# Risk Analysis of Nuclear Deterrence

by **Dr. Martin E. Hellman,** *New York Epsilon '66*

The first fundamental canon of *The Code of Ethics for Engineers* adopted by Tau Beta Pi states that "Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties." When we design systems, we routinely use large safety factors to account for unforeseen circumstances. The Golden Gate Bridge was designed with a safety factor several times the anticipated load. This "over design" saved the bridge, along with the lives of the 300,000 people who thronged onto it in 1987 to celebrate its fiftieth anniversary. The weight of all those people presented a load that was several times the design load[1], visibly flattening the bridge's arched roadway. Watching the roadway deform, bridge engineers feared that the span might collapse, but engineering conservatism saved the day.

Similarly, current nuclear-reactor designs require that the failure rate for a significant release of radioactivity be less than $10^{-6}$ per reactor per year. Estimating such small failure rates is difficult because they depend on events which have never happened, and which we hope never will. Even so, order of magnitude estimates are possible using tools such as fault or event trees. In these approaches, the failure rates of small events (e.g., the failure of a cooling pump or a backup system) and conditional probabilities are combined to produce an overall failure rate for the much rarer catastrophic event that results when a critical subset of those partial failures occurs.

While significant resources have been expended estimating the failure rate of nuclear reactors, I have been unable to find any similar studies for an even more dire event: the failure of nuclear deterrence. I propose that such studies be undertaken and, if the failure rate is found to be unacceptable, a follow-on effort be initiated to find ways to reduce the threat to an acceptable level.[2]

## NUCLEAR TERRORISM VS. NUCLEAR WAR

The threat of nuclear terrorism looms much larger in the public's mind than the threat of a full-scale nuclear war, yet this article focuses primarily on the latter. An explanation is therefore in order before proceeding.

A terrorist attack involving a nuclear weapon would be a catastrophe of immense proportions: "A 10-kiloton bomb detonated at Grand Central Station on a typical work day would likely kill some half a million people, and inflict over a trillion dollars in direct economic damage. America and its way of life would be changed forever." [Bunn 2003, pages viii-ix].

The likelihood of such an attack is also significant. Former Secretary of Defense William Perry has estimated the chance of a nuclear terrorist incident within the next decade to be roughly 50 percent [Bunn 2007, page 15]. David Albright, a former weapons inspector in Iraq, estimates those odds at less than one percent, but notes, "We would never accept a situation where the chance of a major nuclear accident like Chernobyl would be anywhere near 1% .... A nuclear terrorism attack is a low-probability

event, but we can't live in a world where it's anything but extremely low-probability." [Hegland 2005]. In a survey of 85 national security experts, Senator Richard Lugar found a median estimate of 20 percent for the "probability of an attack involving a nuclear explosion occurring somewhere in the world in the next 10 years," with 79 percent of the respondents believing "it more likely to be carried out by terrorists" than by a government [Lugar 2005, pp. 14-15].

[1] *At approximately 100 lb/ft², the density of a human being is about five times that of today's typical automobile traffic. A 2008 Ford Taurus has a density of 40 lb/ft². Inter-car spacing lowers that density by approximately a factor of two, to 20 lb/ft², even in bumper-to-bumper traffic.*

[2] *Classified studies may exist, but could not be used in this effort. Unclassified studies that were missed by my search may also exist and, if adequate, could be substituted for some of the proposed studies. However, experts on national defense, nuclear weapons, and risk analysis whom I consulted as part of that search were unaware of any such studies.*

I support increased efforts to reduce the threat of nuclear terrorism, but that is not inconsistent with the approach of this article. Because terrorism is one of the potential trigger mechanisms for a full-scale nuclear war, the risk analyses proposed herein will include estimating the risk of nuclear terrorism as one component of the overall risk. If that risk, the overall risk, or both are found to be unacceptable, then the proposed remedies would be directed to reduce whichever risk(s) warrant attention. Similar remarks apply to a number of other threats (e.g., nuclear war between the U.S. and China over Taiwan).

This article would be incomplete if it only dealt with the threat of nuclear terrorism and neglected the threat of full-scale nuclear war. If both risks are unacceptable, an effort to reduce only the terrorist component would leave humanity in great peril. In fact, society's almost total neglect of the threat of full-scale nuclear war makes studying that risk all the more important.

## THE COST OF WORLD WAR III

The danger associated with nuclear deterrence depends on both the cost of a failure and the failure rate.[3] This section explores the cost of a failure of nuclear deterrence, and the next section is concerned with the failure rate. While other definitions are possible, this article defines a failure of deterrence to mean a full-scale exchange of all nuclear weapons available to the U.S. and Russia, an event that will be termed World War III.

Approximately 20 million people died as a result of the first World War. World War II's fatalities were double or triple that number—chaos prevented a more precise determination. In both cases humanity recovered, and the world today bears few scars that attest to the horror of those two wars. Many people therefore implicitly believe that a third World War would be horrible but survivable, an extrapolation of the effects of the first two global wars. In that view, World War III, while horrible, is something that humanity may just have to face and from which it will then have to recover. In contrast, some of those most qualified to assess the situation hold a very different view.

In a 1961 speech to a joint session of the Philippine Congress, General Douglas MacArthur, stated, "Global war has become a Frankenstein to destroy both sides. … If you lose, you are annihilated. If you win, you stand only to lose. No longer does it possess even the chance of the winner of a duel. It contains now only the germs of double suicide."

Former Secretary of Defense Robert McNamara expressed a similar view: "If deterrence fails and conflict develops, the present U.S. and NATO strategy carries with it a high risk that Western civilization will be destroyed" [McNamara 1986, page 6]. More recently, George Shultz, William Perry, Henry Kissinger, and Sam Nunn[4] echoed those concerns when they quoted President Reagan's belief that nuclear weapons were "totally irrational, totally inhumane, good for nothing but killing, possibly destructive of life on earth and civilization." [Shultz 2007]

Official studies, while couched in less emotional terms, still convey the horrendous toll that World War III would exact: "The resulting deaths would be far beyond any precedent. Executive branch calculations show a range of U.S. deaths from 35 to 77 percent (i.e., 79-160 million dead) … a change in targeting could kill somewhere between 20 million and 30 million additional people on each side .... These calculations reflect only deaths during the first 30 days. Additional millions would be injured, and many would eventually die from lack of adequate medical care … millions of people might starve or freeze during the following winter, but it is not possible to estimate how many. … further millions … might eventually die of latent radiation effects." [OTA 1979, page 8]

This OTA report also noted the possibility of serious ecological damage [OTA 1979, page 9], a concern that assumed a new potentiality when the TTAPS report [TTAPS 1983] proposed that the ash and dust from so many nearly simultaneous nuclear explosions and their resultant firestorms could usher in a nuclear winter that might erase *homo sapiens* from the face of the earth, much as many scientists now believe the K-T Extinction that wiped out the dinosaurs resulted from an impact winter caused by ash and dust from a large asteroid or comet striking Earth. The TTAPS report produced a heated debate, and there is still no scientific consensus on whether a nuclear winter would follow a full-scale nuclear war. Recent work [Robock 2007, Toon 2007] suggests that even a limited nuclear exchange or one between newer nuclear-weapon states, such as India and Pakistan, could have devastating long-lasting climatic consequences due to the large volumes of smoke that would be generated by fires in modern megacities.

While it is uncertain how destructive World War III would be, prudence dictates that we apply the same engineering conservatism that saved the Golden Gate Bridge from collapsing on its 50th anniversary and assume that preventing World War III is a necessity—not an option.

## NUCLEAR NEAR MISSES

Some might argue that, because World War III would be so destructive, no one in his right mind would start such a devastating conflict and there is no need to worry. But much the same could have been said prior to the first World War, demonstrating that in times of crisis we are often not in our right minds. If civilization is destroyed in a nuclear holocaust, it is likely to start as World War I did—a sequence of events that spirals out of control.

Former Secretary of Defense Robert McNamara sums up what he learned from participating in three world cri-

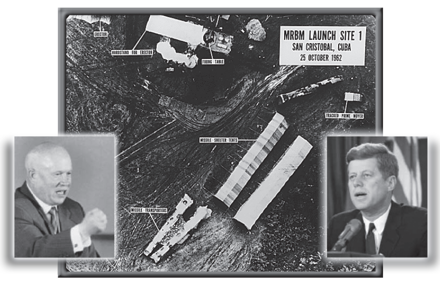
[3] *This article uses failure rate, rather than the more usual Mean Time to Failure (MTTF). The latter quantity is a good indicator of risk in a time-invariant problem where the failure rate $\lambda(t)$ is a constant $\lambda_0$. In that case MTTF=1 / $\lambda_0$. For example, it has been estimated that $\lambda_0 = 10^{-8}$ per year for an extinction event due to a large asteroid hitting Earth, and the corresponding MTTF of 100 million years is an equally good indicator of the risk. But when $\lambda(t)$ is time-varying, the term MTTF is technically incorrect since it is no longer a meaningful average. The quantity that can be meaningfully averaged is $\lambda(t)$. In a time-varying problem, such as a failure of nuclear deterrence, a simplified but useful model averages $\lambda(t)$ over a time period and uses its average value $\lambda_{AVG}$ in a time-invariant approximation to the actual process during that period. Unless otherwise noted, this article tacitly uses that time-invariant approximation.*

[4] *Two Democrats and two Republicans, respectively Secretary of State under President Reagan, Secretary of Defense under President Clinton, Secretary of State under Presidents Nixon and Ford as well as National Security Advisor to President Nixon, and former Democratic chairman of the Senate Armed Services Committee.*

ses—Berlin in 1961, Cuba in 1962, and the Mideast war of 1967—each of which had the potential to go nuclear: "In no one of the three incidents did either … [the U.S. or the Soviet Union] intend to act in a way that would lead to military conflict, but on each of the occasions lack of information, misinformation, and misjudgments led to confrontation. And in each of them, as the crisis evolved, tensions heightened, emotions rose, and the danger of irrational decisions increased." [McNamara 1986, page 13]

Because the Cuban missile crisis was the closest the world has come to nuclear war, it is worthwhile studying its evolution. In 1961, over strenuous Soviet objections, America started deploying nuclear-armed Jupiter IRBM's in Turkey. From our perspective, installing these weapons made sense. They secured NATO's southern flank, helped cement relations with Turkey, and enhanced our nuclear deterrent. The Russians viewed these missiles very differently.

While other factors contributed to Khrushchev's 1962 deployment of similar missiles in Cuba, this disastrous decision started with a nuclear version of tit-for-tat as noted by Khrushchev's speech writer and advisor, Fyodor Burlatsky: "Khrushchev and [Soviet Defense Minister] R. Malinovsky … were strolling along the Black Sea coast. Malinovsky pointed out to sea and said that on the other shore in Turkey there was an American nuclear-missile base. In a matter of six or seven minutes, missiles launched from that base could devastate major centres in the Ukraine and southern Russia. … Khrushchev asked Malinovsky why the Soviet Union should not have the right to do the same as America. Why, for example, should it not deploy missiles in Cuba?" [Burlatsky 1991, page 171]



CUBAN MISSILE CRISIS

Once the crisis started, it developed a life of its own. George Ball, a member of the White House ExComm[5], stated that when a group of Kennedy's advisors met years later "Much to our own surprise, we reached the unanimous conclusion that, had we determined our course of action within the first 48 hours after the missiles were discovered, we would almost certainly have made the wrong decision, responding to the missiles in such a way as to require a forceful Soviet response and thus setting in train a series of reactions and counter-reactions with horrendous consequences." [Ury 1985, page 37]

Douglas Dillon, another member of Kennedy's ExComm, was less concerned and at a 1987 conference commemorating the crisis' 25th anniversary stated: "My impression was that military operations looked like they were becoming increasingly necessary. … The pressure was getting too great. … Personally, I disliked the idea of an invasion [of Cuba] … Nevertheless, the stakes were so high that we thought we might just have to go ahead. Not all of us had detailed information about what would have followed, but we didn't think there was any real risk of a nuclear exchange." [Blight & Welch 1989, page 72]

In contrast to Dillon's belief that some other ExComm members had detailed information about what would have followed an invasion of Cuba, information that later became available showed that none of them had the least idea of what would likely have transpired. Unknown to Kennedy and his ExComm, the Russians had battlefield nuclear weapons in Cuba and came close to giving permission for their use against an American invasion, without further approval from Moscow [Chang & Kornbluh 1998; Blair 1993, page 109; Fursenko & Naftali 1997, pages 212, 242-243, 276]. Not knowing of these weapons, there was strong pressure within the ExComm and from Congress [Fursenko & Naftali 1997, pages 243-245] to invade Cuba and remove Castro once and for all.

Another ominous aspect of the crisis was uncovered when key players from both sides met on its 40th anniversary. A Soviet submarine near the quarantine line had been subjected to signaling depth charges, commanding it to surface, which it eventually did. Not until 40 years later did Americans learn that this submarine carried a nuclear torpedo and that the Soviet submarine captain, believing he was under attack, had given orders to arm it. Fortunately, the submarine brigade commander was on board, over-ruled the captain, and defused the threat of a nuclear attack on the American fleet [Blanton 2002].

The world held its breath as Soviet ships approached the American blockade. If neither side backed down, war seemed inevitable. Finally, Khrushchev stopped the Soviet ships just short of the blockade. While Kennedy won that round of the Cold War, nuclear chicken does not always have a winner. It is a dangerous game, especially when, as in the Cuban missile crisis, winning depends on your opponent having less concern than you for maintaining political power.[6]

We might hope that humanity, after staring World War III in the face, had learned its lesson and that a similar crisis was inconceivable post-1962. Unfortunately, at least two events that could have initiated a new Cuban missile crisis have since occurred. In the 1980s, President Reagan was so disturbed by Cuba supplying weapons to a leftist insurgency in El Salvador that he threatened to reimpose a naval blockade of Cuba [LeoGrande 1981]. Such an action would have

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[5]*The Executive Committee of the National Security Council (ExComm) was the group Kennedy created to help him develop strategies to deal with the Cuban missile crisis.*

[6]*As part of the resolution of the crisis, Kennedy agreed to remove the American missiles in Turkey, but insisted that agreement be kept secret. The 1962 midterm elections occurred soon after the crisis ended, and, with Kennedy seen as winning the standoff, the Democratic Party fared significantly better than anticipated. In contrast, Khrushchev fell from power two years later, partly because of Russia's humiliation in the Cuban missile crisis.*

[7]*Somewhat ominously, after this was written but before it was published, Russian President Vladimir Putin likened the current American deployment to the Cuban missile crisis [Putin 2007]. Although he disclaimed that such a crisis would occur in the friendlier climate that currently exists, those good relations are clearly fraying.*

violated one of our key concessions (lifting the blockade) in return for which the Russians removed their Cuban missiles. Had Reagan reimposed the blockade, the Russians might have threatened to redeploy missiles unless the blockade was immediately lifted. Such a reaction was made more likely by the fact that, at that time, Reagan was in the process of deploying Pershing IRBMs (so-called "Euromissiles") in Western Europe. While not as close to the Soviet border as the Turkish Jupiters, the only way the Soviets could match such weapons was with missiles in Cuba.

And, today, we are in the process of deploying a missile defense in Russia's backyard (Poland and the Czech Republic) over strenuous Russian objections. A possible Russian response would be to threaten deployment of a similar missile defense in Cuba, much as our Jupiter missile deployment in Turkey was the stimulus for Khrushchev deploying his Cuban missiles [Burlatsky 1991, page 171].[7] While these Cuban missiles would be defensive in nature, many Americans would see them as intolerable. Among other concerns, there would likely be fears that these were offensive weapons disguised as defensive ones. (The Russians have voiced a similar concern over our deployment.)

Another Cold War nuclear near miss was a 1983 NATO exercise codenamed "Able Archer." Former CIA director and current Secretary of Defense Robert M. Gates describes the danger in his memoirs:

> "One of the potentially most dangerous episodes of the Cold War was prompted by a NATO command post exercise … [This] exercise, to practice nuclear release procedures, came at the moment of maximum stress in the U.S.-Soviet relationship described above [the Euromissile deployment, Reagan's Strategic Defense Initiative, and the Soviets shooting down Korean Airlines flight 007]. But it also came against the backdrop of Andropov's seeming fixation on the possibility that the U.S. was planning a nuclear [first] strike against the Soviet Union. … Our sources claim to have seen documents that betrayed genuine nervousness that such a strike could occur at any time, for example, under cover of an apparently routine military exercise. … According to [KGB defector] Gordievsky, "the KGB concluded [during Able Archer] that American forces … might even have begun the countdown to nuclear war." … we in the CIA did not really grasp how alarmed the Soviet leaders might have been until … our British colleagues issued an assessment in March 1984." [Gates 1996, pp. 270-272]

Nuclear proliferation and the specter of nuclear terrorism are creating dangerous, new possibilities for initiating major crises. If an American or Russian city were devastated by an act of nuclear terrorism, the public outcry for immediate, decisive—and possibly disastrous—action would be even stronger than Kennedy had to deal with when the Cuban missiles first became known to the American public. Fortunately, a likely byproduct of an effort to reduce the threat of full-scale nuclear war would be also to reduce the threat of nuclear terrorism, an activity that currently is not being given as much respect as it deserves.

### *Want to Help?*

**A brief statement related to this article has been signed by individuals including:**

- **Mr. D. James Bidzos, chairman, Verisign Inc.**
- **Dr. Richard Garwin, IBM fellow emeritus, former member President's Science Advisory Committee and Defense Science Board**
- **ADM Bobby R. Inman, USN retired, former director NSA, former deputy director CIA**
- **Prof. William M. Kays, *CA Γ '42*, former dean of engineering, Stanford University**
- **Prof. Donald Kennedy, president emeritus of Stanford University, former head of FDA**
- **Prof. Martin L. Perl, *NY Z '48*, Stanford University, 1995 Nobel laureate in physics**

**Available online, the statement concludes: "We … therefore urgently petition the international scientific community to undertake in-depth risk analyses of nuclear deterrence and, if the results so indicate, to raise an alarm alerting society to the unacceptable risk it faces as well as to initiate a second phase effort to identify potential solutions." Although the statement is related to this article in THE BENT, the signatories do not necessarily endorse every element of the article, nor do the views expressed in the statement necessarily reflect the views of their organizations. Members of Tau Beta Pi who would like to add their names to the list of supporters or play another role in this effort should visit *nuclearrisk.org/statement.php*.**

## THE FAILURE RATE OF NUCLEAR DETERRENCE

A full-scale nuclear war is not the only threat to humanity's continued existence, and we should allocate resources commensurate with the various risks. A large asteroid colliding with the Earth could destroy humanity in the same way it is believed the dinosaurs disappeared 65 million years ago. Such NEO (near earth object) extinction events have a failure rate on the order of $10^{-8}$ per year [Chapman & Morrison 1994].

During one century, that failure rate corresponds to one chance in a million of humanity being destroyed. While $10^{-6}$ is a small probability, the associated cost is so high—infinite from our perspective—that some might argue that a century is too long a delay before working to reduce the threat. Fortunately, significant threat reduction has recently occurred. Over the last 20 years, NASA's Spaceguard effort is believed to have found all such potentially hazardous large asteroids, and none is predicted to strike Earth within the next century. With a hundred-year safety window in place, resolution of later potential impacts can be deferred for a few decades until our technology is significantly enhanced. Comets also pose a threat, and their more eccentric orbits make them harder to catalog, but their lower frequency of

Earth impact makes the associated risk acceptable for a limited period of time.

Using similar reasoning, if the failure rate of nuclear deterrence is $10^{-6}$ per year, waiting a decade to reduce the threat might be acceptable, resulting in a $10^{-5}$ probability of a failure, although good engineering practice[8] might disagree. If the failure rate of deterrence is an order of magnitude higher, $10^{-5}$ per year, then the risk is increased proportionately, and it is difficult to tolerate even a decade's delay in solving the problem.

Considering the next hypothetical failure rate of $10^{-4}$ per year, the probability of humanity destroying itself during a decade-long effort would be one-in-a-thousand, which is much too large. If the failure rate is $10^{-3}$ per year,[9] the probability increases to approximately 1% over a decade and 10% over a century, and delay is clearly unacceptable. At that level of failure rate, a significant reduction would be required within a matter of years.

If the failure rate of nuclear deterrence is closer to my order of magnitude estimate of 1% per year, then anything short of an all-out effort to change course would be criminally negligent. Each year that we delay in reducing the risk brings with it a 1% chance of disaster, and a decade's delay entails roughly a 10% chance.

While additional research is warranted to better estimate the failure rate of nuclear deterrence, I hope that readers will agree that the evidence presented thus far makes it difficult to support an estimated rate of $10^{-5}$ per year or less. In that case, we must immediately start work to reduce the risk of a failure of nuclear deterrence and not stop until it reaches an acceptable level.

## A PROPOSED FIRST STEP

As a first step toward reducing the risk of a failure of nuclear deterrence, I propose that several prestigious scientific and engineering bodies undertake serious studies to estimate its failure rate. This would serve three important purposes. First, it would determine whether concern is warranted. Second, assuming the risk is found to warrant such action, the studies could help galvanize public support for change. That is critical because public support is a prerequisite for a change of this magnitude. Third, analyzing the failure rate of nuclear deterrence would identify the most probable failure mechanisms, thereby allowing ameliorative efforts to be focused where they would be most useful in reducing the risk.[10]

Estimating the failure rate of nuclear deterrence has similarities with estimating the failure rate of a nuclear reactor design that has not yet failed. In addition to estimating the failure rate, such a study also identifies the most likely event sequences that result in catastrophic failure. Such a failure is composed of a cascade of small failures, and reasonable numbers are often available for many of the variables (e.g., the failure rate of a cooling pump in a reactor). Because some probabilities are difficult to estimate, the resultant failure rate will be at best accurate to an order of magnitude. But, as shown in the previous section, even an order of magnitude estimate will almost surely suffice for determining whether corrective action is required.

It would be beneficial to have several independent studies both to crosscheck one another and to reduce the likelihood that potential failure modes have been overlooked. Another benefit of multiple studies would be increased public awareness. (Readers who want to aid that process, please see the "Want to Help?" sidebar on page 17.)

## LATER STEPS

If the proposed studies show too high a risk, some people who grasp that reality will naturally want to jump to a new societal condition in which the nuclear threat is absent, for example by calling for rapid and complete nuclear disarmament. But such discontinuities are unachievable. Nuclear disarmament is neither the first step nor the last in solving the problem. Because it is not the first, demanding nuclear disarmament before earlier steps have laid an appropriate foundation is counterproductive. Most people will discount such demands as impossible—which they are in the current environment. Shultz, Perry, Kissinger, and Nunn, while calling for an eventual end to nuclear weapons, recognize this when they state:


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Dr. Hellman is a member of the National Academy of Engineering, a fellow of the IEEE and the International Association for Cryptologic Research, a Marconi international fellow, has served on national committees and boards of the IEEE and as associate editor of the *IEEE Transactions on Communications*, and was awarded a 1984 IEEE centennial medal. His article "On the Inevitability and Prevention of Nuclear War" appeared in the Winter 1985 BENT.


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[8] *Engineers design modern nuclear reactors to have catastrophic failure rates less than once per million operating years, and such a failure incurs far less damage than that of deterrence.*

[9] *The Appendix provides preliminary evidence for such an estimate.*

[10] *For example, my preliminary analysis suggests that the state of relations between the U.S. and Russia is a more important determinant of risk than the number of nuclear weapons. The period 1988-90, when both arsenals were near their peak, presented almost no risk, while short periods of high tension produced almost all of the risk. Improved relations also create more fertile ground for reducing the number of weapons.*

[11] *While others hid his contribution in order to take credit, as described in the PBS documentary "Golden Gate Bridge," Charles A. Ellis,* Indiana Alpha 1900, *was the designer of the bridge. See* www.pbs.org/wgbh/amex/goldengate/peopleevents/p_ellis.html.

> *"In some respects, the goal of a world free of nuclear weapons is like the top of a very tall mountain. From the vantage point of our troubled world today, we can't even see the top of the mountain, and it is tempting and easy to say we can't get there from here. But the risks from continuing to go down the mountain or standing pat are too real to ignore. We must chart a course to higher ground where the mountaintop becomes more visible." [Shultz 2008]*

Like a complex engineering project, formulating a solution to the nuclear threat requires breaking it down into a sequence of manageable steps, but with one major difference. The engineer who designed the Golden Gate Bridge[11] knew he needed to construct strong piers at each end before hanging the cables that attached to the piers, and he knew with a high degree of certainty the environment that the cables would find when they were attached. In contrast, the environment in which the solution to the nuclear threat evolves depends on highly unpredictable factors.

When I started work on this issue in 1981, it would have been foolish for me to assume that someone like Gorbachev would come to power in the Soviet Union and alter the landscape in such a radical manner. Yet it would have been equally foolish not to alter my approach once Gorbachev implemented radical changes in his country. Similarly, while undertaking studies to estimate the failure rate of nuclear deterrence is a reasonable first step, we cannot be certain of later steps until we see the new environment in which those steps will be taken.

While the intermediate steps in the process must be formulated with due regard for the uncertain environment in which they will be carried out, it does help to peer deep into the future and try to picture the ultimate state in which we must find ourselves if humanity is to survive. If the failure rate of nuclear deterrence is on the order of one percent per year and it must be reduced below $10^{-6}$ per year, then the world literally needs to become at least ten thousand times safer than it is today *and not allowed to revert to anything remotely resembling today's risk level*. The last, emphasized phrase is crucial because temporarily reducing the risk, without getting society to recognize the long-range goal, would produce a false sense of security that would dampen efforts to solve the problem long before that was appropriate.

Such a false sense of security allowed the inaction of recent years. During the 1980s, when the threat of nuclear war was in sharp focus, public concern helped produce progress that was unattainable in prior decades. But the resultant, friendlier relations between the superpowers reduced public support to the point that we are now facing a renewal of the pushing and prodding that is one of the primary trigger mechanisms for a global war. The Cold War thaw, while welcome, needed to be accompanied by an ongoing commitment even after the immediate threat was significantly reduced.

## POSSIBILITY

Making the world 10,000 times safer than at present may sound utopian and infeasible, and until recently it was. But, with more than 25,000 nuclear weapons in existence today and the ability to build many times that number, the choice is between creating such a world and having no world at all. We are being challenged to adapt to a sudden change in our environment, and, fortunately, adaptability is one of our defining characteristics. Through adaptations of clothing and shelter, humanity has extended its range from a small tropical region to the entire globe, and even walked on the Moon. Through other adaptations, we have learned to fly far higher and faster than birds and to navigate the seas better than fish.

We have also adapted our social structures in ways initially thought to be impossible. Abolishing slavery, a laughable idea just 200 years ago, became the law of the land 60 years later. Women's suffrage, which was initially even more laughable,[12] also came to pass. Some of the arguments that people make today about the impossibility of moving beyond nuclear deterrence were also used as supposed proofs that those earlier changes could never occur. But occur they did.

While engineering conservatism is demanded when designing systems where human lives are at stake, seemingly foolish optimism is a hallmark of successful engineering breakthroughs in the brainstorming phase, which is our position now with respect to ending reliance on nuclear deterrence. "Fulton's Folly" was the first step in supplanting sails with steam. The original proposals to span the Golden Gate were derided as impossible, but engineers optimistically persisted and ultimately succeeded.[13] In 1961, when President Kennedy committed the U.S. to putting a man on the Moon and returning him safely to Earth, engineers did not cry that this violated human nature and should not be considered. Rather, we devoted ourselves to overcoming seemingly insurmountable obstacles and again prevailed. In the same manner, I hope that our profession will courageously rise to this unprecedented challenge, poetically described 20 years ago by a man with whom I had the great honor of working and who made important intellectual contributions to the Soviet reform movement of the 1980s:

> In the philosophy of twentieth-century German and French existentialists (notably K. Jaspers), the term *grenzsituation* (border situation) has been used to designate an experience in which an individual comes face-to-face with the real possibility of death. Death is no longer merely an abstract thought, but a distinct possibility. Life and death hang in the balance.
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> Different human beings respond to the *grenzsituation* in different ways. Some become passive and put their heads on the chopping block, so to speak. Others experience something akin to a revelation and find themselves capable of feats they never before would

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[12] *The early abolitionists included women's suffrage in their platform, but removed it because of fear that it would prolong slavery by decades. In fact, the 19th Amendment did not pass until 55 years after the 13th.*

[13] *The Fall 2007 issue of* THE BENT *has an article that depicts the attitude needed here. In "Success & Failure: Two Faces of Design" (pages 27-30), Dr. Henry Petroski, P.E., notes that many early suspension bridges failed, causing a retreat from that design. But, as Petroski writes, "The German-American engineer John A. Roebling (1806-69) had a different reaction to the failure of suspension bridges .... Rather than taking the numerous examples of failed suspension bridges as a sweeping condemnation of the form, he took them as lessons from which he could learn how to build structures that would succeed."*

have thought possible. In a *grenzsituation*, some timid individuals have become heroes; some selfish individuals have become Schweitzers. And sometimes, in so transcending their normal personalities, they cheat the grim reaper and survive where normally they would not.

Until now, this notion has been applied only to individuals. But I am convinced that today it can be purposefully applied to the world as a whole. The present day global *grenzsituation* resides in the possibility for global death and global life.

This situation, for the first time in history, directly, practically, and not purely speculatively, confronts human thought with the possibility of death for the entire human race. The continuity of history, which earlier had seemed to be a given, suddenly becomes highly questionable.

As with the individual, this global *grenzsituation* may contribute to a "revelation" in human thinking and to a positive change of character previously thought impossible for our species. …

Of course there is also the possibility that, faced with a *grenzsituation*, mankind will go passive and put its collective head on the nuclear chopping block. But before we can learn our true mettle, we must bring the global *grenzsituation* into clear focus for all humanity. Society must see that it has but two possibilities, global life or global death. [Zamoshkin 1988]

**Acknowledgments and Note**

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To clarify the apolitical nature of this article, I should note my belief that neither Democrats nor Republicans have had (or have) policies consistent with the danger posed by continued reliance on nuclear deterrence. The Cuban missile crisis occurred under a Democratic president. Similarly, the Euromissile deployment, which brought so much criticism to President Reagan, was originally championed by President Carter, causing a leading Sovietologist to note that "President Reagan's initial faith in military solutions, rather than political-diplomatic ones, was the culmination of militarized thinking that flourished under President Carter and remains pervasive in the Democratic Party." [Cohen, 1986, page 140] Cohen's conclusion that "the folly is bipartisan" is still applicable today.

**Appendix: Estimating the Failure Rate**

While much less accurate than the in-depth studies proposed herein, it is instructive to estimate the failure rate of deterrence due to just one failure mechanism, a Cuban

Missile Type Crisis (CMTC). Because it neglects other trigger mechanisms such as command-and-control malfunctions and nuclear terrorism, this appendix underestimates the threat. This simplified analysis uses the time-invariant model described in footnote 3. It also assumes that the experience of the first 50 years of deterrence can be extended into the future.

The annualized probability of a CMTC resulting in World War III, denoted $\lambda_{CMTC}(t)$, is

$$\lambda_{CMTC} = \lambda_{IE} P_1 P_2 P_3$$

where $\lambda_{IE}$ is the annualized probability of an initiating event that could lead to a CMTC, $P_1$ is the conditional probability that such an initiating event results in a CMTC, $P_2$ is the conditional probability that the CMTC leads to the use of a nuclear weapon, and $P_3$ is the conditional probability that the use of a nuclear weapon results in full-scale nuclear war.

As noted above, there have been at least three possible initiating events in the first 50 years of nuclear deterrence: the Cuban missiles in 1962, President Reagan's threat to reimpose a naval blockade of Cuba in the 1980s, and the current deployment of an American missile defense system in Eastern Europe. Taking the average rate of occurrence of these possible initiating events, three in 50 years, results in an estimate $\lambda_{IE} = 0.06$. A higher estimate would result if other crises were included as possible initiating events. Examples include the Berlin crisis of 1961, the Six-Day War of 1967, and the Yom Kippur War of 1973, all of which involved at least implied nuclear threats. To temper the possibility of this article being seen as alarmist, it only considers the first three possible initiating events and therefore uses $\lambda_{IE} = 0.06$.

Because one of the three possible initiating events actually resulted in a CMTC, the empirical probability that a possible initiating event results in a CMTC is $P_1 = 1/3$. Because only the first initiating event led to a full-blown CMTC, it might be argued that we learned from that mistake and 1/3 is too large an estimate today. But, the fact that the latter two possible initiating events occurred at all is evidence that we did not adequately learn from the first mistake, or that we learned the wrong lesson. Because these two factors tend to cancel each other, this article uses $P_1 = 1/3$ as a reasonable estimate.

$P_2$, the conditional probability that a CMTC leads to the use of a nuclear weapon, is difficult to estimate because, fortunately, that has never happened. Statements from the participants in the Cuban missile crisis[14] support a range of (0.01, 0.5). Because invasion of Cuba was a strong possibility[15] and the participants stated their estimates before the Russian battlefield nuclear weapons were known in the West, this article replaces the 1% lower bound estimate with 10%, resulting in an estimated range of (0.1, 0.5) for $P_2$. If the actions of all parties with access to nuclear weapons (e.g., the Soviet submarine commander discussed above) are included, an even larger lower limit might be argued.

The last step is to estimate $P_3$, the conditional probability that the use of a nuclear weapon results in full-scale nuclear war. Again, we have the difficulty of estimating the probability of an event that has never happened. While Kennedy did not specify what he meant by the crisis ending in war, his evacuation order to the families of White House staff lends some support to the hypothesis that he meant full-scale nuclear war. McNamara's stated fear that he would not live out the week is also consistent with that interpretation. In that case, the upper bound of 0.5 for $P_2$ is really an upper bound for the product $P_2 P_3$. Again to avoid being seen as alarmist, this article uses an estimated range (0.1, 0.5) for $P_3$.

Since conditional probabilities were used, they can be multiplied, yielding an estimated range of (2E-4, 5E-3) for $\lambda_{CMTC}$, the failure rate of deterrence based on just this one failure mechanism. The upper limit 5E-3 is within a factor of two of my estimate that the failure rate of deterrence from all sources is on the order of one percent per year, and even the lower limit is well above the level that any engineering design review would find acceptable.

Because this estimate is based on a simplified, time-invariant model, it does not apply to the current point in time when relations between the U.S. and Russia are significantly better than they were, on average, during the last 50 years. However, that does not invalidate its conclusions. Russian-American relations are deteriorating, and new trigger mechanisms are coming into play—notably nuclear proliferation, terrorism, and the expansion of NATO right up to the Russian border—making it possible that the next 50 years could be even more dangerous than the last.

Furthermore, atypical times have a disproportionate effect on risk. A significant fraction of the total risk during the last 50 years occurred during the 13 days of the Cuban missile crisis—a period that constituted just 0.07% of that time period. Because crises produce so much of the overall risk, it is important to look beyond today's relatively benign world and also consider the rare, disruptive times when events tend to unfold much less rationally and predictably.[16]

*[14] Kennedy ordered families of White House staff to either leave Washington or be near a telephone [Burlatsky 1991, page 168], providing evidence for his estimate that the crisis could have ended in war as being between one-in-three and even [Blight & Welch 1989, page 84]. During the height of the crisis, Robert McNamara thought he might not live out the week [McNamara 1986, page 11]. At the other extreme, ExComm member McGeorge Bundy estimated 1% [Blanton 1997].*

*[15] In addition to pressure within ExComm for an invasion, Kennedy was subjected to pressure from Congress [Fursenko & Naftali 1997, page ix].*

*[16] Conversely, friendly Russian-American relations reduce the risk. For that reason, and as noted by Putin [Putin 2007], the current deployment of a missile-defense system in Eastern Europe, by itself, is unlikely to precipitate a crisis. But, if relations continue to deteriorate, deployment without regard for Russia's fears carries significant danger.*

## References

[Blair 1993]: Bruce G. Blair, *The Logic of Accidental Nuclear War*, The Brookings Institution, Washington, DC, 1993.

[Blanton 1997]: Thomas Blanton, "Annals of Blinksmanship," *The Wilson Quarterly*, Summer 1997. Accessible online at *www.gwu.edu/~nsarchiv/nsa/cuba_mis_cri/annals.htm.*

[Blanton 2002]: Thomas Blanton interview, "The Cuban Missile Crisis: 40 Years Later," *The Washington Post Online*, October 16, 2002. Accessible online at *discuss.washingtonpost.com/zforum/02/sp_world_blanton101602.htm.*

[Blight & Welch 1989]: James G. Blight and David A. Welch, *On the Brink: Americans and Soviets Reexamine the Cuban Missile Crisis,* Hill and Wang, New York, 1989.

[Bunn 2003]: Matthew Bunn, Anthony Wier, and John P. Holdren, *Controlling Nuclear Warheads and Materials: A Report Card and Action Plan*, Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, 2003. Accessible online at *www.nti.org/e_research/cnwm/cnwm.pdf.*

[Bunn 2007]: Matthew Bunn, *Guardians at the Gates of Hell*, Doctoral Thesis in Technology, Management and Policy, MIT, 2007. Accessible online at *esd.mit.edu/people/dissertations/bunn_matthew.pdf.*

[Burlatsky 1991]: Fedor Burlatsky, *Khrushchev and the First Russian Spring*, Charles Scribner's Sons, New York, 1991.

[Chapman & Morrison 1994]: Clark R. Chapman and David Morrison, "Impacts on the Earth by asteroids and comets: assessing the hazard." *Nature*, Vol. 367, pp. 33-40, 6 January 1994.

[Chang & Kornbluh 1998]: Laurence Chang and Peter Kornbluh, Introduction to *The Cuban Missile Crisis, 1962: A National Security Archive Documents Reader, 2nd Edition*, The New Press, New York, 1998. The Introduction is accessible online at *www.gwu.edu/~nsarchiv/nsa/cuba_mis_cri/declass.htm.*

[Fursenko & Naftali 1997]: Aleksandr Fursenko and Timothy Naftali, *One Hell of a Gamble*, W.W. Norton & Company, New York, 1997.

[Gates 1996]: Robert M. Gates, *From the Shadows: The Ultimate Insider's Story of Five Presidents and How They Won the Cold War*, Simon & Schuster, New York, 1996. (Page numbers refer to the 2006 paperback edition.)

[Hegland 2005]: Corine Hegland and Greg Webb, "Terrorism: The Threat," *National Journal*, April 15, 2005. Accessible at *nationaljournal.com/about/njweekly/stories/2005/0415nj1.htm.*

[LeoGrande 1981]: William M. LeoGrande, "Getting Cuba," *The New York Times*, November 17, 1981, Section A; Page 31, Column 2. Accessible at *american.edu/faculty/leogrande/getting-cuba.htm.*

[Lugar 2005]: Richard G. Lugar, *The Lugar Survey on Proliferation Threats and Responses*, Office of Senator Lugar, Washington, D.C., June 2005. Accessible at *lugar.senate.gov/reports/NPSurvey.pdf.*

[McNamara 1986]: Robert S. McNamara, *Blundering Into Disaster*, Pantheon Books, New York, 1986.

[OTA 1979]: Office of Technology Assessment, "The Effects of Nuclear War," May 1979. Available from NTIS, order #PB-296946. Accessible at *www.fas.org/nuke/intro/nuke/7906/.*

[Putin 2007]: Vladimir Putin, "Press Statement and Answers to Questions following the 20th Russia-European Union Summit, Marfa, Portugal," October 26, 2007. Accessible at *www.kremlin.ru/eng/speeches/2007/10/26/1918_type82914type82915_149706.shtml.*

[Robock 2007]: A. Robock, L. Oman, G. L. Stenchikov, O. B. Toon, C. Bardeen, and R. P. Turco, "Climatic consequences of regional nuclear conflicts," Atmos. Chem. Phys., 7, 2003-12, 2007. The paper and a discussion are accessible at *www.atmos-chem-phys.net/7/2003/2007/acp-7-2003-2007.pdf* and *www.cosis.net/members/journals/df/article.php?paper=acpd-6-11817.*

[Shultz 2007]: George Shultz, William Perry, Henry Kissinger, and Sam Nunn, "A World Free of Nuclear Weapons," *The Wall Street Journal*, January 4, 2007, page A15. Accessible at *media.hoover.org/documents/0817948429_3.pdf.*

[Shultz 2008]: George Shultz, William Perry, Henry Kissinger, and Sam Nunn, "Toward a Nuclear-Free World," *The Wall Street Journal*, January 15, 2008, page A13. Accessible at *www.hoover.org/pubaffairs/dailyreport/13796412.html.*

[Toon 2007]: O. B. Toon, R. P. Turco, A. Robock, C. Bardeen, L. Oman, and G. L. Stenchikov, "Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism," Atmos. Chem. Phys., 7, 1973-2002, 2007. Accessible at *www.atmos-chem-phys.net/7/1973/2007/acp-7-1973-2007.pdf.*

[TTAPS 1983]: Turco, R.P., Toon, A.B., Ackerman, T.P., Pollack, J.B., and Sagan, C., "Nuclear Winter: Global Atmospheric Consequences of Nuclear War," *Science*, vol. 222, 1983.

[Ury 1985]: William L. Ury, *Beyond the Hotline: How We Can Prevent the Crisis that Might Bring On a Nuclear War*, Houghton Mifflin Company, Boston, 1985.

[Zamoshkin 1988]: Yuri A. Zamoshkin, "Nuclear Disarmament: Ideal and Reality," in *Breakthrough: Emerging New Thinking*, edited by Anatoly Gromyko and Martin Hellman, Walker and Company, New York, 1988, pp. 209-213. Accessible at *www-ee.stanford.edu/%7Ehellman/Breakthrough/book/chapters/zamoshkin.html.*