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A step toward what? Nuclear weapons, the test ban, and a world without nuclear testing

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ABSTRACT
Historically, nuclear-explosive testing was not required to develop simple, reliable, gun-type nuclear weapons with highly enriched uranium as the chain-reacting material. Testing may now not be required to build basic implosion weapons using plutonium. This suggests that, even if no state had ever conducted a nuclear test, a nuclear-armed world could still have emerged, but probably without thermonuclear weapons. The examples of the United States, Russia, the United Kingdom, France, and Pakistan suggest that, despite the twenty-year-old Comprehensive Nuclear-Test-Ban Treaty (CTBT), nuclear-weapon states with very different testing legacies expect to continue developing, and in some cases deploying, new nuclear weapons. The entry into force of the CTBT might not significantly constrain nuclear-weapons development for any state, and a worthwhile goal now may be to focus on other agreements to restrict nuclear weapon activities, in particular an agreement to ban nuclear weapons.

KEYWORDS
Comprehensive Nuclear-Test-Ban Treaty; nuclear testing; nuclear proliferation; nuclear weapon ban

The first nuclear weapon ever used in war was developed over seventy years ago, without the kind of nuclear-explosive testing that is forbidden under the Comprehensive Nuclear-Test-Ban Treaty (CTBT). This simple historical fact raises the question of what purpose the treaty serves today, since a state wishing to make a nuclear weapon and so become a nuclear-weapon state could at any time repeat this initial achievement and not be in violation of the CTBT, if it is a signatory. To engage with this question, this article takes a sideways look at some key moments in the evolution of nuclear weapons and the role of nuclear testing from the Manhattan Project onward and reflects on the possibility of a nuclear-armed world similar in key respects to the present one but where there had never been a single nuclear test. Looking forward, it reflects on the relevance of the CTBT as a constraint on the capabilities of nuclear-weapon states, since they can now continue to design and build advanced warheads without testing, and what other kinds of constraints on nuclear weapons may now be needed.

The first bomb was a simple gun-type device—built by the United States during the World War II-era Manhattan Project—that relied on firing one piece of highly enriched uranium (HEU) into another to create a supercritical mass that would sustain an explosive chain reaction. Almost all the engineering details, including the size, weight, and shape of the HEU pieces, are now available in the open literature.[1]

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Work on the gun-type design started in April 1943 and was led by Robert Oppenheimer. A technical history of the weapon-design effort in the Manhattan Project suggests that, for the scientists at Los Alamos, "[t]he gun gadget offered a sense of security to the laboratory because of its perceived simplicity … the gun offered scientists an excellent chance to develop an atomic bomb in time to help with the war effort and fulfill the laboratory's mission to build a bomb."[2]

While the possibility of building a simple nuclear weapon by assembling two pieces of HEU at high speed had been understood at least since March 1940, a second fissile material, plutonium, was proposed in 1940 and created in 1941. The Manhattan Project goal was to weaponize both materials. Compared to HEU, plutonium spontaneously emits neutrons at a much higher rate, which means that, in order to reduce the chance of a premature detonation in a plutonium gun-type weapon, the supercritical mass must be assembled more quickly—that is, one piece of plutonium has to be fired at the other at much higher speeds. The design, construction, and testing of a "gun capable of assembling plutonium" was one of Oppenheimer's initial tasks for the weapon-design effort, since he believed that it would be more difficult than "designing a uranium gun [which] would be a straightforward task."[3]

Los Alamos eventually abandoned the plutonium gun (known as "Thin Man") in July 1944, after "fifteen months of intensive effort had gone into the physical design of the plutonium gun's components, into interior ballistics, and the mechanical properties of plutonium."[4] Attention shifted to using an implosion mechanism for a plutonium bomb. Meanwhile, Oppenheimer "streamlined the uranium gun program" (Little Boy), and the weapon designers "completed and tested the uranium gadget design by February 1945" and "by early May, Little Boy was ready for combat."[5]

The weapon designers believed that "the well-established mechanical techniques of the gun made this weapon type almost certain to work if properly designed."[6] Evidence of remarkable confidence in the gun-type bomb working as designed can be found in a report prepared by a distinguished group of Manhattan Project scientists in early June 1945 and intended for Secretary of War Henry Stimson, over a month before the first-ever nuclear test. The group, based in Chicago and led by Nobel Laureate James Franck, noted that "[i]t took us three years, roughly, under forced draft of wartime urgency, to complete the first stage of production of nuclear explosives," and what had been produced until then were of "comparatively low efficiency and small size."[7]

The Franck report proposed that the United States should carry out "a demonstration of the new weapon … before the eyes of representatives of all United Nations, on the desert or a barren island," since the decision to use the only available nuclear weapon, the gun-type bomb, "without warning on an appropriately selected object in Japan," such as a city, would result in "wholesale destruction of civilian life." The proposal further envisaged that "[a]fter such a demonstration the weapon could be used against Japan if a sanction of the United Nations (and of the public opinion at home) could be obtained, perhaps after a preliminary ultimatum to Japan to surrender or at least to evacuate a certain region as an alternative to the total destruction of this target."[8] There is no discussion or expression of concern in the report that the untested gun-type bomb might not work.

Even though the Los Alamos scientists and the Manhattan Project leadership knew that the United States already had a workable nuclear weapon, they proceeded to organize and carry out a nuclear-weapon-test explosion. The test, on July 16, 1945, at a site at

Alamogordo in New Mexico, was a detonation of the implosion device using plutonium as the fissile material. The test confirmed that this second type of bomb, with a more uncertain design, would work. It also showed the physical effects of a nuclear-weapon explosion were generally as described in a March 1940 memorandum by physicists Otto Frisch and Rudolf Peierls, which first laid out the basic physics and challenges of building an atomic weapon from HEU:

> The energy liberated in the explosion of such a super-bomb … will, for an instant, produce a temperature comparable to that in the interior of the sun. The blast from such an explosion would destroy life in a wide area. The size of this area is difficult to estimate, but it will probably cover the center of a big city.
>
> In addition, some part of the energy set free by the bomb goes to produce radioactive substances, and these will emit very powerful and dangerous radiations.
>
> The effects of these radiations is greatest immediately after the explosion, but it decays only gradually and even for days after the explosion any person entering the affected area will be killed. Some of this radioactivity will be carried along with the wind and will spread the contamination; several miles downwind this may kill people … .
>
> Owing to the spread of radioactive substances with the wind, the bomb could probably not be used without killing large numbers of civilians, and this may make it unsuitable as a weapon for use by this country.[9]

The predictions of nuclear-weapon effects on a city and its people were realized when a gun-type HEU bomb destroyed Hiroshima on August 6, 1945. No further demonstration of nuclear weapons was needed to understand their effects. Nonetheless, the United States used its implosion-type plutonium bomb to destroy Nagasaki on August 9, 1945.

What was the need for further nuclear-weapon tests? The answer came within a few months, as the United States Navy sought a series of nuclear-test explosions to "test the ability of ships of present design to withstand the forces generated by the atomic bomb" as a way to counter political arguments that "the fleet is obsolete in the face of this new weapon."[10]

The result was Operation Crossroads, a series of nuclear-weapon tests at Bikini Atoll in the Pacific Ocean in July 1946. It was also a massive public-relations exercise; the tests were announced in advance, witnessed by 38,200 navy personnel, 550 scientists, fifteen members of Congress, twenty-two foreign observers (including some from the Soviet Union and China), and 168 reporters, and were broadcast live on the radio.[11] Norris Bradbury, who had taken over from Oppenheimer as head of Los Alamos in October 1945 and witnessed the Operation Crossroads tests, remarked, "Crossroads told us nothing new about atomic bombs … my major impression being out there was that this was a monumental waste of time and money. However, it gave the Navy something to do."[12]

Herbert York, the first director of the Lawrence Livermore nuclear weapon laboratory noted that, after Operation Crossroads, "[t]he technical situation of those days … was frustrating for the scientists involved. Many of them wanted to get on with new and different designs (as a minimum, different in terms of weight, explosive yield and general dimensions), but the military services were having difficulty imagining what they would do with anything different."[13] This view suggests that the further development of the bomb and nuclear-weapon tests for the United States were, by and large, separate from any real-world military or strategic requirement or from an arms-race dynamics or even action by any actual adversary. As Cornell University's Matthew Evangelista has described:

> In the United States, impetus for innovation in weapon technology comes from the bottom—from scientists in government of private laboratories and the military officials with whom they are in close contact. The new proposal is pushed up through the bureaucracy until it attracts the attention of supporters in the Congress and the Executive. In this respect, a new weapon starts with a technological idea rather than a response to a specific threat or as a means to fulfill a long-standing mission.[14]

Apart from the initial decision to test the plutonium implosion-device despite the availability of a reliable gun-type HEU bomb, and the decisions to demonstrate each of these types of weapon in actual combat by destroying cities, the decisive moment for nuclear testing came in 1949, after the Soviet Union carried out its first test explosion. This was an implosion-type plutonium bomb just like the first US test and the weapon used on Nagasaki. The Soviet device relied to some degree on technical material secretly provided by Klaus Fuchs, a Manhattan Project scientist who had joined Los Alamos in August 1944 and worked on the implosion mechanism.

In June 1945, Fuchs passed on to Soviet agents what has been described as a "package of documents, which fully described the plutonium bomb that was to be tested at Alamogordo and the one to be dropped at Nagasaki, including their components and important dimensions."[15] The information from Fuchs may have enabled the Soviet Union to prioritize an implosion-type plutonium weapon, but the Soviet Union also went ahead and tested an HEU weapon in 1951. As Stanford University's David Holloway has observed, "even if the Soviet physicists had not been able to devise the implosion method for plutonium, they would have been able to build a gun-assembly uranium-235 bomb by 1951."[16]

A decision by the United States not to build atomic weapons using plutonium, since simple reliable weapons using HEU were available, would have meant there was no need for the first nuclear-weapon-test explosion. Even if other countries had followed the United States in developing nuclear weapons, it is possible to imagine that these countries, too, could have chosen to develop only HEU weapons and not chosen to test them. In 2002, a study by a committee of the US National Academy of Sciences concluded, "For any nation with a modest technical competence, laboratory measurements would suffice for … a uranium-235 gun design, together with firing the gun with a dummy projectile."[17]

A clear example of a state choosing the nuclear-weapons path based on an untested HEU gun-type weapon is South Africa, which built six HEU gun-type weapons, all of which were later dismantled.[18] South Africa completing its first of six nuclear weapons in 1979 and the last in 1989. (There was enough HEU for a seventh weapon but it was never built.) They used computer codes to design the weapons, tests to understand the internal ballistics of the gun, scale-model experiments, and detonation and flight testing using natural uranium instead of HEU (thus creating no chain reaction and having no nuclear yield). They were significantly smaller and lighter than the bomb the United States used against Hiroshima.[19]

Increases in computational power, greater understanding of nuclear processes, and improved instruments for monitoring fast-implosion processes have given weapon designers the capability to make implosion-type weapons using plutonium, without testing. The US National Academy of Sciences committee determined in 2002 that progress in science and technology since the 1940s meant that "with no nuclear testing at all it would be possible for would-be proliferant states to develop U-235 gun-type and simple plutonium or U-235 implosion weapons in which they could have reasonable confidence."[20] The committee further noted that, without testing, a state could go far beyond the Nagasaki weapon and build, albeit "with somewhat less confidence," a much lighter plutonium weapon—one comparable to the Mark-7 tactical nuclear bomb the United States deployed in large numbers starting in the early 1950s, which was carried by a fighter aircraft rather than a large bomber.[21] The Mark-7 was tested in the 1951 Operation Buster-Jangle test series, prior to which the United States had already carried out fourteen nuclear tests (excluding the test in 1945 or the explosions at Hiroshima and Nagasaki).

These judgements suggest that it is possible to imagine a world with a number of nuclear-weapon states, perhaps even the same nuclear-weapon states as today, and thousands of nuclear warheads in the global stockpile, using HEU or plutonium (or both) as the fissile material, without there ever having been a single nuclear test. Seen in this light, nuclear testing served to speed up the process for some states to develop and deploy their nuclear weapons, allowed weapons to be smaller and lighter, and perhaps gave added confidence in these weapons performing as intended and greater insight into nuclear-weapon effects. Nuclear testing was not necessary, however, and may not be a useful marker of becoming a nuclear-weapon state.[22]

"Mankind would be far better off not to have a demonstration of the feasibility of such a weapon"

Nuclear testing was critically important in the development of thermonuclear weapons (hydrogen bombs). These weapons use a fission explosion to drive an even more energetic nuclear-fusion reaction, which in turn can be used to produce more fissions. Modern thermonuclear weapons generally contain about 3–4 kilograms of plutonium in the fission primary and 15–25 kilograms of HEU in the fusion-fission secondary, with perhaps half the total yield from the secondary coming from fission.[23] Here, too, however, history suggests another path was possible, one that could have avoided nuclear testing.

In response to the Soviet Union's first nuclear test in August 1949, the United States asked the Atomic Energy Commission's General Advisory Committee (a group of leading scientists from major US World War II programs, led by Oppenheimer) to recommend if a new and much more powerful kind of nuclear weapon, a thermonuclear bomb, could be built and whether the United States should seek to do so. The October 1949 secret report of the General Advisory Committee said a thermonuclear weapon was possible with a "better than even chance of producing the weapon within five years" and noted that "many tests may be required before a workable model has been evolved," but "no member of the committee was willing to endorse this proposal."[24]

The scientists on the General Advisory Committee were opposed to going forward with the development of thermonuclear weapons, because "there is no limit to the explosive power of the bomb … the use of this weapon would bring about the destruction of innumerable human lives … [and] carries much further than the atomic bomb itself the policy of exterminating civilian populations."[25] Some members of committee went further, arguing that since "a super bomb might become a weapon of genocide," such a weapon should not even be tested: "Mankind would be far better off not to have a demonstration of the feasibility of such a weapon."[26] All seem to have agreed that, even if the Soviet Union built thermonuclear weapons, the United States should not follow suit, since its existing nuclear arsenal represented an adequate threat of catastrophic retaliation.

A decision by the United States to follow the advice of the General Advisory Committee and reject thermonuclear weapons would have eliminated a major impulse for the many decades of US testing that followed. It is reasonable to assume that other states with nuclear-weapon ambitions may have followed suit. Indeed, a post-Cold War insider account of the Soviet thermonuclear-weapons program indicates how thermonuclear-weapon testing by the United States played an important role in motivating and driving forward Soviet thermonuclear-weapon development efforts.[27] This supports the assessment by Evangelista that, in the Soviet Union, "impetus for an innovation in weapons technology is more likely to come from the top, as a response to technological developments abroad, than to emerge unsolicited from the weapon labs and military bureaucracies."[28]

A decision not to pursue thermonuclear weapons could also have taken away the impulse for a test-ban treaty. It was US thermonuclear-weapon testing, particularly the March 1954 test that contaminated the crew of the Japanese fishing vessel, *Lucky Dragon*, that led Indian Prime Minister Jawaharlal Nehru in April 1954 to appeal for "some sort of what may be called a standstill agreement in respect of at least these actual explosions even if arrangements about the discontinuance of production and stockpiling must await more substantial agreement amongst those principally concerned;" in other words, a halt to all nuclear testing pending an agreement to ban nuclear weapons.[29] This wish eventually has come close to being fulfilled, but its effects have not been as hoped.

The advice of the General Advisory Committee was rejected, however. As the scientists had warned, developing and making thermonuclear weapons took a lot of testing. The testing started in 1951. Tests were needed to explore the range of what was possible by way of weapon designs and effects and to reduce the amounts of fissile materials used in the weapons (thus making possible a larger number of weapons from a given amount of material). Tests also aimed to develop and certify different types, sizes, weights, and yields of weapons to meet the demand that a variety of delivery systems be able to carry these weapons.[30] The United States eventually carried out a total of 1,026 nuclear tests (and an additional twenty-eight tests jointly with the United Kingdom), of which 890 were related to weapon design and development.[31]

Along with the decades of testing came the extended debates within and between nuclear-weapon states regarding testing moratoria and international negotiations about banning nuclear tests. Initial calls for a comprehensive test-ban resulted, at first, with the 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water. Calls for a comprehensive ban continued, however, and in 1976, the Soviet Union presented a draft treaty. Soon afterward, in January 1977, newly elected US President Jimmy Carter agreed with the goal of a ban on all testing.[32] Herbert York, the lead US negotiator at the subsequent talks in 1979–80, explained that "[b]y the time

I became the chief negotiator, in January 1979, virtually all the general agreements needed to complete the treaty had been worked out, but only about half the details. Persons with more experience than I thought we should be able to finish the whole process in six more months if we had sufficient 'political will' in back of us. I agreed with that estimate."[33] They failed, in York's judgment, because of internal opposition from the US nuclear-weapon complex, since "most of the military, including the Joint Chiefs of Staff and, essentially, the entire permanent civilian nuclear staff, opposed it openly and strongly."[34]

According to York, the key arguments used by the opponents of a comprehensive test-ban in the late 1970s were that:

> occasional full-scale nuclear tests would be necessary in order to assure that old weapons still worked. Even rebuilt weapons … would have to be subjected to full-scale tests to assure performance … [and] we needed to continue testing in order to build safer and more secure bombs, to develop bombs properly optimized for new delivery systems, and to learn more about weapon effects. Perhaps more important, continued testing was said to be needed in order to preserve a cadre of weapons design experts at the laboratories.[35]

A common feature in the arguments used by test-ban opponents is that nuclear weapons are their own justification, and there was no prospect or vision of a possible world without nuclear weapons or weapons testing or nuclear-weapon designers. More than three decades and a negotiated CTBT later, some of these arguments persist. A key concern may be that nuclear-weapon states fear the withering of nuclear-weapon expertise and thus the weapons themselves through the loss of tacit knowledge that may come only from direct involvement in the weapons' design, development, and testing.[36]

Nuclear weapons forever — without testing

The declared rationale of the CTBT is that "the cessation of all nuclear weapon test explosions and all other nuclear explosions, by constraining the development and qualitative improvement of nuclear weapons and ending the development of advanced new types of nuclear weapons, constitutes an effective measure of nuclear disarmament and nonproliferation in all its aspects."[37] However, according to the official US interpretation of the CTBT, this "does not imply that the Treaty prohibits the development of new types of nuclear weapons, or the improvement of existing weapons."[38]

The United States does not appear to be alone among the nuclear-weapon states in this judgment about the CTBT, but it has been the most transparent about its commitment to sustain the capability to design and deploy new nuclear warheads without nuclear testing. The most recent expression of this commitment was the 2016 National Defense Authorization Act signed by President Barack Obama on November 25, 2015. In Section 4220 (the "Stockpile Responsiveness Program"), this law offers a "Statement of Policy:"

> It is the policy of the United States to identify, sustain, enhance, integrate, and continually exercise all capabilities required to conceptualize, study, design, develop, engineer, certify, produce, and deploy nuclear weapons to ensure the nuclear deterrent of the United States remains safe, secure, reliable, credible, and responsive.[39]

To meet this policy goal, the law requires the secretary of energy and the secretary of defense to manage a "stockpile responsiveness program, along with the stockpile stewardship program … and the stockpile management program … to identify, sustain, enhance, integrate, and continually exercise all capabilities required to conceptualize, study, design, develop, engineer, certify, produce, and deploy nuclear weapons."[40]

The declared objectives of this program are to:

(1) Identify, sustain, enhance, integrate, and continually exercise all of the capabilities, infrastructure, tools, and technologies across the science, engineering, design, certification, and manufacturing cycle required to carry out all phases of the joint nuclear weapons life cycle process …
(2) Identify, enhance, and transfer knowledge, skills, and direct experience with respect to all phases of the joint nuclear weapons life cycle process from one generation of nuclear weapon designers and engineers to the following generation.
(3) Periodically demonstrate stockpile responsiveness throughout the range of capabilities required, including prototypes, flight testing, and development of plans for certification without the need for nuclear-explosive testing.
(4) Shorten design, certification, and manufacturing cycles and timelines to minimize the amount of time and costs leading to an engineering prototype and production.[41]

The policy puts in place an obligation and program (as yet apparently unfunded) of designing, developing, prototype building, flight testing, and certifying new nuclear-warhead designs as quickly and cheaply as possible, which is to continue seemingly indefinitely across generations of nuclear-weapon designers and engineers, all without nuclear testing. It is a commitment to the goal of maintaining nuclear weapons forever, if required.

At the same time, there is demand from supporters of the US nuclear-weapons complex for new types of weapons. John S. Foster Jr., a former director of Lawrence Livermore National Laboratory, reportedly argued in 2014 that

> the labs should design, develop and build prototype weapons that may be needed by the military in the future, including a very low-yield nuclear weapon that could be used with precision delivery systems, an electromagnetic pulse weapon that could destroy an enemy's communications systems and a penetrating weapon to destroy deeply buried targets.[42]

Russia seems to have adopted a similar policy. Rady I. Ilkaev, the scientific director of one of two Russian nuclear-weapon-design laboratories, the Russian Federal Nuclear Center, VNIIEF, (All-Russian Scientific Research Institute of Experimental Physics in Sarov, formerly Arzamas-16) explained that

> The current main areas of nuclear weapons activities in Russia include … The creation of new types of nuclear warheads required for new nuclear weapons capabilities … [and] the development of nuclear warheads with increased effectiveness based on the achievements of computational technology, microelectronics, and micromechanics … [and] the preservation and further development of key technologies for nuclear weapons design and production.[43]

According to Ilkaev, to sustain the means to develop these "new types of nuclear warheads required for new nuclear weapons capabilities," Russia is focused on new technologies and training a new generation of weapon scientists. He reports that Russia's "national program to support nuclear weapons development and reliability comprises two areas: promoting the technologies to maintain, upgrade and certify nuclear warheads and promoting nuclear and thermonuclear weapons science."[44]

It is not just the former superpowers (who between them conducted over 1,700 tests) that seek to continue to develop and prepare to deploy nuclear weapons without testing. In 2013, the United Kingdom released its official *Trident Alternatives Review*, which explained how long it might take to produce various kinds of new nuclear warheads and make them ready for deployment. The study reported that

> it is likely to take 17 years to design, develop, certify and produce a ballistic missile-based thermonuclear warhead, should one be required. This is based on AWE [Atomic Weapons Establishment] taking a relatively well-understood concept through to the production of the first fully-certified warhead, with collaboration with the US on the non-nuclear components. Without live nuclear testing, the programme relies heavily on computer-based modelling and extensive hydrodynamic trials.[45]

The United Kingdom also looked at alternatives that did not build on the existing submarine-launched ballistic-missile (SLBM) warhead design. The *Trident Alternatives Review* reported that "starting promptly in 2016, an initial warhead capability integrated into a cruise missile might be delivered (with some risk) by about 2040, a timescale of 24 years."[46] The report observed that, if required, a much faster schedule was possible for a new ballistic missile warhead or a new cruise missile warhead, noting that "an accelerated warhead programme might be possible but it would come at high risk and would need to be driven as a UK national imperative."[47] It appears this effort may now go forward, following the July 18, 2016, decision by the UK parliament to build the replacement for the current Trident nuclear SLBM system.[48]

France, too, has been working on a new warhead that is entering deployment. Its current SLBM warhead, the TN75, was tested as part of France's series of nuclear tests in 1995–96, just before the CTBT was finalized. It is reported that, since then, France has developed a new warhead, the *Tête Nucléaire Océanique* (TNO), that is to be deployed in 2016 on the new M51.2 SLBM.[49] The new warhead apparently has "improved reliability and a longer life-span."[50] Perhaps more important, the nuclear-weapon complex says the *Tête Nucléaire Aéroportée* warhead, which has replaced the TN-81 warhead for the French air-launched nuclear cruise missile, is "the first nuclear warhead in the world for which its safety and reliability were demonstrated through simulation [and laboratory testing]."[51]

Even Pakistan, a state with a declared nuclear-weapon-testing history that so far includes only six tests over a two-day period in May 1998, now claims to be able to field new types of weapons. According to a semi-official history of Pakistan's nuclear program, on May 28, 1998, Pakistan conducted "five tests of boosted fission HEU devices … [where] the main device produced thirty to thirty-five kt [kilotons], and the remaining four were designed as low-yield weapons," for "a total yield of forty kt," and on May 30, 1998, tested an "eighteen to twenty kt" weapon that "was meant for Pakistan's ballistic missiles and aircraft."[52] These nuclear tests came after extended "cold tests" (without fissile material); HEU implosion design started in 1983, deliverable bomb design started in 1988, and in 1995, the Pakistani Air Force determined that this untested bomb could be dropped from an F-16 fighter.[53] Had India not tested nuclear weapons in early May 1998, it is possible to imagine that Pakistan might not have tested nuclear weapons at all, given that a combat-ready weapon was already available.

Since then, Pakistan has deployed ballistic missiles of various ranges, but it also has tested and deployed ground-launched and air-launched cruise missiles and a short (60-kilometer) battlefield nuclear-capable missile system, and expanded its infrastructure for production of plutonium for weapons.[54] The development history of the cruise-missile warheads is unknown, but it has been noted that the cruise missiles "are both much slimmer than Pakistan's ballistic missiles, suggesting some success with warhead miniaturization based on plutonium instead of uranium."[55] Furthermore, in March 2015, General Khalid Kidwai, the founder and former head of Pakistan's Strategic Plans Division, which manages the nuclear-weapon program and arsenal, said that Pakistan had recently "opted to develop a variety of short range, low yield nuclear weapons, also dubbed tactical nuclear weapons."[56] It is hard to imagine that these warheads have the same low-yield nuclear explosives tested in 1998 since, at the time, the delivery systems had not yet been developed. This does suggest, however, that Pakistan has confidence in its capability to develop new warheads that are possibly significant modifications of previously tested designs.

Two decades after the CTBT, it appears that nuclear-weapon states—either with extensive testing experience (like the United States) or very limited (like Pakistan)—believe they can continue designing and developing weapons without testing, as they anticipated when they agreed to the treaty. To some degree, nuclear-weapon design and development have become a form of technological shadow-boxing, a perpetual training exercise intended to maintain weapon capabilities and weapon designers for an indefinite and uncertain future, disconnected from any actual stated requirements or clearly perceived adversaries.

Is a CTBT still important?

Nuclear weapons were built and used without a test. From the beginning, tests have been driven by the search for plutonium-based weapons; reductions in the amounts of fissile materials used in both plutonium and HEU weapons; the effort to make smaller-sized, lower-mass, and higher-yield weapons; and most importantly, compact thermonuclear weapons. It is possible to imagine a world where no state had ever tested, but in which there were still nuclear-armed states, albeit not with thermonuclear weapons, and in which no one had ever proposed a CTBT.

Reconstituting nuclear weapons in a nuclear-weapon-free world would not be challenging and could be done rapidly, if fissile materials were available. The Committee on International Security and Arms Control of the US National Academy of Sciences in 1997 assessed:

> If all nuclear warheads were eliminated, the current nuclear-weapon states, and probably a dozen or more other countries, could in a national emergency produce a dozen simple fission weapons in as little as a few months, even if no effort had been made to maintain this capability. On the other hand, the production of a hundred lightweight thermonuclear bombs or warheads equipped with modern safety and security devices might take several

> years, even if special efforts had been made to maintain the capability to produce such weapons.[57]

Given this assessment of the nuclear past and assessment of possible futures, if states seeking their first nuclear weapon can build and deploy simple but relatively reliable warheads without testing, while established nuclear-weapon states can continue to design and build with varying degrees of confidence new kinds of advanced warheads also without testing, it is reasonable to ask what purpose is served by the CTBT. Negotiating the CTBT was a long and difficult process, arguably one that took over forty years to come to fruition. During this time, through many UN resolutions, policy initiatives and statements, technical studies, and determined citizen-led activism, the goal of a comprehensive test-ban came to represent the first agreed milestone on an uncertain path toward the elimination of nuclear weapons. Early efforts failed, and it was not clear the eventual negotiations that led to a CTBT would in fact start as planned in 1993. An insider account of the talks describes how in 1993, when Ambassador Yoshitomo Tanaka of Japan announced the decision to start the CTBT talks in the UN Conference on Disarmament in Geneva, "silence descended on the chamber as delegations anxiously waited to hear if anyone dared to object as the gavel fell upon the stone."[58]

The CTBT talks have been described as an intense and extended political and diplomatic exercise involving a "whirlwind of open meetings, closed meetings, intersessional meetings, bilateral and multilateral consultations, informal open-ended consultations, working papers, Chairman's papers, Friend of the Chair papers, national papers and 'non-papers' which was to continue night and day for almost three years."[59] The final outcome of the talks remained uncertain to the very end, and in fact the Conference on Disarmament's Ad Hoc Committee on a Nuclear Test Ban was not able to reach the required consensus on a treaty text, with India and Iran objecting. Eventually, Australia submitted it to the United Nations General Assembly, and on September 24, 1996, it opened for signature.

The demands for the treaty, the actual negotiations, the compromises involved in reaching agreement, and the efforts to obtain states' signatures mobilized officials, political leaders, experts, and publics around the world to engage with each other in an intense and important collective exercise to overcome self-interested nuclear establishments and address the threat of nuclear weapons.[60] The continuing failure after twenty years to bring the CTBT into force compromises the long-held foundational premise that a cooperative multinational negotiation process is the path to nuclear disarmament.

It has long been hoped that the CTBT would be followed by a treaty to ban the production of fissile materials for nuclear weapons, a Fissile Material (Cut-off) Treaty (FMCT). Twenty years of efforts to begin negotiations on such treaty at the Conference on Disarmament have failed, due, at least for the past decade, to Pakistani intransigence, which has been blocking the consensus required to begin talks.[61] Addressing global stockpiles of fissile material, with a view to reducing and eliminating them and ending their production and use for all purposes, would be a more significant constraint on the development and reconstitution of nuclear weapons than the ban on nuclear testing.[62] With the CTBT's entry into force stalled and the FMCT blocked at the starting gate, the prospects for progress on nuclear disarmament begin to look bleak.

A case can be made that the long-established bilateral US-Russian arms-control process has been unravelling following the 2002 withdrawal of the United States from the 1972 Anti-Ballistic Missile Treaty and signs that Russia may be violating and seek to withdraw from the 1987 Intermediate-range Nuclear Forces Treaty.[63] Seen in this light, the step-by-step approach to arms control that has been championed by the nuclear-weapon states, especially the United States, as a slow, steady, and necessary path to disarmament seems more like a random walk, where a step forward may be followed by a long period of standing still and then a step sideways and sometimes a step or two backward. Progress is inadvertent at best, and often transient, more akin to stumbling blindly than the certain passage to a clear destination.

A new focus of the international nuclear-disarmament effort is to begin talks on a treaty to ban nuclear weapons. This has emerged from the humanitarian impact of nuclear weapons campaign that has taken shape over the past two decades, following the 1996 Advisory Opinion by the International Court of Justice, the highest court in the UN system, that "the threat or use of nuclear weapons would generally be contrary to the rules of international law applicable in armed conflict, and in particular the principles and rules of humanitarian law."[64] In December 2015 at the United Nations, 139 countries endorsed the Humanitarian Pledge for the prohibition and elimination of nuclear weapons in a resolution that "calls upon all States to identify and pursue effective measures to fill the legal gap for the prohibition and elimination of nuclear weapons and to cooperate with all stakeholders to achieve this goal."[65]

In October 2016, the UN General Assembly First Committee voted "to convene in 2017 a United Nations conference to negotiate a legally binding instrument to prohibit nuclear weapons, leading towards their total elimination."[66] On October 27, 2016, this resolution was passed with 123 votes for, thirty-eight against, and sixteen abstentions.[67] Stakeholders in the struggle to ban nuclear weapons—be they leaders, officials, or publics, and the broader international community—would see their goal as more achievable if the last great effort to achieve a global nuclear-arms-control treaty, the CTBT, were in force.

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