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The Politics of Verification: Limiting the Testing of Nuclear Weapons

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From 1982 to 1990, the United States and the Soviet Union renegotiated verification arrangements for two unratified arms control agreements that had nevertheless been observed since 1977: the Threshold Test Ban Treaty and the Peaceful Nuclear Explosions Treaty. The negotiations yielded new verification procedures, changed attitudes regarding Soviet compliance, and established useful precedents for further restrictions on nuclear testing. The negotiations also demonstrated how technical arguments can be misused to promote a particular political agenda—in this case, the continued testing of nuclear weapons. By misrepresenting the uncertainties in US monitoring procedures, and then falsely characterizing these uncertainties as a fatal flaw of seismic verification techniques, opponents of a nuclear test ban clouded the sensitive issue of verification enough to delay progress towards a complete ban on nuclear weapons testing. The primary obstacle to further restrictions on nuclear testing was not the feasibility of adequate verification, but rather the unwillingness of several US administrations to address the real question of whether the United States and other nuclear weapon states should, in the interest of global nuclear nonproliferation, end the development of new nuclear weapons designs that require confirmation by underground nuclear tests.

INTRODUCTION

On 25 September 1990, the United States Senate ended a nearly decade-long debate by unanimously consenting to ratification of two arms control agreements that were signed in the 1970s: the Threshold Test Ban Treaty (TTBT) and the Peaceful Nuclear Explosions Treaty (PNET). After completing negoti-

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The views expressed in this paper are the opinions of the authors and not of any institution with which they are affiliated.

ations on extensive verification protocols, the Bush Administration submitted the two treaties to the Senate with a statement declaring that an undefined period of implementation would be required before any further restrictions on nuclear testing could be considered. By prior agreement among the leadership of the Senate, no amendments were offered to a bipartisan resolution from the Foreign Relations Committee that paradoxically endorsed both the continuation of weapons testing and negotiations toward an eventual Comprehensive Test Ban Treaty (CTBT).

Though unratified for over a decade, the TTBT and PNET technically entered into force at their signing. Because neither country indicated an intention *not* to ratify the treaties, both parties were obligated under international law to refrain from any acts that would defeat the objective and purpose of the treaties.[1] Both countries stated that they were complying with the restrictions of the treaties.

Ostensibly, the debate that preceded ratification concerned the need to develop more accurate means of verification that would deter the recurrence of what the US government described as "likely" Soviet violations of the TTBT. However, the long delay in ratification reflected more disputes within the US government on the benefit of test limitation than it did genuine disagreements concerning verification.

President Carter, who began his administration by seeking a complete ban on underground nuclear explosions, withdrew the TTBT and PNET from the Senate. Rather than waste time and effort ratifying what he considered to be an intermediate step that contributed little to stopping the proliferation of nuclear weapons,[2] President Carter chose instead to pursue a complete ban on nuclear testing—a Comprehensive Test Ban Treaty. To proponents of further restrictions on nuclear testing, such as the Carter Administration, ratification of the TTBT and PNET posed a dangerous political risk. They reasoned that progress towards a CTBT could be derailed by affording the opportunity for opponents to attach restrictive conditions to the resolution of ratification that would effectively preclude early agreement on a CTBT.*

The Reagan and Bush Administrations, in contrast, were opposed to further restrictions on nuclear testing, claiming such restrictions were not in the US national interest. They considered ratification of the TTBT and PNET not as a waste of time, but rather as an essential first step that had to be taken before any further restrictions could even be considered. To opponents of further restrictions on nuclear testing, ratification of the TTBT represented a

* Because the US Constitution requires that the United States Senate approve treaties by a two-thirds majority, this provides the possibility of a one-third plus one "minority veto" of any arms control agreement.

treacherous first step on the slippery slope of arms control that could lead to further restrictions on nuclear testing, and a possible Comprehensive Test Ban Treaty. Prompt ratification of the TTBT and PNET in the early 1980s would have focused attention on the potential for negotiating more restrictive measures, which the Reagan and Bush Administrations sought to avoid.

ORIGIN AND STATUS OF NUCLEAR WEAPON TESTING LIMITATIONS

Threshold Test Ban

President Nixon and General Secretary Brezhnev signed the Threshold Test Ban Treaty at the Moscow summit on 3 July 1974, only a month before President Nixon resigned. While both leaders had harbored hopes for a strategic arms limitation agreement at the July summit, they recognized that their mutual inability to hammer out an internal political consensus on the future structure of their respective nuclear forces meant that a negotiated compromise would not be completed in time. Both leaders were therefore eager to reach quick agreement on a Threshold Test Ban Treaty to provide evidence of the summit's "success." The Threshold Test Ban Treaty limits the size of underground nuclear explosions by the United States and the Soviet Union to explosive yields no greater than 150 kilotons, or roughly ten times the yield of the bomb that was dropped on Hiroshima.

Peaceful Nuclear Explosions Treaty

The PNET was signed by President Ford and General Secretary Brezhnev on 28 May 1976. The PNET is a complement to the TTBT that prevents circumvention of the TTBT under the guise of non-military explosions used for industrial purposes such as excavation. The PNET restricts individual peaceful nuclear explosions by the United States and the Soviet Union to yields no greater than 150 kilotons, and group explosions (consisting of a number of individual explosions detonated simultaneously) to aggregate yields no greater than 1,500 kilotons. Due to the technical uncertainties associated with predicting the exact yield of a nuclear weapon test, provisions exist within both the TTBT and the PNET for one or two slight, unintentional breaches per year of the 150 kiloton limit.[3] These provisions are commonly referred to as the "whoops" clause.

The 150 Kiloton Yield Threshold

When the Nixon Administration first formulated its position on the limit above which testing would not be allowed, the director of the Arms Control and Disarmament Agency (ACDA) recommended a 75 kiloton threshold.[4] When President Nixon arrived in Moscow, however, he proposed a 100 kiloton threshold. Before the Soviets could respond, Secretary of State Kissinger amended the US proposal upwards after learning from Washington overnight that Secretary of Defense Schlesinger insisted on a minimum threshold of 150 kilotons.[5]

All three threshold levels were considered to be well within a range that could be readily monitored by seismic stations located outside the borders of the testing country. The 150 kiloton threshold was most likely chosen, not for reasons of verification, but for its minimal impact on the US nuclear weapons program, and for its removal of a possible asymmetry in the capability to conduct high-yield tests. Because high-yield underground explosions at the Nevada Test Site caused damage in Las Vegas, the United States could no longer conduct high-yield explosions in the continental United States. Although large tests could be (and already had been) conducted at an Alaskan site on Amchitka Island, such explosions were complicated by political and environmental considerations. The Soviet Union, on the other hand, was presumed to have continued use of its isolated test site on the Arctic island of Novaya Zemlya where, it was thought, it had tested underground to about 3,000 kilotons (three megatons) prior to the TTBT.[6]

Testing under the Threshold Treaties

Because the TTBT was designed not to take effect until April 1976—to permit completion of a companion treaty governing the conduct of Peaceful Nuclear Explosions (the PNET)—both sides were free for almost two years to test prototypes of a new generation of strategic missile warheads and bombs with explosive yields that, on the US side at least, were on the order of two to seven times greater than the treaty threshold. This period of intense high-yield testing before entry into force of the treaty lessened immediate perceptions of the military significance of uncertainties in estimating the yield of the other side's explosions. Each side assumed that the other had already acquired the high-yield test data it needed for its next generation of strategic weapons. According to the 1987 testimony of the then director of Lawrence Livermore Laboratory,

> Just prior to the [effective date of the] TTBT in 1976, we obtained enough data from high-yield US tests to permit us to certify the yields of new strategic sys-

tems, such as the MX and Trident II warheads, and the B83 bomb. For purposes of assessing the Soviet nuclear threat, we normally assume that they did similar high-yield tests prior to the TTBT.[7]

During the 14 years that elapsed between the effective date of the TTBT and its ratification, the US conducted approximately 220 underground nuclear explosions, and the Soviet Union conducted approximately 278 explosions.[8] In this period the Senate twice failed to complete the ratification process, with a number of senators expressing their concern that the size of Soviet explosions could not be measured with adequate confidence.[9] As a result, the United States continued to abide by a treaty to which the Senate had not given its consent. Meanwhile, the already marginal arms control significance of the TTBT and PNET was diminished by improvements in missile accuracy and nuclear yield extrapolation techniques—which lessened the strategic importance of high-yield tests—and by the phase-out of Peaceful Nuclear Explosions (PNEs). The United States' last PNE was detonated in 1973 as part of a test series under the Plowshares Program.[10] Although the Soviet Union had an active PNE program, environmental concerns within the country effectively brought the program to a halt in September 1988.[11]

Progress toward a CTBT

Since 1985, the Soviet Union and subsequently the CIS, has demonstrated a willingness to stop all testing if the United States would agree to do the same. In August 1985, the Soviet Union began a 19 month unilateral testing moratorium and offered to make the moratorium permanent if the US would join. The Reagan Administration declined to join the moratorium, and the Soviet Union resumed testing in February 1987. Despite the moratorium, the Soviet Union still managed to conduct 61 underground explosions in the four year period from 1984 through 1987. Over the same period, the United States conducted 62 underground explosions.

Two years after the Soviet Union resumed testing, two of its underground tests accidentally released radioactive material into the atmosphere. The accident initiated a Soviet grassroots environmental movement calling for the closure of the test site in Kazakhstan,[12] and a leader of the movement was elected to the Congress of the Peoples' Deputies.[13] At the beginning of 1990, Moscow announced that testing at Kazakhstan would be phased out over three years and moved to an existing test site on the Arctic Island of Novaya Zemlya. Testing in the Arctic, however, also faced opposition, notably from the newly elected President of the Russian Republic Boris Yeltsin, whose election platform included opposition to testing in Novaya Zemlya. The last test in

Kazakhstan occurred on 19 October 1989, and the last test conducted in the former Soviet Union was in Novaya Zemlya on 24 October 1990. In August 1991, the Semipalatinsk test site was permanently closed at the direction of the newly independent Kazakh Republic. Pending a CTBT, future nuclear tests in the newly formed Commonwealth of Independent States are likely to be infrequent and, it appears, restricted to the Arctic test site at Novaya Zemlya or some other remote site within the Russian Republic; and future PNEs seem unlikely.[14]

Russian President Boris Yeltsin, who has continued to seek negotiations on a CTBT, pledged that Russia would adhere to the one-year unilateral moratorium on testing initiated by then Soviet President Gorbachev on 5 October 1991. France, long considered one of the strongest opponents of a ban on testing, joined the moratorium on 8 April 1992, and urged reciprocal action by the United States.

On 27 February 1992 President Yeltsin quietly ordered the Ministry of Atomic Energy to resume preparations for conducting 2–4 tests at Russia's Arctic test site "in case of termination of the existing moratorium."[15] On 13 October 1992, responding to enactment of a nine-month US test moratorium imposed by the US Congress, the Russian Defense Minister announced, "If tests resume, it will not be before mid 1993."

Since the last Soviet/Russian test, the US has conducted over a dozen tests at the Nevada Test Site. In an attempt to forestall stronger legislative controls on the US nuclear test program, President Bush informed Congress in July 1992 that he had directed that future US nuclear tests be limited to six per year and conducted solely for purposes of assuring the "safety and reliability of our deterrent forces."[16]

In September 1992 the Congress approved the Hatfield-Exon-Mitchell Amendment, imposing a moratorium on US nuclear tests until 1 July 1993 and an end to all testing after 31 December 1996, unless another nation continues to test after that date. In the 42 month period between these two dates, the US government may conduct no more than 15 tests, including no more than three tests jointly with the UK, three tests for reliability, and the balance for weapons safety improvements.[17] The legislation also requires the next administration to report to Congress on its preparations to resume CTBT negotiations.

SEISMIC YIELD ESTIMATION

Any nuclear explosion as large as 150 kilotons is readily detected and identified by seismic stations throughout the world. At issue in the verification of the TTBT and PNET is whether the energy released in the explosion ("the yield") can be measured with sufficient accuracy to ensure that the explosion is not in excess of the 150 kiloton threshold limit. When the TTBT and PNET were negotiated in the 1970s, the United States and the Soviet Union intended to rely primarily on seismic measurements to estimate explosive yield and verify compliance.

Seismic yield estimation involves two steps. An average seismic magnitude for the explosion is first measured from the amplitude of seismic waves received at numerous seismic stations around the world.[18] Then the magnitude is translated into the yield of the explosion through empirical formulas determined from past explosions with known yields.

Originally, seismic yield estimation relied exclusively on the use of P-wave magnitudes (m_b). P waves are detectable at large distances even for small seismic events. The designation "P" refers to "primary"; P waves are usually the first waves to arrive at a recording station. P waves (also called compressional waves) travel through the body of the Earth in a manner similar to sound waves—that is, by molecules "bumping" into each other resulting in compression and dilation of the material through which they propagate. The particle motion is in the direction of travel, and the wave can propagate through both solids and liquids. The P-wave magnitude is computed from measurements of P-wave recordings through the formula

$$m_b = \log (A_{max}/T) + C \qquad (1)$$

where, as shown in figure 1, A_{max} is the largest amplitude (corrected for instrument magnification) in nanometers measured peak-to-peak from a short-period recording during the first few seconds of the P wave; T is the duration of one cycle of the wave in seconds near the point on the record where the amplitude was measured; and C is a location-dependent correction term that compensates for the change in P-wave amplitude with distance.

Once a seismic magnitude value has been determined by averaging measurements from several stations, the next step is to translate the magnitude measurement into the yield of the explosion. The data used to derive the original m_b–yield relationship are shown in figure 2 and are based on US tests in Nevada and French nuclear explosions in the Sahara. The general form of the m_b–yield equation is

$$M = A + B \log q + \text{bias correction} \qquad (2)$$

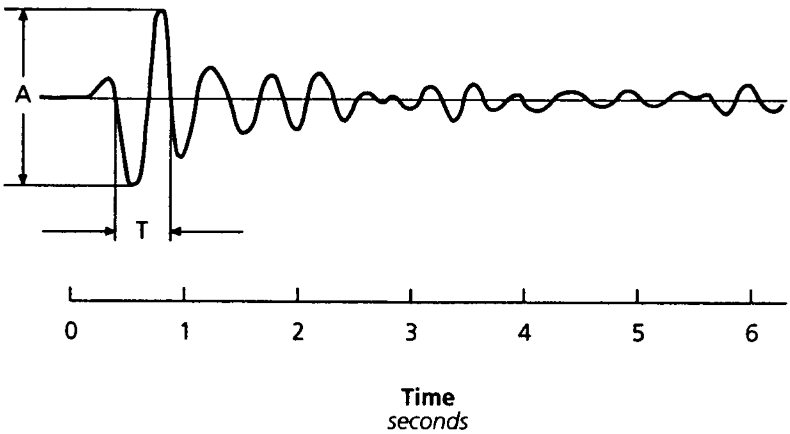

Figure 1: A typical seismic magnitude measurement made on P waves uses the peak-to-peak amplitude (*A*) in the first few seconds of the P wave corrected for the instrument magnification at the dominant period (*T*).

where M is the magnitude measurement, A and B are constants derived from test experience, and q is the yield in kilotons. The specific values of A and B used by the United States are classified. The bias correction term is an adjustment made to compensate for differences in the efficiency of seismic wave propagation through the geologic media underlying various test sites. This correction is particularly important for m_b, because short-period body waves are strongly affected by the physical state (especially temperature) of the medium through which they travel.

Seismic waves traveling under the main test site in Nevada are severely attenuated when compared to most other continental areas, especially those with no recent history of geologic activity. The attenuation (loss of amplitude) in Nevada is due to the high temperatures in the upper mantle, which has resulted in extension of the overlying crust. The high temperatures alter the elastic and absorptive properties of the rock, resulting in attenuation of seismic waves as they pass through. Similar properties exist under the French test site in Algeria, though not under the Soviet test sites in Kazakhstan and Novaya Zemlya or past US test locations in Mississippi and Alaska. As a consequence, seismic signals emanating from explosions in areas with little attenuation, such as Kazakhstan, will be larger than seismic signals from similar sized explosions in Nevada. If the P-wave magnitudes observed from US tests in Nevada are used as a basis for estimating the yields of Soviet explosions, they must be corrected for the bias between the two sites or else the size of the Soviet explosions will be overestimated.

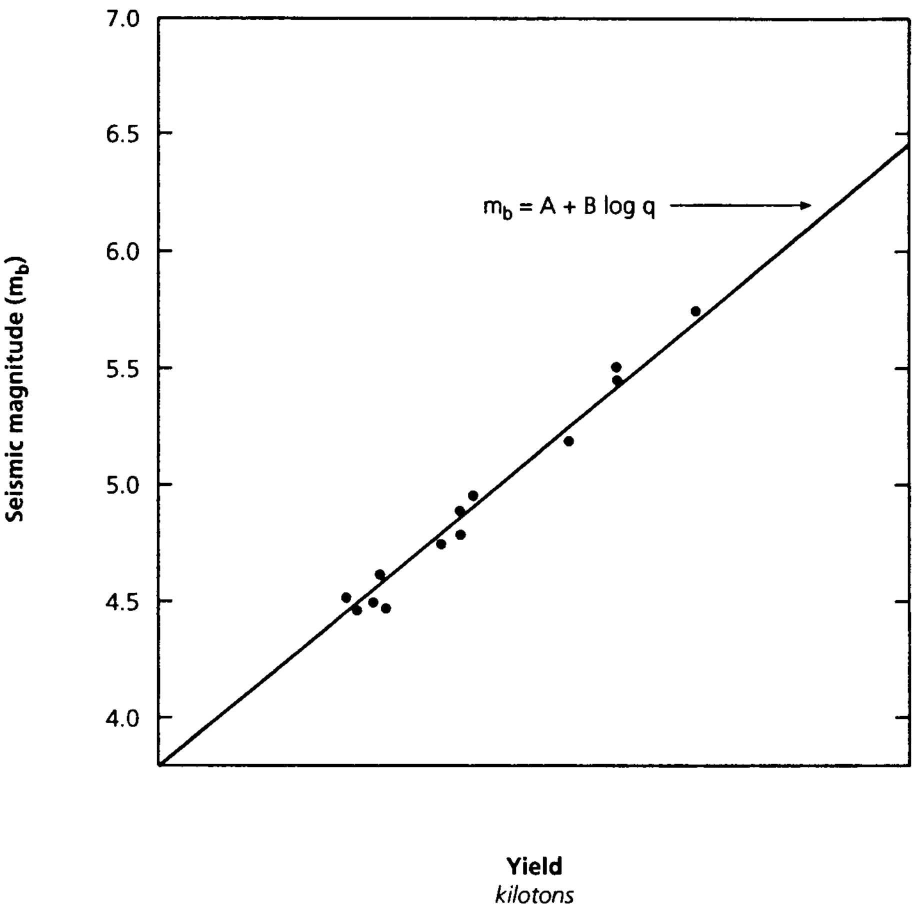

Figure 2: Data from US underground nuclear explosions in Nevada and French explosions in the Sahara for which the United States' empirical magnitude-yield equation is derived.

The need for a bias correction term had been recognized by the US as early as the mid 1960s. The nuclear explosion LONGSHOT, conducted at the Alaskan island site in 1965, had an announced yield of 80 kilotons. When its teleseismic P-wave magnitude was converted into a yield estimate using the Nevada-based formula, however, a value of 300 kilotons, 3.75 times greater than the announced yield, was obtained.[19]

To help determine the proper value of the bias correction between the US and Soviet test sites, and to reduce other sources of uncertainty in making such measurements—such as variations in "coupling" of the nuclear blast energy to different local rock types—the original protocol to the TTBT provided for the exchange of technical data upon ratification, including yield and other data for two nuclear weapons tests, for each geophysically distinct testing area; and it required that all explosions be announced in advance and conducted at these designated sites. Because the United States did not seek ratification of the treaty, however, this data exchange was not accomplished until June of 1988, more than twelve years after the effective date of the treaties.

If the best estimate of the bias correction is used, a few of the yield determinations of Soviet tests still appear to exceed the 150 kiloton limit. All of these tests, however, are within the expected random scatter. In fact, all of the Soviet tests are within the 90 percent confidence level that one would expect if the yields were 150 kilotons or less.[20]

In addition to P waves, magnitudes can also be determined by using the magnitudes of Rayleigh waves (M_s) and Lg waves (m_b(Lg)). Rayleigh waves are a type of surface wave, so named because they travel along the surface of the Earth. The motion of Rayleigh waves is somewhat analogous to that of ripples spreading over the surface of a lake. The Lg wave is composed of a family of seismic waves that are trapped in the upper crust of the Earth. The crust acts as a guide for the waves and efficiently transmits them great distances.* In fact, Lg can be so strong that, contrary to what is implied by its inclusion in the class of "regional" waves, it can be observed at distances well in excess of 2,000 kilometers across continents for large explosions. However, beneath oceans—where the crust is much thinner—Lg fails to propagate even short distances.

A measure of strength of the seismic source based on surface waves, called the "seismic moment" (M_0), can also be used for yield estimation. Seismic moment provides a measure of the force system acting in the Earth that would generate the same seismic waves as those observed from the explosion. The advantage of seismic moment over magnitude is that the computation corrects for contamination of the seismic signal due to the release by the explosion of any pre-existing stress that may exist in the surrounding rock. The release of built-up stress by the explosion creates a surface wave pattern similar to that observed for earthquakes, which is seen superimposed on the signals from the explosion.

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* Lg is a "regional" wave. Regional waves, in contrast with waves such as P waves and Rayleigh waves, are usually observable only at distances of less than 2,000 kilometers. In general, they have larger amplitudes and higher frequency content. Lg can be the most important regional wave because it is typically the largest wave observed on a seismogram at regional distances (less than 2,000 kilometers).

Uncertainty in Seismic Yield Estimates

In 1974, when the TTBT was first negotiated and signed, the yields of Soviet explosions were estimated using only P-wave magnitudes measured by seismic stations outside the Soviet Union. At that time, US seismic yield estimation methods were considered to be accurate within a "factor-of-2" uncertainty.[21] A factor-of-2 uncertainty implies, for example, that given a test with an actual yield of 150 kilotons, 95 percent of the measurements will be between 75 kilotons (150 divided by 2) and 300 kilotons (150 multiplied by 2), with the expected distribution centered on 150 kilotons as shown in figure 3.*

The factor-of-2 uncertainty attributed to US seismic methods was based on the use of only P-wave magnitudes from a test site that had never been calibrated by the United States with explosions of known yield. As a result, US yield estimates for Soviet tests were affected both by random uncertainty associated with the determination of the P-wave magnitude as well as by systematic uncertainty associated with the estimated bias correction between the US site, from which the magnitude-yield relationship had been determined, and the Soviet test sites.

The systematic part of the uncertainty could have been reduced by calibration shots—that is, by announcing the radio-chemically measured yield of explosions for which seismic signals have been recorded. Through such a process, individual magnitude-yield relationships could have been determined for each geophysically distinct area of the Soviet test site. The uncertainty created by applying (with a bias correction) the US magnitude-yield relationship to the Soviet test site would have been removed.

The random part of the uncertainty in yield estimation could have been reduced by combining different magnitude measurements. P-wave magnitude (m_b) is routinely used because the measure can almost always be obtained. P waves are detectable at large distances, even for small seismic events. The surface wave measurements and seismic moments require larger events, because Rayleigh waves are small relative to body waves for explosions. The Lg amplitude is similarly weak for small explosions. Because seismic stations within the Soviet Union were considered unlikely in the 1970s, research concentrated on the use of P-wave magnitudes. With stations inside the Soviet Union, however, yield estimation can be improved through using not only P waves, but also surface waves and Lg waves. Because the random errors of the three types of magnitude measurements are statistically independent for

* The yield distribution is asymmetric due to the normal distribution of m_b and the logarithmic relationship between the yield of the explosion and the measured seismic magnitude.

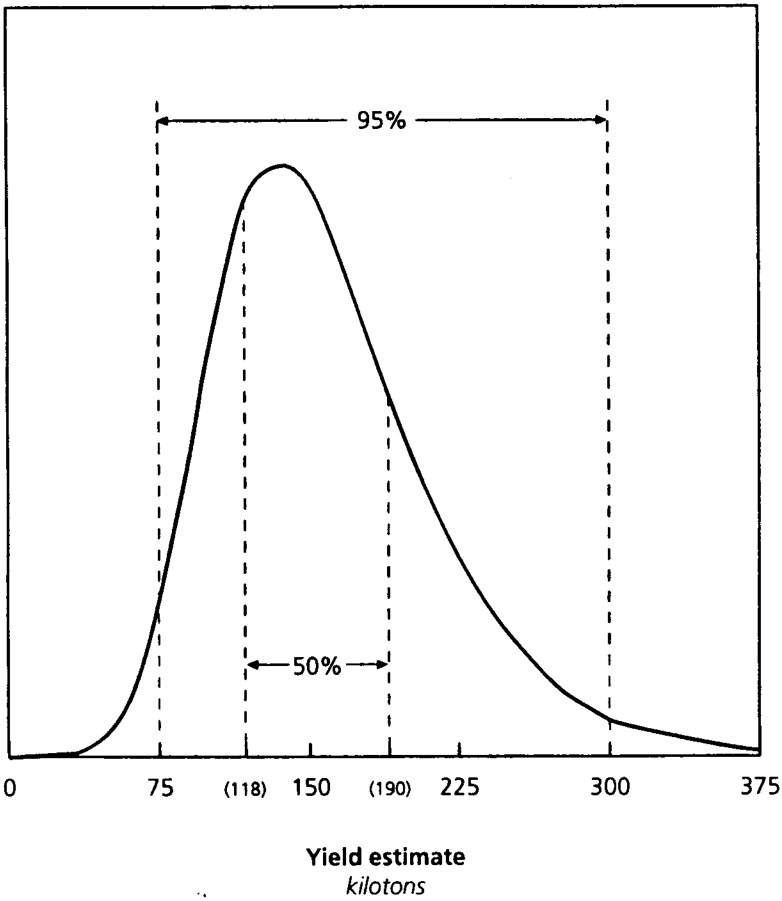

Figure 3: Seismic measurements of a 150 kiloton explosion using a factor-of-two uncertainty would be expected to have a log-normal distribution. The probability that the actual yield lies in a particular range is given by the area under the curve across that range. While 95 percent of the measurements would be expected to fall between 75 and 300 kilotons, over 50 percent of the measurements would be expected to fall between 118 and 190 kilotons. There is only a 2.5 percent chance (1 in 40) that an explosion with a yield of 150 kilotons would be measured as 300 kilotons or greater.

a given event, the uncertainty can be reduced by combining the measurements. Consider as an example, the circumstance where statistically independent methods of yield estimation are combined. The resulting factor of uncertainty (F) is given by

$$F = e^{\ln Ki / \sqrt{Z}} \qquad (3)$$

Table 1: Uncertainty factors resulting from using various numbers of methods having an uncertainty factor of two.

Number of methods	Resulting uncertainty factor
1	2.0
2	1.6
3	1.5

where Ki is the uncertainty factor of each method, and Z is the number of such methods. If, for example, all methods have an uncertainty factor of 2, the random uncertainty is as shown in table 1.

Because combined measurements were not formally implemented, the uncertainty factor of seismic methods continued to be stated to policy makers as a factor of two. The true capability, however, was much better.

US Government's Reaction to Uncertainty

The Nixon and Ford Administrations reasoned that any Soviet program to exploit the range of measurement uncertainty for military advantage—by sustained testing above the threshold—would be detected, and that any individual above-threshold test escaping accurate measurement within this band of uncertainty would not produce military advantages commensurate with those that were denied to the Soviet Union by imposition of the threshold. As a consequence, the original factor-of-2 uncertainty attributed to the monitoring capability of that time was considered by both administrations to be adequate for verifying compliance.

When the TTBT started being observed in April 1976, the Air Force Technical Applications Center (AFTAC), which operates a network for seismic monitoring of test ban treaties, began reporting yield estimates for Soviet tests that were significantly over the 150 kiloton limit. The Carter Administration privately protested the "violations" to the Soviet government, which strongly rejected the US claims. In 1977, AFTAC's scientific review panel unanimously conceded the need for a bias correction. In choosing to adopt a "conservative" approach that would be relatively sure not to underestimate the size of Soviet explosions, however, they recommended a correction factor that was only about half that suggested by the seismic data. The low value was adopted rather than the most likely value. While such an approach minimized the chances of illegal Soviet explosions appearing to be under the threshold limit, it increased the possibility that explosions near the threshold would be overestimated as violations.

Because of this failure to adopt the appropriate bias correction, the executive branch of the US government from 1981 until 1990 repeatedly accused the Soviet Union of "likely" violations of the 150 kiloton limit of the Threshold Test Ban Treaty.[22]

In discussing whether the Threshold Test Ban Treaty could be verified, seismic monitoring capabilities were not only presented in their most minimal capacity (a factor-of-2 uncertainty) by the administration, but the meaning of this uncertainty was also portrayed in the worst light. A number of reports and official statements during the 1980s misrepresented the meaning of a "factor-of-2" uncertainty in yield estimation. For example, witnesses on behalf of the Department of Defense described the uncertainty to the Congress as follows,

> This uncertainty factor means, for example, that a Soviet test for which we estimate a yield of 150 kilotons may have, with 95 percent probability, an actual yield as high as 300 kilotons—twice the legal limit—or as low as 75 kilotons.[23]

with the impact of such violations being as follows,

> The present Soviet MIRV weapons have much smaller yields than those of the weapons deployed in 1974 ... with the majority of Soviet ICBM yields now in the 500 kiloton range, *a violation at the 300 to 450 kiloton level can no longer be dismissed as having little military significance. ...The ability to conduct such tests, at least occasionally, cannot be denied the Soviets under the present treaty provisions*.[24]

In fact, given a factor-of-2 uncertainty, the likelihood of an explosion with a yield of 300 kilotons actually being measured (with 95 percent probability) as 150 kilotons or below is *less than 1 chance in 40*. A country considering cheating would have to recognize that the random uncertainty might not work in its favor. For example, a test at 200 kilotons could look like 250 kilotons rather than 150 kilotons. Just as there is only 1 chance in 40 of a 300 kiloton explosion appearing to within 150 kilotons due to random uncertainty, there is in an equal chance that the random uncertainty would work against the country, making it appear as though the explosion was in excess of 600 kilotons. Because a country violating the treaty cannot count on the random uncertainty working in its favor, the range of uncertainty cannot be equated with a range in which cheating can occur.

Despite a series of reviews that found no technical basis for the charge of Soviet violations,[25] the director of ACDA testified in June 1988,

> After careful and thorough deliberation, the administration has concluded with regard to the TTBT 150 kiloton threshold that there has been "likely violation" of the legal obligations under the TTBT. Furthermore, the totality of evidence strengthens the previous findings of likely TTBT violation.[26]

When asked to explain the reasoning behind this conclusion, the director virtually equated the existence of uncertainty in seismic measurements with evidence of noncompliance.

> The opportunity to verify, not beyond a shadow of a doubt, since there is nothing like that in our understanding, but to verify beyond reasonable doubt that the Soviet Union is complying with the treaty, is really the aim. Right now we don't have that. *That is why we say that it is likely the Soviets are violating the treaty.* [27]

In February 1990, the Bush Administration's first annual report to Congress on Soviet Non-compliance with Arms Control Agreements did not repeat the charge that the Soviet Union had committed "likely" violations of the agreement. Instead, the 1990 report stated that "past evidence suggested" that a number of Soviet tests had exceeded the allowed threshold. The new formulation leaves open the possibility that the problem may well have been with the interpretation of the "past evidence," rather than with Soviet testing above the threshold.

CORRTEX MONITORING

Because of his expressed dissatisfaction with seismic methods of yield estimation, President Reagan called for a renegotiation of the treaties based on the use of an on-site measurement technique called CORRTEX.* The CORRTEX technique measures the radius of the expanding shock wave as a function of time (in milliseconds) by means of an electrical sensing cable placed in a "satellite hole" about ten meters from the explosion (see figure 4). When the explosion occurs, the shock wave moves outward from the center of the explosion, crushing and shortening the cable. By measuring electrically the rate at which the cable is shortened, the rate of expansion of the shock wave can be

* The CORRTEX acronym stands for Continuous Reflectometry for Radius versus Time Experiments.

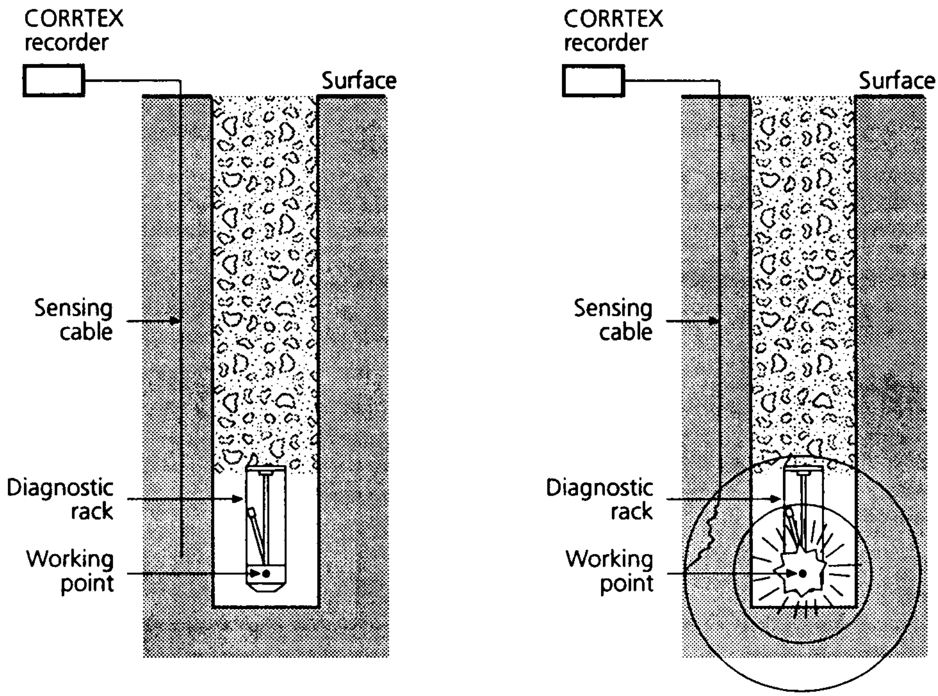

Figure 4: The CORRTEX technique of yield estimation in an on-site measurement system. A hole is drilled parallel to the emplacement hole of the nuclear device and an electrical cable is lowered down the hole. When the explosion occurs, a shock wave moves outward shortening the cable.

calculated. From the rate of expansion of the shock wave and the properties of the surrounding medium, the yield of the nuclear explosion can be estimated. Yield estimates are derived by fitting a simple empirical formula, based on US test experience, to a specific time interval of the CORRTEX data.

Uncertainty is introduced by the sensitivity of CORRTEX measurements to the precise emplacement conditions of both the nuclear device and the sensing cable, the location of the device within the testing canister, and the nature of the materials being used. For example, when measuring the distance from the center of the prospective explosion to the crushing point of the CORRTEX cable at a depth of about seven hundred meters, an error of one meter will cause an error of about 50 kilotons in the yield estimate, for yields near 150 kilotons.[27] If the nuclear device is located at one end of the testing cannister, energy will flow to the opposite end upon detonation changing the apparent yield by a factor of three or four within the standard geometries of horizontal and vertical tests.[28] Errors of 20–30 percent can be incurred simply due to differences in the equation of state of the materials inside the cannister.[29]

COMPARING CORRTEX AND SEISMIC ESTIMATIONS

The accuracy of the CORRTEX yield estimate critically depends on which data are used and how they are weighted. These factors vary with both the size of the explosion and the surrounding rock type, thereby introducing sources of measurement uncertainty that are analogous to the uncertainties in seismic measurements. For example, if data within a 4.5 millisecond "window" are considered for a US explosion of known yield in granite—the 62 kiloton "Piledriver" event—yield estimates range from about 45 kilotons to 175 kilotons, with an average of 110 kilotons if the data are uniformly weighted. Knowing where to select a narrower window on the data, in this case a 3.7 millisecond window, is based on previous test experience for the particular geologic medium and size of test. The narrower window produces a smaller range of yields (from about 45 kilotons to about 75 kilotons), with an average yield estimate of 60 kilotons (if the data are again uniformly weighted) which is very close to the announced yield of 62 kilotons.[30]

On the basis of four monitoring experiments with the CORRTEX satellite hole configuration at the Nevada Test Site, the Reagan Administration predicted in August 1986 that CORRTEX measurements would be accurate to within a factor-of-1.3 uncertainty at Soviet test sites, *if the explosions were larger than 50 kilotons, and conducted in media within US test experience.*[31] In public discussions, however, the latter caveat was often dropped when comparing CORRTEX to seismic methods of yield estimation. In addition, the administration omitted the fact that the strictures on emplacement of the nuclear device, and the detailed knowledge of the surrounding medium that were necessary to produce the reduced level of uncertainty attributed to CORRTEX, would provide similar improvements to the accuracy of seismic methods.

CORRTEX was claimed to be a "direct" measurement that is inherently more accurate than seismic methods.[32] This claim, however, is misleading. Both seismic and hydrodynamic methods estimate yield indirectly—by measuring the motion of the surrounding medium produced by the explosion. Thus both methods depend on how the energy released in an underground explosion is converted into motion, and both methods are affected by the properties of the surrounding medium.

If the Soviet test site were calibrated, and seismic stations within the Soviet Union were used to obtain yield estimates through combined measurements, the uncertainties associated with seismic methods would have been comparable to those of CORRTEX. Such a conclusion was reached in a 1988 study on seismic verification conducted by the United States Congress Office of Technology Assessment (OTA), which stated: "*hydrodynamic* [CORRTEX] *yield estimation will not provide a significantly superior yield estimation capability over what could be obtained through well-calibrated seismic means.*"[33]

In a Congressional hearing on the OTA report, witnesses on behalf of the Reagan Administration tried to discredit the study, charging that it was "*flawed*" and that "*No one should use* [the conclusions of the report] *as the basis for challenging the established course of the negotiation of nuclear testing limitations.*"[34] Because no supporting technical arguments were provided for the administration's charges, the Committee on Foreign Affairs requested that such evidence be provided for the record. When the administration again failed to produce any technical evidence to support its charges against the OTA report, the Committee Chairman appended an unprecedented "Foreword" to the published transcript of the hearing, stating,[35]

> This instance of witnesses on behalf of the administration making unsupportable and unsubstantiated charges is an unfortunate matter which I hope is an anomaly. It is in the interest of both the Legislative and Executive Branches to avert such a development from becoming a dangerous precedent that could adversely influence the arms control and national security policy of this country.

Additional data available since the OTA study has strengthened its conclusion. In 1989 the Soviet journal *Atomnaya Energiya*[36] published an article listing the yields of many Soviet explosions. For four of the more recent explosions in the article for which yields were given, measurements of the seismic wave Lg were available from a seismic station in Norway. Figure 5 shows the reported yields of the Soviet explosions plotted against the measured Lg wave. Six additional data points could be included in figure 5: the yield of the Soviet Joint Verification Experiment (JVE) test, and the yields from five past tests that were provided by the Soviet Union to the United States as part of the TTBT and PNET ratification process. Unfortunately, the United States government refused to release these data,[37] despite permission from the Soviet Union to do so.[38] Efforts to obtain this information resulted in a Freedom of Information Act lawsuit that was dismissed following dissolution of the Soviet Union.[39]

The measurements of Lg were determined from weak signals at great distance. Although there are only four points on the graph, all of the seismic measurements fall within the 30 percent uncertainty (a factor of 1.3) attributed to hydrodynamic methods,[40] supporting the conclusion that seismic methods provide a capability comparable to the factor of 1.3 claimed for CORRTEX.

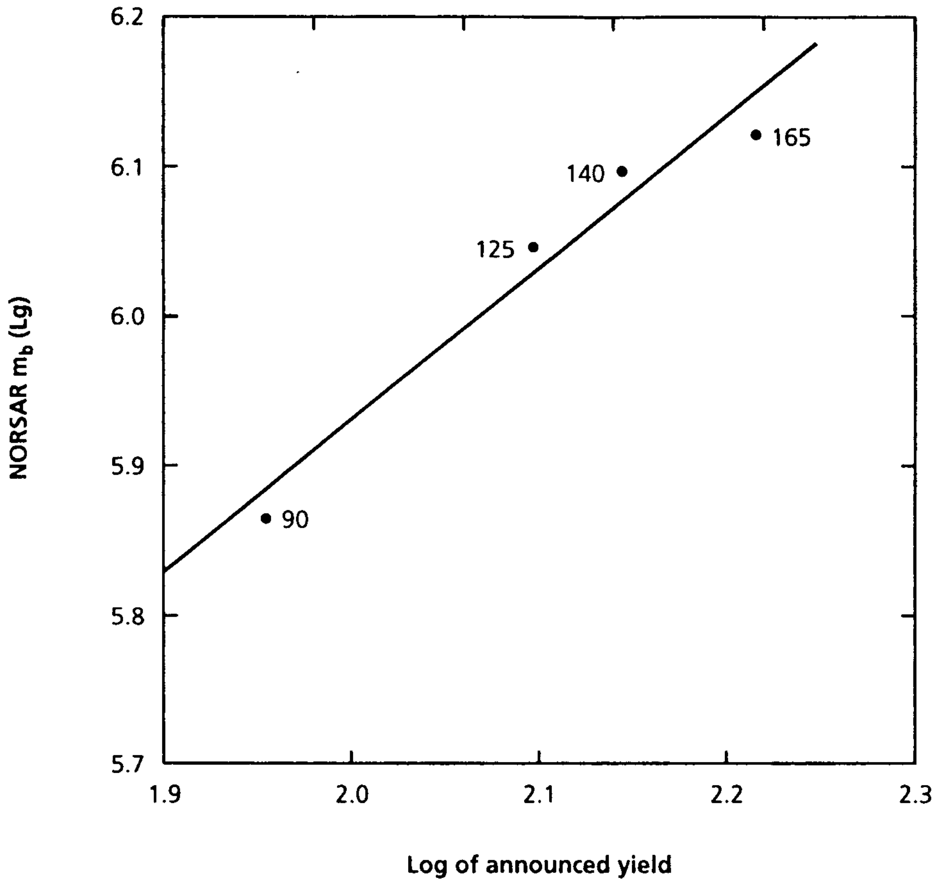

Figure 5: Lg magnitudes for Soviet underground nuclear explosions in Kazakhstan measured from a seismic array in Norway and plotted against the announced yield. All measurements are within a factor-of-1.3 uncertainty.

As a system requiring advance preparation for an explosion at a particular site, CORRTEX has no utility for monitoring clandestine nuclear testing. Consequently, establishing CORRTEX as the preferred verification system for monitoring nuclear testing (while dismissing seismic methods as inadequate) would divert attention from the negotiation of a complete ban on nuclear testing.

As described by the Deputy Assistant Secretary of Defense (Nuclear Forces and Arms Control Policy), soon after his departure from the Reagan Administration in 1988,

> The inherent limitations of CORRTEX are regarded as virtues by those in the

> US government who hope to slow the rush toward additional constraints on—or the complete banning of—nuclear testing. The thinking goes like this: the more time wasted on discussions and experimentation of monitoring techniques irrelevant to the verification of an environment in which there are no legal tests, the easier it will be to stave off demands for the more constraining comprehensive test ban.[41]

White House officials provided a similar view of the Reagan and Bush Adm istration's strategy.[42]

> Privately, officials in the White House have acknowledged to *Scientific American* that they have another aim. By creating the appearance of progress toward a test ban, the officials said, they hope to divert attention from the achievements of genuine test ban proponents and so reduce their momentum.

The strategy for avoiding a CTBT appears to have been to dismiss clai of seismic monitoring potential as unproven, while simultaneously limiti the collection of data from within the Soviet Union that could demonstr otherwise. In 1979, during the CTBT negotiations, the US delegation p posed that an American seismic station be established in the Russian city Obninsk, independent of agreement on a larger CTBT monitoring network. few months later, the Soviets accepted the proposal. In the interim, howev the United States decided that it could not provide the seismographic equi ment in view of the technology transfer controls imposed after the Sovi intervention in Afghanistan. In effect, the United States backed away from i own proposal for establishing an in-country seismic station after the Sovie had accepted it.[43]

The Soviets may have had their own motivation for endorsing CORRTE Soviet motivations for going along with the Reagan and Bush detour from t CTBT negotiations are harder to discern. According to one Soviet foreign mi istry official, after the 18 month Soviet test moratorium failed to elicit a pos tive American response, Soviet negotiations policy—as opposed to merel rhetorical policy—on the test ban became dominated by a desire "not t offend" the Reagan and Bush Administrations in order to achieve agreement reducing strategic nuclear weapons and conventional forces in Europe.[4 Judging by the friendly response of the Soviet nuclear weapons community t the US proposal for on-site measurements, one might also speculate that the too seized upon CORRTEX as a possible way of diverting mounting interna pressures for a complete end to testing.

An ironic footnote to the seismic versus CORRTEX comparison was sup plied by the US–Soviet JVE experiment of 1988. As part of the JVEs, th United States government invited several dozen Soviet scientists to th

Nevada Test Site to witness the use of the US CORRTEX method for measuring the yield of a US underground nuclear explosion. As reported in the Washington Post,[45] the CORRTEX system measured the yield of the explosion as being around 155 to 163 kilotons,[46] an apparent violation of the 150 kiloton limit of the Threshold Test Ban Treaty. The Post article went on to say that despite these measurements, a State Department press advisory declared the explosion was *"in conformity"* with the 150 kiloton limit; and Ambassador C. Paul Robinson stated that *"the test yield was clearly below the* [treaty] *threshold, and neither we nor the Soviets have a problem with that."*[47] The Soviet newspaper TASS recognized the irony and, in reporting the incident under the headline, "American CORRTEX Registers American 'Violation,'"[48] stated,

> Both CORRTEX devices installed at the range, which are favored by the US as a monitoring technique, showed the yield of the American nuclear explosion, witnessed by Soviet specialists, to be over 150 kilotons, i.e. over the limit which the two countries have pledged to observe. At the same time the Soviet teleseismic monitoring means, which were dismissed by the American specialists as unreliable, showed that the yield of the American explosion was 140 kilotons as planned and that the United States did not violate the threshold test ban treaty.

IN-COUNTRY SEISMIC MONITORING

With the ebbing of the Cold War, the issue of verification took a completely new turn, with the establishment after 1986 of a network of seismic stations within the former Soviet Union.

In July 1986, an inter-agency report to Congress suggested in-country seismic monitoring as an area of potential technical cooperation between the United States and the Soviet Union. In July 1987, members of Congress proposed that the US Geological Survey be allowed to install 12 stations in the Soviet Union, in effect continuing under government auspices the seismic monitoring work begun the previous year by the private Natural Resources Defense Council and the Soviet Academy of Sciences. The Soviets gave every indication of being willing to accept such a network, but during negotiations on the FY 1988 Defense Authorization Bill, the White House rejected the proposal, even as it criticized the seismic research community for lacking such data.

> Despite the optimistic predictions and efforts of seismologists over the years, *they have no empirical data, no hard data on which to base their estimations of yields of Soviet nuclear detonations; they only have estimates built on extrapo-*

lations from tests and geological media far from the Soviet Union.[49]

The Reagan Administration informed the House Committee on Foreign Affairs in June 1988 that "setting up seismic stations on Soviet territory to compare data obtained from them to data from CORRTEX would serve no practical purpose," but then went on, paradoxically, to complain, "there is inadequate data to support the claimed accuracy for seismic yield estimates of nuclear tests."[50]

Under a May 1986 agreement between the Natural Resources Defense Council (NRDC) and the Soviet Academy of Sciences, three temporary seismic stations were installed around the Soviet test site in Kazakhstan.[51] Recognizing that the Soviet Union would now allow seismic stations within their country, the US university consortium IRIS negotiated an agreement with the Soviet Academy of Sciences to install seismic stations within the Soviet Union. In April 1988, a Joint Seismic Program was established, with the IRIS Consortium and the US Geological Survey representing the United States, and the Soviet Academy of Sciences representing the Soviet Union.

As figure 6 indicates, seismic stations, networks, and arrays are currently being installed throughout the Commonwealth of Independent States. A comparable number of stations within the US are sending data to Russia under the reciprocal arrangements of the program. General plans call for the networks to include about 20 stations within the Commonwealth of Independent States. This seismic network will establish the technical basis for a verification regime in support of further restrictions or a complete ban on nuclear testing.

CONCLUSIONS

In reviewing the verification debate of the last decade, it appears that the strategy for delaying progress toward a test ban worked, ultimately entangling both the US and the Soviet Union in a largely spurious debate over threshold verification at high yields. By misrepresenting the uncertainties in US yield estimation procedures, and then falsely characterizing these uncertainties as a fatal flaw of seismic monitoring techniques, the sensitive issue of verification became confused and clouded enough to diffuse pressures for more rapid progress toward a complete ban on nuclear testing. The strategy was able to be implemented because of an inherent conflict of interest within the policy evaluation process: the very institutions charged with determining whether such treaties can be verified were opposed to further restrictions on nuclear testing.

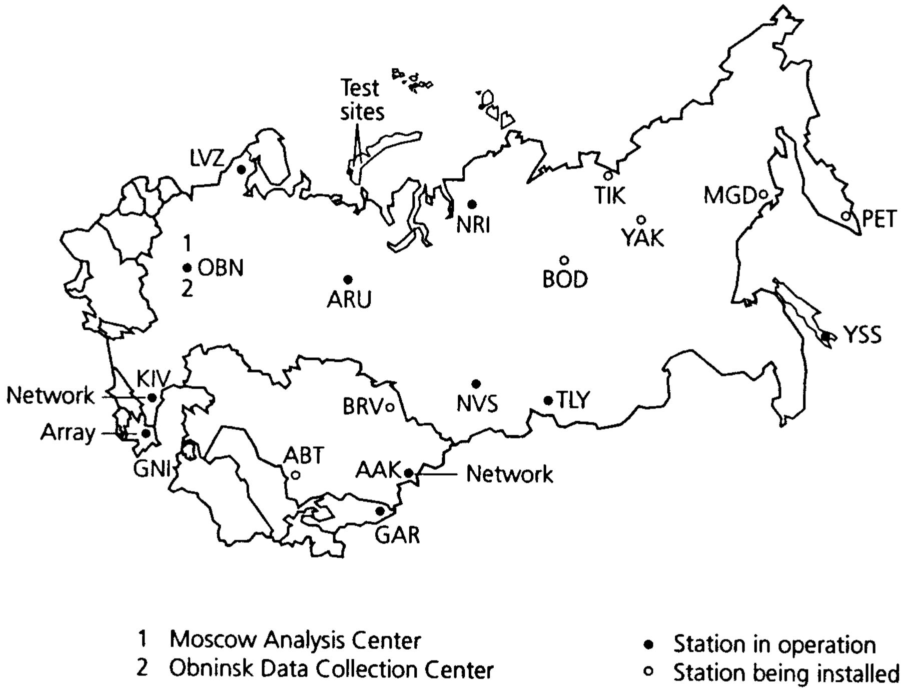

Figure 6: The US–CIS Joint Seismic Program includes seismic stations operating in Ala-Archa (AAK), Arti (ARU), Garm (GAR), Garni (GNI), Kislovodsk (KIV), Lovozero (LVZ), Norilsk (NRI), Novosibirsk (NVS), Obninsk (OBN), Talaya (TLY), and Yuzhno-Sakhalinsk (YSS). Stations are being installed in Alibek (ABT), Bodaibo (BOD), Borovoye (BRV), Magadan (MGD), Petropavlosk-Kamchatka (PET), Tiksi (TIK), and Yakutsk (YAK). In addition, regional telemetered networks are operating in Kirghizia (around the Ala-Archa (AAK) station) and in the Caucasus (near the Kislovodsk (KIV) station). An array of seismic instruments has also been installed around the Garni (GNI) station. The data collection center is located in Obninsk (OBN) and a data analysis center is located in Moscow.

Nevertheless, great strides have been made over the past few years in the area of verification. On-site measurement systems have been accepted and in-country seismic stations are operating continuously. With the breakup of the Soviet Union and the discovery of an advanced nuclear weapons program in Iraq, the proliferation of nuclear weapons is an increasing concern. In view of the CTBT amendment under review by the 117 parties to the Limited Test Ban Treaty, and the need to establish an international consensus concerning extension of the Nonproliferation Treaty in 1995, international pressure for a Comprehensive Test Ban Treaty is likely to surge once again. The US-Soviet precedent of accepting intrusive verification measures establishes a political basis for negotiating an effective global monitoring regime to verify a universal ban on nuclear test explosions.

Progress on a test ban is no longer seriously constrained, as it once was, by technical limits on monitoring capability, but rather hinges on whether the US will be willing to stop testing nuclear weapons. The recent legislation passed by the United States Congress indicates that the answer to that question is "not immediately, but soon."

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NOTES AND REFERENCES

1. Article 18, 1969 Vienna Convention on the Law of Treaties.

2. On the contrary, the PNET was widely viewed as a disservice to nonproliferation by legitimizing the concept of "peaceful" nuclear explosions that could be used as a cover for nuclear weapons proliferation, in the manner of India's self-described peaceful nuclear explosion in 1974.

3. Statement of understanding included with the transmittal documents accompanying the Threshold Test Ban Treaty and the Peaceful Nuclear Explosions Treaty when submitted to the Senate for advice and consent to ratification on 29 July 1976.

4. Comments on the Threshold Test Ban Treaty," by Fred Ikle, Statement for the Select Committee on Intelligence, US Senate, Congressional Record, 25 September 1990, p. S13735

5. R.L. Garthoff, *Detente and Confrontation: American-Soviet Relations from Nixon to Reagan* (Washington DC: The Brookings Institution, 1985) pp. 426-427.

6. Testimony of Roger Batzel, Director, Lawrence Livermore National Laboratory, *Senate Armed Services Committee FY 1986 Authorization for DOE Defense Programs* (Washington DC: US Government Printing Office, 1986) p.170.

7. Roger E. Batzel, "Testimony prepared for presentation before the Senate Armed Services Committee," 26 February 1987, p. 10.

8. See Robert S. Norris and William M. Arkin, "Known Nuclear Tests Worldwide, 1945 to December 31, 1990," *Nuclear Notebook, Bulletin of Atomic Scientists*, April 1991, p. 49; and Thomas B. Cochran et al., "Soviet Nuclear Weapons," *Nuclear Weapons Databook*, Vol.II, p. 171, and Vol.IV, p. 362.

9. Threshold Test Ban Treaty and Peaceful Nuclear Explosions Treaty, Hearing before the Senate Committee on Foreign Relations, 13 and 15 January 1987, S. Hrg. 100-115.

10. The Plowshare program was formed in 1957 to explore the possibility of using nuclear explosions for peaceful engineering purposes. The name is from "...they shall beat their swords into plowshares," *Isaiah* 2:4.

11. Over 100 PNEs have been detonated by the Soviet Union for a variety of applications that include excavating canals and harbors, creating underground storage cavities for gas and oil, and fracturing rock to promote oil and gas flow. In 1991, however, a Soviet trading company proposed using nuclear explosions for commercial purposes to incinerate toxic or radioactive waste. See William J. Broad, "A Soviet Company Offers Nuclear Blasts For Sale To Anyone With Cash," *New York Times,* 7 November 1991, p. A18.

12. On 12 and 17 February 1989 two Soviet underground tests leaked radioactive material into the atmosphere. Although Soviet officials claimed that the leaks were harmless, a cloud of radioactive material drifted over the town of Shagan, about 45 miles from the Semipalatinsk test site.

13. Olzhas Suleimenov's platform included an appeal to shut down the test site and called for a meeting in Alma-Alta, the capitol of Kazakhstan. With just two days notice, 5,000 citizens showed up at the writers' union hall in Alma-Alta to protest the test site.

14. For example, former Soviet plans to build the Kambarata Dam were originally designed to use nuclear explosives. Current plans now call for a series of large chemical explosions.

15. English text of Yeltsin's decree is reproduced in "Report of the Fourth International Workshop on Nuclear Warhead Elimination and Nonproliferation," (Washington DC: FAS/NRDC, 26–27 February 1992) Appendix G-20.

16. See R. Jeffrey Smith, "Bush Rejects Proposed Limits on Underground Nuclear Tests, *Washington Post,* 15 July 1992, p. A16.

17. The Congressional Record, House of Representatives, 24 September 1992, p. H9424.

18. Seismic magnitude was first developed as a means of describing the strength of an earthquake by measuring the motion recorded on a seismometer. To make sure the measurements are uniform, standard methods have been developed. The well known "Richter" magnitude (M_L), for example, is defined as the logarithm (to the base 10) of the maximum amplitude (in micrometers) of seismic waves observed on a Wood-Anderson torsion seismograph at a distance of 100 kilometers from the earthquake.

19. P.G. Richards and L.R. Sykes, "Verification of Limits on Nuclear Testing: A Review of Historical, Technical, and Political Issues," Columbia University, 1990, draft manuscript, p. 26.

20. US Congress, Office of Technology Assessment, *Seismic Verification of Nuclear Testing Treaties,* OTA-ISC-361 (Washington DC: US Government Printing Office, May 1988) pp. 124–126.

21. Originally the factor-of-2 uncertainty was established for the 90 percent confidence level, whereas today it refers to the 95 percent confidence level. The change to the higher confidence level occurred simply because it is the more common convention to use the higher 95 percent confidence level that corresponds to 2 standard deviations. It should be noted, however, that a factor of 2 at the 90 percent confidence level is equivalent to about a factor of 2.5 at the 95 percent confidence level. Thus the accepted

level of uncertainty in 1974 was really about a factor of 2.5 in today's comparison system.

22. Presidential unclassified reports to the Congress on Soviet noncompliance with arms control agreements. See, for example, "Soviet Noncompliance with Arms Control Agreements," United States Department of State, February 1985, December 1985, and March 1987.

23. Testimony of Robert B. Barker, Assistant to the Secretary of Defense for Atomic Energy and leader of formal negotiations on Nuclear Test Limitations before the Committee on Foreign Relations, United States Senate, 13 January 1987 and the Committee on Armed Services, United States Senate, 26 February 1987.

24. ibid., p. 1808.

25. See, for example, US Congress, Office of Technology Assessment, *Seismic Verification of Nuclear Testing Treaties*, OTA-ISC-361 (Washington DC: US Government Printing Office, May 1988) pp. 124–126.

26. "Prepared Statement of Major General William F. Burns (Ret.) Director, US Arms Control and Disarmament Agency" in "Nuclear Testing: Arms Control Opportunities" Hearing, House Committee on Foreign Affairs, 28 June 1988, US Government Printing Office: 1988, p. 15.

27. "Nuclear Testing: Arms Control Opportunities" Hearing, House Committee on Foreign Affairs, (Washington DC: US Government Printing Office, 28 June 1988) p. 47. (emphasis added).

28. R.A. Fiedler, B.W. Callen, F.K. Lamb, and J.D. Sullivan, "Effects of Aspherical Sources on Hydrodynamic Yield Estimation," manuscript in preparation, 1992.

29. B.W. Callen, R.A. Fiedler, F.K. Lamb, and J.D. Sullivan, "Effects of Spherical Sources on Hydrodynamic Yield Estimation" Presented at the 13th Annual PL/DARPA Seismic Research Symposium, 8–10 October 1991, Keystone, Colorado; and "Yield Estimation Using Shock Wave Methods," *Explosion Source Phenomenology,* edited by S.R. Taylor, P.G. Richards, and H.J. Patton, Geophysics Monograph Series **65** (Washington DC: American Geophysical Union, 1991) pp. 73–89.

30. "Hydrodynamic Methods of Yield Estimation," Appendix in *Seismic Verification of Nuclear Testing Treaties,* Congressional Office of Technology Assessment, pp. 132–133. For a more detailed discussion, see F.K. Lamb, B.W. Callen, and J.D. Sullivan, "Yield Estimation Using Shock Wave Methods," *Explosion Source Phenomenology,* edited by S.R. Taylor, P.G. Richards, and H.J. Patton, Geophysics Monograph Series **65** (Washington DC: American Geophysical Union, 1991) pp.73–89; and F.K. Lamb, "Monitoring Yields of Underground Nuclear Tests Using Hydrodynamic Methods," *Nuclear Arms Technologies in the 1990s*, edited by D. Schroeer and D. Hafemeister, AIP Conference Proceedings, Number 178, 1988, pp.109–148.

31. US Department of State, Bureau of Public Affairs, "US Policy Regarding Limitations on Nuclear Testing, Special Report No. 150," August 1986.

32. See, for example, "Verifying Testing Treaties—Old and New: An ACT interview with Ambassador C. Paul Robinson," *Arms Control Today,* July/August 1990.

33. US Congress, Office of Technology *Assessment, Seismic Verification of Nuclear Testing Treaties*, OTA-ISC-361 (Washington DC: US Government Printing Office, May 1988), p. 123.

34. Nuclear Testing: Arms Control Opportunities, Hearing before the Subcommittee on Arms Control, International Security and Science of the Committee on Foreign Affairs, House of Representatives, 28 June 1988

35. Nuclear Testing: Arms Control Opportunities, Hearing before the Subcommittee on Arms Control, International Security and Science of the Committee on Foreign Affairs, House of Representatives, 28 June 1988, p. iii.

36. V.S. Bocharov, S.A. Zelentsov, and V.N. Mikhaylov, "The Characteristics of 96 Underground Nuclear Detonations at the Semipalatinsk Test Range," *Atomnaya Energiya* **67** (3) September 1988, pp. 210–214.

37. Michael R. Gordon, "US Opposes Release of Soviet Nuclear Test Data," *New York Times*, 23 March 1989, p. A7.

38. According to the sworn deposition of T. Cochran of the Natural Resources Defense Council (summarized in "Opinion of Judge J. Gawthrop," 30 May 1991, p. 7. Lawyers Alliance for Nuclear Arms Control / Philadelphia Chapter and Natural Resources Defense Council versus Department of Energy, US District Court for the Eastern District of Pennsylvania, Civil Action #88-7363), Soviet Deputy Foreign Minister Victor Karpov claimed in July 1989 that the Soviet delegation to the JVE negotiations had suggested to the American delegation that the JVE data in question be made public, but that the American delegation refused. The deposition also states that Karpov expressed the view that the release of the JVE data by the United States would not breach Soviet expectations regarding confidentiality of the JVE negotiations.

39. Lawyers Alliance for Nuclear Arms Control / Philadelphia Chapter and Natural Resources Defense Council versus Department of Energy, US District Court for the Eastern District of Pennsylvania, Civil Action #88-7363. In the Freedom of Information Act lawsuit, the former US Ambassador to the Nuclear Testing Talks declared that no agreement on release of the data was ever reached in the talks. His declaration, however, left open the possibility that the lack of agreement could be attributed to US rather than Soviet opposition to release of the data. The Department of Energy argued that it is not required to "negotiate" for the release of the test data. While this is the established precedent under existing law, the Federal District judge in the case found that if the Soviet Union had "already communicated its willingness to release the historic test data, nothing remains for the United States to negotiate." In its effort to withhold the JVE data, the DOE presented the "Catch 22" argument that on one hand, evidence of the Soviet Union's consent to release the data was "hearsay," and, on the other hand, that it could not be required to disclose its own knowledge of the Soviet Union's position on release of the data because such a requirement would force disclosure of information obtained in confidential diplomatic communications.

40. Modified from Paul Richards, "Progress in Verifying Nuclear Test Ban Treaties," *IEEE Technology & Society Magazine*, December 1990.

41. Frank Gaffney, "Test Ban Would Be Real Tremor to US Security," *Defense News*, 5 September 1988.

42. John Horgan, "Test-Ban Countdown," *Scientific American*, October 1988, p. 16.

43. Garthoff, (op. cit.) p. 758.

44. Interview in Moscow by C. Paine, November 1990.

45. R. Jeffrey Smith "Data From Atom Blast Adds to Treaty Verification Questions" *Washington Post*, 8 September 1988, p. A3.

46. CORRTEX cables were inserted in both the satellite hole and the emplacement hole. The two different measurements presumably correspond to the two different holes.

47. If the numbers in the Washington Post story are accurate, CORRTEX performed within its declared capability of 30 percent (a factor of 1.3) even if the size of the explosion was well under 150 kilotons. Because of the uncertainty in any measurement method, it follows that if testing occurs up to the yield limit, some measurements of the largest tests will give results slightly above the yield limit.

48. Vladimir Bogachev, "American CORRTEX Registers American 'Violation,'" *TASS*, 15 September 1988.

49. Robert Barker, Prepared Statement in Armed Services Committee, United States Senate, FY 1988 and FY 1989, Part 4, (Washington DC: US Government Printing Office, 1987) p. 1738.

50. "Nuclear Testing: Arms Control Opportunities," Hearing, Committee on Foreign Affairs, 28 June 1988, (Washington DC: US Government Printing Office, 1988) pp. 141, 149.

51. Under a June 1987 agreement between NRDC and the Soviet Academy, the three stations were relocated, and beginning in 1988, two additional stations were to be established.