Protecting the global nuclear test moratorium

Frank von Hippel, 25 August 2023*

The US has not carried out a nuclear test for three decades (since 1992). Of the nine nuclear-armed states, only North Korea has carried out nuclear tests in the last quarter century (since 1998). North Korea's last test was in 2017, and, in 2018, it announced it would no longer test and partially destroyed its test site. Since 2017 therefore, after more than 2000 nuclear tests over 72 years, there has been a global moratorium on nuclear testing. The development by the less advanced nuclear-armed states of higher-yield, more-compact nuclear weapons has stopped as has the primitive message of threat that the tests sent.

During the Trump Administration, some US opponents of nuclear arms control initiated efforts to end the US testing moratorium:

- In March 2019, four Republican Senate members reportedly sent a letter to President Trump urging him to "unsign" the United States from the CTBT, which would free the US to test.
- In June 2019, the Trump Administration accused Russia of carrying out supercritical tests with a tiny amount of fission yield.
- In mid-May 2020, the Trump Administration's National Security Council reportedly discussed the possibility of a test. The rationale was that "a 'rapid test' could prove useful from a negotiating standpoint as the Trump Administration [was seeking] a trilateral deal to regulate the arsenals of the biggest nuclear powers," i.e. Russia and China. Instead of agreeing with Russia to a five-year extension of the expiring New START agreement, which limits Russian and US deployed strategic ballistic-missile warheads and nuclear bombers, the Trump Administration was insisting that China join Russia and the United States in a new agreement in less than a year, and China was declining.
- In July 2020, John Bolton revealed that the National Security Council had been discussing the possibility of the US testing during his entire 1.5-year tenure as the Trump Administration's National Security Advisor but that the National Nuclear Security Administration saw no need and his priority was, in any case, to get the US out of the treaty limiting intermediate-range land-based nuclear missiles.
- The test moratorium is anchored by the Comprehensive Test Ban Treaty (CTBT), which has been signed by 186 out of the world's 196 countries and ratified by 178. The CTBT has not come into force, however, due to its requirement that 44 specified countries ratify. Of these, eight, including the United States, have not ratified. It is likely that, if the US did ratify, most of the other seven (China, Egypt, India, Iran, Israel North Korea, and Pakistan) would as well.

In the US, treaty ratification requires a positive vote of two thirds of the Senate, however, and, due to Republican opposition, this has proven impossible. A ratification vote in 1999, when the Senate was under Republican control, did not even obtain a majority.

If the US tested, it is quite possible that the test moratorium would collapse. Nuclear-weapon establishments in countries with much less complete weapon-development agendas than the U.S. would press for tests. Specifically, India, Pakistan, and North Korea, with only six tests apiece

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versus the approximately 1000 each that the US and Russia carried out during their Cold War, may wish to complete their development of thermonuclear weapons. The Chinese and Russian nuclear-weapons laboratories – much less lavishly funded than those of the US – might want to do some tests to resolve any doubts they have about the reliability of their nuclear weapons. The United Kingdom, which used the US test site between 1962 and 1991, actually had a test in final preparation when Congress imposed the current moratorium.

A collapse of the test moratorium – especially if caused by the US – would further undermine the nonproliferation regime. There is a special connection between the Comprehensive Test Ban and the Nonproliferation Treaty. In 1995, the five nuclear-weapon state parties to the NPT, led by the U.S., committed to complete negotiations on a CTBT in 1996 as part of a deal with the non-weapon state parties to the Nonproliferation Treaty (NPT), which agreed in exchange to extend indefinitely their commitments not to acquire nuclear weapons. The P5 were unable to bring the CTBT into force but they did deliver a moratorium. If that collapses, some nonweapon states that no longer feel adequately protected from their more powerful neighbors by an increasingly unreliable United States, might feel tempted to acquire their own nuclear deterrents.

The National Nuclear Security Administration, which produces and maintains U.S. nuclear warheads stated, in its Fiscal Year 2020 report to Congress on its nuclear-warhead stockpile stewardship and management plan (p.3-26), "NNSA assumes that a test would be conducted only when the President has declared a national emergency or other similar contingency." In that case and, assuming the suspension of some health and safety regulations, NNSA adds that it could conduct an instrumented test to resolve an issue with the stockpile within 24-36 months. NNSA stated in a 2011 report to Congress on nuclear test readiness (p. iii), "a very simple test for political purposes could be conducted in as little as 6-10 months."

The discussion that follows provides additional background on:

- The history of the CTBT and the testing moratorium,
- The annual review President Clinton committed to and Congress subsequently required by law to determine the level of confidence that all U.S. warheads remain safe and reliable without testing,
- The "science-based stockpile stewardship program on which assessments of the continuing reliability of the US warhead stockpile are based,
- Allegations of Russian cheating, and
- Arguments that have been made against the CTBT based on concerns about the safety and long-term reliability of current US warheads and about the verifiability of the treaty.

The long campaign to end nuclear testing

The worldwide campaign against nuclear testing was triggered in March 1954 when a Japanese fishing vessel, *Lucky Dragon No. 5*, was caught in the fallout from the 15-megaton US Castle-Bravo nuclear test on Bikini atoll. When the boat returned to port two weeks later, seven members were were hospitalized and one died of radiation sickness. The world woke up to the fact that U.S. and Russian multimegaton tests in the atmosphere were injecting huge quantities of radioactive fission products into the stratosphere and that the resulting global "fallout" was contaminating the food chain.

In 1958, responding to the resulting public concerns, Nikita Khrushchev, First Secretary of the Soviet Communist Party, initiated a testing moratorium that the US and UK joined after five months and which lasted for three years. In 1963, after the fright of the 1962 Cuban missile crisis, the three countries agreed to the Limited Test Ban Treaty, which requires all testing to be conducted underground. France and China did not join the treaty but, since 1980, no country has tested in the atmosphere.

A Comprehensive Test Ban Treaty (CTBT) was not achieved in 1963 in part because of a factor of two difference between the number of annual on-site inspections of suspicious seismic events the US insisted upon and the number the Soviet Union – worried about US spying – was willing to allow.

The Limited Test Ban dealt with public concern about radioactive fallout and thereby reduced public pressure for a CTBT, which was still sought, however, by those concerned about the dangers from the continued development of new types of nuclear weapons.

The major development that occurred subsequent to the Limited Test Ban was of compact thermonuclear warheads with yields equivalent to the explosion of hundreds of thousands of chemical explosive but small enough to make possible nuclear-armed cruise missiles that could be launched out of submarine torpedo tubes and the mounting of up to ten independently targetable reentry vehicles on strategic-range ballistic missiles.

In 1985 and 1986, General Secretary of the Soviet Communist Party Mikhail Gorbachev initiated a second Soviet unilateral test moratorium and demonstrated a new Soviet openness to in-country verification by allowing a US NGO, the Natural Resources Defense Council to establish seismic stations around the Soviet test site in Kazakhstan. The following year, the U.S. and Soviet Union agreed to reciprocal on-site calibrations of the seismic signals from the US and Soviet test sites in order to bring into force the 1974 bilateral Threshold Test Ban Treaty. (The TTBT limits Russian and U.S. nuclear tests to less that 150 kilotons yield.)

These displays of Soviet "glasnost" (openness) and the early 1980s massive grassroots US Nuclear Freeze movement revived US Congressional interest in a CTBT.

In 1992, Congress mandated an end to US nuclear testing as of the end of September 1996 on the condition that other countries would stop their testing as well. The Congressional amendment permitted up to 15 tests before the deadline to deal with reliability and safety issues but the Clinton Administration concluded that no additional tests were required.

From 1994 to 1996, the CTBT was negotiated at the UN's Conference on Disarmament in Geneva and was opened for signature at the UN in September 1996.

Of the 44 states listed in Annex 2 of the CTBT whose ratifications are required for the treaty to come into force, however, three (India, Pakistan and North Korea) have not signed and five (China, Egypt, Iran, Israel, and the United States) have signed but not ratified. Of the nine nuclear-armed states, three (France, Russia and the United Kingdom) have ratified. China is believed to be unwilling to ratify before the US does – perhaps because of the conditions the US Senate imposed in 1997 as its price for ratifying the Chemical Weapons Convention after China ratified. Israel is probably waiting for the US to sign as well. The two nonweapon states that have not ratified are Egypt and Iran. Ratification by Israel, the only nuclear-armed state in the Middle East, might persuade them to ratify. It is possible that India might ratify if China did and

Pakistan might ratify if India did. If the other countries did, it is likely that North Korea would as well.

U.S. ratification therefore would be a major breakthrough in bringing the CTBT into force. The constitutionally required two thirds majority Senate vote for ratification of a treaty appears out of reach, however, as long as the dominant voices in the Republican party oppose any treaty constraints on US nuclear weapons.

In the near term, therefore, the preservation of the testing moratorium must be the focus of arms control advocates. Fortunately, the US Science-based Stockpile Stewardship Program (SSSP) has developed significant credibility as an alternative to testing for maintaining confidence that US nuclear warheads remain safe and reliable without testing.

Annual review to determine whether a test is required

When President Clinton submitted the CTBT for Senate ratification in 1997, he included a list of safeguards to deal with Congressional concerns about the continuing safety and reliability of the US nuclear-warhead stockpile in the absence of testing:

A. "The conduct of a Science Based Stockpile Stewardship Program to ensure a high level of confidence in the safety and reliability of nuclear weapons in the active stockpile, including the conduct of a broad range of effective and continuing experimental programs.

B. "The maintenance of modern nuclear laboratory facilities and programs in theoretical and exploratory nuclear technology which will attract, retain, and ensure the continued application of our human scientific resources to those programs on which continued progress in nuclear technology depends.

C. "The maintenance of the basic capability to resume nuclear test activities prohibited by the CTBT should the United States cease to be bound to adhere to this treaty.

D. "Continuation of a comprehensive research and development program to improve our treaty monitoring capabilities and operations.

E. "The understanding that if the President of the United States is informed by the Secretary of Defense and the Secretary of Energy (DOE) – advised by the Nuclear Weapons Council, the Directors of DOE's nuclear weapons laboratories and the Commander of the U.S. Strategic Command – that a high level of confidence in the safety or reliability of a nuclear weapon type which the two Secretaries consider to be critical to our nuclear deterrent could no longer be certified, the President, in consultation with Congress, *would be prepared to withdraw from the CTBT under the standard 'supreme national interests' clause in order to conduct whatever testing might be required*." [emphasis added]

In 2002, Safeguard E. was turned into law via Section 3141 of the Defense Authorization for Fiscal Year 2003. Under this law, the directors of the three NNSA weapon labs – Livermore, Los Alamos, and Sandia – and the commander of US Strategic Command annually lead parallel elaborate assessments – including by "red teams" of sceptics – of the "safety, reliability, performance, or military effectiveness" of each warhead type, resulting in reports to Congress via the secretaries of Defense and Energy and the president, and recommendations as to whether any nuclear tests are required. In 2007, Congress' Governmentability Accountability Office reviewed the process and the assessments submitted in 2005 and 2006.

To date, this annual review has not found any nuclear test to be necessary.

The Science-based Stockpile Stewardship Program

The US nuclear testing moratorium since 1992 has been sustained in part by a deal made between the Clinton Administration and the three nuclear-weapons laboratories: Lawrence Livermore National Laboratory in California (LLNL), Los Alamos National Laboratory in New Mexico (LANL), and Sandia National Laboratories (SNL) which has branches in both states.

In exchange for not testing, the laboratories have been generously funded through the National Nuclear Security Administration's (NNSA) Science-based Stockpile Stewardship Program,which supports experimental and theoretical work to deepen the nuclear laboratories' understanding of the physics of nuclear weapon explosions and maintains and refurbishes the weapons regularly, including remanufacture or replacement of components. Despite concerns expressed by some weapon scientists that there is no substitute for actual testing, this program has received bipartisan and steady support. In Fiscal Year 2023, the NNSA received $17 billion for "nuclear weapons activities" of which $3 billion went to the weapons laboratories for "stockpile research, development and engineering." The total budgets of the weapons laboratories were: LLNL ($2.3 billion, LANL ($4.5 billion) and SNL ($3.0 billion).

Accusations of Russian cheating

In 2020, the U.S. State Department accused Russia, which, unlike the U.S., has ratified the CTBT, of conducting "supercritical nuclear weapons tests since renewing its nuclear explosive testing moratorium in 1996 [and has thereby] demonstrated a failure to adhere to the zero-yield standard, which would prohibit supercritical nuclear tests." The tests in question were apparently such low yield that they did not rupture transportable containment vessels, i.e. equivalent to less than one tenth of a ton of chemical explosives. Such low yield tests, carried out underground, could not be detected from beyond national borders. Some other type of intelligence information must have been involved.

In the past, both Russia and the US have conducted "hydronuclear" tests in this yield range. The original purpose of such tests – which the United States conducted during the 1958-61 testing moratorium – was to establish whether certain US nuclear warheads were "one-point safe," i.e., whether there would be a significant nuclear yield if an aircraft crash or bullet caused a detonation of the chemical explosive around the plutonium "pit" beginning at one point instead of the multiple points involved in the design implosion,.

During the Senate's 1999 CTBT ratification debate, opponents to the CTBT accused Russia and China of conducting hydronuclear tests. The 2020 State Department accusations may be those same accusations recycled.

The Trump Administration's accusation was that Russia was not adhering to the "*U.S.* zero-yield standard" (emphasis added) because the U.S. CTBT negotiators decided "it was unnecessary, and probably would be problematic, to seek to include a definition in the Treaty text specifying in technical terms…what is prohibited by the Treaty."

Even if Russia and China are doing hydronuclear tests, the US nuclear weapon laboratories reportedly see no advantage in doing so themselves. According to the 2012 National Academies review of technical issues relating to the CTBT, "leadership at the national laboratories advised the committee that…if they were given the flexibility to do hydronuclear experiments [they] would rather use the same resources to invest in SSP [Stockpile Stewardship Program] modeling and experiments."

Indeed, according the to NNSA's Report to Congress on the stockpile stewardship program for fiscal year 2020 (chapter 3) the laboratories plan to get better data from sub-critical nuclear tests stimulated by intense gamma-ray bursts to generate billions of fissions within the imploded plutonium. The energy yield would be equivalent to that from the detonation of about one tenth of a milligram of chemical explosive.

On-site radiation measurements could determine whether the number of fissions inside a containment vessel were in the hydronuclear or subcritical range. Authoritative statements have indicated that Russia will not allow such inspections until the CTBT comes into force. In 2023, NNSA Administrator Jill Hruby tried to break the ice by announcing:

> "We are open to hosting international observers for monitoring and verification research and development on our subcritical experiments… We are also open to working with others to develop a regime that would allow reciprocal observation with radiation detection equipment at each other's subcritical experiments to allow confirmation that the experiment was consistent with the CTBT. We have several well-considered technical ideas on how this could be effective.

Opposition in Congress to a Comprehensive Test Ban Treaty (CTBT)

In October 1999, the Senate vote on CTBT ratification was 48 in favor versus 51 opposed. All the Democrats voted in favor except one who voted "present" because he objected to the Republican majority's decision to rush the hearings and the vote. Two Republican senators voted for ratification. The issue could be brought before the Senate again if an administration thought it could muster a two-thirds majority. The Obama Administration expressed an interest in doing so, but eventually decided the chances for success were too slim to risk another failure.

The record of the 14 hours of Senate debate on October 8, 12 and 13, 1999 – as "revised and extended" after the fact – shows starkly different attitudes toward nuclear weapons on the two sides.

CTBT advocates saw the treaty as an important step toward the abolition of nuclear weapons and the fulfillment of a commitment the original five nuclear-weapon states (China, France, Russia, the US and the UK) made in exchange for the 1995 vote by the non-nuclear-armed states to extend indefinitely the duration of the nuclear-weapon Non-Proliferation Treaty, which otherwise would have expired in 1995.

CTBT opponents saw nuclear weapons as the ultimate guarantor of the security of the United States and its allies, and were concerned that a CTBT would prevent the US from making its nuclear warheads safer; make unavailable the most reliable method to verify that they were still functional; block the development of new types of nuclear weapons to deal with new threats and new defenses, and that a CTBT would not be verifiable with the result that, if the Senate ratified, the US would not test while other countries would test clandestinely. Subsequently, two reports by committees of the U.S. National Academies – one in 2002 and one in 2012 – attempted to clarify the technical issues relating to these concerns.

Below, the debates and technical issues are summarized in three areas of controversy:

- Safety,
- Reliability,
- Verifiability.

Safety. One of the concerns expressed by CTBT opponents during the ratification debate was safety:

> "Right now, only one of the nine types of weapons in our nuclear stockpile have all available safety features in place, because adding them would have required nuclear testing. It doesn't make sense to effectively freeze our stockpile before all of our weapons are made as safe as possible" (*Congressional* Record, 13 October 1999, S12516, column 3).

There is a hierarchy of safety issues, however. The greatest concern by far is the possibility of an accidental nuclear detonation. Quantitative design standards for safety against an accidental nuclear detonation were established in 1968 and have been implemented for all US nuclear warheads:

1. *One-point safety*: In the event of a detonation initiated at any one point in the high explosive around the plutonium pit, the probability of achieving a nuclear yield greater than 4 pounds TNT equivalent must be less than one in one million.
2. *Enhanced nuclear detonation safety.* The probability of a premature nuclear detonation of a warhead due to a component malfunction in the absence of any input signals other than monitoring and control signals must be less than one in a billion in the normal lifetime of a warhead prior to launch and prearm signals and one in a million in an abnormal or accident environment.

Requirement #2 led to the introduction into the firing circuits of two strong links and one weak link. The strong links have to be closed for the weapon to arm: one by operator input of a code and one by environmental sensors such as weightlessness or the stabilizing spin provided to ballistic missile warheads before they are released from a long-range missile after boost. The weak link would be broken by, for example, the heat of a fire and would incapacitate the warhead.

An important but much less significant issue is the reduction of the possibility of *plutonium dispersal* in a nuclear-warhead accident. Plutonium oxide is extremely carcinogenic if inhaled. Unlike an accidental nuclear detonation, plutonium dispersal has actually happened in a number of accidents.

One safety feature to reduce this risk is to use insensitive high explosive (IHE) in the plutonium pit implosion system. To detonate IHE requires initiation by a higher shock pressure (90 vs 20 kilobars), or by a higher velocity impact (1200+ vs. 100 miles per hour) over a larger-diameter area (0.5 vs. 0.1 inches), than conventional high explosive. US nuclear bombs and cruise-missile warheads all contain IHE because of a history of plutonium dispersal events in aircraft accidents.

Only one ballistic missile warhead type contains IHE, however, the W-87, originally built for the MX intercontinental ballistic missile (ICBM) and now deployed on the Minuteman III ICBM. The other, older warhead type deployed on the Minuteman III, the W-78, does not have IHE and is proposed for retirement. Reportedly, there are 540 W-87s in stockpile, enough for the current deployment of 400 ICBMs with single warheads, but the National Nuclear Security Administration (NNSA), the agency within the Department of Energy responsible for nuclear warheads, proposes to build more W-87s, so that the ICBMs can be returned to a loading of three warheads each if the current limits on deployed US and Russian warheads expired or are violated by Russia.

The two warhead types deployed on the US Trident II submarine-launched ballistic missiles (SLBMs), the W76 and W88, do not contain IHE. The US nuclear navy has resisted pressure from NNSA for a replacement warhead with insensitive high explosive because it has never had a plutonium dispersal accident and the yield to weight ratio of IHE warheads would be lower than for their current warheads. Also, IHE warheads might not be sufficient to prevent a detonation because the warheads are clustered around the Trident II's third stage, which is fueled with detonable high-energy propellant.

The Hatfield-Exon-Mitchell amendment, section 507 of the Energy and Water Development Appropriations Act for Fiscal Year 1993, allowed up to 15 tests of safety improvement prior to 1997. The Navy refused to avail itself of this opportunity. In the spring of 2020, the Trump Administration announced that a new warhead, the W93, with a previously tested IHE primary, would be designed and built to replace some of the wearheads carried on US ballistic missile submarines.

A second potential safety improvement to reduce the probability of plutonium-dispersal in nuclear-warhead accidents that is not present in most US warheads is a fire-resistant pit. In such pits, the plutonium-containing parts of warheads, have a sturdy outer shell of another metal with a high melting point to protect the plutonium. If the high explosive around the pit did not detonate, this shell could contain the plutonium to temperatures above the approximately 1000 ºC temperature at which jet fuel burns. Only the high-yield (up to 1.2 megatons) B-83 bomb, whose retirement the Trump Administration has postponed, and the W87 warhead have fire-resistant pits. The value of fire-resistant pits on ballistic-missile warheads is reduced, however, by the fact that the solid fuels used in ballistic missiles burn at about 2000 ºC.

In summary, all US nuclear warheads are designed to be one-point safe and are equipped with two strong links and one weak link in their firing circuitry to prevent a nuclear yield in an accident. Warheads with sensitive high explosive can be replaced with warheads with insensitive high explosive without nuclear tests. Most US warheads do not have fire-resistant pits to prevent a dispersal of plutonium oxide in a fire. However, plutonium-dispersal accidents are orders of magnitude less serious than an accidental nuclear detonation and US nuclear warheads have not been involved in fires since the Air Force stopped loading them onto combat aircraft 50 years ago.

Reliability. A second major concern expressed about the CTBT during the 1999 ratification debate concerned the feasibility of maintaining confidence that the weapons would work in the absence of nuclear testing:

> "In this uncertain world, it is not enough to simply retain a nuclear arsenal. We need a true nuclear deterrent. A nuclear arsenal becomes a nuclear deterrent only when we have convinced potential enemies that we will use that arsenal against them if they attack us or our allies with weapons of mass destruction. This means we must do two things. First, we must maintain the arsenal in workable, reliable condition. Second, we must clearly communicate our willingness to use the arsenal. We must not forget: a weapon does not deter if your enemy knows that you won't use the weapon.
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> "Nuclear testing, historically, has performed both the maintenance and communications functions. Testing kept the arsenal reliable and modern. Very importantly, it also signaled to potential enemies that we were serious about nuclear deterrence" (*Congressional Record,* 13 October 1999, S12544).

This sentiment contains both political and technical assertions. Politically, it reflects the concern of CTBT opponents that the salience of threats of nuclear annihilation in response to attack will fade if nuclear weapons are not even tested to demonstrate that they still work. Indeed, some support a CTBT for just that reason: they hope that a CTBT is a step toward nuclear threats becoming unthinkable.

Technically, the Science-based Stockpile Stewardship program is supposed to assure that US nuclear weapons will work if needed. It involves many non-nuclear tests, including X-ray movies of subcritical implosions of pits in containment vessels and laser fusion of millimeter-radius targets of frozen deuterium and tritium at Livermore; and computer simulations of each stage of a nuclear explosion at Los Alamos and Livermore. The results of all of this R&D and of detailed inspections of samples of each weapon type for signs of degradation provide the basis for the annual reports to Congress that have certified that no nuclear tests are required to assure the continuing reliability of US nuclear warheads.

In 2012, after two decades without a test, a National Academies review concluded,

> "Provided that sufficient resources and a national commitment to stockpile stewardship are in place, the committee judges that the United States has the technical capabilities to maintain a safe, secure, and reliable stockpile of nuclear weapons into the foreseeable future without nuclear-explosion testing" (finding 1-4).

Verifiability. A final objection to the CTBT during the 1999 Senate ratification debate was that

> "despite the vast array of expensive sensors and detection technology being established under the treaty, it will be possible for other nations to conduct militarily significant nuclear testing with little or no risk of detection" (*Congressional Record,* 13 October 1999, S12536).

There are two issues here: 1) What size tests are detectable? and 2) What size tests are militarily significant?

Since the beginning of the nuclear test ban debate in the 1950s, various evasion scenarios were proposed, including testing in deep space. The evasion scenario that has been the focus of the greatest debate, however, has been "decoupling": exploding a nuclear weapon in a large underground cavity filled with air to absorb the heat of the nuclear explosion and reduce the shock transmitted into the rock and thereby the resulting seismic signal.

The original exposition of this scenario, in 1961, claimed it would be possible through decoupling to reduce the seismic signal from an explosion with a yield of more that 300 kilotons TNT equivalent to that from a 1-kiloton explosion coupled directly into rock. For 300 kilotons, the spherical cavity required in a bed of salt (favored because cavities can be created in salt by solution mining) would have a diameter of 300 meters (1000 feet). Such a large cavity at the necessary depth to contain a high-yield explosion would collapse as it was emptied of water, however, and a 1966 test of decoupling with an 0.38 kiloton explosion in a scaled cavity with the recommended ratio of volume to explosive yield found a decoupling factor of 70 rather than 300.

In 1996, the signatories to the CTBT established a Preparatory Commission for the Comprehensive Test Ban Treaty Organization in Vienna with an annual budget of about $100 million and tasked it to establish a worldwide International Monitoring System (IMS). This system includes 170 seismic stations, 11 hydroacoustic stations that monitor the oceans, 60 infrasound stations that can detect pressure waves in the air from distant explosions in the atmosphere or from the heave of the surface above an underground explosion, 80 radionuclide stations for detecting fission products from atmospheric tests or leakage from underground tests and a data center. As of 2023, about 90 percent of the stations were certified and operating.

In addition, there are many national systems, of which the US system, under the Air Force Technical Applications Center is the most elaborate. The US system includes satellite detectors to detect the flashes from explosions in the atmosphere or space and aircraft that can sample the air downwind from a suspected test. Norway and the US have a joint Seismic Array Network in Norway and on islands in the Norwegian Sea and Arctic Ocean that monitor the Russian test site on the Arctic island of Novaya Zemlya. China has seismic stations across the border from North Korea's nuclear test site.

The 2012 National Academies review concluded,

> "With the inclusion of regional monitoring, improved understanding of backgrounds, and proper calibration of stations, an evasive tester in Asia, Europe, North Africa, or North America would need to restrict device yield to levels below 1 kiloton (even if the explosion were fully decoupled) to ensure no more than a 10-percent probability of detection for [the International Monitoring System] and open monitoring networks." (Finding 4.6)

Focusing seismological detection capabilities on specific test sites greatly increases the likelihood of detection of tests down to much lower yields.

The report (Table 4-3) also concluded that what a country could accomplish with a test below a yield of one kiloton, beyond what could be accomplished without nuclear testing would be relatively limited:

- One-point safety tests;
- Improved implosion designs, but not tritium-boosted designs or two-stage thermonuclear weapons; and
- Assessing stockpile issues and validating some design codes.

Such a clandestine test program could sustain both theoretical and experimental teams of scientists and technicians, but such benefits are at odds with keeping the activity clandestine.

The National Academies report also concluded:

> "Russia and China are unlikely to be able to deploy new types of strategic nuclear weapons that fall outside of the design range of their nuclear-explosion test experience without several multi-kiloton tests to build confidence in their performance. Such multi-kiloton tests would likely be detectable (even with evasion measures) by appropriately resourced U.S. national technical means and a completed IMS [International Monitoring System] network." (Finding 4-12)
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> "Other States intent on acquiring and deploying modern, two-stage thermonuclear weapons would not be able to have confidence in their performance without multi-kiloton testing. Such tests would likely be detectable (even with evasion measures) by appropriately resourced U.S. national technical means and a completed [International Monitoring System] network." (Finding 4-13)

Nevertheless, it recommended negotiations on test-site transparency with China and Russia to deal with concerns that some of the activities being conducted on their test sites might involve non-zero nuclear yields (pp. 74, 75).

Conclusions

On balance, there appears to be wide agreement that the Stockpile Stewardship Program is working and U.S. nuclear security would be reduced by a resumption of nuclear testing. U.S. nuclear explosion testing would make it easier politically for other countries to test, including new would-be nuclear-weapon states. Given that the US has a modern, reliable and safe nuclear arsenal with little to gain from nuclear testing, it would be counterproductive to lower the bar for other countries that might have more to gain.

At the same time, despite the escape hatch provided by the withdrawal clauses in Article IX of the CTBT, there is currently not sufficient Republican support to make possible US ratification.

In the meantime, given the absence of any need to test, it is important to maintain the nuclear test moratorium, which, in the absence of continued movement toward nuclear disarmament, has become one of the key pillars supporting the remainng legitimacy of the Nonproliferation Treaty.

Suggested readings

National Academy of Sciences 2012 review, *Comprehensive Nuclear Test Ban: Technical Issues for the United States,* https://www.nap.edu/catalog/12849/the-comprehensive-nuclear-test-ban-treaty-technical-issues-for-the. Discusses: verification capabilities, how the US maintains confidence in the safety and reliability its warheads in the absence of nuclear testing, and what other countries could achieve by testing below the detection threshold.

Government Accountability Office, *Nuclear Weapons: Annual Assessment of the Safety, Performance, and Reliability of the Nation's Stockpile* (2007). Describes the Congressionally-mandated separate annual reviews by the Department of Energy's three national nuclear-weapon laboratories and by the advisors to the Commander in Chief of Strategic Command, including "red teams" of the reliability and safety of each US warhead including whether or not a nuclear test might be required if there is a problem, https://www.gao.gov/new.items/d07243r.pdf.

"The Big Science of Stockpile Stewardship," *Physics Today,* August 2016, https://doi.org/10.1063/PT.3.3268

"The Decision to End U.S. Nuclear Testing," *Arms Control Today*, December 2019, https://www.armscontrol.org/act/2019-12/features/decision-end-us-nuclear-testing. Describes the history starting with Gorbachev's 1985 test moratorium

"Transparency for nuclear weapons test sites," *Physics Today,* May 2020, https://physicstoday.scitation.org/doi/10.1063/PT.3.4463. Describes the Trump Administration's allegations of Russian violations of the test moratorium with experiments in containers with nuclear yield of up to about a milligram of fission.

"White House held talks over resuming US nuclear tests, John Bolton says," *The Guardian,* 22 July 2020, https://www.theguardian.com/us-news/2020/jul/22/john-bolton-us-nuclear-tests-white-house.