MONITORING FOR NUCLEAR EXPLOSIONS

Detecting a test of a nuclear weapon has become so effective and reliable that no nation could expect to get away with secretly exploding a device having military significance

By Paul G. Richards and Won-Young Kim

KEY CONCEPTS

- Seismic monitoring can now detect a nuclear explosion with a yield of a kiloton or more anywhere on Earth. In many places, detection is far more sensitive than that.
- President Barack Obama is likely to ask the U.S. Senate to reconsider its 1999 vote against the Comprehensive Nuclear-Test-Ban Treaty (CTBT).
- Treaty opponents have argued that some signatories would cheat by testing explosive nuclear weapons in secret, putting non-cheaters at risk.
- The objection that secret tests could go undetected is no longer seriously credible.

—The Editors

> As president, I will reach out to the Senate to secure the ratification of the CTBT [Comprehensive Nuclear-Test-Ban Treaty] at the earliest practical date and will then launch a diplomatic effort to bring on-board other states whose ratifications are required for the treaty to enter into force.
>
> *—Barack Obama, September 10, 2008*

As this article goes to press, Iran's nuclear program is rapidly expanding its capacity to enrich uranium. The terrorist attacks in Mumbai, India, last November have once more raised the specter of a nuclear weapons exchange between India and Pakistan—a "regional war" that could kill tens of millions of both countries' citizens and lead to severe change in global climate. North Korea, having joined the nuclear club with its first successful explosive test of a fission weapon on October 9, 2006, has reportedly separated enough weapons-grade uranium to build at least half a dozen atomic bombs. Eight countries have openly tested nuclear weapons, and Israel is presumed to have them as well. The possibility that terrorists could get their hands on such weapons is the worst nightmare of the U.S. Department of Homeland Security and its counterparts around the world.

Yet there are hopeful signs for reducing nuclear tensions as well. By the end of 2008, 180 countries had signed the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which forbids all nuclear explosions, including the explosive testing of nuclear weapons. That treaty, adopted by the United Nations General Assembly in September 1996 and promptly signed by President Bill Clinton and many other world leaders, aims to restrict the further development of nuclear weapons by countries that have them and to prevent countries that do not possess them from building them with any confidence that the devices will work on the battlefield.

Even though the CTBT has not yet come into force, every nation that signed it—including the U.S. and Russia—has maintained a moratorium on nuclear weapons testing at least since the U.N. voted to adopt it. (The three nations that have tested nuclear weapons since 1996—India, North Korea and Pakistan—have not signed the treaty. For a brief historical and political background on the CTBT, see the box on page 76.)

FRANCE EXPLODED this nuclear weapon at Mururoa Atoll in French Polynesia on July 3, 1970. Atmospheric explosions are now banned by treaty and relatively easy to detect. Most monitoring efforts today focus on detecting explosions underground.

In the U.S. this moratorium on testing has continued despite serious opposition to the treaty itself. In 1999 the U.S. Senate declined to give its constitutional "advice and consent" to the ratification of the agreement, and soon after the 2000 election President George W. Bush declared the CTBT not to be in the interests of national security.

The reason some senators voted against the treaty was concern about whether adequate tools exist for detecting attempts at clandestine nuclear testing—and thereby pinpointing treaty violations. Why renounce testing, the argument goes, if the U.S. cannot tell whether other countries are cheating? While we sleep, other countries could secretly conduct tests that would increase their ability to harm the interests of the U.S. and its allies.

In our view, those concerns about monitoring are groundless—and have been for several years. The scientific and technical community has developed a well-honed ability to monitor militarily significant nuclear test explosions anywhere in the world, above ground or below, and to distinguish them from mine collapses, earthquakes, and other natural or nonnuclear phenomena. For example, the yield of the North Korean test conducted underground in 2006 was less than a kiloton (the equivalent of 1,000 tons of TNT). Yet it was promptly detected and identified. Given such demonstrated capabilities, as well as continuing improvements in monitoring, the concerns about clandestine nuclear testing no longer provide defensible grounds for opposing the CTBT.

Learning What to Look For

The science of monitoring nuclear explosions is as old as nuclear testing itself. From the beginning, the major rationale for the U.S. to monitor was to collect basic information about the capabilities of potential adversaries. A second important reason has been to support international treaties on nuclear arms control. If each country that is party to a comprehensive test ban has reason to believe that any attempt to hide a nuclear test will very likely fail, the fear of international sanctions may deter the country from testing at all. More than 2,000 explosive nuclear tests have been conducted since the end of World War II—in the atmosphere, underwater and underground. From that record inves-

NO PLACE TO HIDE

Monitoring aims to ensure that trying to conceal a nuclear explosion is a fool's errand. Among many ways the explosions signal their existence are:

- Seismic waves, which travel through solid rock
- Hydroacoustic waves, sound waves that can travel great distances through the oceans
- Infrasound, low-frequency sound that propagates thousands of miles through air
- Airborne radioactive particles and gases
- Shifts in ground level, particularly from an underground explosive test, detectable from space
- Light flashes bright enough to be seen from space
- X-rays visible from space

SYGMA/CORBIS (*nuclear explosion*); LUCY READING-IKKANDA (*icons*)

tigators have gained vast experience in acquiring and interpreting the signals of a nuclear blast.

Nuclear test explosions generate a variety of potentially detectable signals. An explosion in the atmosphere, for instance, emits an intense flash of light, which can be imaged by satellite. The roar of an explosion quickly dissipates at frequencies in the range of human hearing, but at "infrasound" frequencies—lower than 20 hertz—sound waves travel vast distances in air. Infrasonic "listening" posts equipped with microbarometers detect the very small changes in atmospheric pressure that make up the infrasound signal.

Radioactive isotopes of certain stable elements are created by all nuclear explosions, and in an atmospheric test they are blown high into the air as gases. As they cool, some of them, such as radioactive xenon, remain in the gas phase as a telltale sign of a nuclear explosion. Others condense and combine with dust to form particles that can drift around the world. As early as 1948, the U.S. Air Force monitored American atmospheric test explosions in the Pacific and confirmed that such radioactive particles are big enough to collect by pumping air through filter paper similar to that used for making coffee.

Radioisotope detection soon proved its worth. On September 3, 1949, a WB-29 bomber flying east of Kamchatka Peninsula gathered data proving that, four days earlier, the U.S.S.R. had become the second country in the world to test a nuclear device. The mix of isotopes in the debris—notably plutonium and uranium 238—told a story of its own: the Soviets had tested a bomb that was almost an exact copy of the 21-kiloton explosive the U.S. had dropped on Nagasaki.

Quite early in the U.S. nuclear program, explosions were tested underwater as well as in the atmosphere. Sound travels very efficiently in water, particularly when the sound energy is trapped by slight changes in temperature and salinity that define the so-called sound fixing and ranging channel: the SOFAR layer. It became obvious that underwater explosions with a yield as small as a few millionths of a kiloton could therefore be monitored with hydrophones, or underwater microphones, by placing them near the SOFAR layer in seawater between 2,000 and 4,000 feet deep.

Seismic Monitoring

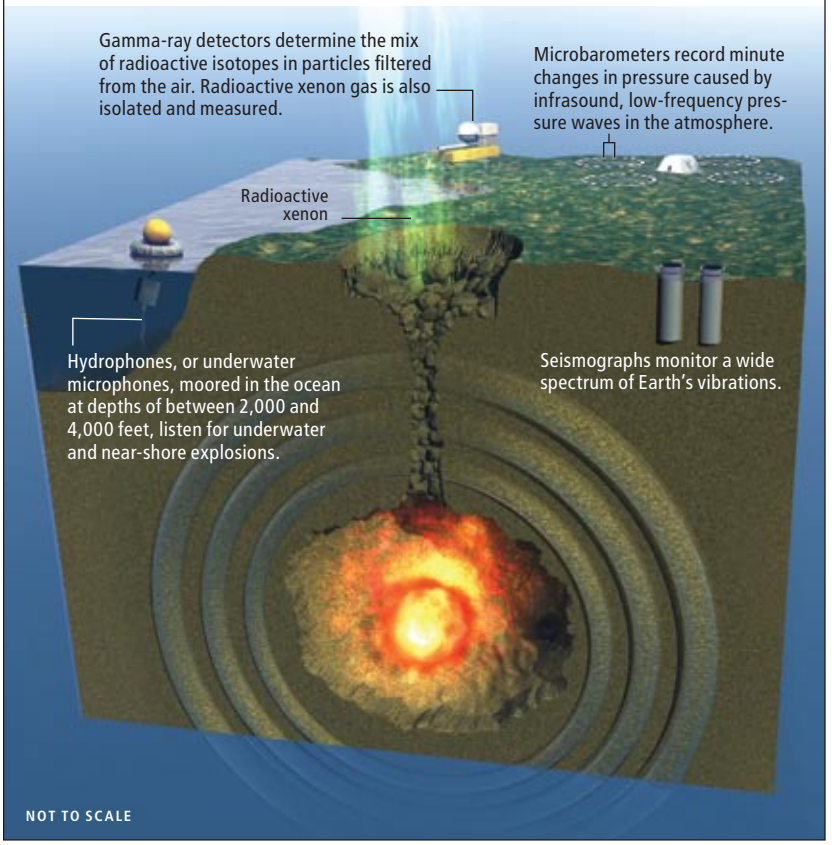
In 1963, following long and intense negotiations, the U.S., the Soviet Union and the U.K. (the first three members of the "nuclear club") signed the Limited Test Ban Treaty. The LTBT banned nuclear testing in outer space, in the atmosphere and underwater. Parties to the treaty, however, could still test nuclear explosions underground. For that reason, the information conveyed by seismic waves—elastic wave energy that travels through Earth as a result of an impact, collapse, slippage, explosion or other force that impinges on the planet—quickly became a major focus of the monitoring community. Fortunately, the sensors needed for detecting earthquakes can do double duty in detecting bomb blasts. But learning how to distinguish earthquakes from bomb blasts took several years, and refinements of that work continue to this day.

The main difficulty arises from the great variety and number of earthquakes, chemical explosions and other nonnuclear phenomena generating seismic signals every day. Any good mon-

[HOW IT'S DONE]

Monitoring Technologies That Support the CTBT

The International Monitoring System (IMS) set up by the Comprehensive Nuclear-Test-Ban Treaty (CTBT) Organization in Vienna incorporates detectors that search for four kinds of characteristic signals of a nuclear explosion (*below*), particularly a device exploded underground.

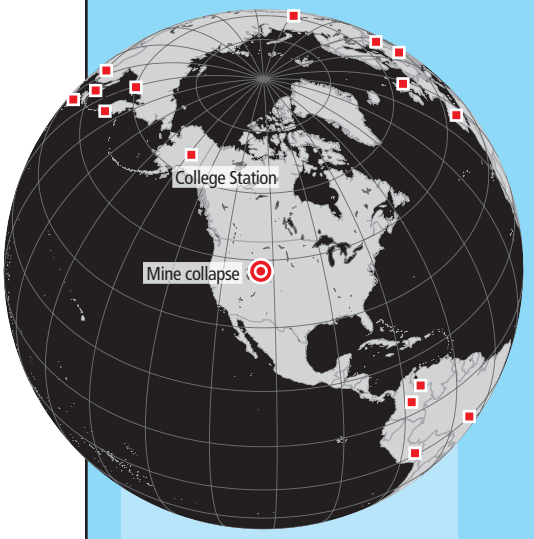


ALFRED T. KAMAJIAN

[SCREENING DATA]

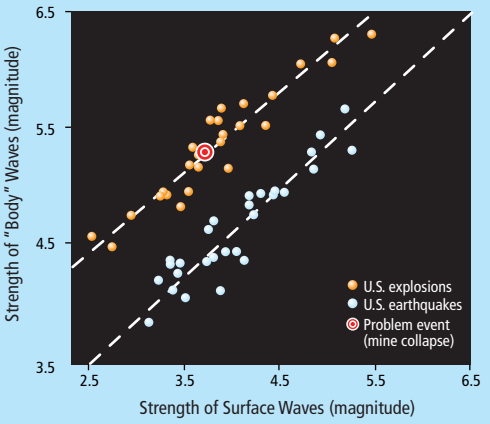
How to Tell a Blast from a Crash

Distinguishing the seismic signals of a nuclear explosion from those of other seismic events is one of the main challenges for monitoring; misidentifications can lead to false accusations and international incidents. Identifying a reliable seismic difference between an underground explosion and the collapse of a large mine was an important advance of recent years.



The collapse of a mine in southwestern Wyoming sent long-range seismic "body" waves around the world. (Body waves pass through the solid interior of Earth.) The waves were picked up by seismic stations at least 2,000 miles away (*squares*).

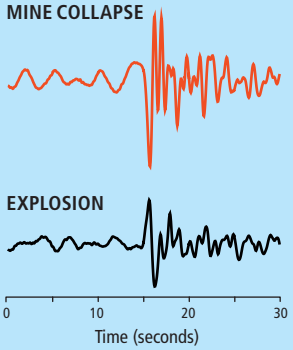
MISTAKEN IDENTITY?



Underground explosions (*orange circles*) are readily distinguishable from earthquakes (*light blue circles*) by the ratio of the strengths of two kinds of seismic waves: body waves and surface waves. The graph shows how explosions and earthquakes tend to fall into separate populations. By that discriminant, however, the Wyoming mine collapse (*red target*) looked much like a nuclear explosion.

On further study, seismologists noted that the seismogram of the body wave from the mine collapse begins with a deep trough, whereas that from a nuclear explosion begins with a sharp peak (*below*). Both were made at College Station, Alaska. The downward motion recorded in the seismogram of the mine collapse reflects the initial implosion of rock surrounding the center of the event.

MINE COLLAPSE



MAPPING SPECIALISTS (*globe*); LILA RUBENSTEIN (*graph*); LUCY READING-IKKANDA (*seismograms*); SOURCE: "DISCRIMINATING BETWEEN LARGE MINE COLLAPSES AND EXPLOSIONS USING TELESEISMIC *P* WAVES," BY DAVID BOWERS AND WILLIAM R. WALTER, IN *PURE AND APPLIED GEOPHYSICS*, VOL. 159, NO. 4; FEBRUARY 2002

itoring network cannot avoid detecting those signals. Worldwide, for instance, more than 600 earthquakes a day eventually find their way into an international summary report, and mining operations in industrialized countries explode millions of tons of blasting agents a year. In all, about 25 seismic events above a magnitude of four take place every day, and that number goes up by a factor of about 10 for each drop of one unit in magnitude (say, from 25 to 250 events a day for a drop in magnitude from four to three).

At most locations on Earth, magnitude 4 corresponds to an explosive yield of less than a kiloton for an underground explosive device packed inside a small cavity in hard rock, from which seismic signals radiate efficiently. In other locations the rock is softer and more of the energy from the explosion is absorbed, reducing its measured seismic magnitude. Some policy makers have worried that a country might try to reduce the seismic signal by modifying the immediate environment of the test. For example, a large cavity hollowed out of rock could partly muffle the seismic waves from a blast, but for any militarily useful test explosion the cavity would have to be so big it would collapse or attract attention in other ways—for example, the excavated material would have to be concealed from satellites. The risk of discovery would be very high.

In practice, with seismic monitoring alone, all nuclear explosions down to yields of one kiloton can be detected with 90 percent reliability by examining between about 50 and 100 seismic events a day. To detect nuclear explosions with lower yields, the number of seismic events that must be examined goes up. Even one kiloton, however, is quite small for a nuclear explosion, and according to a 2002 report by the U.S. National Academy of Sciences, a test of that size would be of little use to a testing country attempting to make larger nuclear weapons—particularly if the country had little prior experience with nuclear testing [*see box on page 75*].

Where to Focus, What to Ignore

Monitoring a nuclear explosion begins with the detection of signals, followed by an attempt to gather and associate all the signals recorded by various monitoring stations that originate from

A GUIDE TO ACRONYMS

AEDS Atomic Energy Detection System

AFTAC Air Force Technical Applications Center

CTBT Comprehensive Nuclear-Test-Ban Treaty

IMS International Monitoring System

IRIS Incorporated Research Institutions for Seismology

LTBT Limited Test Ban Treaty

NPT Treaty on the Non-Proliferation of Nuclear Weapons

[FINDING CHEATERS]

How Monitoring for the Treaty Covers Earth

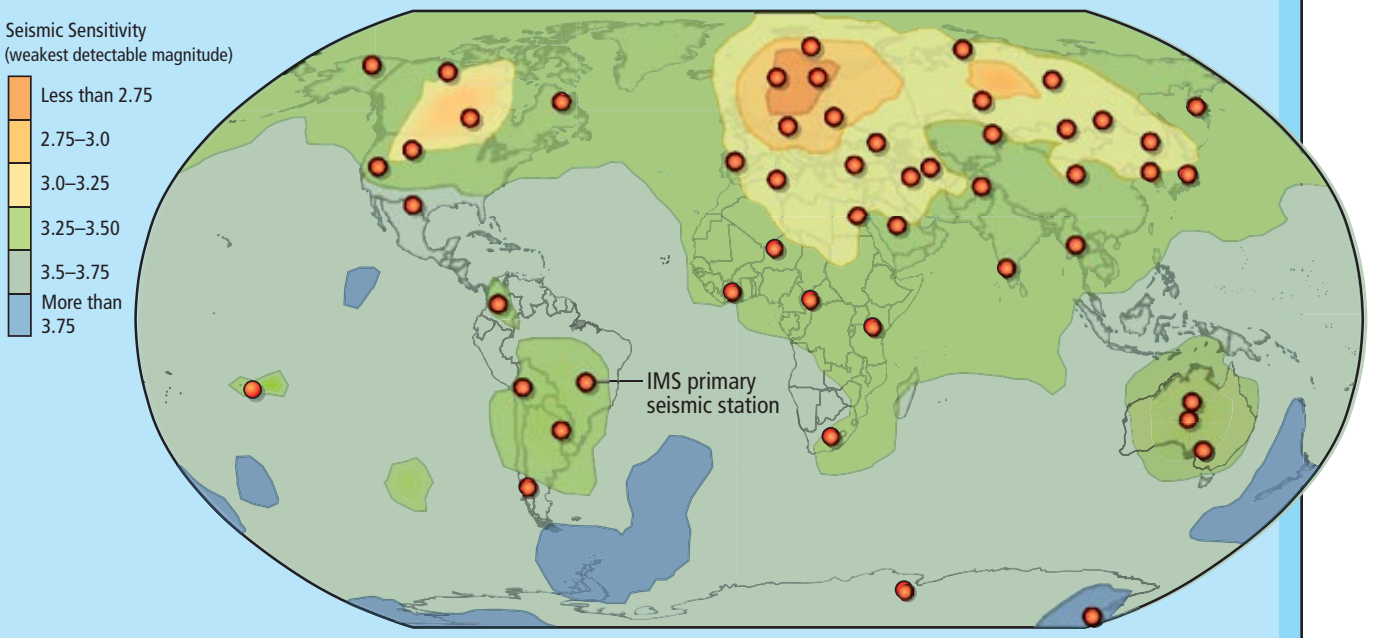
The IMS primary seismic network can detect a nuclear explosion that generates seismic waves of approximately magnitude 3.75 anywhere in the world—which is sensitive enough to monitor any test explosion likely to give militarily useful information. But the IMS is taking no chances catching cheaters. As the map shows (*below*), for explosions in most parts of the world the network is sensitive enough to monitor far weaker seismic signals.

The extra margin of sensitivity is important because the seismic signal strength depends on many factors, other than explosive "yield," that a rogue state might manipulate to hide a test, including the kind of rock that surrounds the explosion (*table at right*). Yield is usually expressed as the mass of TNT, in kilotons, that would explode with equivalent energy.

Rough Yields of Underground Explosions Corresponding to Seismic Magnitudes

Seismic magnitude	Yield in hard rock (kilotons)	Yield in soft rock (kilotons)
2.75	0.005	0.04
3.0	0.01	0.08
3.25	0.03	0.2
3.5	0.05	0.3
3.75	0.1	0.6

DETECTION THRESHOLDS BY REGION



the same event. The final steps are to estimate the location of the event, primarily from the differences in the arrival times of signals at different stations, and to identify it. For example, did it have the characteristics of a meteor breaking up in the atmosphere, a mining blast, a test of a nuclear weapon? And if the latter, how big was it? What was its yield? What country carried it out?

The vast majority of seismic events can be classified automatically by computer algorithms; only the hard cases are flagged by the software for human intervention. Specialists have been monitoring earthquakes and mine blasts for many years and have thereby become well acquainted with the way many of their features are reflected in the seismic record. That knowledge, in turn, has helped inform efforts to identify nuclear test explosions. In particular, several kinds of seismic events became touchstones as protocols were developed for identifying a particular event as a nuclear explosion.

One kind of event was a series of mine collapses—one in 1989 in Germany and two more in 1995, one in Russia and the other in the U.S. Seismic stations throughout the world detected all three, but the data raised concerns because at great distances the classic method of distinguishing explosions from other seismic events was incorrectly suggesting the events were underground explosions. In that classical method, seismologists compare the strength of long-wavelength seismic waves traveling over Earth's surface with that of body waves, which pass deep through the planetary interior. For example, a shallow earthquake and an underground explosion might set off body waves of the same strength, but if so, the surface waves from the earthquake would be significantly stronger than they would be for the underground explosion.

MAPPING SPECIALISTS

A closer analysis of the seismic waves from the mine collapses showed that those waves could not have come from an explosion, because they began with a trough rather than a peak: the ground had initially moved inward toward the source rather than outward, just as one would expect from a mine collapse [*see box at top of page 73*]. The episode was important because it showed that such an event could be reliably distinguished from an underground explosion on the basis of seismic recordings alone.

A second event illustrated the importance of the seismic distinction between two kinds of body waves for monitoring nuclear explosions. In 1997 a small seismic shock of magnitude 3.5, along with an even smaller aftershock, was detected below the Kara Sea, near Russia's former nuclear test site on the Arctic island of Novaya Zemlya. Were the Russians violating their obligations as a signatory of the CTBT?

The surface waves from the event were too small to measure reliably, and so once again the classic method of identifying an explosion—comparing the strength of the long-wavelength surface waves with that of the body waves—could not be applied. But the detection of "regional" seismic waves, which pass through the upper mantle and crust of Earth and which can be measured within about 1,000 miles of an event, resolved the issue. They enabled seismologists to distinguish compressional, or *P*, waves from shear, or *S*, waves generated by the event. (*P*-waves travel as oscillating regions of compression and rarefaction along the same direction in which the waves propagate; *S*-waves oscillate at right angles to the propagation direction.)

It was known that the *P*-waves from an explosion are typically stronger than the *S*-waves, but that distinction was just beginning to be applied at frequencies above five hertz. This time the measured ratio of the strengths of the *P*- and *S*-waves at high frequency—and the fact that the main shock had an aftershock—showed that the Kara Sea event was an earthquake.

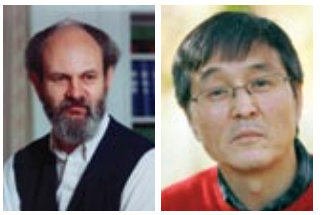
More Eyes to Catch Cheaters

A third touchstone event, the North Korean nuclear test explosion of October 9, 2006, illustrated the importance of recording seismic waves as close as possible to their source. The blast left traces on sensors worldwide even though its yield was estimated at less than a kiloton. But regional seismic data were required to determine that the signals came from an explosion and not from an earthquake. In the event, the world was well prepared. Several seismic stations were close by, including one in the network of the International Monitoring System (IMS), the CTBT's own system for monitoring nuclear explosions.

After the seismic detection of the Korean test and the announcement of the test by North Korea, radioactive matter in the air and on the ground in Asia, as well as downwind across the Pacific Ocean at an IMS station in Canada, decisively confirmed the explosion as nuclear. Detecting the radioactivity was itself highly reassuring. The topography of the North Korean test site suggests that the explosion was deeper than most other subkiloton tests. Yet the test still leaked radioactive material.

Experience with these and other special seismic events has shown that the best seismic data for resolving a specific monitoring issue can sometimes come from stations that are not part of any treaty-monitoring network. Those stations, built with other goals in mind, can provide the dense coverage that makes it possible to strengthen the evidence derived from dedicated monitoring networks. Monitoring stations in the Korean region, for instance, are so dense that underground explosions with a yield

[THE AUTHORS]



Paul G. Richards (*left*) is Mellon Professor of the Natural Sciences at the Lamont-Doherty Earth Observatory at Columbia University. Since the mid-1980s his work has focused on using seismological methods to study nuclear weapons test explosions and their implications in both the scientific and political worlds. **Won-Young Kim** (*right*) is a Doherty Senior Research Scientist, also at Lamont-Doherty. His research focuses on the analysis of "regional" seismic signals from sources within about 2,000 miles to study earthquakes and to identify sources of underground explosions.

WHAT GOOD IS A TEST?

If the risk were taken to try to evade CTBT monitoring systems with a secretly conducted nuclear explosion, countries relatively experienced with nuclear testing would learn nothing that would add much to the nuclear threat they already pose to the U.S., and countries inexperienced with testing could expect to learn very little beyond what could be achieved with an untested weapon. Here is what inexperienced countries might learn by testing at various explosive yields:

Yield (kilotons)	Detectable?	Purpose or Plausible Achievement
Less than 0.0001	Unlikely	One-point safety tests* (with difficulty)
Between 0.0001 and 0.01	Unlikely	One-point safety tests
Between 0.01 and 1–2	Probably; concealable in some circumstances	Some improvement in weight and efficiency of "unboosted"† fission weapons; proof test of compact weapons yielding as much as 2 kilotons
Between 1–2 and 20	Almost always	Development of low-yield boosted fission weapon; eventual development and full testing of low-yield thermonuclear (fusion) weapon; proof test of fission weapon with yield as high as 20 kilotons

* A one-point safety test seeks to prove that no nuclear explosion would take place even if the chemical explosive that surrounds the fissionable material is accidentally set off at a single point.

† A boosted weapon incorporates tritium and deuterium to increase the number of neutrons, causing more fission in the nuclear explosive and thus greater yield.

SOURCE: *TECHNICAL ISSUES RELATED TO THE COMPREHENSIVE NUCLEAR TEST BAN TREATY.* NATIONAL ACADEMY OF SCIENCES. NATIONAL ACADEMIES PRESS, 2002.

COURTESY OF LAMONT-DOHERTY EARTH OBSERVATORY, COLUMBIA UNIVERSITY (*Richards*); BRUCE GILBERT/EARTH INSTITUTE (*Kim*)

[TIMELINE]

Fifty Years of Nuclear Testing and Monitoring

- **July 16, 1945:** World's first test of a nuclear device is conducted by exploding a bomb on a tower at Trinity site, Alamogordo, N.M.
- **August 6, 1945:** First atomic bomb is dropped on Hiroshima; three days later a second atomic bomb is dropped on Nagasaki.

- **1947:** General Dwight D. Eisenhower orders an effort to monitor the nuclear tests of other countries.
- **August 29, 1949:** The U.S.S.R. becomes the second nation in the world to test a nuclear device (also in the atmosphere).
- **September 3, 1949:** The Soviet explosion is detected by an American plane that collects radioactive debris in the upper atmosphere. It is the first nuclear explosion monitored by a country other than the testing power.
- **October 3, 1952:** The U.K. becomes the third nuclear weapons state, when it explodes its first nuclear device (also in the air).
- **Mid-1950s:** Many national and international groups bring public attention to the genetic hazards of radioactive materials produced by the continuing nuclear testing.
- **September 19, 1957:** First underground nuclear test explosion is conducted at the Nevada test site.
- **February 13, 1960:** France tests its first nuclear device.
- **October 31, 1961:** The Soviet Union explodes the largest device ever tested, the "Big John," with a yield of more than 50 megatons. It was promptly detected all around the world.
- **August 5, 1963:** Limited Test Ban Treaty is signed by the U.K., the U.S. and the U.S.S.R., banning testing in the atmosphere, underwater and in space. China and France refuse to sign.
- **October 16, 1964:** China tests its first nuclear device, becoming the fifth nation to do so.
- **July 1, 1968:** Sixty-one countries sign the Non-Proliferation Treaty, prohibiting the transfer of nuclear weapons technology to nonnuclear weapons states. India, Israel, North Korea and Pakistan refuse to sign.
- **May 18, 1974:** India tests its first nuclear device (underground).
- **1992:** The U.S. under President George H. W. Bush declares a moratorium on all nuclear testing.
- **September 10, 1996:** The United Nations General Assembly votes in favor of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), which prohibits all nuclear test explosions.
- **September 24, 1996:** President Bill Clinton signs the CTBT for the U.S. By the end of that day 66 nations, including the four other nuclear weapons states (China, France, Russia and the U.K.) sign the treaty. India, North Korea and Pakistan do not sign.
- **May 11 and 13, 1998:** India conducts two sets of underground nuclear tests, breaking a de facto global moratorium on testing that had prevailed since the CTBT was opened for signatures in 1996.
- **May 28, 1998:** In response to India's renewed testing, Pakistan conducts two sets of its own underground nuclear tests.
- **October 13, 1999:** U.S. Senate votes to withhold its advice and consent to the CTBT.
- **2001:** Shortly after taking office, President George W. Bush declares the CTBT is not in U.S. interests. He continues the U.S. moratorium on testing.
- **October 9, 2006:** North Korea tests its first nuclear device (underground).
- **December 31, 2008:** 180 countries have signed the CTBT, including 41 of 44 countries that must sign it before it can go into force. Only India, North Korea and Pakistan remain holdouts.

as low as a few percent of a kiloton can be detected there.

Well-tested networks of seismic stations for rapidly analyzing, assembling and distributing large amounts of seismic data already exist, quite independently of the IMS. Thousands of seismometers have been set up throughout the world to evaluate earthquake hazards and to determine our planet's internal structure. In the U.S., the U.S. Geological Survey and the Incorporated Research Institutions for Seismology, a consortium of more than 100 American universities, are jointly building and operating seismic data systems. As of the end of 2008, IRIS was receiving current seismic data from 71 networks that operate 1,797 stations, including 474 outside the U.S. An international group, the Federation of Digital Seismic Networks, plays a huge and still growing role in the data collection. Such networks are well suited to picking up unanticipated nuclear test explosions, as well as high-quality regional signals from events that might seem suspicious if they were analyzed by a sparse global network alone. Those data can thereby supplement data from the IMS and the various national treaty-monitoring networks.

One network of particular note among all the foregoing networks is the monitoring system the U.S. still maintains specifically for detecting nuclear explosions. The Atomic Energy Detection System (AEDS) is operated by the Air Force Technical Applications Center (AFTAC) out of Patrick Air Force Base in Florida and includes an extensive global network of seismometers. AFTAC reports on the data from the AEDS network within the U.S. government. If the CTBT finally goes into force and the AEDS or some other national facility detects a suspicious event, such data can be presented in an international forum, thereby augmenting information gathered by the IMS.

How Low Must You Go?

Even though existing technologies can ferret out rather small bomb tests and technical advances in monitoring will undoubtedly continue, one practical caveat must be made. It is obviously not possible to detect explosions of every size, with 100 percent reliability, all the way down to zero explosive yield. In this sense, monitoring is imperfect. But does it really matter that a technologically sophisticated country could perhaps conceal a very small nuclear explosion from the rest of the world, even though the

KEYSTONE/GETTY IMAGES (*newspaper*); BETTMANN/CORBIS (*explosion*)

[BACKGROUND]

A Brief History of the CTBT

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) is closely related to the Non-Proliferation Treaty (NPT), which went into effect in 1970 and is now agreed to by more than 180 countries. In signing the NPT, nations undertook not to allow nuclear weapons technology to pass from the nuclear to the nonnuclear weapons states.

Throughout the NPT negotiations, most nonnuclear states wanted a complementary set of commitments from the nuclear states that they would not further develop their nuclear weapons technology. The CTBT is the most detailed and far-reaching of these commitments. Yet despite its many signatories, the CTBT cannot go into effect until it is both signed and ratified by 44 countries that, during the final negotiations, were understood to have some capability to run nuclear reactors. As of the beginning of 2009, 35 of those 44 countries had ratified—including Russia and almost all NATO members. Among the nine holdouts are six that have signed but not ratified (China, Egypt, Indonesia, Iran, Israel and the U.S.) and three that have not even signed (India, North Korea and Pakistan).

The 1999 defeat of the CTBT in the U.S. Senate placed the treaty in the limbo it occupies in the U.S. today. When George W. Bush took office, he did not revoke Bill Clinton's signing (*right*), but he did state his opposition to the treaty. The Bush administration also cut off part of the U.S. share of funds for the CTBT's International Monitoring System. There was never any possibility that the treaty would come before the full Senate for reconsideration as long as Bush was in office. With new information, however, including input from the Obama administration, the Senate could reconsider the treaty and conduct a second vote.

—P.G.R. and W.-Y.K.

GREG GIBSON *AP Photo*

explosion served no practical purpose in a nuclear weapons program? The goal of monitoring systems is to ensure that the yield of a successfully concealed nuclear test explosion would have to be so low that the test would lack military utility.

In the 1950s President Dwight D. Eisenhower was willing to agree to a comprehensive test ban even if monitoring was not sensitive enough to detect explosions with yields less than a few kilotons. Today monitoring is much more effective. Is the CTBT worth scuttling if a nuclear device of less than a kiloton might in principle be exploded without being detected? The 2002 analysis by the National Academy of Sciences argues that, on the contrary, ratifying the CTBT would be a positive development for U.S. national security.

Nevertheless, some leaders in the military and in nuclear weapons laboratories have opposed the CTBT. They argue that it prevents the U.S. from verifying the continuing viability of its current nuclear arsenal or from developing more sophisticated nuclear weapons. But the reliability of proven designs in the U.S. stockpile of nuclear weapons does not, in practice, depend on a program of nuclear test explosions. Rather reliability is ensured by nonexplosive testing that is not restricted by the CTBT. As for new nuclear weapons, the CTBT is an impediment—just as it was intended to be—and its restrictions on U.S. weapons development must be weighed politically against the merits of the restrictions it imposes on all signatories.

Our discussion has touched on several important technical issues related to weapons development and monitoring that arise as the U.S. judges whether ratifying the CTBT is in the national interest. Unfortunately, individuals and organizations with strong opinions on the CTBT have sometimes turned such issues—the assessment of monitoring capability in particular—into a surrogate battleground for an overall political evaluation of the treaty itself and the trade-offs it implies. We would urge, instead, that the main debate focus on the merits of the treaty directly and remain separate from technical, professional reviews of monitoring capability.

If the CTBT finally does go into force, the de facto moratorium on international testing would become formally established. The treaty could then become what it was always intended to be: a vital step in strengthening global efforts to prevent the proliferation of nuclear weapons and a new nuclear arms race. ■

MORE TO EXPLORE

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For more information about monitoring technologies, the history of nuclear testing, the development of the CTBT and the Preparatory Commission for the CTBT Organization in Vienna, visit **www.ctbto.org**