that the effective arrival rate of events A_i as events of type A is the product of x_i and p_{ij}. Incorporating all the above, the arrival rate x is given by

$$x = \sum_i x_i \prod_j p_{ij} \tag{Eq. 2}$$

For example, consider the probability $F_{NRA}(t)$ of a non-resolved MDC-level alarm (NRA) occurring during a period of time t in either the United States or Russia. The OR statement indicates that the two nations' processes are merged. x_2 is the arrival rate of MDC-level alarms in each nation. $p[NR]$ is the conditional probability that a particular MDC-level false alarm would not be resolved, given false alarm event A_2. The annual ($t = 1$) probability of this event can be estimated using the following equation:

$$F_{NRA}(t) = 1 - \exp(-2x_2\, p[NR]) \tag{Eq. 3}$$

MDC false alarm resolution times are assumed to be exponentially distributed with a mean resolution time y.[49] So, for decision time w, the probability $p[NR]$ that a particular MDC false alarm would still be non-resolved (NR) before decision time elapses is

$$p[NR] = \exp\left(-\frac{w}{y}\right) \tag{Eq. 4}$$

For probability of conditions with some duration, the analysis assumes that the probability of a condition at any point in time is the product of the annual rate or probability of the condition and the duration of the condition if it occurs. For example, the probability that there is a U.S.-Russia crisis at any point in time is the product of the annual probability of a crisis and the duration of a crisis if one occurs (where duration is in terms of fraction of a year).

For probability of other conditions (and for most other model parameters), this paper uses the following procedures to estimate probability distributions for use in Monte Carlo simulation uncertainty of model inputs and outputs. Where limited estimates or data are available, such as from surveys or judgment of analysts[50] or small empirical samples,[51] the model used here generally represents parameters using one of the following: uniform distributions that define only the lower and upper bounds of the parameter value; triangular distributions that define a most-likely value as well as lower and upper bounds; or probabilistic sampling directly from the empirically observed historical data.[52] In addition, for conditional probabilities of occurrence *p* for which effectively zero historical occurrences have been observed out of *n* total cases when it could have occurred, this paper uses a probability distribution function *f*(*p*) given by

$$f(p) = (n+1)(1-p)^n \quad \text{(Eq. 5)}$$

which can be derived as a Bayesian posterior distribution with a uniform prior and binomial likelihood function.[53] The main uses of Equation 5 in this paper are the estimation of (A) the conditional probability that TAC-level attack indicators will be promoted to a MAC, and (B) the conditional probability of leaders' decision to launch in response to mistaken MAC-level indicators of being under attack.

These model parameter estimation procedures have several advantages. First, they allow the use of available empirical data, even where data are very limited and/or where no failure events are known, to estimate failure rates and event probabilities. Second, they allow estimation of uncertainties in model parameters, at least in terms of possible ranges for parameter values, which is generally recommended for quantitative risk and simulation models with a high degree of uncertainty.[54] The analysis includes exploratory, sensitivity and uncertainty analyses.

However, some probabilities or failure rates are likely to be over-estimated (e.g. parameters for which uniform probability distributions are used). Nevertheless, the overall risk model may result in under-estimation of the overall risks of inadvertent nuclear war because of the many possible failure modes that the model does not account for. On balance, less weight should be given to specific model output values than to ranges and overall trends in results.

Modeled Risk Reduction Measures

For inadvertent nuclear war risk reduction, the analysis focuses on two measures that appear to have the following characteristics: they have potential to reduce inadvertent nuclear war risks; they have not received much attention or modeling in previous publicly available analyses; and they seem (at least initially) relatively unlikely to introduce the kinds of risk-inducing strategic instabilities that critics have argued would result from some "de-alerting" measures and even with total nuclear disarmament.[55]

The first measure is the suggestion of Mosher et al. for either, or preferably both, of the United States and Russia to move and keep strategic ballistic missile submarines (SSBNs) far enough away from each other's coasts to substantially increase the amount of time between when the launch of submarine-launched ballistic missiles (SLBMs) would be detectable and when they would arrive at their targets. In other words, the move could effectively increase counterattack launch decision time for indicated SLBM attacks. Limited decision time is an important inadvertent nuclear war risk factor for both SLBMs and land-based ICBMs, especially for short flight time SLBMs.[56] There is some potential for verification of exchanged information on location of SSBNs to make the overall implementation of the SSBN moves credible to the other nation, unlike some de-alerting measures that would be unobservable by the other nation and therefore perhaps not credible.[57] Both Russian and U.S. SLBMs have sufficient range to be launched from inter-continental ballistic missile (ICBM) distances, i.e. from the continental United States to locations in Russia or vice versa. This paper assumes that moving SSBNs would increase decision times, and therefore would increase the probability that any particular MDC would be resolved before decision time elapses, but moving SSBNs would not change the underlying annual MDC occurrence rates or resolution times.

The second inadvertent nuclear war risk reduction measure is the suggestion of Podvig for part-time lowering of alert level. This paper considers cases where one or both nations would be at lowered alert half of the time and at normal alert levels half of the time. It assumes that if a false indication of an attack occurred during a period when that nation is at lowered alert, it would not lead to a counter-attack. The analysis also assumes that lowering of alert levels would be performed in such a way that at any particular moment, it would not be detected reliably by the other nation, as suggested by Podvig,[58] who stated that, "If the forces can be taken off and on alert covertly, the attacker could never determine the right moment for his attack. Both sides would have to assume that the forces of their adversary are on full alert." If de-alerting can be detected more reliably, then more extensive de-alerting schemes may be more appropriate for risk reduction. A major reason that a number of potential de-alerting measures have not yet been implemented is because of difficulties with verification of alert status and detection of re-alerting in all relevant areas.[59]

COMPUTATIONAL MODEL

The inadvertent nuclear war probability estimation computational model was implemented with the Analytica software package from Lumina Decision Systems.[60] The computational model modules are shown in the on-line supplement to this paper.[61] The complete model is available from the authors by request.

To estimate probability distributions of outputs, the computational model performs Latin hypercube (a type of Monte Carlo) sampling of input parameter values. The model sample size is 10,000 iterations, which is expected to be sufficiently large to avoid introducing excessive sampling error.[62] The model varies input parameter values according to the probability distributions given later in this section and in the Appendix.

The following are several of the most important model parameter values and rationales. Except where specifically noted (e.g. in parametric sensitivity analyses), the parameter values from this section and the Appendix are used throughout this paper. It is also assumed that random parameter values are uncorrelated except where noted due to conditionality.

The assumed annual probability of occurrence of a U.S.-Russia crisis is given by the Triangular (0, 0.02, 0.06) distribution. The lower bound is 0 if U.S.-Russia crises are no longer possible. The most likely value of 0.02 is based on the Hellman best estimate of one crisis in 50 years; that corresponds to counting Cuban Missile Crisis as only historical crisis. The upper bound value of 0.06 is based on the Hellman estimate of three possible events in 50 years, and roughly corresponds to counting as several of the historical alerting incidents in the Appendix. The upper bound value is also somewhat consistent with Gottfried and Blair[63] that a crisis might arise "perhaps once in a generation." If a U.S.-Russia crisis occurs, its assumed duration in days is Uniform (13, 30). Tension levels and inadvertent nuclear war probabilities were high in the Cuban Missile Crisis for a period somewhere between 13 days[64] and 30 days[65] depending on whether leaders' tensions or military alert levels dominate risks in crisis.

The model assumes equal probabilities of selection of the annual rates of "usual" MDC and TAC level mistaken indicators of nuclear attack for 1977 through 1983 as given by Marsh and Wallace et al. Consistent with that empirical data, the model uses an annual TAC rate of zero TACs per year with probability 4/7 and two TACs/year with probability 3/7, and the model has an equal probability of using any one of the following annual MDC rates: 43; 70; 78; 149; 186; 218; or 255 MDCs per year. In the principal analyses, it is assumed that ranges of MDC and TAC rates have not substantially changed since the period between 1977 and 1983. This paper also includes parametric analysis of the sensitivity of model results to effects of changes in assumed false alarm rates, e.g. if false alarm rates have been only some fraction of what they were between 1977 and 1983.

The model's assumed rates of a nuclear terrorist attack are calculated using likelihood-weighted selection from the Lugar survey's estimates of probability of a nuclear attack somewhere in the world over a ten-year span, converted to implied expected annual rates using a rearrangement of Equation 1, and using other factors given in the Appendix. The Lugar survey's 10 year nuclear attack probability estimate bins range from 0 to 1 probability of attack, but the survey-indicated likelihood of each probability bin varies. The survey-indicated most likely probability bin, 0.05 probability of attack, has a 23 percent likelihood of being selected by the model in this paper. (The model uses 0.99 instead of 1 as the highest 10 year attack probability bin, to avoid nonsensical results when converting from 10 year probabilities to implied expected annual rates.) To find the probabilities of a nuclear terrorist attack, the survey's nuclear attack probabilities are multiplied by a factor of 0.79, because 79 percent of Lugar survey respondents thought that nuclear attack would be by terrorists (with the other attacks being made by a government).

MODEL RESULTS

Results of Inadvertent Nuclear War Risk Estimation

In general, estimates are reported to only one significant digit, to help avoid giving a false impression of precision. Table 1 gives the mean and median estimated annual probability of inadvertent nuclear war for both the Danger Calm base case set of assumptions and for the Safe Calm sensitivity case set of assumptions. The mean estimated annual probability with the Safe Calm case that assumes that inadvertent nuclear war is impossible during periods of low U.S.-Russia tensions, 0.01, is approximately half of the inadvertent nuclear war probability with the Danger Calm base case assumptions, 0.02. (A slightly lower ratio is present with median values.) In other words, the overall inadvertent nuclear war rate associated with high U.S.-Russia tensions comprises roughly half of the Danger Calm base case model estimated inadvertent nuclear war risk. That also means that the overall inadvertent nuclear war rate associated with *low* U.S.-Russia tensions comprises the other half of the base case model estimated inadvertent nuclear war risk.

There is significant uncertainty in the model-estimated annual inadvertent nuclear war probability, which can be represented by model-generated output probability distributions. Figure 3 gives the probability density functions (PDFs) for the annual probability of inadvertent nuclear war. The PDFs indicate that the model-estimated most-likely values are at the bottom end of the distributions in both cases, but that the probability distributions are long-tailed. The 90 percent confidence interval (extending from the 5th percentile estimate to the 95th percentile model estimate) ranges from 0.0002 to 0.07 in the base case, and from 0.00001 to 0.05 if excluding launch during low tensions.

Table 1. Model-Estimated Annual Probability of U.S. or Russian Launch in Response to Mistaken Indicators of Attack by Other Nation

Probability Statistic	Danger Calm Assumptions	Safe Calm Assumptions
Mean	0.02	0.01
Median	0.009	0.003

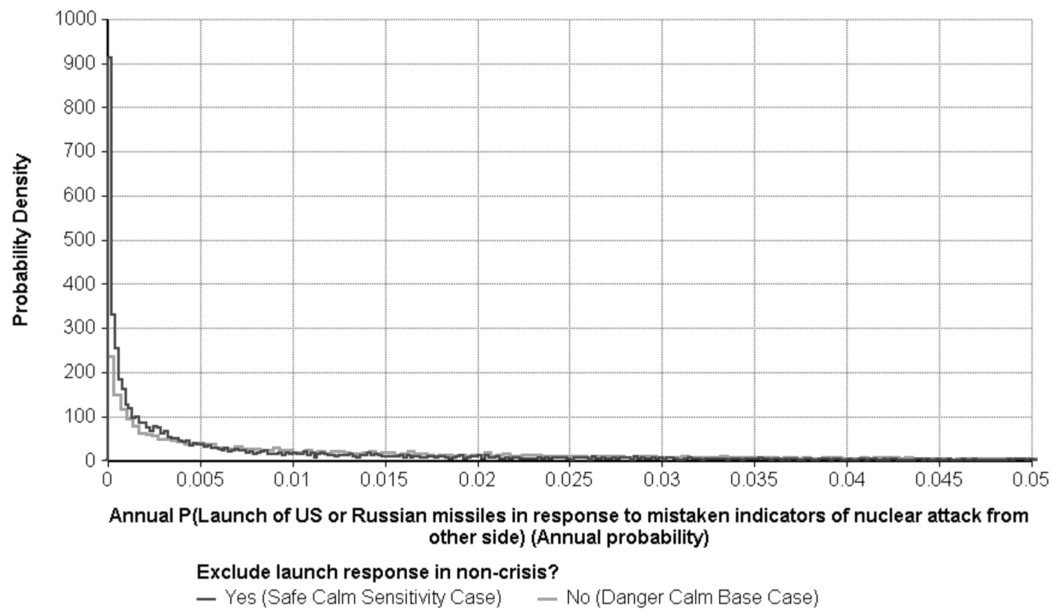

Figure 3. Probability Density Function of Model-Estimated Annual Inadvertent Nuclear War Probability

Table 2 gives the median model-estimated annual rates of mistaken MAC-level indications of attack associated with both the usual types of false alarms that have already been seen in U.S. early warning systems, as well as from nuclear terrorist attack. The median estimated overall rate for the usual false alarm events is at least an order of magnitude higher than for nuclear terrorist attack (i.e. one order of magnitude with the Danger Calm base case assumptions and three orders of magnitude with the Safe Calm sensitivity case assumptions). Given the assumptions in this model, nuclear terrorist attack appears far less likely to cause inadvertent nuclear war than the other types of events that have already caused false alarms in U.S. and Russian early warning systems.

Moving Strategic Submarines far from Other Nation's Borders to Increase Decision Time

Table 3 gives the results of moving SSBNs far enough away from the other nation's borders that any submarine-launched missiles would have flight times equivalent to land-based ICBMs, credibly enough that the other nation believes it. Results for the following cases are presented: the status quo case; where only one nation credibly moves SSBNs; and the case where both nations credibly move SSBNs. The results indicate that substantial inadvertent nuclear war risk reductions could be achieved by moving SSBNs further away from each other's borders, even if the move is only implemented by just one nation.

Table 2. Median Estimated Overall Annual Rates of Mistaken MAC-level Indicators of Nuclear Attack

Assumptions	Due to Usual False Alarm Events	Due to Nuclear Terrorist Attack
Danger Calm	0.01	0.0006
Safe Calm	0.003	0.0000008

Table 3. Effect of Moving SSBNs on Median Model-Estimated Annual Inadvertent Nuclear War Probability

Assumptions	Status Quo	One Nation Moves SSBNs Credibly	Both Nations Move SSBNs Credibly
Danger Calm	0.009	0.005	0.003
Safe Calm	0.003	0.001	0.0003

Effects of Inadvertent Nuclear War Risk Reduction Options

Part-time Lowered Alerts

Table 4 gives the results of modeling the effects of the part-time lowered alert suggested by Podvig, where a false indication of an attack during a period of lowered alert would not lead to a counter-attack. The results indicate that the reduction in probability of the inadvertent nuclear war scenarios considered is approximately proportional to the average lowered-alert time fraction for the two nations. For example, if both the United States and Russia are temporarily de-alerted half the time, that cuts the overall modeled inadvertent nuclear war risk by approximately half. Even if only one nation uses a half-time lowered alert policy, that reduces overall modeled inadvertent nuclear war risk by approximately 25 percent.

Table 4. Effect of Temporary Lowering of Alert Level on Median Model-Estimated Annual Inadvertent Nuclear War Probability

Assumptions	Status Quo Alert Levels	One Nation at Lowered Alert 50 Percent of Time	Both Nations at Lowered Alert 50 Percent of Time
Danger Calm	0.009	0.007	0.005
Safe Calm	0.003	0.002	0.001

Additional Sensitivity Analysis and Uncertainty Analysis

This section presents further exploration of model sensitivities to assumptions. First is a relatively simple sensitivity analysis involving parametric variation of the "usual" MDC and TAC rates. For the purposes of this specific analysis, a factor is introduced that allows simple parametric adjustment of the ratio of (1) the MDC and TAC rates used in the model for the period 1975 to 2012 as compared to (2) the rates observed in the United States in between 1977 and 1983.[66] The ratio is parametrically varied over the range from 0 to 1. (A value of 1 for this ratio implies that the distribution of rates observed between 1977 and 1983 were applicable from 1975 until 2012; a value of 0.5 for the ratio implies that the actual rates are now, and have been, only half of what they were in the period 1977–1983.) Figure 4 shows the results of this parametric analysis where all other assumptions are as previously stated. The figure shows that the effect of a reduction in "usual" false alarm rates on inadvertent nuclear war probability is not entirely proportional to the change in false alarm rates. This is more evident with the Danger Calm assumptions than with the Safe Calm assumptions, but is present for both (and is also more evident with mean than median inadvertent nuclear war probabilities, though only median estimates are shown in Figure 4). This nonlinearity is mainly because the model assumes that the probability of promotion of a TAC to a MAC depends on the number of TACs estimated to have occurred (using Equation 5 with n equal to the number of model-estimated TAC occurrences to date). In the model, a lower rate of usual false alarms results in a higher model-estimated probability that a TAC would be promoted to a MAC. These effects offset false alarm rate reductions.

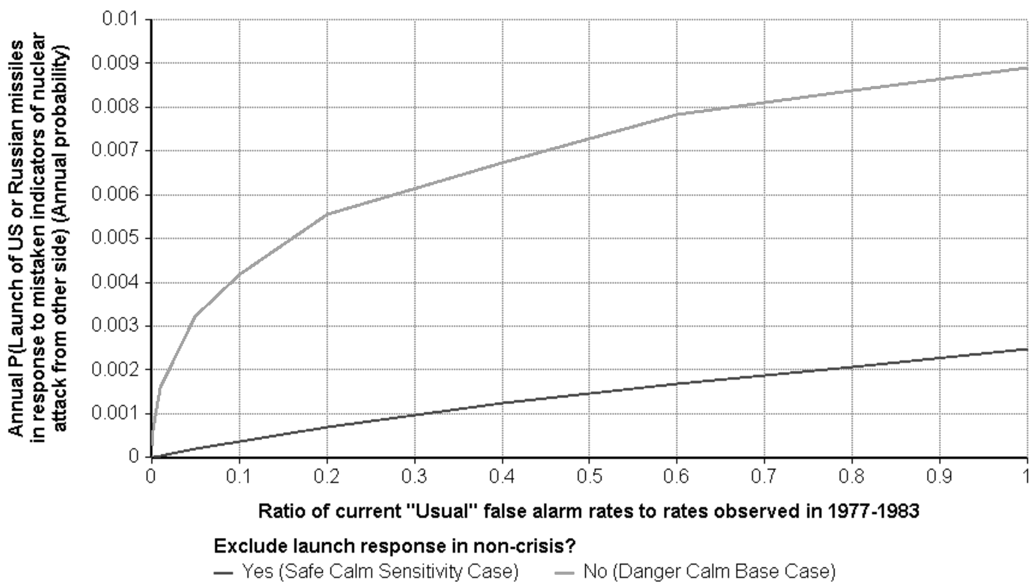

Figure 4. Dependence of Median Model-Estimated Annual Inadvertent Nuclear War Probability on MDC and TAC Rates

Second, to identify the input parameters whose uncertainties (as reflected in assumed probability distributions) most affect uncertainties in model outputs, uncertainty importance analysis is performed using Analytica. It uses the absolute rank-order correlation between each input sample and the output sample as an indicator of the strength of monotonic relations between each uncertain input and a selected output.[67] The analysis suggests that relatively important sets of factors include the decision times associated with MDCs (sampled over the nation receiving the indicators), the annual number of TACs, the baseline probability that an indicated attack is an ICBM instead of an SLBM, and the probabilities that leaders will launch missiles in response to mistaken MAC-level indicators of nuclear attack. (The relative importance of those factors depends on whether the Danger Calm or Safe Calm assumptions are used, and on the level of U.S.-Russia tension.) Those results are not surprising, given the role of those factors in the inadvertent nuclear war models of Wallace et al. and Sennott,[68] and because features of their models are incorporated here. Other model input parameter uncertainties generally have significantly less effect on model output uncertainties. For example, even though the model has seemingly great uncertainty about nuclear terrorist attack probability, that uncertainty has relatively little importance in this context, probably because of the much lower estimated annual rate of nuclear terrorism as compared with other, more frequent false indicators of nuclear attack.

DISCUSSION

Evaluating Model Validity

Given that no nuclear war between the United States and the USSR or Russia has occurred in the last four decades, relatively low war probability predictions seem intuitively more likely than relatively high war probability predictions. Statistical significance tests may provide a more quantitative check of the sensibility of the estimates of the model. For example, with the use of a binomial distribution to find the confidence interval for an event probability *p*, given that zero such events has yet occurred in *n* independent random trials, *p* lies within the interval [0, *u*] with (1 – α) confidence, where $u = 1 - \alpha^{\left(\frac{1}{n}\right)}$ gives the upper limit of the confidence interval.[69] If using α = 0.05 to find *u* as the upper limit of a 95 percent confidence interval, and given *n* = 37 independent trials (i.e. each year from 1975 to 2012) without an event occurring, then *u* = 0.08. In other words, given that there has been no inadvertent nuclear war between the United States and Russia during the 37-year period for which this paper assumes its modeled systems and response procedures have been in place, there could be a statistical argument for rejecting (with 95 percent confidence) a probabilistic model that produced a best estimate (i.e. a mean value) for annual nuclear war probability above 0.08. Because the model used in this paper produce best estimates of annual probability of inadvertent U.S.-Russia war that are well below 0.08, this statistical test does not suggest rejecting the model's estimates with 95 percent confidence. However, many readers may intuitively feel that even an annual nuclear war probability of eight percent seems too high to be useful discriminator of the model's validity. In any case, it could be more productive to check or revise specific assumptions or parameters within the model, such as with additional data on rates and probabilities of false-alarm events, when new information becomes available. It could also be useful to use additional empirical data to check assumptions of the model that were based primarily on mathematical-modeling reasoning rather than on empirical data, because of the limited amounts of empirical data available. One example is the assumption in Equation 4 that MDC false alarm resolution times are exponentially distributed.[70]

One additional validity check often used in simulation modeling is the comparison of results of different models or assessments. Perhaps the model with the most easily comparable outputs (i.e. annual probability of nuclear war) is that of Hellman, which used an approach and assumptions different from the approach in this paper to estimate that "the failure rate of [US-Russia nuclear war] deterrence from all sources is on the order of one percent per year." That is approximately equivalent to this paper's Danger Calm median estimated annual probability of inadvertent nuclear war. However, it should be noted that the estimate of Hellman is for "all sources" and not just for the inadvertent nuclear war scenarios examined here. The Hellman estimate does not depend on explicitly estimating false-alarm rates, nor on estimating the probability of a U.S. or Russian leader launching an attack in response to a false alarm.

Model Limitations

The model applied here necessarily employs numerous approximations to reality. As previously stated, the model assumes that the Soviet/Russian early-warning systems and response procedures are similar enough that they can be approximated as being equivalent to those of the United States, at least at the level of detail assumed in the model. Even if the basic structure of the model is reasonably accurate, it is quite possible that there are significant differences between the United States and Russia in the real-world values of some model parameters, such as in rates of false attack indicators.

As previously mentioned, this paper assumes that all variables in the model are random and uncorrelated, except where conditionality is specified. It also assumes that the timing of specific false attack indicator events are (at least as far as can be determined from the perspectives of the U.S. or Russian early warning systems and decision makers) essentially random. For example, the model assumes that terrorists do not intentionally time their attack to coincide with a U.S.-Russia crisis, so if both occur at the same time, that is due entirely to chance. However, that may not be true. In addition, some terrorist nuclear attack scenarios seem more likely than others to be interpreted by U.S. or Russian early warning systems as indications of nuclear attack from the other nation. For example, Blair[71] provides one publicly available discussion of a nuclear terrorist attack scenario that could arguably provide indications to Russia of a nuclear attack from the United States. Such scenarios might be pursued by terrorists without intent to cause inadvertent nuclear war, perhaps because a related opportunity presents itself to them before an opportunity for another nuclear attack that would otherwise seem easier or more likely to succeed. This paper does not identify such scenarios. However, assessment of such issues can and should be made, partly by building upon the framework developed here.

The parameter estimation sources and methods used here have important limitations. None of them seem inconsistent with the paper's primary goal of providing ranges of estimates using available information, because the sources and methods are used primarily to establish parameter value distributions or that reflect uncertainties in available data. However, the limitations do seem likely to introduce biases, or at least somewhat surprising estimates. One example is the use of asymmetric distributions to represent uncertainties in several parameters, in which mean and median values are greater than the most likely value. Another important category of examples results from the fact that for many scenarios considered, very few or no applicable historical cases are publicly known to have occurred. The methods used to estimate failure rates for system components without known failures are better suited to providing a range of estimated failure rates than to producing a best-estimate value of the failure rate based on small amounts of data, though the latter depends on the statistical estimation approach used.[72] The shortcomings of the approach may be most obvious in the treatment of the probability of a decision by leaders to launch an attack in response to false indicators of nuclear attack. No such event has yet occurred. The authors of this paper are currently aware of just one historical instance of a MAC-level event, the 1995 Norwegian rocket incident, where early warning system indicators of nuclear attack led to either a U.S. or Russian leader explicitly considering an immediate nuclear response to indicators of an attack.[73] The extensive descriptive, normative and prescriptive literatures on nuclear decision making address a number of complex and diverse organizational and cognitive processes and patterns that could affect actual responses to indicators but most of which is not specifically incorporated in this paper.

Using information on the occurrence of historical incidents to estimate the frequency or probability of similar events occurring in the future also has other shortcomings. For example, some of the conditions and procedures present during the time of the historical incident may have already changed, or may change in the near future. The data on MDC and TAC rates used in this paper are approximately three decades old, and it is important to note that this paper's principal analyses assume that these rates have not changed substantially despite any underlying changes in technology, procedures and strategies between the 1970s and 2013. (Although the authors of this paper are not aware of more recent false alarms in the U.S. than reflected in the MAC and TAC rate data used in this paper, that may be primarily because NORAD has chosen not to release information on false alarm rates since the mid-1980s[74] rather than because false alarms have not been occurring. In addition, other kinds of notable incidents have occurred recently, such as the unintended flight in 2007 of six U.S. nuclear-armed cruise missiles[75] and the break in communication between 50 U.S. nuclear ICBMs and their controllers for 45 minutes on 23 October 2010,[76] suggesting that nuclear operations, systems and safeguards have not become free of surprising errors since the end of the Cold War.) This paper assumes that the overall structure of dual phenomenology sensors used by the United States and Russia is essentially unchanged, which seems consistent with more recent discussions[77] though it also seems likely that some details of sensors in use have changed by now. Even if the overall structure is generally unchanged, the rates of MDC and TAC-equivalent events may have changed. In addition, even if nothing important has changed in early-warning sensor systems since 1983, the limited number of data years, from 1977 to 1983, provides only a small sample for event rate estimation.

The estimates used in this paper for the probability of a nuclear terrorist attack, and of U.S.-Russia crisis, also seem likely to be overestimates. The Lugar survey estimates of probability of nuclear terrorist attack seem likely to be overestimates of the respondents' true beliefs, because the apparent design of the survey seems likely to have introduced a combination of anchoring bias[78] and range equalizing bias.[79] The Hellman estimate of the annual probability of a crisis between the United States and Russia is based on fairly simple extrapolation from both U.S.–USSR and U.S.-Russia relations, which is dominated by U.S–USSR relations during the Cold War because of their longer history (the U.S.–USSR Cold War lasted for approximately four decades, and Russia has been in place for only two decades). One might reasonably presume that the probability of a U.S.–Russia crisis is lower than a U.S.–USSR crisis was during the Cold War. However, relations could also degrade in a variety of scenarios and may already be somewhat strained by events such as the presence of U.S. missile defenses in Europe.[80] On a related topic, according to the model, if inadvertent nuclear war during periods of low U.S.-Russia tension is impossible, then the overall annual probability of inadvertent nuclear war is approximately proportional to the probability of a crisis.

POLICY IMPLICATIONS AND IMPLEMENTATION CONSIDERATIONS

Based on the assumptions of the model, nuclear systems and postures of the United States and Russia continue to pose significant risks of inadvertent nuclear war; consistent with earlier studies of inadvertent nuclear war risks. The analysis also indicates that there could be substantial value in the risk-reduction strategies considered here, though there are issues to consider before implementation.

The model estimates probability of inadvertent nuclear war for periods of both low tensions and high (crisis-level) tensions between the U.S. and Russia. Although the model assumes that U.S.-Russia crises are rare, such crises represent approximately half of the model-estimated total inadvertent nuclear war risk under Danger Calm base case assumptions. False alarms occurring during low U.S.-Russia tensions comprise the other half of the base case model estimated inadvertent nuclear war risk. Although many authors focus on stability in crisis situations, if the Danger Calm base case assumptions are correct (i.e., that U.S. or Russian leaders would consider launching missiles in response to attack indications during a period of apparently low tensions between the U.S. and Russia) then the model suggests that there could also be substantial danger during periods of low tension. Though much has been done in the past to minimize risks of inadvertent nuclear war during peacetime, there could be significant value in seeking adjustments to U.S. and Russian nuclear postures to further reduce the probability of inadvertent nuclear war during low-tension periods.

The analysis in this paper agrees with other work such as Mosher et al. in suggesting that one of the most important inadvertent nuclear war risk factors is the short launch decision times that result from a strategy of launching counterattack missiles before an arriving attack takes effect. The analysis suggests that there could be significant benefit from each nation moving its strategic submarines (SSBNs) far enough away from each other's coasts to substantially increase the amount of time between when the launch of submarine-launched ballistic missiles (SLBMs) would be detectable and when they would arrive at their targets. However, additional work may be necessary to develop appropriate methods for verification of exchanged information on location of SSBNs to make the moves credible to the other nation. In addition, it would be appropriate to assess new risks, such as the potential for one nation to use an expectation by the other nation that it would no longer use SSBNs for short-range attacks in order to launch a surprise attack using SSBNs.

This analysis also corroborates the inadvertent nuclear war risk-reduction suggestion of Podvig for part-time lowering of alert levels, assuming that lowering of alert levels could not be detected reliably by the other nation. If temporary lowering of alert levels is implemented, it would be prudent for detectability of temporary lowering of alert levels to be continually tested (i.e. via red teams). If lowering of alert level becomes verifiable, alert-level verification could become part of a more extensive de-alerting agreement. However, there is a possibility that one nation would develop an alert-level detection means before the other, which could increase first-strike instability.

The way in which the suggestion of Podvig for part-time lowered alert has been modeled in this paper was somewhat simplistic to facilitate analysis. The original suggestion of Podvig was for the United States and Russia to "introduce a policy of keeping their forces off alert most of the time". Presumably this would be especially true during low-tension periods; in the limiting case, both sides might keep their forces at lowered alert close to 100 percent of the time during low tension periods. This would essentially mimic the Safe Calm sensitivity case where inadvertent nuclear war could occur anytime during crisis periods but not at all during a non-crisis period.

Finally, both the United States and Russia should work to identify and assess the probabilities of a scenario by which terrorists could cause inadvertent nuclear war, either as a specific objective of the terrorists, or as an unintended consequence of a nuclear terrorist attack. Although the model indicates that the annual rate or probability of such events is orders of magnitude less likely to be a source of inadvertent nuclear war than the false alarms that the United States and Russia are used to dealing with, it is also possible that the analysis has neglected important aspects of intelligent-adversary behavior of terrorists[81] that would result in higher probability that terrorists would initiate nuclear war between the United States and Russia. For example, terrorists might have both the intent and capability to (1) carry out attacks that resemble first-strike nuclear missile attacks from the other nation, such as by launching nuclear missiles,[82] (2) increase the probability of a crisis between the United States and Russia either with a nuclear attack or via other actions, or (3) detonate a nuclear device specifically during a period of crisis between the United States and Russia.[83]

APPENDIX

Additional Information on Modeled Systems and Scenarios

Systems and response procedures described here are assumed to have been used since approximately 1975, and current C3I systems and launch protocols have been in place for the past 37 years. There is limited publically available data on the historical frequency of MDCs, TACs or MACs in the United States, or their equivalents in the USSR and Russia, over the same period. In the United States, during the period 1977–1983, the number of MDCs per year ranged from 43 to 255, and the number of TACs per year were either zero or two.[84] No MACs are known to have ever occurred in the United States.[85] In the USSR or Russia, the 1983 satellite sensor warning incident was roughly equivalent to a TAC that was not promoted to the level of a MAC, and the 1995 Norwegian scientific rocket incident was roughly equivalent to a MAC in which leaders made a decision not to counterattack in response to the initially serious indicators of a possible submarine-launched Trident missile.[86]

The decision procedures depend on the level of tensions between the United States and a nuclear adversary, and associated strategic intelligence. In the United States, a high level of nuclear tensions would produce high strategic-intelligence estimates of the current likelihood of an attack (somewhat similar to a Bayesian prior estimate of attack probability, to be combined with incoming satellite and radar data). As Blair[87] put it, “NORAD in effect assigned equal weight to infrared satellite sensors, ground radar sensors, and strategic intelligence. Positive indications from any two of these sources were sufficient to justify a high-confidence assessment. This formula posed a danger that heightened nuclear tensions (strategic warning) could have combined with a false alarm from a tactical sensor to convince NORAD that a Soviet attack was under way.”

Strategic intelligence warning has not necessarily been used in precisely the same way in Soviet/Russian systems as in U.S. systems. However, statements about their procedures suggest that in a crisis, Soviet/Russian nuclear forces could or would be put on “high alert”, that “putting the troops on high alert probably would be accompanied by the transfer of the battle management system from regular combat duty to combat mode.” Under such conditions “the satellite signal may not play such a significant role” as it otherwise would in activating the Kazbek communication system for leaders’ orders, i.e. in a crisis situation Soviet/Russian satellite systems may not have the same dual-phenomenology role that they would during low-tension conditions in confirming indications of an incoming first strike attack. Furthermore, "a 'missile attack' signal can be transmitted even if it is based only on data reported by radars" though in those cases "the criteria for the reliable identification of targets could be somewhat stricter and the tracking time somewhat longer than for missile launches detected directly by the satellite system."[88]

Historical information on frequency and duration of U.S.-Russia crises (roughly corresponding with periods of significant heightening of nuclear alert levels) is somewhat limited. In U.S. forces, the main instance of significantly heightened strategic alert, i.e. at least a Defense Condition / DEFCON 3 alert level is the 1962 Cuban Missile Crisis. The main period of high tension is often regarded to been the 13 days from 15 October 1962 when senior U.S. leaders were told of the missiles in Cuba, until U.S. and Soviet leaders reached agreements on 28 October 1962,[89] though U.S. forces were at either DEFCON 3 or DEFCON 2 alert levels for a total of 30 days beginning on 22 October 1962 when U.S. President Kennedy announced the blockade[90] and Soviet forces were on alert for virtually the same 30 day period.[91] Other known cases of U.S. forces at alert levels of at least DEFCON 3, such as the brief DEFCON 3 alert in the Yom Kippur War of October 1973, arguably do not qualify as U.S.-Russia crises posing the same risk of inadvertent war between the United States and Russia as the Cuban Missile Crisis, though they also arguably posed greater than normal peacetime risks.[92] Another case of DEFCON 3 alert was during the terrorist attacks of 11 September 2001.[93]

In Soviet and Russian forces, instances of heightened alert include several during the Cuban Missile Crisis,[94] with combined durations that may have been somewhat longer than the U.S. forces' alerts;[95] during the 1968 invasion of Czechoslovakia and during parts of the period of high East-West tensions in the early 1980s[96], especially around the time of the KAL 007 shoot-down and the ABLE ARCHER exercises in late 1983.[97]

Early warning systems could provide dangerous signals besides ones that specifically indicated the launch or movement of a missile. Even sensor outages could be interpreted as an indication of an attack. In the United States, "NORAD had become worried that an inexplicable outage of a tactical sensor might actually be the handiwork of saboteurs. This threat (and jamming) was considered serious enough to justify treating an outage as a positive indication of attack in the context of a nuclear crisis."[98] (Soviet/Russian procedures were somewhat analogous. Under conditions of a crisis "the delivery of a first strike can be considered, under Russian military doctrine, in the case of an attack on key elements of the early warning system or the command, control and communications systems." [99]) This paper treats unresolved MDCs as one example of an outage of a tactical sensor, based partly on the similarities in MDC occurrence rates and durations given by Marsh and Wallace et al. and the sensor outage rates and durations given by Blair.[100]

Usually, TACs comprise a small subset of MDCs where one detector system (usually, a satellite with infrared detectors of hot missile plume gases) indicates a launch and a different detector system (i.e. a ground-based radar) provides a confirming indication of launch. If there are confirming indications of launch from more than one separate ground-based radar systems, then NORAD reports high confidence in its assessment of the threat, otherwise NORAD reports low confidence. At least under normal circumstances, only high-confidence threat assessments will lead to a MAC where the leader then decides whether to launch an attack in response.[101] However, during periods of high U.S.-Russia tensions or crises, "positive indication from only one tactical sensor system" would be required for a high-confidence threat assessment. In addition, "the loss of a tactical sensor to presumed hostile action" would be treated as the equivalent of a “a positive tactical indication” of an attack.[102] Thus, under conditions of a U.S.-Russia crisis, this paper treats an unresolved MDC as an additional type of event that would be treated as a TAC-level indication of an attack, similar to Wallace et al. and Sennott.

This paper separately estimates rates of inadvertent nuclear war during both low-tension and high-tension periods, to account for the possibility that conditional probabilities of launch prevention failure could be substantially higher in periods of high U.S.-Russia tensions than during low-tension periods. This is partly because the literature suggests that leaders will be more psychologically or strategically predisposed to launch missiles in response to apparently credible indicators of an attack during a crisis period than during a low-tension period.[103] It is also because of this paper’s assumptions about the technical features of early warning systems and nuclear postures.

Additional Model Input Parameter Values

Table A1: Decision Times (minutes)

<table>
<tr><th colspan="2">Scenarios</th><th>Launch Under Attack</th><th>Launch On Warning</th><th>References and Comments</th></tr>
<tr><td rowspan="2">For Russia receiving indications of attack</td><td>ICBM</td><td>Triangular (2, 11, 20)</td><td>Triangular (9, 16, 23)</td><td rowspan="4">“Clean and informed decision time” values based on “Optimistic”, “Best Guess”, and “Pessimistic” values from Wallace et al.[104] The mode values of 0.001 minutes are effectively 0 minutes, as in the “Best Guess” values of 0 minutes in Wallace et al.</td></tr>
<tr><td>SLBM or equivalent</td><td>Triangular (0, 0.001, 1)</td><td>Triangular (0, 0.001, 1)</td></tr>
<tr><td rowspan="2">For United States receiving indications of attack</td><td>ICBM</td><td>Triangular (8, 15.25, 22.5)</td><td>Triangular (15, 20.25, 25.5)</td></tr>
<tr><td>SLBM or equivalent</td><td>Triangular (0, 0.001, 2.5)</td><td>Triangular (0, 3.25, 5.5)</td></tr>
</table>

Table A2: Other Model Input Parameter Values

Parameter Name	Values	References and Comments
P(Launch response | mistaken MAC-level indicators of nuclear attack during low U.S.-Russia tensions)	$f(p) = 2(1-p)$ i.e. Equation 5 with $n = 1$	One historical case seemed applicable, the 1995 Norwegian rocket event in Russia,[105] so $n = 1$ in Equation 5.
P(Launch response | mistaken MAC-level indicators of nuclear attack during U.S.-Russia crisis)	Uniform(0, 1)	No historical cases seemed applicable, so a uniform distribution was used (i.e. an uninformative Bayesian prior, or $n = 0$ in Equation 5).
Mean resolution time y for MDCs (minutes)	Triangular(1, 3.5, 6)	Based on Wallace et al.[106] and Sennott.[107]
Probability of ICBM attack indicators vs. SLBM or equivalent attack indicators	Uniform(0,1)	Both nations can operate SSBNs near each other. Russia has long been concerned about U.S. SSBNs near Russia.[108] Though Russian SSBNs may have been using relatively limited patrol areas in recent years,[109] reportedly they are resuming permanent patrols in international waters[110]
Probability of nation receiving indicators	Equal probability for United States and Russia	–
P(Nuclear terrorist attack would be in United States or Russia | nuclear terrorist attack somewhere in world)	Uniform(0,1)	These are somewhat arbitrary because of the lack of data or expert judgment. However, this simple parameter decomposition roughly parallels the "usual" false alarm fault tree, and the product of uniform distributions gives a probability distribution with most density much closer to 0 than to 1, which seems reasonable.
P(Resemblance of nuclear terrorist attack to TAC-level indicators of nuclear attack from the other nation | nuclear terrorist attack)	Uniform(0,1)	
P(Promotion of nuclear terrorism TAC-level indicators of nuclear attack to MAC level)	Uniform(0,1)	

[1]. Alan Robock, Luke Oman, and Georgiy L. Stenchikov, "Nuclear Winter Revisited with a Modern Climate Model and Current Nuclear Arsenals: Still Catastrophic Consequences," *Journal of Geophysical Research* 112, D13107 (2007), 9.
[2]. Carl Sagan, "Nuclear War and Climatic Catastrophe: Some Policy Implications," *Foreign Affairs* 62, 2 (1983), 274, 291-293. Paul R. Ehrlich et al., "Long-Term Biological Consequences of Nuclear War," *Science* 222, 4630 (1983), 1299.
[3]. Bruce G. Blair, *The Logic of Accidental Nuclear War* (Washington, DC: Brookings, 1993), 2-9.
[4]. Robert Powell, *Nuclear Deterrence Theory: The Search for Credibility* (New York: Cambridge University Press, 1990), 3. Thomas C. Schelling, *The Strategy of Conflict* (Cambridge, Massachusetts: Harvard University Press, 1960), 187-203.
[5]. Scott D. Sagan, Moving Targets (Princeton, New Jersey: Princeton University Press, 1990), 176-178. Karas, *De-Alerting Strategic Nuclear Weapons,* 7-22.
[6]. Pavel Podvig, "The Operational Status of the Russian Space-Based Early Warning System," *Science & Global Security* 4 (1994), 364.
[7]. Bradley A. Thayer, "The Risk of Nuclear Inadvertence: A Review Essay," *Security Studies* 3, 3 (1994), 442-445. Joseph Cirincione, "The Continuing Threat of Nuclear War," in *Global Catastrophic Risks*, ed. Nick Bostrom and Milan M. Cirkovic (Oxford: Oxford University Press, 2008), 381-401. Martin Hellman, "How Risky Is Nuclear Optimism?" *Bulletin of the Atomic Scientists* 67, 2 (2011), 47-56.
[8]. Hans M. Kristensen and Robert M. Norris, "Reviewing Nuclear Guidance: Putting Obama's Words into Action", Arms Control Association http://www.armscontrol.org/act/2011_11/Reviewing_Nuclear_Guidance_Putting_Obama_Words_Into_Action (accessed 10 January 2012). Pavel Podvig, "Reducing the Risk of an Accidental Launch," *Science & Global Security* 14 (2006), 75-76.
[9]. Scott D. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons* (Princeton, New Jersey: Princeton University Press, 1993), 99-100,221,225-246.
[10]. Michael D. Intriligator and Dagobert L. Brito, "Accidental Nuclear War: An Important Issue for Arms Control," in *Proceedings of the 18th Pugwash Workshop on Nuclear Forces*, ed. Derek Paul, Michael D. Intriligator, and Paul Smoker (Ontario, Canada: Samuel Stevens & Company, 1990), 9. David Mosher, Lowell H. Schwartz, David R. Howell, Lynne E. Davis, *Beyond the Nuclear Shadow: A Phased Approach for Improving Nuclear Safety and U.S-Russian Relations* (Santa Monica, California: RAND, 2003), MR-1666-NSRD, 14-15.
[11]. Robert Ayson, "After a Terrorist Nuclear Attack: Envisaging Catalytic Effects," *Studies in Conflict & Terrorism* 33, 7 (2010), 20.
[12]. Graham T. Allison, *Nuclear Terrorism: The Ultimate Preventable Catastrophe* (New York: Times Books, 2004), 1-120.
[13]. NCTAUUS, *The 9/11 Commission Report* (Washington, DC: National Commission on Terrorist Attacks Upon the United States, 2004), 380. Matthew Bunn, "Guardians at the Gates of Hell: Estimating the Risk of Nuclear Theft and Terrorism–and Identifying the Highest-Priority Risks of Nuclear Theft" (Massachusetts Institute of Technology, 2007), 37–43.
[14]. Bruce G. Blair and Garry D. Brewer, "The Terrorist Threat to World Nuclear Programs," *The Journal of Conflict Resolution* 31, 3 (1977), 379-403. Bruce G. Blair, "Could Terrorists Launch America's Nuclear Missiles?" Time.com http://www.time.com/time/nation/article/0,8599,2030685,00.html (accessed October 19th, 2010).
[15]. Schelling, *Strategy of Conflict*, 186-203. Blair, *Logic of Accidental Nuclear War*, 1-9.
[16]. Henry S. Rowen, "Catalytic Nuclear War," in *Hawks, Doves & Owls: An Agenda for Avoiding Nuclear War*, ed. Graham T. Allison, Albert Carnesale, and Joseph S. Nye Jr. (New York: W.W. Norton & Co., 1985), 148-163.

[17]. Paul J. Bracken, "Accidental Nuclear War," in *Hawks, Doves & Owls: An Agenda for Avoiding Nuclear War*, ed. Graham T. Allison, Albert Carnesale, and Joseph S. Nye Jr. (New York: W.W. Norton & Co., 1985), 25-53.
[18]. Martin Hellman, "Risk Analysis of Nuclear Deterrence," *The Bent of Tau Beta Pi*, Spring (2008), 18.
[19]. T.J. Bedford and R.M. Cooke, *Probabilistic Risk Analysis: Foundations and Methods* (New York: Cambridge University Press, 2001), 99-152.
[20]. Charles Perrow, *Normal Accidents: Living with High-Risk Technologies* (New York: Princeton University Press, 1984), 62-100. Sagan, *The Limits of Safety*, 11-52.
[21]. Daniel Frei, *Risks of Unintentional Nuclear War* (Totowa, New Jersey: Allanheld, Osmun & Co., 1983), 222–223. Michael D. Wallace, Brian L. Crissey, and Linn I. Sennott, "Accidental Nuclear War: A Risk Assessment," *Journal of Peace Research* 23, 1 (1986), 23-24.
[22]. Nick Bostrom and Milan M. Cirkovic, "Introduction," in *Global Catastrophic Risks*, ed. Nick Bostrom and Milan M. Cirkovic (New York: Oxford University Press, 2008), 2-3. Anders Sandberg and Nick Bostrom, "Global Catastrophic Risks Survey", Future of Humanity Institute, Oxford University http://www.fhi.ox.ac.uk/__data/assets/pdf_file/0020/3854/global-catastrophic-risks-report.pdf (accessed 12 January 2012).
[23]. Hellman, "Risk Analysis of Nuclear Deterrence", 20-21.
[24]. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 11-23.
[25]. Barbara Marsh, “The Probability of Accidental Nuclear War: A Graphical Model of the Ballistic Early Warning System” (Naval Postgraduate School, 1985), 23-71. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 11-27.
[26]. Blair, *Logic of Accidental Nuclear War*, 55. Pavel Podvig, ed., *Russian Strategic Nuclear Forces*, Paperback ed. (Cambridge, Massachusetts: MIT Press, 2004), 567,577-578.
[27]. Wallace, Crissey, and Sennott, "Accidental Nuclear War," 13, 26–27.
[28]. Zia Mian, R. Rajaraman, and M.V. Ramana, "Early Warning in South Asia – Constraints and Implications," *Science and Global Security* 11 (2003): 128–131.
[29]. Blair, *Logic of Accidental Nuclear War,* 168-218. Sagan, *The Limits of Safety*, 119.
[30]. Marsh, “Probability of Accidental Nuclear War”, 33-60. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 13-15.
[31]. Wallace, Crissey, and Sennott, "Accidental Nuclear War”, 15-20.
[32]. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 14-23. Blair, *Logic of Accidental Nuclear War,* 155, 168-218.
[33]. Marsh, “Probability of Accidental Nuclear War”, 26–27,47–49,63–66.
[34]. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 14, 22-24. Blair, *Logic of Accidental Nuclear War*, 168-218.
[35]. James R. Low, “De-Alerting the U.S. And Russian Nuclear Arsenals: An Unlikely Method of Arms Control” (Master's Thesis, Naval Postgraduate School, 1999), 66-68. Pavel Podvig, "History and the Current Status of the Russian Early-Warning System," *Science & Global Security* 10 (2002), 21-26.
[36]. Podvig, "Reducing Risk of Accidental Launch,” 80. Albert Carnesale, Joseph S. Nye Jr., and Graham T. Allison, "An Agenda for Action," in *Hawks, Doves & Owls: An Agenda for Avoiding Nuclear War*, ed. Graham T. Allison, Albert Carnesale, and Joseph S. Nye Jr. (New York: W.W. Norton & Co., 1985), 232.
[37]. M.E. Pate-Cornell and Paul Fischbeck, "Probabilistic Interpretation of Command and Control Signals: Bayesian Updating of the Probability of Nuclear Attack," *Reliability Engineering & System Safety* 47, 1 (1995), 27-36.
[38]. Karas, *De-Alerting Strategic Nuclear Weapons*, 17.
[39]. Marsh, “Probability of Accidental Nuclear War”, 62. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 21.
[40]. Blair, "Could Terrorists Launch America's Missiles?".

[41]. Richard G. Lugar, *The Lugar Survey on Proliferation Threats and Responses* (Washington, DC, 2005), 13-17.
[42]. Matthew Bunn, "A Mathematical Model of the Risk of Nuclear Terrorism," *The Annals of the American Academy of Political and Social Science* 607, 1 (2006), 106-107. Bunn, "Guardians at the Gates of Hell", 119-121.
[43]. Graham T. Allison, "Nuclear Deterrence in the Age of Nuclear Terrorism," *Technology Review*, October 20, 2008, 68-73.
[44]. CDI, "Hearing of the Energy and Water Subcommittee of the House Appropriations Committee; Subject: Weapons Activities Oversight; Chaired by Representative Peter Visclosky (D-in); Witnesses: Senator Sam Nunn, Co-Chairman and Ceo, Nuclear Threat Initiative; Dr. William Perry, Former Secretary of Defense; General James E. Cartwright, Commander, U.S. Strategic Command; Dr. Richard Garwin, IBM Fellows Emeritus at the Thomas J. Watson Research Center; Location: 2362b Rayburn House Office Building, Washington, D.C.; Time: 10:00 AM EDT; Date: Thursday, March 29, 2007", Center for Defense Information / Federal News Service http://www.cdi.org/PDFs/Energy %20and%20Water%20Subcommittee%20Hearing.pdf (accessed 28 May 2012).
[45]. Elizabeth A. Casman, M. Granger Morgan, and Hadi Dowlatabadi, "Mixed Levels of Uncertainty in Complex Policy Models," *Risk Analysis* 19, 1 (1999), 33-42. M.G. Morgan and M. Henrion, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Cambridge: Cambridge University Press, 1990), 39-44.
[46]. Bernard Bereanu, "On the Probability of Self-Activation of the World Nuclear Weapons Stockpile," *Methods of Operations Research* 44 (1981), 507-520. Marsh, "Probability of Accidental Nuclear War," 61-71. Wallace, Crissey, and Sennott, "Accidental Nuclear War," 21.
[47]. Dimitri P. Bertsekas and John N. Tsitsiklis, *Introduction to Probability*, 2nd ed. (Belmont, Massachusetts: Athena Scientific, 2002), 309-325.
[48]. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 21.
[49]. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 22.
[50]. Lugar, *Lugar Survey on Proliferation,* 13-17. Hellman, "Risk Analysis of Nuclear Deterrence", 20-21.
[51]. Marsh, "Probability of Accidental Nuclear War", 62. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 21.
[52]. Morgan and Henrion, *Uncertainty*, 85-96, 198-205.
[53]. Robert T. Bailey, "Estimation from Zero-Failure Data," *Risk Analysis* 17, 3 (1997), 380.
[54]. Morgan and Henrion, *Uncertainty,* 39-44. Averill M. Law and W. David Kelton, *Simulation Modeling and Analysis*, Third ed. (New York, New York: McGraw-Hill, 2000), 292-298.
[55]. K.C. Bailey and F.D. Barish, *De-Alerting of U. S. Nuclear Forces: A Critical Appraisal* (Livermore, California: Lawrence Livermore National Laboratory, 1998), UCRL-LR-132030, 8-13. Josef Joffe and James Davis, "Less Than Zero: Bursting the New Disarmament Bubble," *Foreign Affairs* 90, 1 (2011), 7-13.
[56]. Mosher et al., *Beyond the Nuclear Shadow,* 39-44, 67-77. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 13-25.
[57]. Mosher et al., *Beyond the Nuclear Shadow,* 70-77. Bailey and Barish, *De-Alerting of Nuclear Forces*, 10-13.
[58]. Podvig, "Reducing Risk of Accidental Launch," 89.
[59]. Bailey and Barish, *De-Alerting of Nuclear Forces,* 10.
[60] Lumina Decision Systems, professional version 4.2.3.7.
[61] The on-line supplement has been published with the article at the Journal Website and at http://scienceandglobalsecurity.org/archive/2013/06/analyzing_and_reducing_the_ris.html
[62]. Gerald J. Hahn and Samuel S. Shapiro, *Statistical Models in Engineering* (New York: J**o**hn Wiley & Sons, 1967), 241–245.

[63]. Bruce G. Blair and Kurt Gottfried, "Introduction," in *Crisis Stability and Nuclear War*, ed. Bruce Blair and Kurt Gottfried (New York: Oxford University Press, 1988), 3.
[64]. Hellman, "Risk Analysis of Nuclear Deterrence", 21.
[65]. Wallace, Crissey, and Sennott, "Accidental Nuclear War."
[66]. Marsh, "Probability of Accidental Nuclear War." Wallace, Crissey, and Sennott, "Accidental Nuclear War", 21, 26.
[67]. Morgan and Henrion, *Uncertainty,* 275-276. Lonnie Chrisman et al., "Analytica User Guide," (Los Gatos, California: Lumina Decision Systems, 2007), 277-278.
[68]. Linn I. Sennott, "Overlapping False Alarms: Reason for Concern?," in *Breakthrough: Emerging New Thinking*, ed. Anatolii Andreevich Gromyko and Martin E. Hellman (New York: Walker and Company, 1988), 39-44.
[69]. James A. Hanley and Abby Lippman-Hand, "If Nothing Goes Wrong, Is Everything All Right?" *Journal of the American Medical Association* 249, 13 (1983), 1743-1745. John Quigley and Matthew Revie, "Estimating the Probability of Rare Events: Addressing Zero Failure Data," *Risk Analysis* 31, 7 (2011), 1120-1132.
[70]. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 22, 27.
[71]. Blair, "Could Terrorists Launch America's Missiles?".
[72]. Quigley and Revie, "Estimating Probability of Rare Events", 1120-1132.
[73]. Low, "De-Alerting Nuclear Arsenals", 70-73.
[74]. Lyle V. Anderson, ""Unintended" Nuclear War: The American Cosmos and Global Chaos," *Journal for Peace and Justice Studies* 1, 1 (1988), 26.
[75]. Barbara Starr, "Air Force Investigates Mistaken Transport of Nuclear Warheads", CNN.com http://articles.cnn.com/2007-09-05/us/loose.nukes_1_nuclear-weapons-nuclear-warheads-missiles?_s=PM:US (accessed July 22nd, 2012).
[76]. Blair, "Could Terrorists Launch America's Missiles?".
[77]. Mosher et al., *Beyond the Nuclear Shadow*, 15-31.
[78]. Morgan and Henrion, Uncertainty, 106-107.
[79]. R.L. Boring, "A Review of Expertise and Judgment Processes for Risk Estimation," in *Proceedings of the European Safety and Reliability Conference (ESREL 2007)* (2007), 6.
[80]. Hellman, "Risk Analysis of Nuclear Deterrence", 17.
[81]. Vicki M. Bier, Louis Anthony Cox Jr., and M. Naceur Azaiez, "Why Both Game Theory and Reliability Theory Are Important in Defending Infrastructure against Intelligent Attacks," in *Game Theoretic Risk Analysis of Security Threats*, ed. Vicki M. Bier and M. Naceur Azaiez (New York: Springer, 2009), 1-11.
[82]. Blair, "Could Terrorists Launch America's Missiles?".
[83]. Ayson, "After Terrorist Nuclear Attack": 20.
[84]. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 21.
[85]. Marsh, "Probability of Accidental Nuclear War", 49.
[86]. Low, "De-Alerting Nuclear Arsenals", 68–74. Peter Vincent Pry, *War Scare: Russia and America on the Nuclear Brink* (Westport, Connecticut: Praeger, 1999), 37,214–238. Geoffrey Forden, Pavel Podvig, and Theodore A. Postol, "False Alarm, Nuclear Danger," *IEEE Spectrum* 37, 3 (2000).
[87]. Blair, *Logic of Accidental Nuclear War*, 192–193.
[88]. Podvig, ed., *Russian Strategic Nuclear Forces*, 60–62.
[89].Bruce G. Blair and Kurt Gottfried, eds., *Crisis Stability and Nuclear War* (New York: Oxford University Press, 1988), 18–19, 172–189.
[90]. Sagan, *The Limits of Safety*, 62–65,95–96.
[91]. David Larson, *The 'Cuban Crisis' of 1962: Selected Documents and Chronology* (Boston, Massachusetts: Houghton Mifflin, 1963), 315, 326. Wallace, Crissey, and Sennott, "Accidental Nuclear War," 21, 26.

[92]. Sagan, *The Limits of Safety*, 212–216. Blair and Gottfried, eds., *Crisis Stability and Nuclear War*, 198–212.
[93]. NCTAUUS, *The 9/11 Commission Report*, 544.
[94]. Blair, *Logic of Accidental Nuclear War*, 23–25.
[95]. Matthew Aid, "National Security Agency Releases History of Cold War Intelligence Activities: Soviet Strategic Forces Went on Alert Three Times During September-October 1962 Because of Apprehension over Cuban Situation, Top Secret Codeword History of National Security Agency Shows" http://www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB260/index.htm (accessed 5 July 2012). Thomas R. Johnson, *American Cryptology During the Cold War, 1945-1989: Book Ii: Centralization Wins, 1960-1972 (Declassified, Excised Copy)* (Center for Cryptological History, US National Security Agency, 1995), 330–331.
[96]. Blair, *Logic of Accidental Nuclear War*, 25.
[97]. Pry, *War Scare*, 41–44. Benjamin Fischer, "A Cold War Conundrum: The 1983 Soviet War Scare", Center for the Study of Intelligence, US Central Intelligence Agency https://www.cia.gov/library/center-for-the-study-of-intelligence/csi-publications/books-and-monographs/a-cold-war-conundrum/source.htm (accessed 5 July 2012).
[98]. Blair, *Logic of Accidental Nuclear War*, 194.
[99]. Podvig, ed., *Russian Strategic Nuclear Forces*, 60.
[100]. Blair, *Logic of Accidental Nuclear War*, 193.
[101]. Marsh, “Probability of Accidental Nuclear War”, 49.
[102]. Blair, *Logic of Accidental Nuclear War*, 193.
[103]. Blair, *Logic of Accidental Nuclear War,* 1.
[104]. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 16-20.
[105]. Low, “De-Alerting Nuclear Arsenals”, 68–74. Mosher et al., *Beyond the Nuclear Shadow*,17–18. Pry, *War Scare*, 214–238.
[106]. Wallace, Crissey, and Sennott, "Accidental Nuclear War", 22, 27.
[107]. Sennott, "Overlapping False Alarms", 39-44.
[108]. Mosher et al., *Beyond the Nuclear Shadow*, 68.
[109]. Hans M. Kristensen, "Russian Nuclear Submarine Patrols", Federation of American Scientists http://www.nukestrat.com/russia/subpatrols.htm (accessed December 2, 2012). Hans M. Kristensen, "Russian Nuclear Missile Submarine Patrols Decrease Again", Federation of American Scientists http://www.fas.org/blog/ssp/2008/04/russian-nuclear-missile-submarine-patrols-decrease-again.php (accessed December 2, 2012).
[110]. NT, "Russian SSBNs to Resume Patrols in International Waters in June 2012", Naval Today http://navaltoday.com/2012/02/07/russian-nuclear-powered-ballistic-missile-submarines-to-resume-patrols-in-international-waters-in-june-2012/ (accessed December 2, 2012).