Nuclear weapons dangers and policy options

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NUCLEAR WEAPONS

With the end of the Cold War, most physicists turned their attention away from the nuclear threat. It is now time for us to reengage in the debate over how to reduce the dangers from nuclear weapons.

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dangers & policy options

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Three months after nuclear weapons leveled Hiroshima, J. Robert Oppenheimer gave voice to a dark vision. In a 16 November 1945 speech to the American Philosophical Society, he said, "If they are ever used again, it may well be by the thousands, or perhaps by the tens of thousands." The number of US and Soviet nuclear warheads rose to extremely high levels during the Cold War, giving substance to that vision. With the end of the Cold War, however, the size of the US nuclear stockpile declined dramatically, and the number of Russian nuclear warheads is believed to have dropped in parallel. START (Strategic Arms Reduction Treaty), which came into force on 5 December 1994, and New START, which came into force on 5 February of this year, formalized limits on the strategic arsenals of the US and Russia.

Although the global nuclear stockpile is at its lowest level since 1958 (see figure 1), its destructive power remains enormous. The explosive power of each of the 4000 active US nuclear warheads is equivalent to hundreds of thousands of tons of TNT—an order of magnitude beyond the 15- to 20-kiloton yields of the warheads that destroyed Hiroshima and Nagasaki. It is therefore unfortunate that the downward impulse created by the end of the Cold War appears to be spent. In June 2013 President Barack Obama proposed to reduce the number of deployed US and Russian strategic weapons by one-third and to seek reductions in the number of nondeployed and nonstrategic weapons, but no negotiations were launched.

Nuclear weapons policy has prompted a spectrum of views. At one end is a strong movement to eliminate nuclear arsenals and the danger they pose to civilization. At the other are governments that see as essential the deterrence of major war that nuclear weapons can provide. Those governments include the Trump administration, whose views have just been laid out in the 2018 *Nuclear Posture*

Review.[1] In this article we review the present situation and describe what we think could be done to prevent a renewed nuclear arms race and to reduce the danger of accidental nuclear war.

Forty more years

All countries with nuclear weapons are currently engaged in modernizing their nuclear arsenals. During the next three decades, the US plans to spend more than $400 billion to replace its triad of intercontinental ballistic missiles (ICBMs), ballistic-missile submarines (SSBNs), and strategic bombers and to replace or extend the lives of its nuclear warheads.[2] As figure 2 shows, the US Department of Defense's projected expenditures on nuclear weapons for the period 2025–34 are at a level that was exceeded only twice during the Cold War.

Because of the failure to engage Russia in further reductions and the unwillingness of the US to reduce unilaterally, the DOD modernization programs are sized to maintain current force levels. And because the new weapons systems are designed to have service lives of more than 40 years, the modernization program will enable the US to maintain those force levels out to 2075. That time horizon can be read as a signal to the world that the US does not expect significant nuclear reductions for the foreseeable future, despite Obama's 2009 commitment in Prague "to seek the peace and security of a world without nuclear weapons."

Can we risk the indefinite continuation of the nuclear status quo? Some who have been responsible for commanding US nuclear forces think not. George Lee Butler, commander in chief of the US Strategic Command during 1992–94, stated, "We escaped the Cold War without a nuclear holocaust by some combination of skill, luck, and divine intervention, and I suspect the latter in greatest proportion."[3]

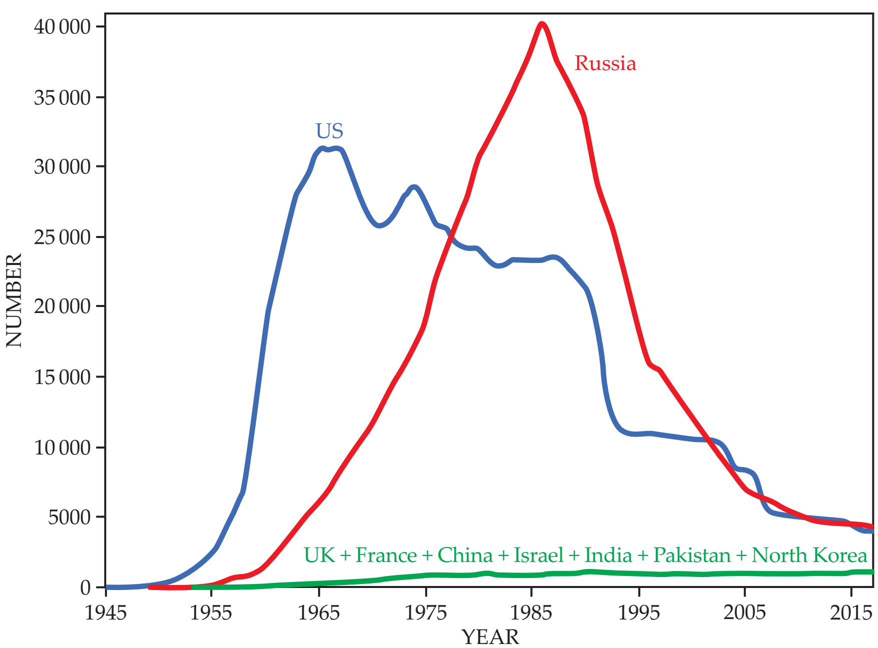

FIGURE 1. NATIONAL STOCKPILES of active nuclear warheads.[13] No official numbers have been published for countries other than the US. Thousands of additional warheads in Russia and the US await dismantlement.

Butler made clear that the danger he feared was not a deliberate Soviet or US nuclear attack but rather an accidental nuclear war. His concern was greatest about the danger from false alarms of incoming attacks by nuclear-armed ballistic missiles. Both the US and Russia have postured their silo-based ICBMs to be launched within the 10- to 30-minute window between the detection of a ballistic-missile attack by early warning satellites and radars and the detonation of the incoming warheads. Some of Russia's ballistic-missile submarines alongside their piers and mobile missiles in their garages are believed to be similarly postured. During the Cold War, there were alarms of incoming Soviet nuclear attacks that were identified as false before the deadline for launching a US counterattack.[4] On at least one occasion, according to reports, a Soviet early warning satellite falsely gave an alert of a US attack, but the responsible Soviet military officer refused to pass on the information without radar confirmation.[5]

Counterforce, a strategy for instability

US nuclear weapons are aimed primarily at military targets, with Russian and Chinese nuclear delivery systems the highest priority. That counterforce targeting accounts for both the large size of the US and Russian nuclear forces and the reluctance of either side to reduce the size of its force without corresponding reductions by the opposing side. The professed goal of the strategy is to reduce the damage an adversary could inflict in an all-out war. However, because a large fraction of vulnerable US and Russian nuclear missiles are postured to be launched on warning of an attack, counterforce targeting would more likely trigger than limit massive nuclear retaliation.

The concern that increased counterforce capability would lead to increased instability led one of us (Garwin) to oppose a Nixon administration program to improve the accuracy of US submarine-launched ballistic missiles (SLBMs). Instability concerns have come to the fore again because of the "superfuze," a seemingly modest upgrade in US SLBM fuzing that can lead to a tripling of a warhead's kill probability against a silo target.[6]

A 2001 study estimated that 8 million–15 million people would be killed and millions more seriously injured by the direct effects of blast, fire, and radioactive fallout resulting from a US attack on Russia's nuclear forces[7] (see figure 3). Indirect casualties would result from the collapse of essential infrastructure and the effects of smoke and ozone depletion on climate. Their number is harder to estimate and therefore is usually ignored. It could, however, vastly exceed the number of direct casualties.

Russia and the US have each long had a triad of strategic nuclear delivery vehicles: ICBMs, SLBMs, and long-range bombers. The table on page 36 enumerates each type of delivery vehicle and the approximate number of warheads they carry.

In the US, ICBMs are deployed in reinforced concrete silos sunk into the ground. In addition to silo-based ICBMs, Russia deploys some of its ICBMs on mobile launchers to make them more difficult to target. The US has reduced the number of warheads carried by its ICBMs to one warhead each, to make the missiles less attractive targets and thereby enhance crisis stability. Russia has not made a corresponding reduction.

Most US strategic warheads are carried by SLBMs. Each current SSBN is equipped to carry 20 SLBMs, each of which can carry up to eight warheads; on average, they actually carry about half that number. US SSBNs are virtually impossible to detect in the vastness of the oceans. On average, about 8 of the 14 US SSBNs are at sea, four are in port for replenishment, and two are in dry dock for major overhaul. Russia typically has about four SSBNs at sea.

Long-range bombers dominated US strategic nuclear forces in the 1950s, but they have become much less central and are located at only three bases today. With the end of the Cold War, the US and Russia ended the practice of keeping a fraction of their strategic bombers loaded with nuclear weapons, ready to take off. Given warning, however, they could be armed and dispersed to airfields around the country within a day or two.

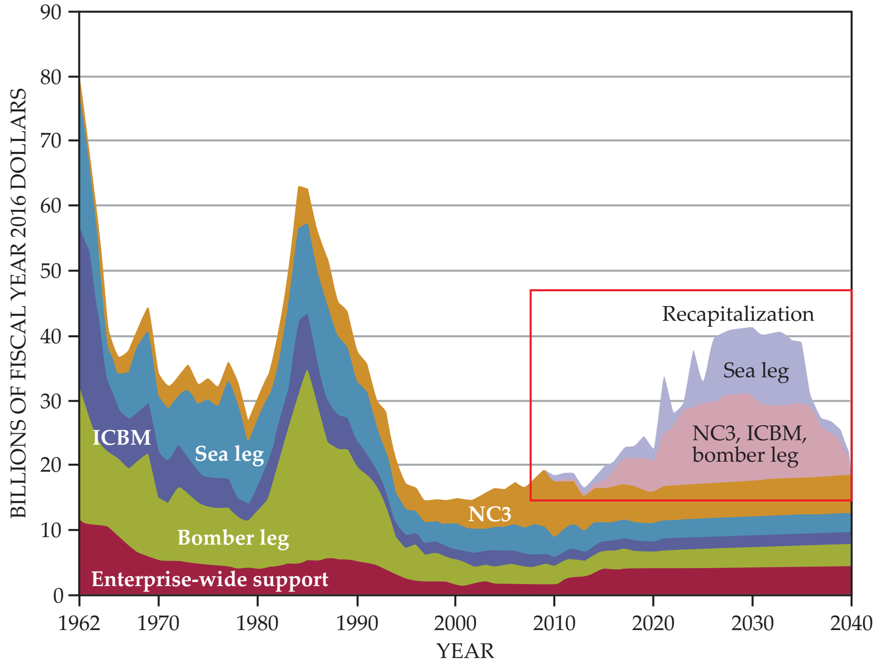

FIGURE 2. US DEPARTMENT OF DEFENSE EXPENDITURES on nuclear weapons delivery vehicles and nuclear command, control, and communications (NC3). The two historical peaks are associated with the Eisenhower through Johnson administrations and the Reagan administration, respectively. The projected plateau indicates recapitalization plans for new strategic bombers, ballistic-missile submarines, and intercontinental ballistic missiles (ICBMs). The plot does not show life-extension, modernization, and other expenditures on nuclear warheads by the National Nuclear Security Administration; those currently run at about $10 billion per year. (Adapted from ref. 14.)

Each leg of the US triad has strengths and weaknesses. The silo-based ICBMs are of the greatest concern because of their launch-on-warning posture. During their first campaigns, Presidents George W. Bush and Obama both declared that this hair-trigger posture was dangerous, but once in office, both found it impossible to change. Butler found Strategic Command to be so fixated on its mission to destroy a high percentage of the nuclear-weapons-related targets in Russia that

> when they realized that they could not in fact assure those levels of damage if the president chose to ride out an attack, what then did they do? They built a construct that powerfully biased the president's decision process toward launch *before* the arrival of the first enemy warhead. And at that point, all the elements, all the nuances of limited response just went out the window. The consequences of deterrence built on massive arsenals made up of a triad now simply ensured that neither nation would survive the ensuing holocaust.[8]

Many other experts, including former secretary of defense William Perry, have since come to similar conclusions and now argue that US ICBMs should be eliminated. The vulnerability of US silos is strictly a problem of the US nuclear confrontation with Russia; no other country has enough nuclear warheads to threaten the survival of US or Russian silo-based ICBMs. We agree that phasing out silo-based ICBMs would improve strategic stability—and it would also reduce modernization costs.

Fooling the defense

Ballistic-missile defense (BMD) has been a contentious issue since the Soviet Union launched the *Sputnik 1* satellite in 1957. The two dimensions of the controversy concern the ability to neutralize BMD systems with relatively inexpensive countermeasures and the fear that BMD systems will prompt potential adversaries to increase their offensive strategic nuclear forces to ensure they can overwhelm the defense.

All BMD systems deployed today to defend the continental US involve the intercept of incoming warheads in space. Many relatively simple countermeasures would be effective against such systems. Figure 4 shows one possibility: lightweight decoys. A 2012 National Research Council report, *Making Sense of Ballistic Missile Defense*, noted,

> Discriminating between actual warheads and lightweight countermeasures has been a contentious issue for midcourse defense for more than 40 years. . . . Based on the information presented to it by the Missile Defense Agency (MDA), the committee learned very little that would help resolve the discrimination issue in the presence of sophisticated countermeasures. In fact, the committee had to seek out people who had put together experiments . . . and who had understood and

> analyzed the data gathered. Their funding was terminated several years ago, ostensibly for budget reasons, and their expertise was lost. (page 131)

Of course, counter-countermeasures exist, but after more than 50 years of analysis, the advantage remains decisively on the side of the offense.

Offense disguised as defense?

History shows that conservative military leaders are unwilling to rely on countermeasures alone to neutralize defenses. A notable declassified example was the response of US military planners to the 64 Galosh interceptors that the Soviet Union deployed around Moscow in the late 1960s. Although the US equipped its missiles with countermeasures, it also added at least 100 extra warheads targeted on Soviet BMD radars and launchers to ensure the defeat of the Galosh system.[9] Congress once understood that exoatmospheric BMD "makes no sense no matter how you look at it," to quote 1970 Senate testimony from physicist Marvin Goldberger. But during the past decade Congress has been spending about $8 billion per year, mostly on systems that could be easily neutralized even by North Korea, whose incipient ICBMs have provoked the Trump administration to propose a multibillion-dollar budget increase for BMD systems.

One alternative is boost-phase defense—attacking ballistic missiles before they can reach space. That was the idea behind the Reagan administration's vision of hundreds of orbiting multi-megawatt laser battle stations, justly ridiculed with the appellation Star Wars. However, more modest, limited-range sea- or air-based interceptor missiles could be effective against ballistic missiles launched by a small country like North Korea without having the reach to threaten missiles launched from the interiors of China and Russia. Unfortunately, that option has been neglected because of continued insistence by a significant faction of BMD supporters that it may yet be possible to mount an effective defense against all ballistic missiles, including Chinese and Russian.

Having seen that the offense–defense dynamic made it impossible to cap their nuclear arms race, the US and Soviet Union negotiated the Anti-Ballistic Missile (ABM) Treaty in 1972, which, with its added 1974 protocol, limited each country to 100 interceptors at one site. In 2001, however, three months after 9/11, Bush announced that the US would withdraw from the ABM Treaty on the basis that "terrorists, and some of those who support them, seek the ability to deliver death and destruction to our doorstep via missile."[10] As with the invasion of Iraq in March 2003, there was no effective congressional opposition to that decision.

Moreover, little opposition has developed since Bush's announcement, despite evidence of troubling Chinese and Russian reactions. For example, speaking at the Saint Petersburg International Economic Forum on 17 June 2016, President Vladimir Putin described his concerns about the US BMD buildup:

> We are being told that this is part of a defensive, not offensive, capability, that these systems are intended to ensure defense against aggression. This is not true. This is not the way things are. A strategic missile defense system is part of an offensive strategic capability and is tightly linked to offensive missile strike systems. Some high-precision weapons are used to carry out a pre-emptive strike, while others serve as a shield against a retaliatory strike, and still others carry out nuclear strikes. All these objectives are related and go hand in hand with the use of high-precision conventional weapons.

In his remarks, Putin introduced another Russian concern: US development of highly accurate long-range conventional cruise and ballistic missiles that could be used to attack Russian nuclear forces. The fear is that because such weapons would not be nuclear armed, the US might be more willing to undertake a counterforce first strike with them to weaken the effectiveness of Russia's deterrent forces.

In March of this year, Putin announced that Russia was developing five new nuclear weapons systems to overcome and evade US BMD: a heavy multiwarhead ICBM that can

US and Russian nuclear weapons (5 February 2018)	Russia		US	
	Delivery vehicles	Warheads	Delivery vehicles	Warheads
ICBMs	320	800	399	399
SLBMs	160	600	212	945
Long-range bombers (New START counting rules)	50	50	49	49
TOTAL (New START counting rules)	**527**	**1444**	**660**	**1393**
New START limits	700	1550	700	1550
Nonstrategic		1850		300
Reserve		790		2050
TOTAL STOCKPILE		**4300**		**4000**

NUMBERS OF WARHEADS on intercontinental ballistic missiles (ICBMs), submarine-launched ballistic missiles (SLBMs), and long-range bombers.[15] Under the New START treaty, whose strategic-arms limits were to be met by 5 February 2018, Russia and the US are limited to 1550 deployed strategic nuclear warheads. Although many of the entries in the table are approximate, the totals under the New START counting rules are exact. Because the treaty counts bombers as carrying only one warhead each, the actual number of warheads stored on their bases will be greater, as is reflected in the values given for the total stockpile. As indicated, both countries have nonstrategic and reserve warheads. Not shown are warheads in the dismantlement queue numbering about 2500 for Russia and 2600 for the US.

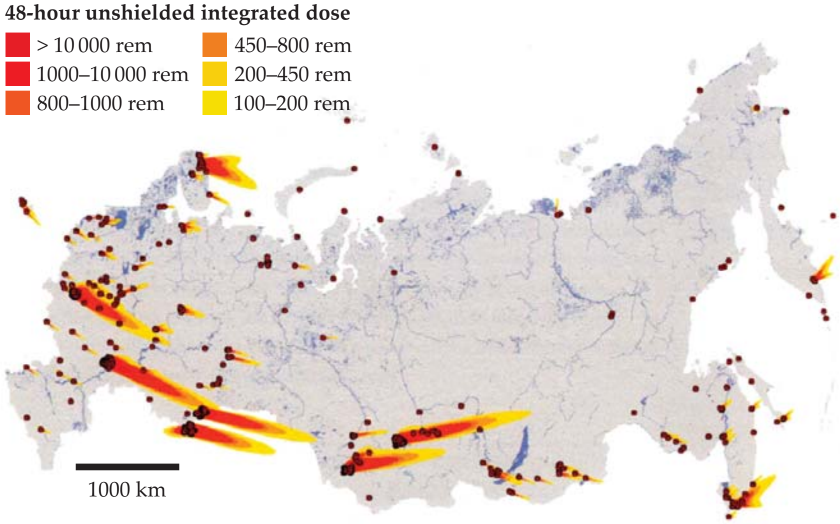

FIGURE 3. FALLOUT PLUMES from a possible US 1289-warhead counterforce attack on Russia's nuclear forces. The largest plumes are from intercontinental-ballistic-missile bases with 30–120 silos each. The largest plumes from the Kola and Kamchatka peninsulas result from attacks on ballistic-missile submarine bases. Smaller plumes throughout the nation are from attacks on mobile missile bases, bomber bases, and nuclear warhead storage facilities. The dots without fallout plumes are from airbursts over nuclear weapons production sites, command headquarters, military radio transmitters, and satellite communications sites; the bursts are assumed to be high enough that their fireballs would not contact the ground and produce local fallout. (Adapted from ref. 7.)

deliver its warheads over the South Pole as well as the North, hypersonic glide vehicles boosted by ICBMs, long-range nuclear-powered cruise missiles and drone submarines, and a medium-range hypersonic cruise missile to penetrate regional defenses.

According to the 2017 DOD report to Congress, *Military and Security Developments Involving the People's Republic of China*, the People's Liberation Army "is developing a range of technologies in an attempt to counter U.S. and other countries' ballistic missile defense systems." (page 60) Those developments include a buildup of long-range warheads able to reach the US and consideration of putting China's nuclear missiles in a launch-on-warning posture.[11]

Comprehensive test-ban treaty

Since the 1950s a ban on nuclear weapons explosive testing has been seen as key to capping the development of new types of nuclear explosives. In 1996 a treaty to ban all nuclear tests was completed, and President Bill Clinton signed it on behalf of the US. At present 166 countries have ratified the Comprehensive Nuclear-Test-Ban Treaty (CTBT), and only North Korea has tested since 1998. That nation's September 2017 test of what could be a two-stage thermonuclear bomb with a yield of more than 100 kilotons illustrates the danger of leaving the testing door open.

The CTBT is still not in force for any country, however, because it must be ratified by all 46 states that possessed nuclear power or research reactors in 1996. Eight of those states—China, Egypt, India, Iran, Israel, Pakistan, North Korea, and the US—have not ratified it. Many policy analysts believe that if the US were to ratify it, most of the other seven could be successfully pressured to do so as well. Ratification in the US Senate requires a two-thirds majority, however, and most Republicans remain opposed to the treaty. The Trump administration has indicated that it has no plans to test but that it will not submit the CTBT for Senate ratification.

The US nuclear weapons labs opted for a well-funded, science-based stockpile stewardship plan as an alternative to testing, and the laboratory directors have certified annually that they are confident in the safety and reliability of the US warheads. (See the article by Victor Reis, Robert Hanrahan, and Kirk Levedahl, PHYSICS TODAY, August 2016, page 46.) In fact, they are now confident enough in their laboratories' computer simulations of the physics of nuclear warhead explosions that, to reduce the risk of a plutonium-dispersal accident, they are proposing to replace the fission triggers, or primaries, in some ballistic-missile warheads with previously tested primaries that have insensitive high explosive. (The primaries in US bomber warheads already have insensitive high explosive.) The US Navy, which, unlike the US Air Force, has never had a plutonium-dispersal accident, takes the position that the upgrade is unnecessary. Some analysts have raised the concern that deploying warheads whose components have never been tested together would create uncertainties that are difficult to resolve without nuclear testing.

The Trump administration's *Nuclear Posture Review* calls for developing a low-yield SLBM warhead to assure adversaries and to reassure allies that the US has nuclear options to deal with every contingency, including a Russian attack with a low-yield warhead that would demand a proportionate response.[1] That path of action would not require the design of a new warhead since current US warheads can be converted to low yield by removing the fission–fusion secondary (the part of a two-stage device that is triggered by the primary). The yield of the fission primary—on the order of 10 kilotons—can be further reduced by removing or disabling the reservoir that injects a mixture of deuterium and tritium gases to boost the fission yield with fusion neutrons. US nuclear bombs and cruise-missile warheads already are of variable yield, and in particular include low-yield options.

It is impossible to verify a zero-yield test ban. In 2012, a National Academies review, *Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty*, acknowledged the concern that other countries could significantly advance their nuclear weapon designs by means of undetectable tests with yields of less than one percent of the power of current warheads. But the review concluded that such a danger is far outweighed by the risk of advances that could be made with higher-yield tests such as those North Korea has carried out since 2006.

Presidential authority and no first use

The Obama administration's 2010 *Nuclear Posture Review* considered, but did not adopt, a policy that the sole purpose of US nuclear weapons is to deter nuclear attack. Currently, the

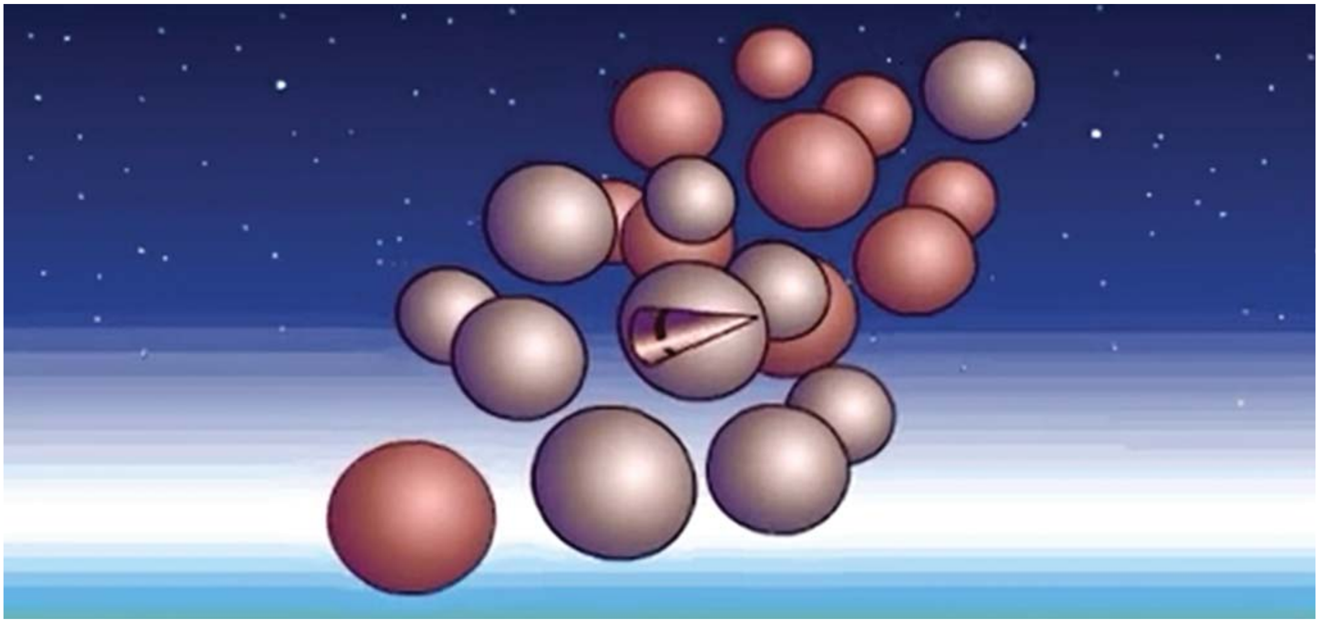

FIGURE 4. ONE POSSIBLE COUNTERMEASURE to the interception of ballistic-missile warheads in space. An aluminized balloon is inflated around a warhead to make it indistinguishable to radar from accompanying decoy balloons. Small, battery-powered heat sources introduced into the decoys make them indistinguishable to IR sensors. (Image from the Union of Concerned Scientists video *Missile Defense Countermeasures*, 2011; see also ref. 16.)

president, as commander in chief, has unchecked authority to order the use of nuclear weapons and can do so even in the absence of a nuclear attack on the US or its allies. The Trump administration has made clear that it believes the option of first use adds to the deterrence of nonnuclear attacks. Russia has had that position since at least 2010. China has a no-first-use policy.

Given the geographical situation and conventional military capabilities of the US, it is hard to imagine an attack on the country other than with nuclear weapons that could threaten its survival too quickly to allow consultation with Congress. But US policy is complicated by formal commitments to defend the other 28 members of NATO plus Japan and South Korea, and its less formal commitments to defend other countries. Some of the countries the US is committed to defend insist that the US must be free to use nuclear weapons in response to a nonnuclear attack. According to the *New York Times*, when Obama was considering the adoption of a no-first-use policy in 2016, "Defense Secretary Ashton B. Carter and Secretary of State John Kerry also expressed concern that new moves by Russia and China, from the Baltic to the South China Sea, made it the wrong time to issue the declaration."[12] Concerns expressed by Japan and South Korea reportedly played a large role in the debate, especially after presidential candidate Donald Trump indicated he might prefer that those two countries develop their own nuclear weapons rather than continue to depend on the US nuclear deterrent.

The worries of some US allies about a no-first-use policy are based on a general belief that nuclear weapons can deter conventional aggression, rather than on specific scenarios in which first use of US nuclear weapons would be necessary to respond to a conventional attack. Our view, however, is that threats of first use lack credibility and are not an effective deterrent because the first use of nuclear weapons would be seen as disproportionate and unnecessary, as US experience in the Korean and Vietnam Wars demonstrated. In addition, opposition to no first use weakens nonproliferation efforts. The US spends four times as much on defense as China and nine times as much as Russia; together, the US and its allies account for more than 70% of global military spending, almost four times the expenditures of all potential adversaries combined. It is difficult to argue that other countries do not need nuclear weapons if the US and its allies say that they must have the option to use nuclear weapons in response to a nonnuclear attack.

Physicists' role

Nuclear weapons policy is made by career government officials who give high priority to the need for a strong deterrent force and to preparedness for fighting a nuclear war should deterrence fail. They do not, unfortunately, give adequate attention to the possibility of a mistaken launch on warning or to perceptions in Russia and China that the US is trying to achieve a first-strike capability through a combination of counterforce and missile defense.

Occasionally, however, the control of the nuclear bureaucracy—at least temporarily—has been broken by public resistance. One instance occurred in the late 1960s, when the US Army proposed deploying nuclear-armed interceptors in suburban neighborhoods. The resulting not-in-my-backyard uprising attracted congressional attention and ultimately forced President Richard Nixon, who had made BMD an important element in his political platform, to scale back the program in the ABM Treaty in exchange for similar limits on the Soviets.

Another revolt erupted in the early 1980s, when defense officials in the Reagan administration warned that the Soviet military thought it could fight and win a nuclear war and that to deter the Soviets the US needed to adopt a similar posture. The resulting public outcry forced the Reagan administration to change its focus to BMD and then to arms control after Mikhail Gorbachev took over leadership of the Soviet Union in 1985 with an urgent desire to end the nuclear arms race.

These days, activism in the US is not focused on nuclear issues. But an underlying anxiety that a reckless president might trigger a nuclear war has created a need for information and analysis on alternatives to the status quo. The physics community has a special relationship to nuclear weapons policy. Physicists invented and refined nuclear weapons and historically have made major contributions to efforts to limit the dangers they pose. We urge concerned physicists to inform themselves and contribute to a new national debate over how to reduce those dangers.

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