Policing the Peace: Verifying the Threshold Test Ban

"The Threshold Test Ban Treaty in its current form is not effectively verifiable. ... The TTBT as written is the most glaring example of 'verification by trust' that I can think of."

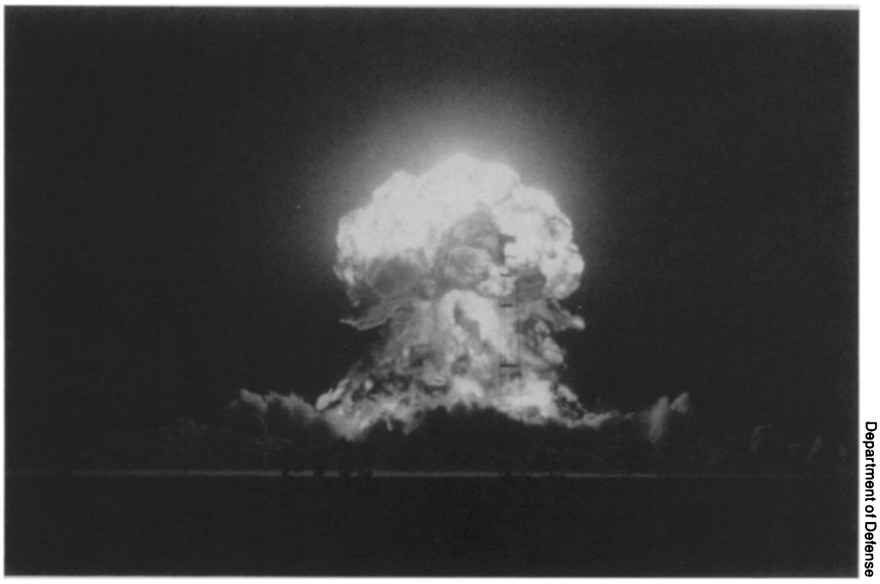
—Robert Barker,
Deputy Assistant Director for
Verification and Intelligence,
Arms Control and Disarmament Agency

"Both the Threshold Test Ban Treaty and the peaceful nuclear explosions treaty can be verified with high confidence."

—Lynn R. Sykes, seismologist,
Lamont-Doherty Geological Observatory

First of two articles

By STEFI WEISBURD



Department of Defense

Since the first atomic bomb was dropped on Hiroshima, the world has amassed at least 50,000 nuclear weapons capable of wrenching the planet with an equivalent of about 20 billion tons of TNT. The 40th anniversary of the Hiroshima bombing and the resumption of arms control talks between the Soviet Union and the United States this fall have prompted a resurgence of interest in one of the oldest approaches to slowing the skyrocketing nuclear arms race: test ban treaties.

At the heart of technical discussions about test bans lies the question of verification—how well can each country tell if the other is violating any agreement? Governments continue to develop a host of different technologies — from satellite surveillance to seismic networks, the United States' main tool for test ban verification — for keeping an eye and ear on other countries. But in spite of technological and scientific advances in the past four decades and a more recent convergence of views on some scientific issues, the seismic verification question is still hotly debated among a number of scientists and policymakers in the United States. On many issues, "there is an agreement that there is promise," says Willard J. Hannon, a program manager in the Seismic Monitoring Research Program at Lawrence Livermore (Calif.) National Laboratory. "But there are differences as to the extent that the promise has been proven." Some believe that scientists know enough today to adequately verify a long-term treaty, but others disagree.

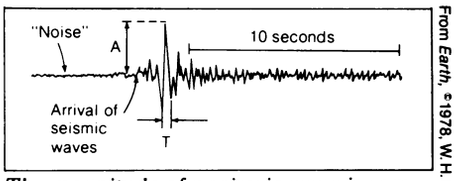
The first step to verification is detection. With the present state of technology, most experts agree that seismic networks can easily detect events well below the 150 kiloton (KT) limit of the Threshold Test Ban Treaty (TTBT). Indeed, three years ago, seismologists Lynn R. Sykes at Lamont-Doherty Geological Observatory in Palisades, N.Y., and Jack F. Evernden at the U.S. Geological Survey in Menlo Park, Calif., wrote in SCIENTIFIC AMERICAN: "In 1963 [when the Limited Test Ban Treaty was signed] the reliability of measures for the verification of a treaty banning explosions larger than about 1 kiloton may have been arguable, but it no longer is." With its present network of seismic stations, spread over about 35 countries, the United States can detect explosions with yields less than 3 KT (which trigger magnitude 4 or 5 seismic signals) with high confidence, says Robert R. Blandford, a program manager in the Geophysical Sciences Division of the Defense Advanced Research Projects Agency (DARPA) in Arlington, Va.

The big, and politically sticky, issue surrounding the TTBF has been in estimating the yield of a nuclear explosion once it has been detected and identified as such. An incorrect yield estimate, for example, could lead one country to falsely accuse the other of cheating on the TTBT. Or, at the other extreme, it could enable another nation to test weapons that not only violate the TTBT but give that other country a significant military advantage.

The general method that has been used to estimate yield is to derive a relationship between the yields of bombs detonated at the Nevada Test Site (NTS) and the magnitude of certain seismic waves they generate. The problem lies in using this same yield-magnitude relationship to predict the yields of explosions in the Soviet Union and elsewhere. "If we simply applied just this relationship, we'd get enormous yields for the Soviet explosions — up to 700 and 800 KT," says Thomas Bache at Science Applications International in San Diego.

This is because the underlying geology of the two regions is quite different, and the body waves — seismic signals that travel down through the mantle and crust — are affected by this geology. At the NTS region, where the rocks are younger and

hotter than those below the Soviet Union, seismic signals are thought to be attenuated more than in the USSR. The result is that a 150 KT explosion might have a magnitude of 5.8 at NTS, but the same explosion at the Soviet test site would measure 6.15, says Sykes, who served on the U.S. delegation to negotiate the TTBT.



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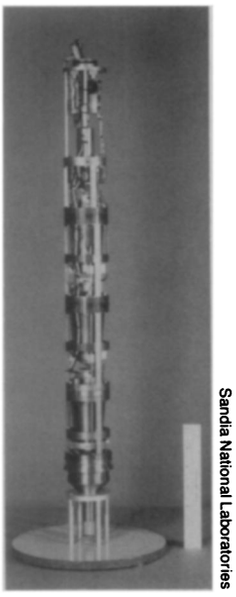
The magnitude of a seismic wave is computed from its seismograph recording by taking the logarithm of the wave's amplitude (A) after it has been divided by the period (T), which is the duration of one oscillation of the wave. A correction factor is added to allow for the weakening of the wave with distance from its source.



Sandia National Laboratories

This package of seismometers and circuits, ensuring that data are not tampered with, is buried about 100 meters into the earth. Each seismometer basically consists of a mass supported by springs. When a seismic wave passes, the housing of the seismometer moves while the mass tends to remain at rest. The relative movement between the mass and housing is a measure of the earth's motion.

Almost every scientist involved now agrees that some sort of correction factor or "bias" must be added to yield estimates. The disagreement is over what number should be used. Based on a classified value for the bias, Reagan administration officials have repeatedly said that Soviet nuclear testing activities for a number of tests constitute a likely violation of the TTBT — that about 10 explosions each have had yields probably exceeding 150 KT. Sykes has long argued that the government has consistently underestimated the bias. He and many other scientists, both in and out of the government, contend that a more reasonable bias value puts the Soviets substantially in compliance with the treaty. Bache counters that there are not nearly enough data on the Soviet test sites to resolve the question and he points to studies indicating that the U.S. government's value is too *large*, resulting in estimates that are too low. The Reagan administration still maintains that the Soviet yields probably violated the TTBT, but it seems to be drawing more and more on what it says is "nonseismic" evidence of Soviet cheating.

Administration officials have been careful to use the word "likely" in their statements on Soviet violations because all yield estimates are inexact. Sykes places this uncertainty at 30 percent at one standard deviation, which he says is really not that different from the 41 percent estimate of government sources. Sykes estimates that if the Soviets were to violate the TTBT with a 300 KT test (which is thought to be militarily significant), and given a 41 percent uncertainty in yield, there would be an 84 percent chance that the U.S. seismic network would register the explosion as being at least as large as 212 KT, and there would be a 98 percent chance that the event would be reported as greater than 150 KT. Sykes concludes that these probabilities are sufficiently high to deter the Soviets from cheating.

But the Reagan administration and others apparently disagree and think the accuracy should be improved. The big problem with verification today is that the Soviets have easy access to geologic and seismic information about the United States while data about the USSR are rarely made available to U.S. scientists, says Bache. "We just make guesses about the USSR," he says. "And then we argue among ourselves." Some of the un-

The Long, Hard Road of Test Ban Treaties

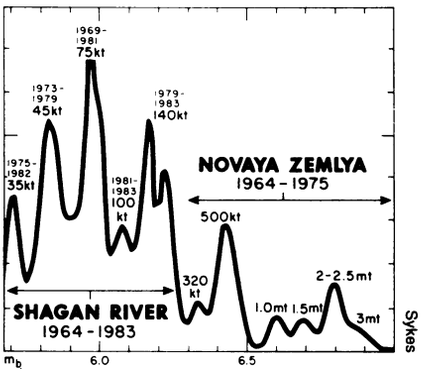
Since the Eisenhower administration, the United States and the Soviet Union have pursued a Comprehensive Test Ban Treaty (CTBT) in hopes of putting an end to all nuclear explosions in or near the earth. But 30 years after the Soviets made the first overture to halt nuclear weapons testing, both countries continue to detonate about 30 nuclear weapons per year.

The attempts to negotiate a CTBT have been frustrated by political and technical concerns over verification. According to Warren Heckrotte, a past member of the U.S. delegations for a number of treaty talks, the U.S. position from the start has been that "adequate verification" required U.S. seismic stations inside the USSR. U.S. officials also wanted to be able to inspect, with radiation and seismic equipment, the sites of events that could not be classified as either an earthquake or an explosion. The Soviets, on the other hand, originally maintained that National Technical Means — equipment such as seismic stations and satellites operated by one nation outside the country whose activities were being monitored — were all that was needed for verification. But, over the years, the Soviet position gradually changed, says Heckrotte, a physicist at Lawrence Livermore (Calif.) National Laboratory. With each new treaty signed over the last 20 years the Soviets moved closer and closer to allowing the United States its requirements:

- *Limited Test Ban Treaty (LTBT). Unable to reach any agreement on early CTBT talks, the Soviet Union, the United Kingdom and the United States in 1963 signed instead the LTBT, which prohibits nuclear testing in the atmosphere, oceans and space. The LTBT was ratified by the U.S. Senate in 1963.*
- *Threshold Test Ban Treaty (TTBT). The TTBT, signed in 1974, limits underground nuclear weapons tests to a maximum of 150 kilotons each. The treaty requires that each party provide the other with data such as the locations of tests and the properties of the rocks close to the test sites as well as the yield, time, depth and coordinates for two nuclear weapons tests from each geophysically distinct test area. This information has not been exchanged, largely because the U.S. Senate has yet to ratify the treaty.*
- *Peaceful Nuclear Explosions Treaty (PNET). Unlike the United States, which stopped its peaceful nuclear explosion program in the mid-1970s, the Soviet Union uses a few nuclear explosions for peaceful purposes such as creating large underground cavities for the storage of gas condensate. In 1976 the PNET was signed, which ensures that no single peaceful nuclear explosion exceed 150 kilotons and no group of peaceful explosions exceed 1.5 megatons. For total group yields greater than 150 kilotons, the Soviets agreed, for the first time, to allow U.S. personnel to observe and measure the yields of the explosions in the USSR. Again, however, this has never been carried out, in part because the treaty was never ratified by the U.S. Senate.*

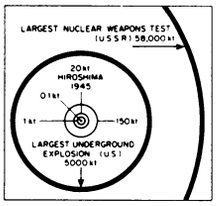
By the end of the latest round of CTBT talks, the Soviets had agreed in principal to having U.S. seismic stations in their country as well as to on-site inspections — the two original U.S. requirements for adequate verification. In spite of the change in Soviet attitudes, however, the Reagan administration withdrew the United States from the CTBT talks in 1982, citing problems that still exist with verification. U.S. officials say they are reluctant to submit the TTBT for ratification (even though the Senate passed a resolution urging Reagan to do so) because they do not think the TTBT can be verified either. According to Robert Barker, Deputy Assistant Director for Verification and Intelligence at the Arms Control and Disarmament Agency, the United States has approached the Soviets but thus far they have "rejected all our proposals to meet and confer on verification improvements." —*S. Weisburd*

certainty about yield estimates could be reduced if the provisions of the TTBT and PNET, involving the exchange of information on tests and geology, were carried out (see box). But because neither treaty has been ratified by the United States, the Soviets have not been compelled to comply with this aspect of the treaties.



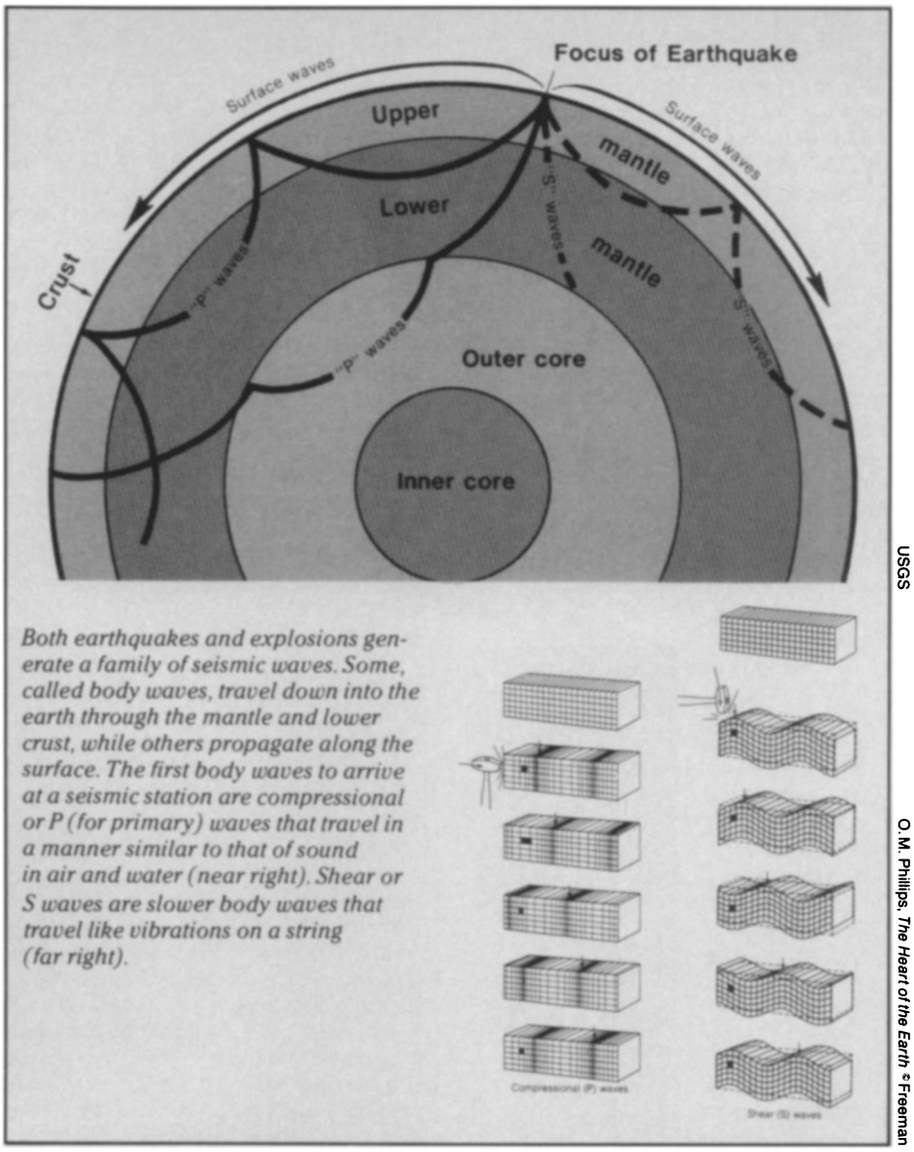
Sykes

A histogram represents the number of Soviet tests conducted over time as a function of m_b, or the magnitude of the body waves they generated. According to Sykes, the yields estimated for these explosions indicate that the Soviets have not exceeded the 150-kiloton limit set by the Threshold Test Ban Treaty since the agreement was signed in 1976. The Reagan administration, however, does believe that the Soviet tests are likely to have violated the treaty.



Sykes

The yields of various weapons detonated to date. The Threshold Test Ban Treaty caps the maximum yield of a test today at 150 kilotons. Many U.S. scientists believe that the technology exists to detect explosions in the USSR with yields measuring about 1 kiloton.



USGS

Both earthquakes and explosions generate a family of seismic waves. Some, called body waves, travel down into the earth through the mantle and lower crust, while others propagate along the surface. The first body waves to arrive at a seismic station are compressional or P (for primary) waves that travel in a manner similar to that of sound in air and water (near right). Shear or S waves are slower body waves that travel like vibrations on a string (far right).

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The debate over yield estimates was reportedly rejuvenated within the government this year after two advisory panels to the Department of Defense (DOD) considered the use of surface waves — seismic signals that travel along the surface of the earth — in addition to the body waves now used in yield estimates of big explosions. In a May 13 letter to DARPA, Thomas H. Jordan, a geophysicist at Massachusetts Institute of Technology and chair of the DOD Technical Review Panel on Nuclear Test Ban Verification, summarized the panel's findings: "Although serious problems have been identified in the procedures currently employed to determine yield from M_s [surface wave magnitude] observations, the Panel is unanimous in its belief that methods for obtaining reliable yield estimates from surface-wave data are now available." The thrust of the panel's report was that the most recent analysis of surface wave data indicates that the body wave bias value presently used is too low, fortifying the view that the official estimates of Soviet yields are too high.

The advantage of surface waves is that, unlike body waves, their propagation is not affected by the properties of the mantle and lower crust. But they can be contaiminated by other surface signals, essentially small earthquakes triggered by an explosion in a process called tectonic release when the crust is in a state of stress. But scientists can tell which signals have been contaminated the least and some maintain that the tectonic signals can then be filtered out.

Bache, however, argues that "no one can be sure that they can correct for tectonic release with any great precision." Others disagree. Jordan thinks that by applying new seismic models and data analysis methods, the accuracy of surface wave measurements can be made comparable to that of body waves. Hannon also thinks that surface waves have a potential for complementing body wave measurements for large explosions but adds that more research is needed to explore how surface waves depend on the geology near the source of the event.

In the midst of all the technical debates and calls for more research, one idea emerges that is openly agreed upon by all involved: There is no such thing as a perfect verification system. There will always be uncertainties in the estimates of yields for a TTBT. And for a Comprehensive Test Ban, there will always be limits to the minimum magnitude of seismic waves that can be detected and identified as nuclear explosions.

The solution to verifying test bans, as well as to curbing the nuclear arms race — if there is one — is fundamentally political, say many scientists. How much uncertainty are we willing to live with? How much information are we willing to share in order to minimize those uncertainties? These are questions that ultimately get resolved at the negotiating table, not at the scientists' blackboard. □

Next: Verifying a Comprehensive Test Ban Treaty and the promise of monitoring high-frequency signals.