

Working toward a world without nuclear weapons

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Limiting the number of warheads is a good beginning, but getting to the end state calls for new thinking. Six specific steps can start us down that path.

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This article is based on the 2010 Max von Laue Lecture that I was invited to give in March at the German Physical Society meeting in Bonn, Germany. In physics, von Laue is greatly admired for discovering x-ray diffraction by crystals, work for which he received the Nobel Prize in 1914. Von Laue is also universally admired for acting with honor and speaking out with courage against Nazi policies of racial discrimination and in support of scientific integrity during the darkest and most dangerous days of the Hitler regime.

Von Laue and Albert Einstein, both born in 1879, were members of the generation of physicists whose revolutionary discoveries led civilization across a one-way bridge into today's new era. It is the era in which, for the first time in history, we can literally destroy the civilization built over the past 3000 years. That is the danger we have created with thermonuclear weapons able to release explosive energy of unimaginable destructiveness.

Shortly after the first atom bomb was exploded, Einstein warned us that "the unleashed power of the atom has changed everything save our modes of thinking and we thus drift toward unparalleled catastrophe." He challenged humanity to change its thinking before it is too late. A few years later, when efforts commenced to turn the primitive atomic bombs that obliterated Hiroshima and Nagasaki into mere triggers of modern thermonuclear weapons hundreds to thousands of times more powerful, the two great physicists Enrico Fermi and I. I. Rabi warned, "It is clear that the use of such a weapon cannot be justified on any ethical ground which gives a human being a certain individuality and dignity even if he happens to be a resident of an enemy country. . . . It is necessarily an evil thing considered in any light."

And yet today, 65 years after the end of World War II and two decades since the dismantling of the Berlin Wall and the dissolution of the Soviet Union into the dustbin of history, we are still living in a world armed with approximately 20 000 nuclear bombs. And a growing number of nations are seeking to join the nuclear weapons club.

Why? What are those weapons for? What purpose do they serve in the modern world? Do large arsenals of deployed nuclear weapons, many of which are ready for launch within minutes of notice, contribute to our national security, or are they themselves part of the problem? Cannot we do

better than living under a continuing danger of a nuclear holocaust?

Relying on nuclear weapons for deterrence is becoming increasingly hazardous and decreasingly effective in a world in which nuclear know-how, materials, and weapons are spreading ever farther and faster. With the spread of advanced technology, we face a growing danger that nuclear weapons may fall into the hands of rogue states or terrorist organizations that do not shrink from mass murder on an unprecedented scale.

It is encouraging that increasing concerns about those dangers and the imminent challenges they pose have triggered important initiatives by world leaders during the past two years (see figure 1 and the news story on page 24); I will discuss them below.

The vision of zero

I have talked a lot with George Shultz, the former US secretary of state and a close friend and colleague at Stanford University in California, about arms control and the devastating consequences of nuclear explosions. In recent years we have shared increasing concerns about the growing danger of proliferation and the inadequacy of current efforts to meet the challenge. The world seems to us to be teetering on the edge of a new and more perilous era, with nuclear proliferation becoming ever more likely and imminent (see figure 2). The spread of nuclear knowledge and technology, as evident in the actions of North Korea and Iran, makes it all too clear that this is a danger on our doorstep that requires urgent action.

In 1986 a remarkable meeting between US president Ronald Reagan and Soviet general secretary Mikhail Gorbachev took place in Reykjavik, Iceland, at which they agreed on the revolutionary goal of eliminating *all* nuclear weapons. Figure 3 illustrates the subsequent downturn in the sizes of the global nuclear arsenals. But their vision to eliminate all nuclear weapons, though sincere and serious, remains unfulfilled.

In October 2006, on the 20th anniversary of that meeting, Shultz and I organized a conference in an effort to rekindle and advance the vision of zero. The success of that conference and the overwhelming positive worldwide response to articles reporting its conclusions (see my article on page 54 of the June 2007 issue of *PHYSICS TODAY*) inspired us to convene a



Figure 1. World leaders engaged. Left: Russian president Dmitry Medvedev, Czech Republic president Vaclav Klaus, and US president Barack Obama share a toast in Prague Castle after the US and Russia sign the New START treaty on 8 April 2010. Right: Pakistani prime minister Syed Yousuf Raza Gilani and Obama have a bilateral meeting in Washington, DC, on 11 April 2010. (Official White House photos by Pete Souza.)

second conference one year later. We prepared substantive analyses of the specific steps we had identified as essential to making progress toward our goal. The second conference further informed and strengthened our convictions of the importance of the twin objectives of achieving a world without nuclear weapons and of using that vision as a compass both to guide thinking in the formulation of nuclear policies and to generate global cooperation.¹

Following that second conference, the Norwegian government made an offer we couldn't refuse. Its Foreign Office proposed to host a conference in Oslo in February 2008 to carry our message to the international community and to learn the thoughts and reactions of colleagues from other countries. We met with about 100 academic, military, and former government individuals from 29 countries, including all the nuclear powers. We found strong support to rekindle and realize the vision of a nuclear-free world, but with an important condition: The nuclear states had to show their sincerity, their honest commitment to working together toward a world with a level playing field. The days were over, we heard, for a two-tier system in which some nations had and many did not have nuclear weapons. And the same held true for having two tiers of nations that can and cannot enrich uranium. Such enrichment is a dual-use technology that can provide fuel for both civilian power reactors and nuclear weapons.

Many attendees expressed concerns that the major nuclear powers—the US, Russia, China, the UK, and France—were not living up to the commitment in article VI of the Treaty on the Non-Proliferation of Nuclear Weapons (also known as the Non-Proliferation Treaty, the NPT) to work toward getting rid of all of their weapons (see the box on page 32). They viewed continuing efforts to modernize and improve current nuclear forces as inconsistent with that goal; they were no longer willing to sit passively and watch this pattern of behavior continue without advancing their own nuclear capabilities. Yes, they were impressed by the reduction in the numbers of nuclear warheads (figure 3), but they were deeply concerned with the growing threat of proliferation and frustrated by the unwillingness of the US in partic-

ular to join the large majority of nations that have ratified the Comprehensive Test Ban Treaty (CTBT).

The good news is that no law of nature stands in the way of ridding the world of nuclear weapons. The political problems can, in principle, be overcome. The bad news is that as Einstein once said, "Politics is much harder than physics." Still, it is very encouraging that many world leaders today actively embrace, and are willing to cooperate to achieve, the vision of Reykjavik.

President Obama has endorsed the need to escape the trap of nuclear deterrence as we have known it for the past half century. As he remarked in his acceptance of the Nobel Peace Prize in Oslo in December 2009, "A decade into a new century, this old architecture is buckling under the weight of new threats. The world may no longer shudder at the prospect of war between two nuclear superpowers, but proliferation may increase the risk of catastrophe. Terrorism has long been a tactic, but modern technology allows a few small men with outsized rage to murder innocents on a horrific scale." Importantly, that message has broad bipartisan support in the US.

Obama and Russian president Dmitry Medvedev, the leaders of the two states with the largest nuclear arsenals, first met on 1 April 2009. In their joint statement, they officially committed their countries "to achieving a nuclear free world, while recognizing that this long-term goal will require a new emphasis on arms control and conflict resolution measures, and their full implementation by all concerned nations." Toward that end the US and Russia resumed formal negotiations toward a step-by-step process of new and verifiable reductions in their strategic offensive arsenals, culminating a year later with the New START treaty (figure 1). That treaty calls for modest reductions in deployed strategic forces and a commitment to move ahead with further and broader reductions in the two countries' respective nuclear arsenals.

At a special summit meeting chaired by Obama on 24 September 2009, the UN Security Council, in its first comprehensive action on nuclear issues since the mid-1990s, unanimously adopted Resolution 1887, which aims "to seek

a safer world for all and to create the conditions for a world without nuclear weapons.”

A subsequent summit on national security issues, held in Washington, DC, on 12–13 April 2010 and attended by leaders from more than 40 countries, resulted in a communiqué with a work plan that included commitments to secure all vulnerable nuclear material in four years.

A six-step start

Such expressions of support by world leaders are encouraging, but the challenge remains daunting. To move ahead still requires difficult but necessary steps. Here, for example, are six specific steps whose implementation presents challenges that must be overcome on the way to a world without nuclear weapons. Whether or not one agrees with the goal, these steps remain crucial to reducing nuclear dangers in the near term.

► **Ratify New START.** If the US Senate and the Russian Duma ratify New START,² it will replace the now-expired START I, have a 10-year duration, and be extendable for another five years. New START calls for modest numerical reductions by each country of deployed strategic nuclear warheads to no more than 1550, including those deployed on intercontinental-range land- and submarine-based ballistic missiles and suitably equipped heavy bombers. The new limit is 30% lower than the maximum of 2200 set by the 2002 Treaty of Moscow (SORT). The START I treaty had put a significantly higher ceiling of 6000 on the total of “attributed” warheads—the maximum number that deployed launchers can accommodate. New START also calls for steep cuts in numbers of strategic nuclear delivery vehicles, to about half of the 1600 permitted for each side in START I. Unlike SORT, New START includes a broad set of effective verification measures designed to provide high confidence in the ability to detect in a timely manner any militarily significant violations. Those provisions are updated from START I.

I believe that reengaging in formal arms-control negotiations is an important beginning that sets the stage for deeper reductions accompanied by essential monitoring and verification principles. I welcome clear indications from both parties of a readiness to pursue deeper reductions and urge that the discussions begin even before New START is ratified.

The path to much deeper reductions will be challenging. Over the past several decades the US and Russia learned to agree on rules for counting deployed warheads, or warheads designated as deployed. But monitoring nondeployed warheads will require an increased level of intrusiveness to verify

compliance. Long before the numbers decrease from today’s levels into the hundreds, other nations will have to enter into the discussions, and will need to exercise restraint in their build-ups as we and the Russians build down.

► **Include tactical nuclear weapons.** The US and Russia must limit not just strategic or long-range intercontinental delivery systems and warheads but also shorter-range tactical nuclear weapons, many of which are currently deployed on or near the borders of Europe. Reviewing the role of such weapons has already stirred debate in a number of NATO countries.

On 25 October 2009, German foreign minister Guido Westerwelle said the German government would “enter talks with our allies so that the last of the nuclear weapons still stationed in Germany, relics of the cold war, can finally be removed.” Turkey, which hosts a handful of US tactical nuclear bombs, officially supports inclusion of all nonstrategic nuclear weapons in the disarmament process. That position was emphasized in a *New York Times* op-ed piece published 1 February 2010 by the Polish and Swedish foreign ministers, Radek Sikorski and Carl Bildt.

A desirable objective would be to withdraw the tactical nuclear weapons to secure, consolidated locations and ultimately include them in the efforts to eliminate all nuclear weapons. That process will present even greater challenges than posed by strategic weapons, since it will require enhanced transparency and cooperation among all countries involved. The smaller and more portable nuclear weapons designed for forward tactical deployment are particularly alluring to terrorist groups. As long as those weapons remain, they and all nuclear material must be secured to the highest possible standards.

► **Negotiate a verifiable cutoff on the production of fissionable bomb material.** It is not at all impossible for substate units who get their hands on as little as 50 kg of highly enriched uranium to assemble a crude nuclear device of the type that was dropped on Hiroshima. The most effective tools for mitigating that risk are to decrease the size of nuclear arsenals and to provide strong security protection while reducing the large quantity of weapons-usable material worldwide.

► **Establish international control of the nuclear fuel cycle.** The growing worldwide demands for energy and for limiting greenhouse gases have led to a resurgence of interest in building nuclear reactors. But that brings an increased potential for the spread of sensitive nuclear fuel cycle technologies—both at the front end through enrichment of uranium and at the back end through reprocessing weapons-usable fuel. Any nation with an indigenous infrastructure for enriching uranium also has the technical infrastructure to build a nuclear bomb. That is what makes it a dual-use technology.

Here is an illustrative example: To power a light-water reactor, uranium fuel must be enriched to about 4% of the fissioning isotope ^{235}U ; producing one gigawatt of electric power annually will burn about 1000 kg of that isotope. A primitive bomb of the type that destroyed Hiroshima needs uranium enriched to about 90% ^{235}U . But the gas centrifuges commonly used for the enrichment must do only about 40% more work to produce 1 kg of bomb fuel than to produce 25 kg of reactor fuel containing 1 kg of ^{235}U . Because the 50 kg of fuel in the bomb is no more than 5% of the 1000 kg that a reactor will burn each year, an enrichment plant that can fuel a reactor is already large enough in principle to fuel several simple bombs.

A country that acquires uranium enrichment technology for nuclear power consistent with article IV of the NPT (see the box at left) thus becomes a latent nuclear power. That is the underlying issue we face with Iran. The only way to con-

Excerpts from the Treaty on the Non-Proliferation of Nuclear Weapons

“Considering the devastation that would be visited upon all mankind by a nuclear war and the consequent need to make every effort to avert the danger of such a war and to take measures to safeguard the security of peoples . . .” the signatories agree to 11 separate “articles,” two of which are mentioned here.

Article IV ensures “the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination and in conformity with articles I and II of this treaty.”

Article VI obligates all parties “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.”

The NPT is available at <http://www.state.gov/t/isn/trty/16281.htm>.

tain and control the danger of proliferation is with a mechanism for international control of the entire fuel cycle at all stages. Such a cooperative regime will also need to guarantee the availability of fuel to all nations that agree to comply with the NPT. That will be difficult because of concerns about placing valuable proprietary information under international control. Several nations are exploring the development of such a nuclear power infrastructure.

► **Sharpen the NPT's verification teeth.** Currently, nations must declare their nuclear power sites and allow access to them to verify that no fuel is being diverted for military uses. But what about nondeclared sites where the International Atomic Energy Agency currently has less authority to make on-site challenge inspections? The problem is as evident in the current tensions with Iran and North Korea as it was in the run-up to the Iraq war. Efforts are under way to remedy the problem: About one-half of the NPT signatory nations have signed on to additional protocols that permit on-site challenge inspections of all suspect activities. Uniform global acceptance of those protocols is being sought. But the "verification teeth" also must carry the intention and ability to be enforced. The words must mean something.

The CTBT linchpin

► **Bring the CTBT into force.** The CTBT bans all explosive tests that produce any nuclear yield from a nuclear chain reaction. Such tests are needed to validate new weapon designs that incorporate technology more advanced than the primitive bomb dropped on Hiroshima. (See the article on the CTBT by Jeremiah Sullivan in *PHYSICS TODAY*, March 1998, page 24.)

The US was the first signatory of the CTBT in September 1996. Since then the treaty has been signed and ratified by 153 countries—80% of all nations—including all US NATO allies, Russia, and Japan. All 44 nations identified in the text of the CTBT as nuclear capable must ratify the treaty before it enters into force. So far 35, or all but 9, have done so. Those nine countries include the US. China is a key holdout waiting for us to act, while India and Pakistan have not yet even signed the CTBT and are unlikely to do so unless the US ratifies it. Also yet to ratify the CTBT are Egypt, Israel, and Iran, which have signed it, and North Korea, which has not. On 3 May, Indonesia announced its intent to ratify the treaty. US President Bill Clinton sent the CTBT, which he called the "longest sought, hardest fought prize in the history of arms control negotiations," to the Senate in 1996. When the Senate considered it three years later, it fell far short of winning the necessary two-thirds majority. The Senate debate that preceded the vote was cursory and the main issues were never adequately discussed.

Ratification of the CTBT by the US is a big deal. The nation's lack of leadership to bring it into force is a cause for growing concern in many nations and was evident in our meeting in Oslo two years ago. Why has the US been unwilling to ratify the treaty despite growing support worldwide? Technical issues raised in the 1999 Senate debate focused on two concerns: our ability to maintain a safe, reliable, and secure nuclear deterrent without underground explosive tests until we no longer need the weapons; and the ability of the International Monitoring System (IMS) to detect explosive yields down to such low levels that tests evasively performed below that level would be essentially useless to a cheater. Now, 10 years later, those two concerns have been addressed.

After the moratorium on underground tests was initiated in 1992 by President George H. W. Bush, the US established a broad science-based Stockpile Stewardship Program (see the article by Raymond Jeanloz in *PHYSICS TODAY*, De-

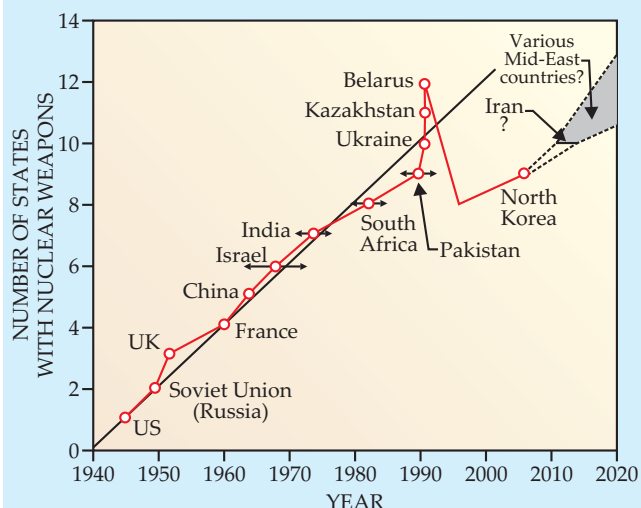


Figure 2. The number of nuclear weapons states grew for about 50 years at a rate of about one every five years (black line). When the Soviet Union was dissolved, Ukraine, Kazakhstan, and Belarus relinquished nuclear weapons from their territories; South Africa did as well. Despite that downward blip, the trend remains dangerously upward.

cember 2000, page 44). There is now general agreement among experts in the US that the program has advanced the scientific understanding of nuclear explosions so greatly that the directors of the nuclear weapons laboratories now assert that there is no present need to conduct nuclear test explosions; the current deterrent requirements of safety, security, and reliability are assured.

For example, Los Alamos and Lawrence Livermore national laboratories, using data mined from previous tests plus new laboratory work, conducted a thorough study that has removed a critical concern about the stability of plutonium in the pits. Weapons scientists now confirm that pit lifetimes are at least 85–100 years.

The JASON group, an independent defense advisory panel of senior scientists with full access to pertinent classified information, last year completed a study commissioned by the government that concluded more broadly that the "lifetimes of today's nuclear warheads could be extended for decades, with no anticipated loss in confidence, by using approaches similar to those employed in LEPs [Life Extension Programs] to date." But looking to the future, the study team also emphasized the need to provide adequate and stable funding for the program to ensure the safety, reliability, and effectiveness of the shrinking US arsenal. Such investment will also strengthen trust and confidence in the technical capabilities of the US to undertake the necessary steps to reduce nuclear dangers worldwide. The 2010 Nuclear Posture Review issued on 6 April 2010 by the Department of Defense discusses the Obama administration's views on those issues.

The resolution of the second technical question, concerning the ability to verify compliance with the treaty consistent with the security needs of the US, is also much stronger now than in 1999. Two detailed studies—one commissioned by President Clinton and led by former chairman of the Joint Chiefs of Staff General John Shalikashvili in 2000–2001 and one by the National Academy of Sciences in 2002—drew favorable conclusions. Then, in the fall of 2006, North Korea detonated a nuclear device of very low yield—only about

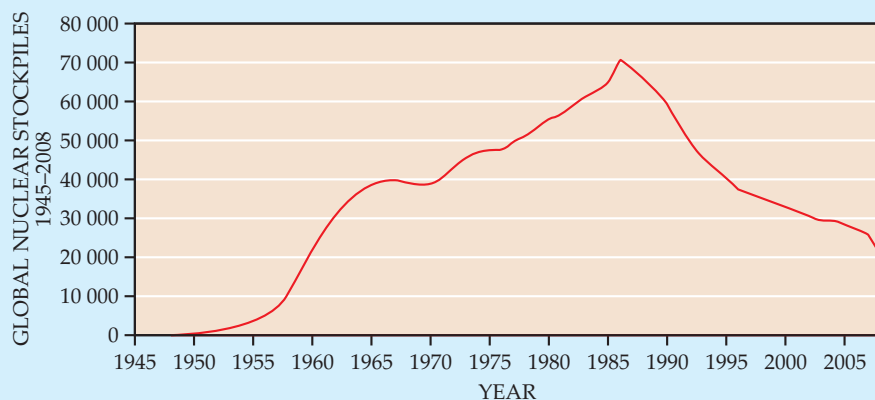


Figure 3. The number of nuclear weapons reached a staggering peak in the mid-1980s. At the US–Soviet Reykjavik summit in 1986, the goal of a nuclear-weapons-free world was enunciated, and the global stockpiles have decreased ever since. Still, getting the number to zero will take hard work and a worldwide commitment.

3% of the Hiroshima bomb—that was clearly detected, localized, and identified by many stations, near and not so near North Korea. That event, and a second North Korean one in 2009 of somewhat higher yield, confirmed the impressive sensitivity of the IMS. Now about 80% complete, it will eventually consist of more than 300 globally deployed sensors of different kinds: seismic (50 primary, 100 secondary), hydroacoustic (11), infrasound (60; 0.001–20 Hz), and radionuclide (80 for detecting aerosols, of which 40 include systems for detecting noble gases, such as xenon-133, that escape into the atmosphere). Not only is the IMS already working very well, but unlike many reconnaissance systems, it doesn't require human direction and is constantly vigilant. Beyond the IMS, further enhancement comes both from individual nations' intelligence systems and from national research facilities around the world that share their findings and have their own capabilities to locate, identify, and calibrate such events. Would-be cheaters thus face an intimidating array of challenges to any attempted clandestine test.

During the coming year, I hope the US Senate, after careful preparation, will again consider the CTBT. There are good reasons why legitimate skeptics back in 1999 could now support ratification.

The end state

So far I have been talking about what the late Michael Quinlan, former permanent undersecretary in the UK Ministry of Defense, has called “disarmament mechanics.” But once we cross the threshold into the end state of zero nuclear weapons, we will encounter new conceptual issues of great difficulty. Some people may think it is absurdly premature to discuss more than casually what a world without nuclear weapons would be like. After all, the path to reach that goal is a long one, with major obstacles to surmount. But to generate a serious commitment from nations around the world, we all must understand the goal well enough to make it seem credible.

Upon entering the end state, we would be in an entirely new situation of deterrence with no deployed or reserve nuclear weapons. That situation was first described in 1984 by Jonathan Schell.³ As he emphasized, it would not be a return to the pre-nuclear-weapons world of 1944, because we would retain the knowledge of nuclear weapons; they wouldn't have to be reinvented.

During the final approach to zero, nuclear weapons nations will probably maintain enough nuclear infrastructure to ensure the effectiveness of their shrinking stockpile. The capability for weapon reconstitution won't automatically dis-

appear. But then we face a daunting challenge to the whole idea of going to zero: If some nations retain such a hedge capability to reconstitute nuclear forces, would it be an invitation to a reconstitution race? Could conditions of stable strategic deterrence be developed under such conditions? Does getting to zero truly offer realistic prospects for establishing a safer world—at least safer than less radical alternatives for reducing nuclear arms and limiting their spread?

These are questions we must begin to face. Answers will require new conceptual thinking. For example, what are the necessary elements of an adequate nuclear infrastructure, one with a capacity for limited and timely reconstitution of a deterrent? What activities, facilities, or weapons-related items should be limited or prohibited? What can be done to ensure early and reliable warning of a so-called breakout attempt? Former ambassador James Goodby and I are working on these questions at the Hoover Institution, as are several others at other institutions, notably George Perkovich and James Acton.⁴ We have made a start on a very difficult problem that I hope will draw serious attention, particularly from the scientific community.⁵

Getting to zero and monitoring the end state will require comprehensive cooperation and improvements in all types of verification tools: national technical means, data exchanges, on-site inspections, continuous perimeter and portal monitoring, tags and seals, sensors and detection devices, and remote viewing as conducted already by the International Atomic Energy Agency.

As we arrive at the end state, we will have banned the existence of a ready-to-use arsenal, but we will not have eliminated the capability to rebuild one. Inequalities will remain between states that once had nuclear weapons and those that didn't. Inevitably, as confidence increases in managing stability in a world without nuclear weapons, such disparities will decrease with time. But until they wither away, we will face a major challenge to monitor and verify permissible activities, even after reaching zero.

It is important to recognize that we will not reject or otherwise do away with deterrence in a world without nuclear weapons. A successful deterrent policy has the virtue of avoiding military conflict. To achieve it, and to establish a stable world at peace, a nation must be prepared to respond effectively to hostile actions. But deterrence does not require nuclear weapons, and as I and others have argued, our world is better off without them.

The path to zero starts with reducing the numbers of warheads and progresses by stretching out the time scale for their reconstitution. Today's delay between a decision and the

actual launch of nuclear weapons can be as short as minutes. After we have removed all of them and are relying on a "virtual arsenal" that has to be reconstituted, that delay would be measured in months or longer. As the numbers of nuclear weapons decrease toward zero, so will their damage potential, but until we actually reach that goal, we will still be vulnerable to the devastating effects—both physical and societal—of one or a few bombs delivered and detonated covertly by rogue states or suicidal terrorists in urban areas.

A lot of hard work lies ahead on both technical and policy issues. Those who see hope for a world without nuclear weapons need to get to work on achieving it.

I thank James Goodby for valuable comments in the preparation of this paper.

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