Conclusion: Strategic Stability & Nuclear War

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If the fear of nuclear war has faded as the Cold War recedes into the misty past, we may need to remind ourselves of what these weapons can do. At least five of the nine countries that currently possess nuclear weapons can deliver thermonuclear warheads, each with the explosive equivalent of several hundred thousand tons of TNT, nearly halfway around the Earth.[1] The intercontinental ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs) that would deliver them at this range are called "strategic" because they can reach into an adversary's homeland to destroy leadership, military, infrastructure, or civilian targets. Warheads on different missiles are characterized by their yield (explosive energy) and their accuracy. Estimates in the open literature suggest that the United States, for example, can deliver a 455 kiloton warhead launched from a Trident ballistic missile submarine over six thousand miles to detonate within the length of a football field of its target.[2] The yield of 455 kilotons means that the energy released would equal the explosive energy of 455,000 kilograms (about one million pounds) of high explosive (TNT), which would be more than thirty times the energy released by the nuclear weapon detonated by the United States over Hiroshima during World War II. Depending on the relative location of the submarine launching the SLBM and its intended target, the time between the launch and the detonation of the warhead could be as short as six to ten minutes.[3] An adversary might have only that much warning time to recognize that an attack was underway and react.

Some Russian and Chinese strategic missiles are thought to carry warheads of even larger explosive yields. For example, the Russian SS-19 Mod 3 ICBM carries six independently targetable warheads (MIRVs) that reportedly have a yield as high as 750 kilotons.[4] Figure 1 shows the effects of one such 750-kiloton warhead exploding 1 mile (1.6 kilometers) above New York City, centered on Midtown Manhattan.[5] The four concentric rings in the figure illustrate the effects of the explosion. Moving outward from the point of detonation: Within the first ring

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Figure 1
Nuclear Blast above Midtown Manhattan

The map illustrates the immediate consequences of the hypothetical explosion of a 750-kiloton warhead that detonated 1 mile (1.6 kilometers) over Midtown Manhattan. More than 1.8 million people would be killed nearly instantly, and over 2 million more immediately wounded. The effects of likely massive urban fires are not included in these casualty estimates, nor are later deaths from radiation exposure. Source: Alex Wellerstein, NUKEMAP, https://nuclearsecrecy.com/nukemap/. Map data © OpenStreetMap contributors, published under a Creative Commons Attribution-ShareAlike 2.0 Generic (CC BY-SA 2.0) license; and Imagery © Mapbox.

(radius 2.5 kilometers) the blast is so strong that even heavily built concrete buildings are demolished. Virtually every person within this area is killed in the blast. This ring extends entirely across the island of Manhattan from the East River to the Hudson. The second ring (radius 5.7 kilometers) reaches into New Jersey and the boroughs of Brooklyn and Queens. It marks the distance out to which residential buildings collapse. At this distance, "injuries are universal and fatalities are widespread." The third ring (radius 11 kilometers) shows the effects of the immediate thermal radiation (high intensity ultraviolet, visible, and infrared light emitted by the explosion). Out to this distance, anyone with a line of sight to the detonation suffers third-degree burns to exposed skin. Finally, the fourth ring (radius 15 kilometers) marks the distance out to which windows shatter, with resulting injuries from flying glass. Overall, more than 1.8 million people would be killed nearly instantly, and over 2 million more immediately wounded. These numbers ignore the effects of firestorms – massive urban fires driven by hurricane-force winds that may result from the nuclear detonation[6] – as well as longer-term radiation and fallout. Of course, many hospitals and firehouses would be destroyed, and many medical personnel immediately killed, limiting the life-saving potential of first-responders.

These results are for a single large strategic warhead. Under the 2011 New START arms control treaty, Russia and the United States agreed to reduce their numbers of deployed strategic warheads to 1,550 on each side.[7] China, France, and the United Kingdom have smaller numbers of warheads on missiles, estimated at about 290, 300, and 225 warheads, respectively.[8] In a nuclear war, or a conventional war that escalated to the use of strategic nuclear weapons, many – perhaps hundreds or more – such detonations might take place.

This must never be allowed to happen. One way to try to ensure that it never does is to threaten nuclear-armed adversaries with nuclear retaliation from forces that would credibly survive an initial attack (the "first strike"). Potential attackers would then presumably be deterred from launching a first strike because they would feel certain to suffer devastating nuclear retaliation.[9] Yet this deterrent posture carries with it an inescapable, perhaps small but difficult to quantify, possibility of inadvertent or mistaken nuclear war.[10]

Another way to try to ensure that the worst never happens is to eliminate all nuclear weapons worldwide. But this approach raises its own challenges. One is how to reduce and then eliminate nuclear weapons with sufficient verification that all countries could feel confident that no weapons were hidden in violation of the disarmament agreements. A second is that weapons know-how cannot be unlearned and relevant capabilities fully undone, so that in a major war or political crisis, there could be pressure to recreate rapidly and perhaps preemptively use nuclear weapons. That is, a world of zero nuclear weapons could prove

dangerously unstable. Experts have dedicated much attention to these challenges, but they are far from solved.[11] At the same time, as this volume of *Dædalus* has highlighted, a future world in which stability is preserved through nuclear deterrence also faces considerable known and unknown challenges.

But there are other possible security catastrophes that states also wish to prevent: for example, full-scale conventional war among the major powers. World War II resulted in the deaths of over sixty million people.[12] The major powers have not waged total war against one another since 1945, even if many other smaller conflicts have been fought. There is more than one reason for this "Long Peace," but it is likely that the existence of nuclear weapons has induced caution on the part of the major powers over being drawn into major war.[13] The successful mating of fusion warheads to ICBMs or SLBMs has for this reason been termed the "nuclear revolution," because the likelihood of major war among states equipped with these weapons has been, some argue, greatly reduced by removing any doubt in the minds of national leaders about the horrific outcome of such a war.[14] Ballistic missile defense systems remain all but useless against more than a small number of incoming strategic warheads, so there is no reliable defense.[15] Therefore, in a face-off among nuclear-armed states, rational leaders provided with competent technical information must recognize that their country lies open to destruction. There is no denying the devastating consequences of thermonuclear war. Since full-scale conventional war could escalate to nuclear war, rational leaders would not risk waging full-scale war on another ICBM- or SLBM-wielding thermonuclear power.[16] And so, as some have argued, peace at this level has endured.

Various countries at various times have claimed other vital uses for nuclear weapons. Before it gave up its small, indigenous nuclear weapons arsenal, apartheid South Africa imagined that threatening the use of its weapons would force the great powers to negotiate an end to any conflict that menaced it.[17] Pakistan's senior generals have been clear that Pakistan would use nuclear weapons first if needed to repel a purely conventional Indian invasion.[18] It seems likely that North Korea's Kim Jong-un views the threat to use his country's nuclear weapons as his ultimate guarantor of regime and personal survival.[19] Finally, some countries, at least under certain leaders, may have pursued nuclear superiority (more nuclear missiles, with more nuclear warheads, say, than one's adversary) under the belief that this putative superiority in itself would confer other advantages or intimidate adversaries away from certain courses of action.[20] Not unrelatedly, some countries may pursue nuclear weapons to protect themselves against the possibility of nuclear blackmail or coercion.[21]

And so, we find ourselves in our current dilemma. Countries desire the security afforded by their own or their allies' nuclear weapons, but as long as these weapons exist, there remains a chance that they could be used in

limited or even vast numbers. This could result from escalation in the context of an ongoing conventional war, with one side concluding it had no choice but to strike first; or it might result from an erroneous conclusion made under time pressure that another state has launched a nuclear attack; or from a miscalculation by a leader who is not realistically informed or who has rebuffed efforts to be so informed; or even via an irrational leader coming to power and making heinous decisions. It is sobering that since the end of World War II, nuclear adversaries have considered the use of nuclear weapons in preventive war, have explicitly or implicitly threatened the use of nuclear weapons, and, in the Cuban missile crisis, have come close to misjudgments that would have led to nuclear war.[22] Concerns over escalation to the use of nuclear weapons are therefore justified by the historical record. At the same time, there has been no wartime use of nuclear weapons and no full-scale war between major powers since 1945.

Nuclear-armed states have aimed to reduce the likelihood of the various pathways to nuclear weapons use by seeking to create conditions of *strategic stability*. Strategic stability is usually taken to include both crisis stability and arms race stability. *Crisis stability* means that even in a conventional war or faced with a possible nuclear attack, states would not use nuclear weapons for fear that such escalation would bring certain disaster. Crisis stability must be robust even against inadvertent or mistaken nuclear escalation. *Arms race stability* means that nuclear powers do not have incentives to pursue weapons or weapon deployments resulting in action-reaction cycles that undermine crisis stability.

The goal of this volume has been to examine whether current directions in international affairs and a concomitant technological evolution are eroding strategic stability and placing the world at greater risk of nuclear weapons use – and if so, what might be done about it. In particular, this volume had its genesis in three particular concerns that appear to threaten strategic stability: the increasing complexity of nuclear relationships in a world of multiple and increasingly capable nuclear powers; the near-collapse of bilateral strategic arms control between the United States and Russia; and the development and possible deployment of new technologies whose characteristics overall seem likely to be destabilizing. Separately or combined, each of these trends could make escalation to nuclear weapons use more likely. These are wide-ranging multilateral challenges, but this volume has focused primarily on the triangular relationship among China, Russia, and the United States, with only occasional discussion of other nuclear powers. This reflects a practical decision to begin with these core relationships, not a belief that only those relationships matter. Subsequent work will expand this focus.[23]

During the Cold War, countries looked to a variety of means to prevent escalation to nuclear war, without forsaking what they perceived as the security benefits of their nuclear arsenals. The dream of a successful defense against a large-scale nuclear attack never ended, but the technical reality remained that warheads

launched from ICBMs and SLBMs were extremely difficult to intercept, and that an attacker's countermeasures were technically simpler and less expensive than a defender's interceptors.[24] Absent a credible defense against strategic missiles, other approaches came to the fore.

The least subtle of these was deterrence. In broad terms, deterrence in the nuclear context seeks to alter an adversary's cost-benefit calculation with respect to the use of nuclear weapons.[25] Its most stark realization was in the condition of mutual assured destruction (MAD) between the United States and the Soviet Union. Once secure second-strike systems were in place, each side understood that full-scale nuclear war would mean mutual annihilation, regardless of who struck first. Each country was deterred, they hoped, from reaching for the nuclear trigger by a recognition that no conceivable benefit was worth this level of "assured destruction."

In less stark manifestations of deterrence, countries sought to supplement the threat of punishment with steps that would deny an adversary's efforts to achieve their goals in launching an attack: so-called deterrence by denial. For example, an adversary might imagine that small-scale nuclear weapons could be employed in limited fashion to secure a desired objective without leading to unacceptable further escalation. Deterrence by denial meant fashioning capabilities that would dissuade an adversary from trying, thus cutting off a dangerous path to even greater nuclear weapons use. If nuclear weapons were nevertheless used in a limited way, some theorists argued that adversaries, faced with an opponent whose escalatory options were superior, might still be deterred from moving to higher levels of nuclear destruction.[26]

Beyond deterrence, the United States and the Soviet Union, and then Russia, engaged in a variety of arms control measures that were intended to reduce the incentives either side might have for escalating to nuclear weapons use.[27] Arms control sought to improve the adversaries' knowledge of one another, both through technical transparency into each other's military capabilities and by enhancing leadership communication in crisis. Consequently, escalation through fear, misunderstanding, or worst-case analyses would be less likely. Jon Wolfsthal, in his essay for this volume, highlights several major U.S.-Soviet arms control treaties that embodied these objectives.[28] The 1972 Anti-Ballistic Missile (ABM) Treaty sought to limit strategic missile defense deployments to spare each side a costly defensive arms race that could, at its worst, provide the false impression that launching a first nuclear strike was credible due to an effective defense against an adversary's reply. The 1987 Intermediate Nuclear Forces Agreement (INF) stabilized the U.S.-Russian nuclear relationship by eliminating the two countries' intermediate-range nuclear missiles in Europe and elsewhere, thereby freeing Moscow and European capitals from the fear of nuclear destruction from a nonstrategic missile that, because of the shorter ranges involved, could eliminate leadership, command and

control, or other targets with warning times much shorter than those of ICBMs. The second Strategic Arms Reduction Treaty (START II), signed by the United States and the Russian Federation in 1993, required the removal of MIRVed warheads from ICBMs. This would have reduced incentives for a first strike against vulnerable land-based missiles hosting multiple warheads. (The treaty, however, never entered into force.) All these agreements instantiate a view of arms control motivated by the desire to enhance strategic stability, rather than the intention to reduce the size of nuclear arsenals as such. Yet there were also arms control agreements that seemed more concerned with simple measures of parity than with enhancing stability.[29]

As the archives open, we are learning that the impulses prompting leadership in the two countries to turn to arms control were as broadly political as they were an effort to manage nuclear risks. James Cameron, in his essay in this volume, stresses this larger geopolitical context for arms control. Perhaps this should be unsurprising, since such a long-lasting foreign policy tool might be expected to serve many constituencies in order to survive over many decades. Cameron argues in particular that arms control, including the 1970 Treaty on the Non-Proliferation of Nuclear Weapons (NPT), was used by the United States and the Soviet Union "to preserve their dominance of global politics at the expense of their allies' military options."[30] Similarly, as he and other historians have shown, bringing U.S. allies under the protection of its nuclear umbrella was a powerful way to avert nuclear proliferation among those allies. In particular, both the United States and the Soviet Union valued the 1963 Limited Test Ban Treaty as a barrier to Germany pursuing a nuclear option. The crucial interplay between deterrent practices and arms control in the pursuit of broader objectives did not cease with the end of the Cold War. Looking ahead, if nuclear arms control is to have a future not only between the United States and Russia but among the other major nuclear powers, it will only be if leaders see it as a way to achieve larger geopolitical objectives as well as a safer nuclear world.

Another view of the nuclear threat, one whose roots reach back to some of the scientists who produced the first atomic bomb, was that measures such as deterrence and arms control could not guarantee strategic stability in perpetuity, and that international security ultimately would require the elimination of nuclear weapons.[31] The recognition that nuclear weapons bring peril as well as stability was one motive behind Article VI of the NPT, which calls for their ultimate elimination.[32] Throughout the Cold War, there was an ebb and flow of efforts by elements of civil society or on the part of non-nuclear-weapon states to pursue international security though nuclear disarmament.[33] The focus in this volume on relations among and strategic approaches of the three leading nuclear-weapon states – the United States, Russia, and China – risks paying too little attention to the views of non-nuclear-weapon states who find the continuing strategic face-off (claims for

the efficacy of deterrence or no) to be deeply troubling. Harald Müller and Carmen Wunderlich, in their essay discussing the Treaty on the Prohibition of Nuclear Weapons, trace the ways in which the apparent lack of attention on the part of the nuclear-weapon states to their Article VI NPT commitments and their backtracking on past commitments have encouraged 122 nations to negotiate – though not yet bring into force – a treaty to ban nuclear weapons altogether.[34]

All these approaches to maintaining strategic stability have been affected by the transition from the largely bilateral nuclear rivalry of the Cold War to today's more complicated nuclear world. Disturbingly, the trends we identify here – increasingly complex relations among increasingly capable nuclear-armed states, the collapse of formal arms control, destabilizing technological advances – are not merely moving in parallel, but may reinforce one another in powerful ways. Steven Miller, in his lead essay for this volume, argues that the effects of the transition from a predominantly U.S.-Russian nuclear weapons relationship to a Chinese-Russian-U.S. nuclear triangle can already be seen in important outcomes.[35] Miller argues that while accusations of treaty noncompliance were the proximate cause of U.S. withdrawal from the INF, strategic calculations reflecting the more complicated three-way Chinese-Russian-U.S. relationship undergirded this decision: because of the bilateral INF treaty, neither Russia nor the United States could match China's growing missile capabilities in the 500–5,500 kilometer range. A bilateral treaty was no longer well suited for a trilateral military relationship.

Miller gives a second example of increasing complexity due to multilateral nuclear decision-making. In the case of ballistic missile defense, steps taken by the United States to defend itself against small numbers of North Korean ICBMs or (possible future) Iranian ICBMs are seen by China and Russia as laying the groundwork for a more extensive and effective system to counter their own strategic nuclear forces. (And, Miller argues, the Trump administration has given them additional cause for this interpretation.) Steps taken in response by China will potentially affect India's decisions about its own nuclear forces. Beijing sits at an apex of two nuclear triangles, one with the United States and Russia, the other with India and Pakistan. At a minimum, as Miller approvingly quotes former Ambassador Steven Pifer, "Strategic stability appears increasingly a multilateral and multidomain construct."[36] Miller is doubtless correct when he concludes that formal treaty-based bilateral arms control, a classic tool for managing strategic stability, is less and less suited for the world in which we now live. Nor is multilateral arms control likely to fill the void. As Miller warns: "Bilateral arms control is collapsing but seems in any case insufficient; trilateral arms control seems necessary but so far remains impossible; multilateral arms control is comatose; and regional arms control is desirable but is as yet nonexistent."[37]

Any successful path forward will depend on the United States, Russia, and China finding some measure of common ground. If the essays in this volume by Anya Loukianova Fink and Olga Oliker, Li Bin, and Brad Roberts make one thing clear, that will not be easy. Reconstructing the perspectives of Russia, China, and the United States, respectively, the authors each describe a set of concerns fundamentally at odds with those of at least one of the other two. For Roberts, striving to pursue an approach to nuclear deterrence that lowers the risk of nuclear war remains key for the United States, but the context in which the United States must conduct this pursuit is altogether different. Russia, he argues, is no longer a potential partner in seeking to reduce nuclear risks, but a dangerous adversary striving to create a nuclear posture serving its aggressive foreign policy agenda.[38] The risk to be averted, therefore, is first and foremost that U.S. deterrence will fall short. By Fink and Oliker's retelling, Russia, in contrast, sees the situation in reverse: Russia's nuclear forces are designed to deter the primary threat posed by the United States. As its once dominant role in a shifting global setting fades, Russia's leadership contends, the United States counts on its military power, underpinned by nuclear weapons, to threaten and coerce others. It seeks nuclear superiority and now focuses on new technologies and weapons systems intended to degrade the Russian nuclear deterrent and make nuclear weapons more usable.[39]

Not only have U.S. and Russian views on what threatens strategic stability sharply diverged, making preserving, let alone extending, the nuclear arms control process a fading prospect, but the way each side now both defines the specific threat that it sees in the other side's weapons programs and doctrinal shifts and prepares to counter them seems likely to increase the chance of inadvertent escalation across the nuclear threshold. In the meantime, Li argues, the disparity between the size of the U.S. and Russian nuclear arsenals and those of all other countries means that the numerical aspects of U.S.-Russian arms control treaties "cannot apply to China."[40] In other words, formal multilateral arms control is, as Miller suggested, not currently an available option. As the United States begins to treat China as a rising geopolitical threat and its enhanced nuclear forces as a source of concern, China's changing perceptions of global trends, the nature of the nuclear world, and the challenges it faces, according to Li, widens the gulf.

Complicating all issues of mutual understanding and potential escalation is the arrival – likely in the absence of any related arms control measures – of a set of new technologies that overall will probably make nuclear forces and their associated command and control appear more vulnerable. The most immediate of these is cyberspace operations. In his essay, James Acton systematically describes the ways in which cyber weapons differ from traditional weapons and, in particular, those aspects of cyber operations that seem especially destabilizing.[41] He acknowledges, however, that credible approaches to mitigate this threat are

inadequate to the need. Christopher Chyba, in his essay, examines a wide range of new technologies, and proposes a framework to think through a given technology's impact on strategic stability. The intent of his framework is to help ensure that consideration (by any country) of new technologies systematically confronts the variety of ways in which destabilizing effects may result, so that possible mitigating steps can at least be considered.[42]

How, then, are we to work within this world to lessen the chances of escalation to the use of nuclear weapons? Most of our authors propose elements of a response, but Linton Brooks, James Timbie, and Nina Tannenwald, in their essays, take this question as their primary focus. There is consensus that the United States and Russia should take advantage of New START's provision that allows the two parties to extend the treaty by five years beyond its looming 2021 expiration deadline. Brooks emphasizes that the transparency and predictability measures implemented in New START benefit the United States more than Russia because the United States is inherently the more open of the two countries. Moreover, while much of the information exchanged between the two sides *could* be obtained by national intelligence, this would require the diversion of these resources away from other intelligence requirements. And still, some of the information provided by New START, Brooks warns, "cannot be obtained in any other way."[43]

Yet Brooks – in agreement with other authors in this volume – acknowledges that a replacement treaty is nevertheless unlikely.[44] Timbie is clear about why further arms control treaties of any kind between Russia and the United States seem improbable. "Russia," he notes, "has taken the position that further agreements must address third-country forces, missile defense, and precision conventional systems."[45] But it is unlikely that China will agree to enter a formal treaty process, and the United States is unlikely to negotiate treaty commitments limiting missile defense. To this, one might add the seeming unwillingness of the current U.S. Senate to ratify treaties of nearly any kind, and arms control treaties in particular.

With the end of New START, bilateral arms control between the United States and Russia in the sense of formal legally binding treaties comes to an end. Brooks emphasizes that it is important to analyze carefully what the consequences of this loss of information and restraint will be, and to understand what mitigating steps may be taken to compensate for at least some of what will be lost. To this end, Timbie proposes an extensive list of transparency measures, numerical limits, and constraints on behavior that could be agreed upon as political, rather than legal, agreements. Verification would of necessity be weaker than with New START, but perhaps some limited verification measures could nevertheless be put in place. This would circumvent the U.S. treaty-ratification problem, even if the agreements are more fragile, more easily repudiated by incoming presidential administrations, and less well verified. Given the Russian concerns that Timbie

himself identifies, it is unclear how realistic these proposals may be. But at the least, they should be vigorously explored.

With the decline of treaty-based arms control among the nuclear-weapon powers, Tannenwald calls for all nuclear-armed states to move toward a "regime of nuclear restraint and responsibility."[46] Restraint, in her view, should "primarily take the form of reciprocal commitments and unilateral measures to avoid an arms race and reduce nuclear dangers." And responsibility means committing to "responsible deterrence," which not only prioritizes strategic stability and the immediate goal of preventing nuclear war but retains the ultimate goal of disarmament. Nuclear disarmament is, after all, a treaty requirement that the United States accepted when it ratified the NPT for, as Article VI of the U.S. Constitution states, ratified treaties are "the supreme law of the land."[47] Nevertheless, the willingness of the United States publicly to embrace this obligation has varied greatly from administration to administration, and in the current state of affairs, this "ultimate" goal may seem very distant indeed. In the meantime, Tannenwald suggests a series of measures that could be pursued absent formal treaties, some by all nuclear-armed states, some by the United States, Russia, and China, and some unilaterally by the United States. One challenge is to ensure that unilateral measures would be effective beyond just the United States, France, and the United Kingdom. We see Tannenwald's suggestions as reinforcing the calls by Müller and Wunderlich for the advocates of the Treaty on the Prohibition of Nuclear Weapons and the advocates of deterrence to work harder to find common ground to prevent the worst outcomes from coming to pass.

The authors of this volume bring a diversity of views to the issue of strategic stability in this new multipolar world. Nevertheless, there is broad, albeit not universal, agreement on several points:

1) Russia and the United States should extend New START's expiration date from 2021 to 2026. They should then use that time to pursue a successor treaty that would further extend the transparency, predictability, and numerical limits (and ideally, lower limits) that New START provides. Yet most authors of this volume fear that extension is not likely, and that even if the treaty were extended, a formal successor treaty is unlikely to be realized.

2) If formal bilateral arms control treaties prove impossible, Russia and the United States should work to put in place politically binding agreements to capture much of the security and stability benefits that will be lost with the formal treaty process. However challenging such agreements may prove to be, the two states should vigorously explore these options.

3) On a bilateral or a multilateral basis, the United States, Russia, and China should pursue discussions intended to improve understanding of one another's strategic concerns and views on which actions by an adversary would be especially concerning or dangerous. Until that happens, the widening gap in the outlook

and actions of these three major actors will only make this new nuclear environment less manageable and more dangerous.

4) China, Russia, and the United States should also actively work to see whether and where common ground can be found concerning efforts to mitigate arms spirals and restrain the development, deployment, or use of destabilizing technologies. They should then pursue politically binding agreements to advance these goals, albeit with a clear eye to the limits of verification that would exist in this format.

In addition, we embrace certain recommendations that were made by individual or a few authors:

5) The United States should strengthen *resilience* in its many forms – including to early warning, command and control, and communications – as a key mechanism both for deterrence (by denial) and for mitigating the risk of escalation of nonconventional attacks (such as cyber- or bio-attacks) or conventional warfare (including attacks in space) to the use of nuclear weapons.[48]

6) While military intelligence and operations will increasingly incorporate artificial intelligence (AI) into the interpretation of large amounts of empirical data, AI should nevertheless not be allowed, either intentionally or inadvertently, to enter or creep into actual decision-making for nuclear weapons use.

7) Little is to be gained, and perhaps much lost, by insisting on the opposition between those who emphasize deterrence as the central element of strategic stability and those who see a necessity for nuclear disarmament. In the U.S.-Russian-Chinese context, steps that would enhance stability by constraining weapons numbers or deployment of specific destabilizing technologies, or by improving communication regarding concerns about, and likely responses to, an adversary's possible strategic or tactical actions, could serve both causes.

The world has lived with nuclear weapons for seventy-five years. Although the number of states with nuclear weapons has grown slowly, the weapons themselves, while being used for many purposes, have not been detonated in war since the end of World War II. But the new era we have entered is more complex, both politically and technically, and seems likely to be less constrained by treaty, and therefore less transparent and less predictable, than any time in the past half-century.

It remains possible that New START can be extended and continue to serve as one basis for bilateral stability between the United States and Russia. In this future, there would remain many dangers, and the United States, Russia, and China would still need to engage in extensive dialogue to mitigate and manage them. Absent New START, the challenges would prove much greater. This volume has attempted, first, to help us understand what this coming world may look like and, second, to present recommendations that may provide a modest beginning to avoiding the worst outcomes in these possible futures.

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ENDNOTES

[1] First-generation nuclear weapons split the nuclei of either high-enriched uranium or plutonium to produce a million times more energy per kilogram than is the case for chemical high explosives. These are called *fission* weapons. Even greater amounts of energy per kilogram, by perhaps another factor of one hundred, is produced in *fusion* weapons. These weapons (also called hydrogen or thermonuclear weapons) use a fission weapon trigger (or "primary") to create the pressures and temperatures needed to fuse hydrogen nuclei together (in the "secondary") to produce helium, releasing even greater amounts of energy and typically driving additional fission as well. See, for example, Kosta Tsipis, *Arsenal: Understanding Weapons in the Nuclear Age* (New York: Simon & Schuster, 1983).

[2] Hans M. Kristensen and Matt Korda, "United States Nuclear Forces, 2020," *Bulletin of the Atomic Scientists* 76 (1) (2020): 46–60.

[3] See Tsipis, *Arsenal*, chap. 7.

[4] See ibid., chap. 5; and Center for Strategic and International Studies Missile Defense Project, "SS-19 'Stiletto,'" Missile Threat, August 10, 2016, https://missilethreat.csis.org/missile/ss-19/ (last modified June 15, 2018); compare to Hans M. Kristensen and Matt Korda, "Russian Nuclear Forces, 2019," *Bulletin of the Atomic Scientists* 75 (2) (2019): 73–84.

[5] Alex Wellerstein, NUKEMAP, https://nuclearsecrecy.com/nukemap/. Nuclear weapons effects based on E. Royce Fletcher, Ray W. Albright, Robert F. D. Perret, et al., *Nuclear Bomb Effects Computer (Including Slide-Rule Design and Curve Fits for Weapons Effects)*, CEX-62.2 (Washington, D.C.: U.S. Atomic Energy Commission Civil Effects Test Operations, 1963); and Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons* (Washington, D.C.: U.S. Department of Defense and U.S. Department of Energy, 1977).

[6] Such as was created at Hiroshima, and also by conventional bombing of cities such as Dresden, Hamburg, and Tokyo. See Lynn Eden, *Whole World on Fire: Organizations, Knowledge, and Nuclear Weapons Devastation* (Ithaca, N.Y.: Cornell University Press, 2006).

[7] The actual numbers are somewhat higher, since the counting rules under New START treat each strategic bomber as delivering only one warhead. See The Treaty between the United States of America and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive Arms (New START Treaty), Article III, https://2009-2017.state.gov/t/avc/newstart/c44126.htm.

[8] Hans M. Kristensen and Matt Korda, "Chinese Nuclear Forces, 2019," *Bulletin of the Atomic Scientists* 75 (4) (2019); Hans M. Kristensen and Matt Korda, "French Nuclear Forces, 2019," *Bulletin of the Atomic Scientists* 75 (1) (2019): 51–55; and Robert S. Norris and Hans M. Kristensen, "The British Nuclear Stockpile, 1953–2013," *Bulletin of the Atomic Scientists* 69 (4) (2013): 69–75.

[9] The essays in this volume have focused (albeit not exclusively) on nuclear deterrence among the United States, Russia, and China. Not every nuclear power has adopted a posture of assured retaliation. See Vipin Narang, *Nuclear Strategy in the Modern Era: Regional Powers and International Conflict* (Princeton, N.J.: Princeton University Press, 2014).

[10] Barry R. Posen, *Inadvertent Escalation: Conventional War and Nuclear Risks* (Ithaca, N.Y.: Cornell University Press, 1991).

[11] See, for example, Joseph Rotblat, Jack Steinberger, and Bhalchandra Udgaonkar, *A Nuclear-Weapon-Free World: Desirable? Feasible?* (San Francisco: Westview Press, 1993); George Perkovich and James M. Acton, eds., *Abolishing Nuclear Weapons: A Debate* (Washington, D.C.: Carnegie Endowment for International Peace, 2009); and George P. Shultz, Sidney D. Drell, and James E. Goodby, eds., *Deterrence: Its Past and Future* (Stanford, Calif.: Hoover Institution Press, 2011).

[12] Antony Beevor, *The Second World War* (New York: Little, Brown & Co., 2012).

[13] John Lewis Gaddis concludes: "It seems inescapable that what has really made the difference in inducing this unaccustomed caution has been the workings of the nuclear deterrent." See John Lewis Gaddis, "The Long Peace: Elements of Stability in the Postwar International System," *International Security* 10 (4) (1986): 99–142, and references therein. Ward Wilson is skeptical of this conclusion; see Ward Wilson, "The Myth of Nuclear Deterrence," *Nonproliferation Review* 15 (3) (2008): 421–439. See also Robert Rauchhaus, "Evaluating the Nuclear Peace Hypothesis: A Quantitative Approach," *Journal of Conflict Resolution* 53 (2) (2009): 258–277.

[14] Robert Jervis, *The Meaning of the Nuclear Revolution: Statecraft and the Prospect of Armageddon* (Ithaca, N.Y.: Cornell University Press, 1989).

[15] Dietrich Schroeer, *Science, Technology, and the Nuclear Arms Race* (Hoboken, N.J.: John Wiley & Sons, 1984), chap. 10.

[16] Confidence in the unwillingness of nuclear powers to go to full-scale war might, however, encourage these same powers to risk lower levels of conflict or violence: the "stability-instability paradox." See Glenn Snyder, "The Balance of Power and the Balance of Terror," in *Balance of Power*, ed. Paul Seabury (San Francisco: Chandler, 1965); and Rauchhaus, "Evaluating the Nuclear Peace Hypothesis."

[17] Anthony Liberman, "The Rise and Fall of the South African Bomb," *International Security* 26 (2) (2001): 45–86.

[18] Sadia Tasleem, *Pakistan's Nuclear Use Doctrine* (Washington, D.C: Carnegie Endowment for International Peace, 2016), https://carnegieendowment.org/2016/06/30/pakistan-s-nuclear-use-doctrine-pub-63913.

[19] Scott D. Sagan, "The Korean Missile Crisis: Why Deterrence Is Still the Best Option," *Foreign Affairs* 96 (6) (2017): 72–82; and Patrick McEachern, "More than Regime Survival," *North Korea Review* 14 (1) (2018): 115–118.

[20] See Matthew Kroenig, "Nuclear Superiority and the Balance of Resolve: Explaining Nuclear Crisis Outcomes," *International Organization* 67 (1) (2013): 141–171. For a contrary argument, compare with Todd Sechser and Matthew Fuhrmann, *Nuclear Weapons and Coercive Diplomacy* (Cambridge: Cambridge University Press, 2017).

[21] Major General Yang Huon, former deputy commander of China's strategic rocket forces, has written that "China's strategic nuclear weapons were developed because of the belief that hegemonic power will continue to use nuclear threats and nuclear blackmail." Yang Huon, "China's Strategic Nuclear Weapons," https://fas.org/nuke/guide/china/doctrine/huan.htm.

[22] See, for example, Lyle J. Goldstein, *Preventive Attack and Weapons of Mass Destruction* (Stanford, Calif.: Stanford University Press, 2006). See also William Perry, "The Risk of 'Blundering' into Nuclear War: Lessons from the Cuban Missile Crisis," *Arms Control Today*, December 2017, https://www.armscontrol.org/act/2017-12/features/risk-'blundering'-into-nuclear-war-lessons-cuban-missile-crisis; and Graham Allison, "The Cuban Missile Crisis at 50: Lessons for U.S. Foreign Policy Today," *Foreign Affairs* 91 (4) (2012): 11–16, https://www.foreignaffairs.com/articles/cuba/2012-07-01/cuban-missile-crisis-50.

[23] American Academy of Arts and Sciences, "Deterrence and the New Nuclear States," project chairs Scott D. Sagan and Vipin Narang, https://www.amacad.org/project/deterrence-and-new-nuclear-states.

[24] Schroeer, *Science, Technology, and the Nuclear Arms Race*; and David Hafemeister, *Physics of Societal Issues: Calculations on National Security, Environment, and Energy* (New York: Springer, 2007), chap. 3.

[25] Glenn H. Snyder, "Deterrence and Defense," in *The Use of Force: Military Power and International Politics*, 3rd ed., ed. Robert J. Art and Kenneth N. Waltz (New York: University Press of America, 1983), 25–43.

[26] Herman Kahn, *On Escalation: Metaphors and Scenarios* (Westport, Conn.: Greenwood Press, 1965).

[27] Thomas C. Schelling and Morton H. Halperin, *Strategy and Arms Control* (New York: Twentieth Century Fund, 1961); and "Arms Control," *Dædalus* 89 (4) (Fall 1960)

[28] Jon Brook Wolfsthal, "Why Arms Control?" *Dædalus* 149 (2) (Spring 2020).

[29] Thomas C. Schelling, "What Went Wrong with Arms Control?" *Foreign Affairs* 64 (2) (1985): 219–233.

[30] James Cameron, "What History Can Teach," *Dædalus* 149 (2) (Spring 2020).

[31] See, for example, Dexter Masters and Katherine Way, eds., *One World or None: A Report to the Public on the Full Meaning of the Atomic Bomb* (New York: McGraw-Hill, 1946).

[32] Article VI of the NPT reads, in its entirety, "Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control." See "Treaty on the Non-Proliferation of Nuclear Weapons (NPT)," https://www.un.org/disarmament/wmd/nuclear/npt/text.

[33] Matthew Evangelista, *Unarmed Forces: The Transnational Movement to End the Cold War* (Ithaca, N.Y.: Cornell University Press, 1999).

[34] Harald Müller and Carmen Wunderlich, "Nuclear Disarmament without the Nuclear-Weapon States: The Nuclear Weapon Ban Treaty," *Dædalus* 149 (2) (Spring 2020).

[35] Steven E. Miller, "A Nuclear World Transformed: The Rise of Multilateral Disorder," *Dædalus* 149 (2) (Spring 2020).

[36] As quoted in ibid.

[37] Ibid.

[38] Brad Roberts, "On Adapting Nuclear Deterrence to Reduce Nuclear Risk," *Dædalus* 149 (2) (Spring 2020).

[39] Anya Loukianova Fink and Olga Oliker, "Russia's Nuclear Weapons in a Multipolar World: Guarantors of Sovereignty, Great Power Status & More," *Dædalus* 149 (2) (Spring 2020).

[40] Li Bin, "The Revival of Nuclear Competition in an Altered Geopolitical Context: A Chinese Perspective," *Dædalus* 149 (2) (Spring 2020).

[41] James M. Acton, "Cyber Warfare & Inadvertent Escalation," *Dædalus* 149 (2) (Spring 2020).

[42] Christopher F. Chyba, "New Technologies & Strategic Stability," *Dædalus* 149 (2) (Spring 2020).

[43] Linton F. Brooks, "The End of Arms Control?" *Dædalus* 149 (2) (Spring 2020).

[44] Ibid.

[45] James Timbie, "A Way Forward," *Dædalus* 149 (2) (Spring 2020).

[46] Nina Tannenwald, "Life beyond Arms Control: Moving toward a Global Regime of Nuclear Restraint & Responsibility," *Dædalus* 149 (2) (Spring 2020).

[47] "This Constitution, and the Laws of the United States which shall be made in Pursuance thereof; and all Treaties made, or which shall be made, under the Authority of the United States, shall be the supreme Law of the Land." Constitution of the United States of America, Article VI, https://www.archives.gov/founding-docs/constitution-transcript#toc-article-vi-.

[48] The U.S. Department of Defense has defined *resilience* as "The ability of an architecture to support the functions necessary for mission success with higher probability, shorter periods of reduced capability, and across a wider range of scenarios, conditions, and threats, in spite of hostile action or adverse conditions." A recent study suggests that the resilience of potentially targeted systems can be improved in many ways, including disaggregation, distribution, diversification, protection, proliferation, and deception. See Office of the Assistant Secretary of Defense for Homeland Defense & Global Security, *Space Domain Mission Assurance: A Resilience Taxonomy* (Washington, D.C.: Office of the Assistant Secretary of Defense for Homeland Defense & Global Security, 2015), https://fas.org/man/eprint/resilience.pdf.