
False Accusations, Undetected Tests And Implications for the CTB Treaty

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Recent events have raised concerns about the ability of the United States to monitor compliance with the Comprehensive Test Ban Treaty (CTBT). The false accusation by the Clinton administration last year of a Russian underground nuclear weapons test at Novaya Zemlya, the surprise resumption of nuclear testing in May by India, and the lack of seismic signals from some of the announced Indian and Pakistani tests have been attributed to failures of the U.S. intelligence community, and have been presented as evidence that the CTBT cannot be verified and should not be ratified by the United States. An analysis of these events reveals, however, that while there may be deficiencies in intelligence procedures, the technical capability of the United States to detect underground nuclear weapons tests is remarkably good. Given that the objective of the CTBT is to deter proliferation by preventing the development of more advanced nuclear weapons, recent events demonstrate that the evolving verification regime can effectively monitor compliance with that goal.

While the treaty's International Monitoring System (IMS) is preparing to meet the routine requirements for CTBT verification, it is only one source of data that can be used to detect clandestine underground nuclear weapons tests. In addition to the

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global network used by the United States for national monitoring purposes (which shares some IMS stations), in many areas of the world seismic stations installed for scientific purposes such as studying earthquakes provide a capability that far exceeds that of the treaty's monitoring system. The intelligence community could take advantage of these resources to further improve U.S. monitoring capabilities. As more such data becomes available and global communications continue to improve, it now appears that the basic tenets of "good science"—consideration of all data, independent review and open access—may also, in many cases of relevance, be the new basic tenets for good treaty monitoring.

Monitoring the Test Ban

Since 1963, the United States has been monitoring the Limited Test Ban Treaty, which prohibits the testing of nuclear weapons in the atmosphere, in space and

underwater. With the possible exception of one ambiguous event in 1979, we have high confidence in the global accounting of all above-ground tests. The monitoring of testing underground has been the greatest technical challenge, and one that has consumed, either sincerely or disingenuously, most of the negotiations during the four decades the world has pursued a comprehensive test ban.

For underground explosions, the principal monitoring burden falls upon seismology. The seismic signal from an explosion must be detected, the source of the resulting seismic waves must be located by combining data from several seismic stations, and the seismic signal must be recognized as originating from an explosion rather than a naturally occurring earthquake. It is therefore the capability of the seismic monitoring system that defines the baseline capability of the CTBT verification system.

The IMS and its associated International Data Center (IDC) began prototype operations in January 1995. When fully operational, the system's seismic monitoring network will consist of 50 primary stations and 120 auxiliary stations. The primary stations are used to detect seismic events, and the auxiliary stations are used to help determine an event's location, magnitude and seismic characteristics. The network is expected to detect all seismic events anywhere in the world of magnitude 4 or larger on the Richter scale, and to locate those events within a 1,000-square-kilometer error ellipse, the maximum area permitted for an on-site inspection under the terms of the treaty. In addition, the IMS is supplemented with a radionuclide monitoring network, a hydroacoustic network to monitor underwater disturbances, an atmospheric infrasound network, and an on-site inspection mechanism. More than three-quarters of the seismic stations are already

operational, and the prototype IDC is currently detecting and locating nearly 100 seismic events each day. Hence, the worldwide monitoring regime is already partly in place and provides a means for assessing future performance.

Verification, of course, can never be achieved with 100-percent confidence. There will always be some level of nuclear testing below which the United States will not be able to monitor with high confidence using seismic means alone. Discovery of very small tests below the seismic threshold would depend on unquantifiable information from human or signal intelligence or photo reconnaissance. Although, the possibility of such information provides a further deterrent to the clandestine testing of low-yield nuclear devices, our ability to enforce the objectives of the treaty is measured by the efficacy of the monitoring system. In the case of the CTBT, the objective

of the treaty is to deter proliferation. The approach is both technical and political: The technical approach is to limit the arms race by restricting the development of more advanced nuclear weapons that require testing, specifically, thermonuclear weapons. The political approach is to remove nuclear testing as an emblem of power and prestige, and as a potent, albeit casualty-free, gesture of intimidation.

From the technical perspective, it is generally accepted that a first-generation nuclear weapon of simple design and modest yield can be developed without testing. For weapons that are readily deployable on ballistic missiles or on the battlefield, as well as more powerful thermonuclear weapons, testing would almost certainly be necessary to attain confidence in their capability. For effective deterrence of such weapons development, the baseline goal for the seismic monitoring system has been

detection and characterization of explosions corresponding to a magnitude of about 4 and larger. This threshold roughly translates to an equivalent yield of 1 kiloton (1,000 tons) of high explosives, if the energy of the explosion is efficiently transmitted, or "coupled well," to the surrounding rock. In many places around the globe, including the locations discussed in this article, the monitoring threshold is significantly better than the IMS baseline.

The Austrian statesman Prince von Metternich wrote that "war is diplomacy by other means." The same can be said for underground nuclear testing. Some policymakers look back at the Reagan military buildup as the final "offensive" that helped win the Cold War. A vigorous U.S. nuclear weapon testing program, with explosions chattering unmistakably on seismometers in the Soviet Union, was viewed as an essential component of U.S. resolve in the face of the perceived Communist threat. In May 1992, China reminded the world of its thermonuclear capabilities with a magnitude 6.6 explosion at its Lop Nor test site.

In May 1998, India added a twist to these tactics: Indian officials held a news conference and announced a test series that enabled New Delhi to claim a thermonuclear capability. India's move also provided Prime Minister Atal Behari Vajpayee with the political opportunity to self-proclaim: "India is now a nuclear-weapons state." The predictable outcome was a regional arms race on the subcontinent. Less than three weeks later, on May 28, Pakistani Prime Minister Nawaz Sharif announced, "[W]e have settled a score and have carried out five successful nuclear tests." Islamabad upped the ante two days later with another test.

The CTBT regime is responsible for confirming that all signatory states forgo the technical benefits of nuclear testing. Allegations of a clandestine Russian test at the Novaya Zemlya test site in August 1997 provide a useful test of the regime's monitoring efficacy in this regard. And, the recent testing by India and Pakistan—both non-signatories of the CTBT and the nuclear Non-Proliferation Treaty (NPT) which, for non-nuclear-weapon states, contains an implicit ban on testing by its prohibition against the production or acquisition of nuclear explosive devices—provides a perspective on the political utility of the CTBT.

Novaya Zemlya

On August 20, 1997, Secretary of State Madeleine Albright issued a *demarche* to the Russian Government, asserting that a prob-



AFP Photo/John MacDougall/Corbis

Above, Indian soldiers patrol the edge of the collapse crater formed by the May 11 underground nuclear test at Packhran.

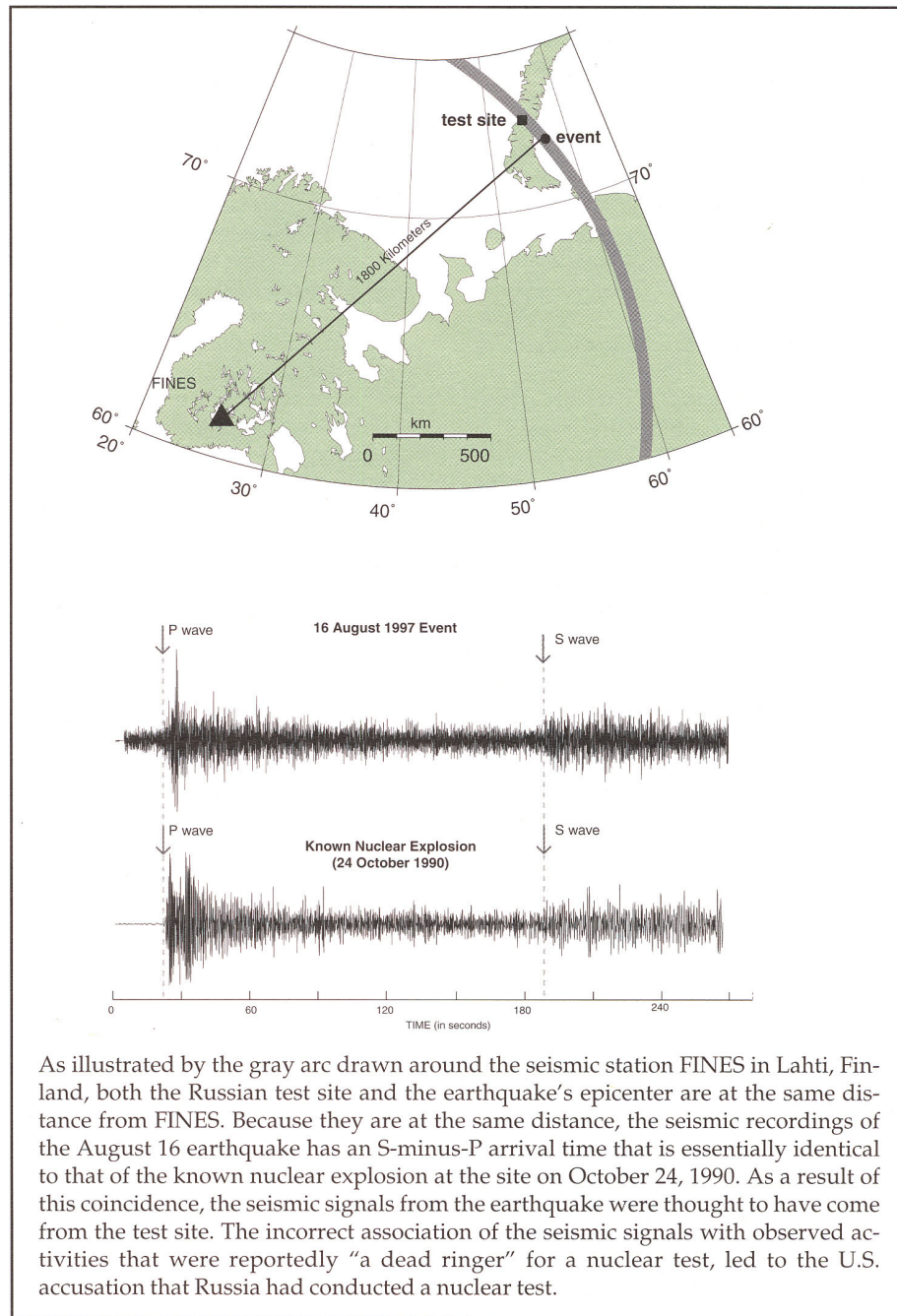
able underground nuclear explosion had taken place on August 16 at the Russian test site on the Arctic island of Novaya Zemlya. Such an explosion would violate international law by defeating the “object and purpose” of the CTBT (which Russia, the United States and nearly 70 other countries signed in September 1996), and would constitute a violation of the announcement requirements for the 1974 Threshold Test Ban Treaty. At the same time that the U.S. government was claiming that a “probable explosion” had occurred, independent seismologists were publishing analyses demonstrating that the August 16 event was a naturally occurring earthquake in the Kara Sea, more than 130 kilometers from the test site. How could the administration have mistaken such an earthquake for an underground nuclear explosion?

According to press reports, the United States had observed, via satellite imagery, activities at the Novaya Zemlya test site on August 14 and August 16 that were “a dead ringer” for preparations for a nuclear test. Although such activities could indicate a nuclear weapons test, they could also have a more innocent explanation: they could have been associated with subcritical or hydrodynamic experiments at the test site. Such experiments use conventional high explosives to create high pressures on nuclear weapons materials, such as plutonium, in a configuration where no self-sustaining nuclear fission chain reaction takes place. Because there is no nuclear yield, these experiments are not prohibited under the CTBT.

The United States conducts such experiments at the Nevada Test Site, and Russia has stated that it conducts similar experiments at its test site on Novaya Zemlya. The on-site preparations and safety procedures for these types of tests are nearly identical to those followed for the detonation of a nuclear device and, presumably, would appear to satellite surveillance as “a dead ringer” for an actual test. Because they release a relatively small amount of energy from the conventional explosives, these experiments do not produce significant seismic signals and would not normally be detected by seismic networks. But on the morning of August 16, a magnitude 3.5 seismic event was, in fact, detected.

The standard procedure for locating seismic events uses the difference in arrival times between the compressional waves (P waves) and slower shear waves (S waves), much as one can deduce the distance to a thunderstorm by timing the interval between the lightning flash and the thunder that follows. Although they are generated

Figure 1: Recordings at FINES (Finland)



simultaneously, S waves travel through the Earth at approximately one-half the speed of P waves. The difference between the arrival times, called the S-minus-P arrival time, is a measure of the distance to the seismic event. The general rule of thumb is that the seismic event occurred about 8 kilometers away for each second that separates the P waves and S waves.

By coincidence, the Russian test site and the epicenter of the August 16 earthquake are almost exactly the same distance from a seismic station in Lahti, Finland

(known by its code name FINES), which the United States uses to monitor the Russian test site and which is part of the IMS primary network. (See Figure 1.) According to one report, “Analysts suspected the seismic activity was a test, based on comparisons with seismic signatures detected during nuclear tests carried out by the Russians in 1990.”¹ The only known Soviet test in 1990 was the October 24 test at Novaya Zemlya. Figure 1 shows the recording at FINES for both of these events. As expected, the S-minus-P arrival times appear nearly iden-

tical, thus leading analysts to infer that the seismic signals came from the test site.

By relying on only stations that are part of the U.S. monitoring system and ignoring data from other stations, the initial analysis resulted in an error ellipse that included both the earthquake's epicenter and the Russian test site. (See Figure 2, left.) The coincidence of a seismic event located at the same time and in the same place as observed activity that resembled preparations for a nuclear test would have led a community, trained to be suspicious of coincidences, to assume that the Russians had detonated a nuclear explosion.

In many ways, the occurrence of an earthquake in such a place and at such a time seems simply the random occurrence of bad luck. This bad luck, however, was self-inflicted by the intelligence community. If the analysis had included other available data, as was done by the prototype IDC, the location would have demonstrated that the seismic event did not correspond to the observed activity at the test site. For example, using data from another seismic station in Kevo, Finland (known by its code name KEV), the S-minus-P arrival time differences between the known nuclear explosion at Novaya Zemlya on October 24, 1990, and the August 16 event show that the

August 16 event must have occurred at least 80 kilometers away from the Russian test site. (See Figure 3.)

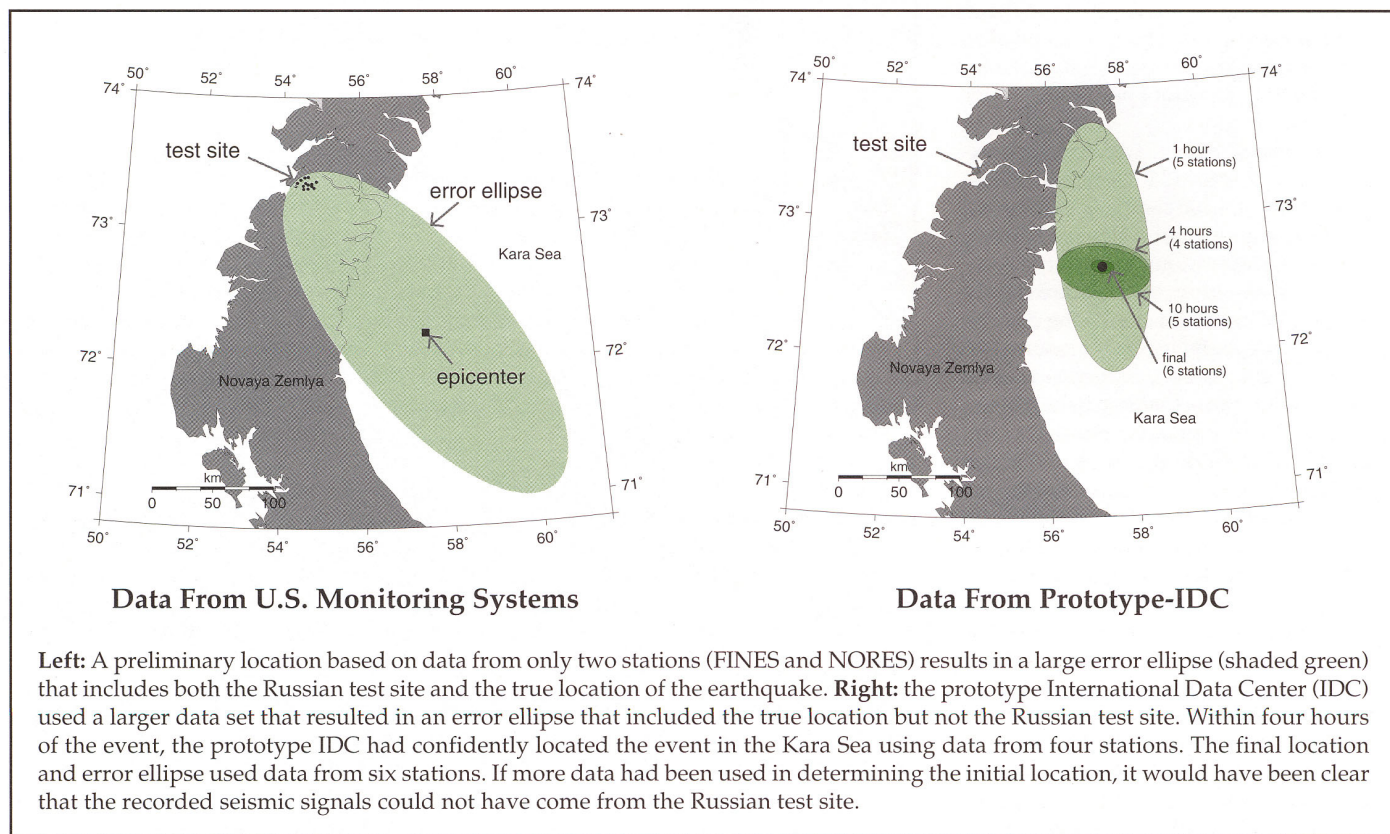
Despite the relatively small magnitude of the August 16 event (3.5), it was detected at six stations used by the prototype IDC. Figure 2 (right) illustrates the prototype IDC location estimate one hour after the event (using three stations), four hours after the event (using four stations), 10 hours after the event (using five stations), and the final location (using six stations). If the U.S. intelligence community had followed procedures similar to the prototype IDC and not excluded much of the available data, it would have been known within the first few hours that the event was located offshore and away from the Russian test site. The August 16, 1997 miscall was more the result of flawed methodology than bad luck.

In retrospect, location was not the only discriminant available to identify the August 1997 event as an earthquake. Explosions and earthquakes impact the surrounding rock differently, and so create P waves and S waves differently. P waves, which resemble sound waves, are created by compression. They are generated by explosions, in either rock or water, more strongly than S waves. S waves are created

by shearing motions. Earthquakes, in which rock slides along a fault surface, can generate large S waves relative to P waves. The open seismic station at Kevo, Finland, which had recorded several small explosions at the Russian test site, was closer to Novaya Zemlya than the station in Hamar, Norway (NORESS) and FINES. Comparison of these archived seismic records with the KEV record of the August 1997 event demonstrates clearly that the S wave of the latter is large relative to the S wave of the nuclear tests. (See Figure 3.) This confirmed the conclusion that the event was an earthquake.

The Novaya Zemlya incident demonstrates that monitoring requires the use of all available resources. As more seismic stations are installed and as nations continue to use test sites for hydrodynamic experiments, there will be more coincidences like August 16. Areas, such as Novaya Zemlya, that are generally considered seismically inactive at thresholds of magnitude 4.0 to 4.5, will appear seismically active at the lower magnitude levels of 2.5 and below that are detectable with regional coverage (that is, within a few hundred kilometers). Open networks in the western United States, where the seismicity is even greater and the coverage more extensive, provide

Figure 2: Location of the Novaya Zemlya Incident



a detection threshold below magnitude 2.2 for the U.S. nuclear test site in Nevada (equivalent to a yield of 0.02 kilotons (20 tons) of high explosive). In fact, on the day the United States conducted its second hydrodynamic test, four earthquakes were recorded at the Nevada Test Site.

Nuclear Testing in South Asia

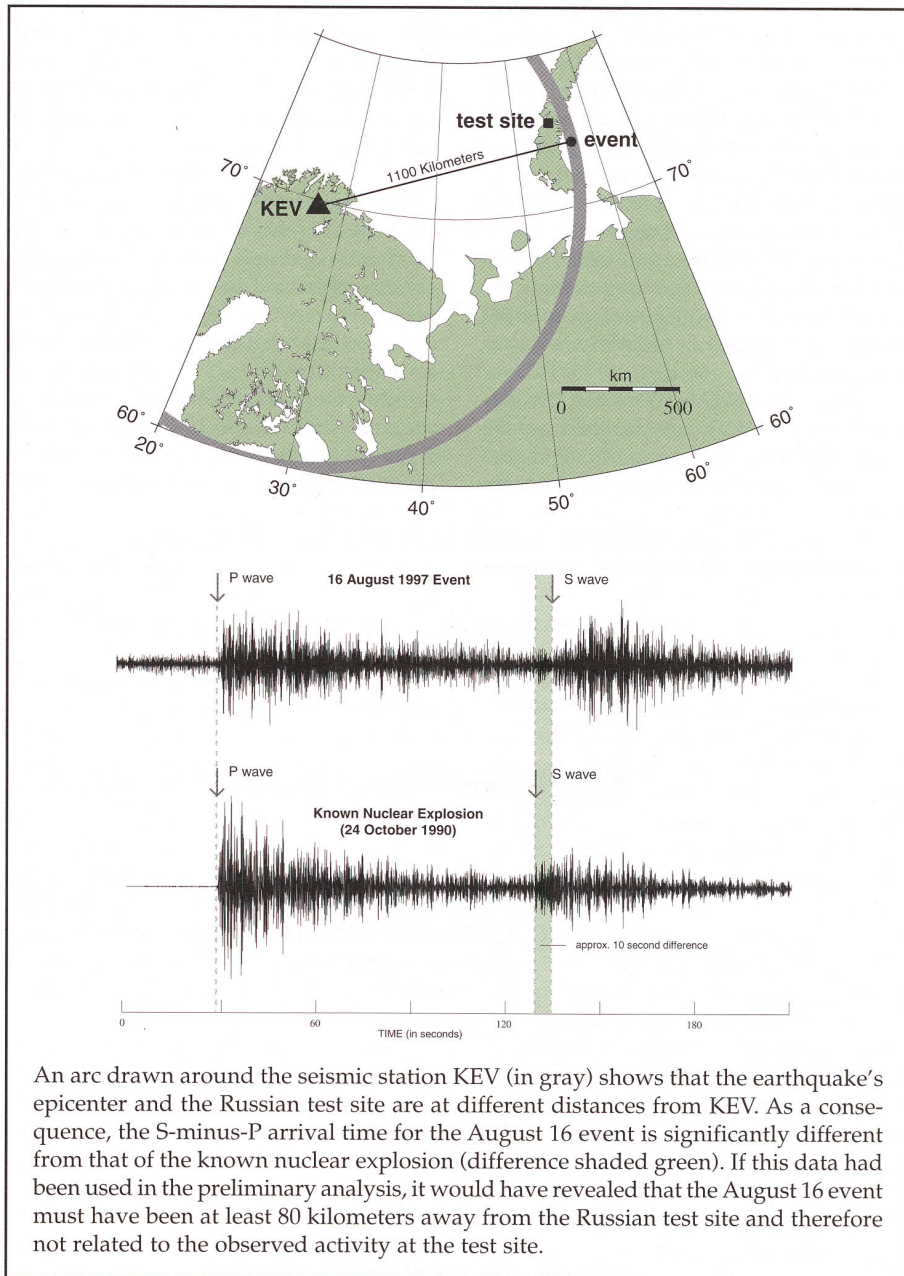
As previously discussed, the CTBT monitoring system must meet not only the technical objectives of the treaty, but also the political objectives. The capability of the monitoring system to perform in this role has been recently demonstrated during the resumption of testing by India and Pakistan.

On May 11, 1998, India announced the detonation of three underground nuclear explosions. After two more tests on May 13, Indian scientists provided some specifics about the explosions. They described the purpose of the tests as being to refine the design of a fission bomb and to develop a thermonuclear weapon. According to the scientists, the May 11 tests included a 43-kiloton thermonuclear explosion, a 12-kiloton fission explosion and a 0.2-kiloton fission explosion. The nuclear devices were detonated simultaneously in two deep holes, drilled roughly 1,100 yards apart. The May 13 tests were reported to have had yields in the range of 0.2 to 0.6 kilotons, and were intended to develop a capability for future hydrodynamic experiments. The May 13 devices were also detonated simultaneously.

Although India's tests reportedly took the U.S. intelligence community by surprise, the seismic waves that they created were recorded by 62 stations used by the prototype IDC. Indian officials could not hope that a seismic signal with magnitude 5.2 would evade detection, and the seismic waveforms were unmistakably explosive in nature. (See Figure 4.) In addition to confirming that a nuclear explosion had occurred at the Indian test site, the seismic data allows independent evaluation of the validity of India's claims.

Most of the energy released in an underground explosion (as is the case with an earthquake) is lost as heat or is expended to fracture rock close to the shot point. Less than 1 percent of the energy goes into seismic waves that travel long distances. The effectiveness with which explosions generate seismic waves strongly depends on how well the explosions are coupled to the surrounding rock, and how efficiently the region transmits seismic waves. Extrapolating from U.S. explosions at the Nevada Test Site and from measuring yields of Russian

Figure 3: Recordings at KEV (Finland)



An arc drawn around the seismic station KEV (in gray) shows that the earthquake's epicenter and the Russian test site are at different distances from KEV. As a consequence, the S-minus-P arrival time for the August 16 event is significantly different from that of the known nuclear explosion (difference shaded green). If this data had been used in the preliminary analysis, it would have revealed that the August 16 event must have been at least 80 kilometers away from the Russian test site and therefore not related to the observed activity at the test site.

tests in Kazakhstan and Novaya Zemlya, French tests in Algeria and Chinese tests at Lop Nor, a magnitude 5.2 seismic event at the Indian test site should correspond to an underground nuclear explosion with an equivalent yield of approximately 12 kilotons of high explosives. Without explosions of known size with which to calibrate the relationship between seismic magnitude and explosive yield at this particular site, the 12-kiloton estimate has significant uncertainty. The true yield could be as low as 5 kilotons or as high as 25 kilotons because of the previously described geological factors.

The absence of any other seismic signals, either before or after the magnitude 5.2 signal, confirms that if India did conduct three separate tests on May 11, all three devices must have been detonated within a fraction of a second and in close proximity. Simultaneous detonations were common in the testing programs of both the United States and the former Soviet Union, primarily for economic reasons. However, the size of the seismic signal is inconsistent with India's claims about the yield of its explosions. From Indian announcements, the May 11 seismic signal was created by the cumulative release of 43-, 12- and 0.2-

kiloton explosions. In other words, we would expect to see a seismic signal produced by about 55 kilotons. The seismic measurements, however, indicate a yield (12 kilotons) less than a quarter of that. In fact, 5.2 is among the largest of several estimates of Richter magnitude for the Indian tests obtained from open seismic data, other estimates have been as low as 4.7.² Assertions by Indian officials that interference effects would lower the combined yield do not hold up to scrutiny, owing to the wide distribution of recording stations and the broad range of oscillation periods in the recorded data.

Geological explanations for the discrepancy between announced yield and the recorded seismic signals could include the possibilities that the explosion was poorly

coupled to the surrounding rock, or the region surrounding the test site does not transmit seismic waves efficiently. Recordings of earthquakes and other seismic evidence indicates that the region of the Indian test site transmits seismic waves quite well, ruling out the latter explanation. Poor coupling to surrounding rock could occur if the seismic signals were muffled by detonating the explosion in a large underground cavity. Such a scenario does not make much sense in this case, however, as the Indian test was meant to be seen by the world.

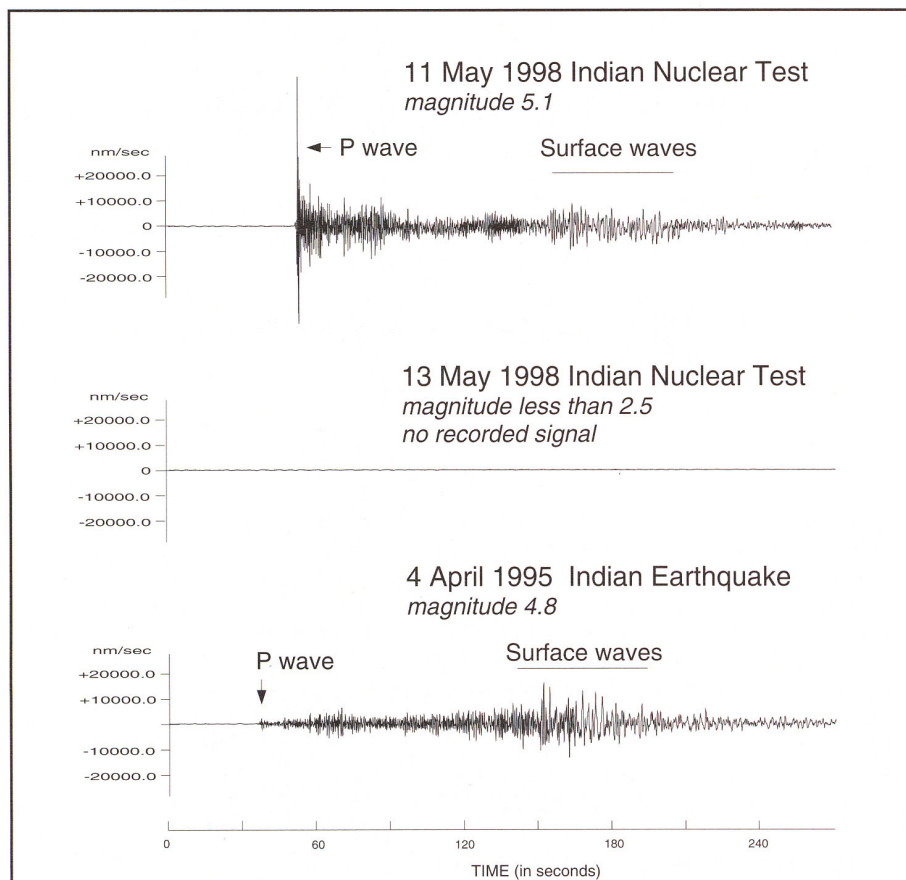
The only other test that occurred in the Rajasthan desert was the 1974 Indian test, which produced a seismic signal of magnitude 4.9. Although India initially announced the yield as 12 kilotons, later reports suggested that the yield was only 8

kilotons, or perhaps even smaller. The yield determined from the seismic magnitude is roughly 5 kilotons. The collapse crater formed by the 1974 Indian test is also consistent with an explosive yield of 3 to 5 kilotons. Close examination of seismograms from a seismic monitoring array in Canada that recorded both Indian tests suggests that the yield ratio of the 1998 and 1974 tests is close to two. Even if the 12-kiloton announced yield for the 1974 test is taken as correct, the May 11, 1998 test series scales to only half that claimed.

India's claims for May 13 tests appear even less plausible than those for May 11. Even though their announced yields of 0.2 and 0.6 kilotons are below the targeted global threshold of the CTBT monitoring system, one would still expect to see the seismic signal from these explosions at stations close to the test site. The IMS does not yet have stations operating in either India or Pakistan, but there are other stations, not part of the official monitoring system, from which data are available. One of these stations, in Nilore, Pakistan, is only 750 kilometers from the Indian test site. The station, which is part of the IRIS Global Seismographic Network, was installed by the University of California, San Diego, and is operated in cooperation with the Pakistani Nuclear Centre. The data from Nilore are available in near real-time via the Internet. For May 13, there is no seismic signal recorded at Nilore corresponding to India's announced nuclear tests.

Judging from the signal-to-noise ratio at Nilore for the May 11 test (600:1 overall, and 250:1 at the higher frequencies one expects for small nuclear tests), we would expect to see any seismic event at the Indian test site with magnitude larger than 2.5. An explosion of about 0.01 kilotons (10 tons) or larger should be evident in the Nilore data. Later Indian press releases said that detonation occurred in "a sand dune." If the device was poorly coupled to the surrounding rock, either because it was detonated in loose sediment or for similar reasons, it is possible for a somewhat larger blast to escape detection. In a rather generous estimate of possible geological factors, a magnitude 2.5 event could correspond to an explosion of up to 0.1 kilotons, well short of the 0.8-kiloton total yield claimed. Larger amounts of muffling have been achieved in the U.S. and Russian nuclear testing programs by exploding a device in a large cavity, but there is no indication that India had attempted this type of evasion scenario. India's claim for May 13 has either been misinterpreted or New Delhi has overstated what occurred.

Figure 4: Events Recorded at Nilore, Pakistan



Above, recording of India's nuclear explosion at the IRIS Global Seismographic Network Station in Nilore, Pakistan, 750 kilometers from the Indian test site. Although this station is not part of the U.S. monitoring system (it was installed for scientific purposes), it is the closest open seismic station to the Indian test site. May 11 (top) shows the clear signature of an explosion, which can be compared to an earthquake of approximately the same magnitude (bottom). As seen in the middle, the record for May 13 shows no apparent signal, indicating that the May 13 test would have a combined yield of less than 0.01–0.02 kilotons, or if poorly coupled, 0.1–0.2 kilotons. The Indian government has claimed a combined yield of 0.8 kilotons for this date.

Pakistan Responds

In response to India's announcement of five nuclear tests, the prime minister of Pakistan announced six nuclear tests, five on May 28 and one on May 30. Pakistan's intentions were signaled in advance when data from the Nilore stations stopped being transmitted two hours before its first test.

Seismic waves, however, are not hindered by political boundaries, and the Pakistani tests were well recorded by other seismic stations throughout the region. The magnitude 4.6 seismic event on May 28 was recorded by 65 stations used by the prototype IDC, and the magnitude 4.3 seismic event on May 30 was recorded by 51 stations.

The magnitude 4.6 signal would indicate an explosion with an equivalent yield of about 10 kilotons of high explosives. The size is either the largest individual test or the sum of the yields of the simultaneous tests. The May 30 Pakistani test is 0.3 magnitude units smaller than the May 28 tests, indicating an explosive yield for May 30 that is half of May 28, or around 5 kilotons. Pakistan announced the yield of its first day of tests as having a total yield of 40 to 45 kilotons, including a large explosion of 30-35 kilotons. For the second day of tests, Pakistan announced a yield of 15-18 kilotons. As with India, the seismically estimated yields are significantly lower than what has been announced.

It must be remembered that both India and Pakistan are motivated strongly by domestic politics. India's ruling coalition led by the Hindu-chauvinist Bharatiya Janata Party (BJP) in Parliament has a thin majority that was in danger of collapsing from the moment it acceded to power in March 1998. Commentators on Indian politics note that a nuclear test was one of the few policy initiatives in the BJP election platform that would not splinter the voter base of its coalition. Middle-class Indians, especially, expressed strong support for the tests, and for the BJP as a result.

Once India tested, the Pakistani government concluded it had no alternative but follow suit. Since the end of British colonial rule in 1947, Pakistan has lost three wars to India over disputed territory in the Kashmir, including a humiliating two-week war in 1971 when Pakistan lost what is now Bangladesh.

When India announced its nuclear capability in 1974 with what they termed a "peaceful" nuclear explosion, Pakistan began its own nuclear weapons development program.

Implications for the CTBT

The advent of digital data, global communication networks, global positioning systems, geosynchronous time and other technologies have irrevocably changed the environment for gathering intelligence and monitoring arms control agreements. Thousands of openly accessible resources now produce data that can be used to detect a clandestine nuclear explosion. Internet sites containing such data are likely to appear before intelligence information can be digested by governments or before memos can work their way through bureaucratic channels. In this new environment, the technological challenge may no longer be the acquisition of data, but rather the coherent integration of the vast and continually evolving network of global information sources. In many cases, some of the expertise required for making such assessments will lie outside of the federal government.

These recent incidents involving false accusations and allegedly missed violations are not a failure of the CTBT monitoring system, but rather a symptom of the transition from the past procedures of the Cold War to the new environment of open multi-use resources. In the case of the August 1997 event near Novaya Zemlya, intelligence analysts neglected to use openly available data that was outside of their official monitoring system. A false alarm resulted. In the case of India's and Pakistan's tests, the variety of independent assessments of explosive yield, from widely differing sources of open data, lends weight to the suspicion that the South Asian nuclear blasts were not as large as claimed, with possible implications as to how advanced their respective programs truly are.

In each incident, some of the most important data were provided by resources that are not part of the official monitoring system. There are thousands of seismic stations deployed around the world as part of regional networks designed to study seismicity and assess earthquake hazards. For many areas, the dense coverage of these regional networks provides a detection capability that is better than that of the official systems. All of these resources provide a strong additional deterrent to any country considering violating the CTBT. With time, this capability will continue to improve as more seismic stations are installed, more research is performed and more data become available directly through global computer communication networks.

The discrepancies between the seismic data and the announcements made by In-

dia and Pakistan have been taken by some as evidence that the CTBT monitoring network is not up to the task. A careful review of the facts, however, indicates that such an assessment is inaccurate. Not only has the CTBT monitoring system demonstrated the capability to detect testing by both nations, it has provided an independent means to assess their claims. By performing an announced nuclear test, a nation makes a diplomatic show of strength. Unlike the appearance of an aircraft carrier battle group or even a May Day parade, nuclear testing is an international gesture that can be evaluated by other nations only with wide bounds of uncertainty. The nation that performs such a show of strength cannot be relied upon to present an objective assessment of its own technical abilities.

Despite the accumulation of seismic data and scientific interpretation, with all evidence pointing unambiguously toward skepticism of governmental claims, many policy-makers would want corroboration from other data sources before pronouncing a final verdict on the Indian and Pakistani tests. Any lingering doubts about the conclusions drawn from the monitoring data are difficult to resolve without access to the testing site. There is no current prospect of this. In a future without a CTBT, the international community would have little hope of inspecting the site of a rogue explosion.

While the world may never know the extent to which India and Pakistan overstated their nuclear tests, the lessons offered by the May events are clear. Without the global norm against nuclear testing provided by the CTBT, the United States could find itself again in an environment where genuine threats and high-stakes bluffs are communicated through nuclear testing. A ratified CTBT is the best tool to restrain this type of dialogue. [ACT](#)

NOTES

1. Bill Gertz. "Russia suspected of nuclear testing," *The Washington Times*, August 28, 1997, p. A1.
2. Richter-magnitude estimates can vary owing to geographic differences in the propagation efficiency of seismic waves. Magnitude 5.2 is a revised estimate from the U.S. Geological Survey (USGS), based on a large body of seismic data accumulated in the weeks following the explosion. The initial USGS estimate, based on less data and widely reported in the media, was 5.4. The prototype International Data Center estimated the Indian test to have magnitude 4.7. An estimate of 5.1 can be made based solely on data from the Nilore, Pakistan observatory. All estimates of nuclear yield in this article are based on the largest Richter magnitude that has not been revised, namely 5.2.