Verification highlight

CTBT Evasion Scenarios: Possible or Probable?

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Evasion in a cavity

A possible way to evade seismic detection of a clandestine underground nuclear test is to detonate the device in a large underground cavity, but the individual actions needed to hide the evasion are complex and can be detected and the potential military gains are relatively small. This scenario is known as cavity decoupling. If the cavity is sufficiently large, the resulting seismic waves are muffled and detection becomes more challenging.

Cavity decoupling was the most commonly cited concern during the U.S. Senate debate on the Comprehensive Nuclear-Test-Ban Treaty (CTBT) in 1999. The 2002 U.S. National Academy of Sciences (NAS) report on Technical Issues Related to the Comprehensive Nuclear–Test–Ban Treaty examined 10 evasion scenarios from the U.S. intelligence community. It concluded that: *"…the only evasion scenarios that need to be taken seriously at this time are cavity decoupling and mine masking."*

The seismic signal of a small nuclear test in a cavity can be reduced by a factor of 70, but such a covert test has additional detection risks from the other elaborate activities needed to do the test. Thus, a successful covert test is possible, but not probable, and if it took place it would not be militarily significant under the U.S. definition of effective verification of an arms control treaty, as described on page 24.

Fully decoupled explosions

An explosion is 'fully' decoupled (reduction in the measured yield by a factor of 70) if the size of the cavity is large enough to reduce blast pressure on cavity walls below the elastic limit of the media. In salt, the cavity radius in metres must be larger than 25 multiplied by the cube root of the yield in kilotons. The only "fully" decoupled nuclear test was a very small 0.38 kiloton (kt) test in Mississippi, USA, in 1966, which was exploded in a 34–metre diameter salt cavity. In 1976 the Soviet Union partially decoupled with a test in a salt cavity in Azgir, Kazakhstan.

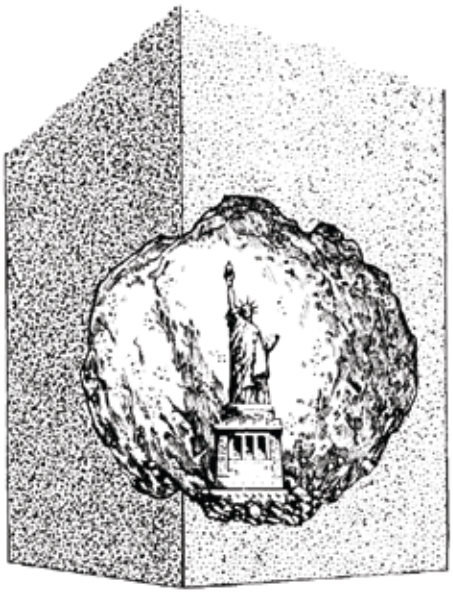

FIGURE 1. MINIMUM CAVITY REQUIRED TO FULLY DECOUPLE A 5 KT EXPLOSION. THE 73-METRE STATUE OF LIBERTY IS 15 PERCENT LESS THAN THE DECOUPLING DIAMETER OF 85 METRES. [SEISMIC VERIFICATION OF NUCLEAR TESTING TREATIES, U.S. OFFICE OF TECHNOLOGY ASSESSMENT (OTA), 1988]. IMAGE COURTESY OF OFFICE OF TECHNOLOGY ASSESSMENT, 1988.

Salt is the preferable medium because tests in hard rock vent radioactivity more easily and because it is easier to create a large cavity in salt by solution mining, which uses flowing water to dissolve salt to make the cavity. Ninety percent of Soviet underground tests at Novaya Zemlya in the Arctic Ocean vented, as did 40 percent of all Soviet tests.[1] It is highly likely that a significant amount (more than 0.1 percent) of radionuclides, especially radioxenon, would be released and then detected by the CTBT's International Monitoring System (IMS). The former U.S. Congressional Office of Technology Assessment issued a report in 1989 on The Containment of Underground Nuclear Explosions, which concluded that: *"Since 1970, 126 [U.S.] tests [out of 723] have resulted in radioactive materials reaching the atmosphere with a total release of about 54,000 Curies. Of this amount, 11,500 Curies [roughly one-fifth] were due to containment failure and late–time seeps."*[2]

Venting from smaller tests can be harder to contain, as the last four U.S. tests that vented had yields less than 20 kt. Some scientists hypothesize that smaller explosions may not sufficiently enclose cavities with a glassified cage in which the explosion melted the rock to glass to prevent venting. Available salt formations of the proper depth and thickness are limited, and are usually in regions that transmit seismic waves readily and are less seismically active, making detection easier. Suitable salt deposits can be found in China, Kazakhstan, Iran, northern Pakistan, Russia and the United States.

The NAS panel determined that an explosion in a cavity: *"…cannot be confidently hidden if its yield is larger than 1 or 2 kilotons."* Other observers quote higher thresholds, which are possible, but not probable. The higher the estimate, the more likely the clandestine test will be detected. The higher estimates ignore the additional capacity of the IMS's auxiliary seismic network, the ability to discriminate with higher frequency components, and they ignore the critical steps listed on page 23. Arrays of seismographs and other seismic capabilities can detect and identify events with yields considerably less

[1] V. Khalturin, T. Rautian, P. Richards and W. Leith, "A Review of Nuclear Testing by the Soviet Union at Novaya Zemlya, 1955–1990," *Science and Global Security* 13, 1–42 (2005). Also NAS–CTBT study, pg. 45 and P. Podvig (ed.), *Russian Strategic Nuclear Forces* (Cambridge: MIT Press, 2004), pp. 440 and 483–566.

[2] For more information see Department of Energy, *Radiological Effluent Released from U.S. Continental Tests 1961-1992*, DOE/NV (Rev. 1) UC-702, August 1996.

than one kt at distances of more than 2,000 km. And advances in regional seismology (seismic waves from distances less than 1500 km that travel within 100 km of the surface) have been dramatic in the past decade. Moreover, a successful clandestine test must avoid a significant "yield excursion", which is particularly difficult for new nuclear weapon States. The NAS panel noted that an inexperienced State that wanted to prevent detection: *"...would probably try to limit test yields to 0.1 kiloton or less,"* which is not militarily significant.

Cheating is a many step process

In the 1999 U.S. Senate debate, Treaty opponents pointed to a classified CTBT National Intelligence Estimate and other intelligence community documents that made cavity cheating appear too easy by not properly taking into account the six factors listed below. Even if each of these tasks could be carried out with high confidence (i.e. a 90 percent chance of success), there would be a cumulative 50 percent chance of avoiding detection of one test and only a 15 percent chance that three tests could be carried out without detection. Note that the small three kt, May 2009 North Korean test was observed at 61 IMS stations. It should be noted that U.S. national technical means, when directed at regions of concern, are more capable than the IMS system. It is unlikely that a State could simultaneously overcome all of the following technical hurdles at the same time at a significant yield:

FIGURE 2: THE VENTING OF BANEBERRY AT THE NEVADA TEST SITE, WHICH WAS UNCHARACTERISTICALLY LARGE. [U.S. ATOMIC ENERGY COMMISSION, 1970].

1) Violators must avoid significant yield excursions. All successful first tests, if carried out in a cavity, would be detected by the IMS: United States (21 kt), Soviet Union (20 kt), United Kingdom (25 kt), France (65 kt), India (12 kt), Pakistan (9 kt), North Korea (0.6 kt observed by 22 IMS stations in October 2006).[3]

2) It is necessary to conceal the materials removed to create a test shaft and cavity from satellites.

3) Crater and surface changes due to testing must be hidden from space-based interferometric synthetic aperture (InSAR), a remote sensing technique

[3] A 90 percent success rate on seismic cheating is a 10 percent detection rate, much lower than the usual 90 percent detection rate. This lowers the detection threshold by 0.5 mb units (O. Dahlman, et al, *Nuclear Test Ban,* Springer 2009, pg. 167).

that uses radar satellite images and other technologies. The North Korean, Indian and Pakistani test sites were located with commercial satellite images.

4) Practically all the radioactive gases and particles must be trapped. The sensitivity of radioxenon detectors has greatly surpassed specifications. Detectors on airplanes can fly into radionuclide plumes.

5) Cheaters must avoid detection of weak seismic signals by closer stations and arrays. The P/S (pressure to transverse wave) ratio above 6 Hz has very successfully discriminated earthquakes from explosions.[4]

THE 1964 SALMON EVENT, A FIVE KT DETONATION CONDUCTED 280 METRES DEEP IN A MISSISSIPPI SALT DOME, CONFIRMED THE THEORY OF DECOUPLING AS A MEANS OF CONCEALING CLANDESTINE NUCLEAR EXPLOSIONS. IN THIS PHOTO, EXPERIMENTERS ARE LOWERING A CANISTER CONTAINING THE NUCLEAR EXPLOSIVE FOR THE SALMON EVENT.

[4] K. Walter, "Sleuthing Seismic Signals," *Science and Technology Review*, March 2009, pp. 5–12

6) Cheaters must prevent detection by national technical means, which are more powerful than the IMS when directed at suspicious areas. Human intelligence provided the locations of Iran's centrifuges and other clandestine sites.

What kind of cheating would matter?

The principal risk that needs to be avoided is that a country could alter the strategic balance or significantly disadvantage national security. The 2002 NAS report concluded that: *"Countries with lesser prior test experience and/or design sophistication would also lack the sophisticated test-related expertise to extract much value from such very-low-yield tests as they might be able to conceal."* The NAS panel judged that: *"States with extensive prior test experience are the ones most likely to be able to get away with any substantial degree of clandestine testing."* Low yield tests by nuclear weapon States should not, by themselves, materially change the strategic balance. Moreover, several clandestine tests are needed to change design parameters, improving the chance of detection.

Military significance of violations

The CTBT provides a strong deterrent against nuclear testing since it strengthens the global norm against testing. This is evidenced by the 2008 United Nations General Assembly resolution on the CTBT (175 in favour with only the U.S. voting against), the few tests that have been conducted since 1996, and the CTBT's 181 Member States. Furthermore, there have been consensus declarations at all of the Conferences on Facilitating the Entry into Force of the CTBT, including by those States that have not yet ratified. The *possibility* of avoiding seismic detection with a cavity should not be confused with the *probability* of detection during the six steps outlined above.

Finally, we need to consider the military significance of violations. The U.S. standard for *effective verification* of an arms control treaty was defined in 1988 by Ambassador Paul Nitze during the Foreign Relations Committee's consideration of the Intermediate Nuclear Forces (INF) Treaty, as follows:
"....if the other side moves beyond the limits of the treaty in any militarily significant way, we would be able to detect such violation in time to respond effectively and thereby deny the other side the benefit of the violation."

Thus, cheating that could threaten national security in a militarily significant way must be detected in sufficient time. In the case of a nation that already has nuclear weapons, effective verification is determined by the military significance of the additional nuclear weapons capabilities it might obtain by cheating, beyond those it had before the treaty was in place.

A worst–case analysis was carried out by the Senate Foreign Relations Committee for START I and START II ratifications. The Executive Reports issued by the Committee on the START Treaties in 1992 and 1995 concluded that potential treaty violations were not militarily significant, namely the Soviets (and then the Russians) would gain little with massive cheating in their ability to hurt U.S. strategic forces beyond what they could achieve without resorting to this.

These results allowed the Senate to determine that the two START Treaties were effectively verifiable. By the same standard, the CTBT is effectively verifiable. Evasive cheating in cavities is possible, but not probable and data extraction is more complicated. Without a CTBT the probability of a nuclear test would be considerably higher because of reduced monitoring without the IMS and a diminished global norm against testing without a CTBT.

Net benefit analysis

General John Shalikashvili, former chairman of the U.S. Joint Chiefs of Staff, concluded in *Findings and Recommendations Concerning the Comprehensive Nuclear Test Ban Treaty* in 2001:
"I believe that it is very much in our national interest to secure these benefits through entry into force of the Test Ban Treaty. If this opportunity is lost, the United States' ability to lead an effective global campaign against nuclear proliferation will be severely damaged."

Shalikashvili commented on evasions with these conclusions:

- There will always be some gap between zero-yield and the lower limit of remote sensing capability to detect, identify, and locate an explosion. With on-site inspections and other sources of information, though, it is more likely that very low-yield testing would be detected or deterred with the Test Ban Treaty than without it.

- Experienced nuclear weapon States such as Russia, and to a lesser extent China, could engage in some evasive testing. However, tests that are small and infrequent enough to avoid detection would not permit them to develop new weapon systems that would undermine the U.S. nuclear deterrent, and eventually even such violations are likely to be caught.

- The verification regime established under the Treaty will enhance the United States' own very capable nuclear test monitoring system and foster new techniques to improve verification. ■

Biographical note

Professor David Hafemeister of the USA was the lead staff on technical matters for the ratification of START, the Treaty on Conventional Forces in Europe (CFE) and the Threshold Test-Ban Treaty (TTBT) while serving at the Senate Committees on Foreign Relations and Governmental Affairs from 1990 to 1993. He has also worked on non-proliferation issues for the State Department, the Arms Control and Disarmament Agency and the National Academy of Sciences. In 1996 Hafemeister received the Leó Szilárd Award. Over recent years, he has authored several books and papers on CTBT verifiability. ■

New publication coming in October 2009

Science for Security: Verifying the Comprehensive Nuclear-Test-Ban Treaty

The publication is dedicated to the International Scientific Studies Conference (ISS09), which took place in Vienna, Austria, from 10 to 12 June 2009. ISS09 was attended by around 500 scientists and 100 diplomats from 100 countries who came together to present and discuss results from the ISS project, which has engaged the scientific community since early 2008.

The purpose of the ISS is twofold: to conduct independent assessments of the capabilities and readiness of the Comprehensive Nuclear-Test-Ban Treaty's (CTBT) verification regime; and to identify scientific and technological developments that might enhance these capabilities as well as improve the cost-effectiveness of the products and services of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO).

During ISS09, scientists presented more than 200 posters covering all of the areas relevant to CTBT verification. This was the first time ever that such a comprehensive collection of scientific work related to the CTBT has been submitted.

Many of the scientists closely involved in the ISS project have contributed articles to the publication, offering their summaries and analyses of the issues presented and discussed at ISS09, including world-renowned seismologists Paul Richards and Lynn Sykes.