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FALSE AND MISLEADING CLAIMS ABOUT VERIFICATION DURING THE SENATE DEBATE ON THE COMPREHENSIVE NUCLEAR TEST BAN TREATY

By Lynn R. Sykes

Lack of verifiability and concern about the Stockpile Stewardship Program were cited repeatedly in the U.S. Senate debate about ratification of the Comprehensive Test Ban Treaty (CTBT) last October. The great emphasis on verification surprised many since an elaborate International Monitoring System (IMS) was set up under the Treaty and the United States possesses many additional monitoring tools. This should have come as no surprise, however, given the repeated claims by treaty opponents for 45 years that other nations will cheat and that we will not be able to detect evasively conducted nuclear tests.

Concerns about verifiability as well as the reliability of weapons in the U.S. stockpile, in fact, have long served as proxies for the larger issues of what best ensures our national security and prevents nuclear war. Several claims that were either wrong or inflated about lack of verifiability, which were not challenged during the very abbreviated testimony and debate of October 1999, are examined here. I argue that U. S. verification goals can be met. I then propose several things that might be done to move the Senate closer to ratifying the Treaty. The recent votes by the Russian Duma for the CTBT and START II have rekindled interest in arms conrol issues in the U.S.

Vote Scheduled Abruptly

On September 30, 1999 Senate Majority Leader Lott abruptly scheduled a vote on the Treaty after refusing to bring it to the floor since it was submitted to the Senate in 1997. One of the most damaging articles to treaty ratification was reported on the front page of the *Washington Post* three days later by Roberto Suro. In "CIA Is Unable to Precisely Track Testing," he stated that the Central Intelligence Agency has concluded that it cannot monitor low-level nuclear tests by Russia precisely enough to ensure compliance with the CTBT. He stated that twice in September 1999, "the Russians carried out what might have been nuclear explosions at its Novaya Zemlya testing site in the Arctic. But the CIA found data from seismic sensors and other monitoring equipment were insufficient to allow analysts to reach a firm conclusion about the nature of the events, officials said." Suro said congressional staffers were briefed on the new CIA assessment before Lott scheduled the vote on the CTBT. The position of the CIA ensured that verification would figure prominently in the upcoming Senate debate.

Opponents Prepared Carefully

We know now that Senators Cloverdell and Kyl, who strongly opposed the Treaty, and their staffs worked in secret for months to compile briefing books of materials opposing the CTBT before Lott's sudden announcement. One of Senator Helms's staff stated that he worked exclusively for two years on arguments to defeat the Treaty. These unreviewed materials were made available to Senators likely to vote against the CTBT but not to Democrats or other Republicans who were likely to, or leaned toward, ratification. Letters opposing the Treaty that were obtained from several former national security and de-

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fense officials were cited repeatedly in the Senate debate. Knowledge about these extensive preparations to defeat the Treaty was successfully hidden from Democratic Senators, their staffs, and the Clinton Administration.

Although the Test Ban Treaty was cited by officials in the Clinton Administration as one of the President's top foreign policy priorities, little was done until a few days after Lott's announcement to either aggressively promote the Treaty in the Senate, especially among moderate Republicans, or to describe its main benefits. No high-level official in the Executive Branch was designated to promote and organize support for the Treaty. Most supporters of the Treaty only began active efforts on its behalf a few days before the short hearings by Senate committees. In retrospect, it is clear that many Senators who were thought to be undecided had already made up their minds to vote against the CTBT. An analysis of the Treaty's technical issues was hampered by the elimination of Congress's Office of Technology Assessment (OTA).

During the Senate hearings, physicists Sidney Drell and Richard Garwin testified about the Stockpile Stewardship Program. Only one witness, General John A. Gordon, Deputy Director of the CIA, testified about verification specifically. His Secret testimony was part of a closed session. In his testimony, Drell did state, "This treaty can be effectively verified. With the full power of its international monitoring system and protocols for on-site inspection, we will be able to monitor nuclear explosive testing that might undercut our own security in time to take prompt and effective counteraction." In contrast, C. Paul Robinson, Director of the Sandia National Laboratories, told the Senate, "If the United States scrupulously restricts itself to zero-yield while other nations may conduct experiments up to the threshold of international detectability, we will be at an intolerable disadvantage."

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The Federation of American Scientists (FAS), founded October 31, 1945 as the Federation of Atomic Scientists by Manhattan Project scientists, engages in research and advocacy on science- and-society issues, especially global security.

Current war and peace issues range from nuclear war to ethnic conflict and from nuclear disarmament to arms sales; sustainable development issues include disease surveillance, climate modification, poverty, food security and environment. FAS also works on human rights of scientists and on reductions in secrecy.

The CIA Role Was Damaging

The CIA played a major role in the false allegation that Russia detonated a small nuclear test on August 16, 1997 in violation of the Treaty. The Russians have conducted several of what they claim were sub-critical (hydrodynamic) experiments at their test site. These were observed by the U.S., presumably with satellite imagery. Such experiments, if they involve no release of nuclear energy, are permitted under the CTBT. The U.S. has conducted a few experiments per year of that type at the Nevada Test Site. Past nuclear tests and sub-critical experiments used much of the same equipment. They were conducted underground, making it difficult to ascertain if the nuclear yield was zero or very small. No seismic waves were detected from the Russian test site on the days sub-critical experiments reportedly occurred. Seismic observations provide an upper limit on the size of any nuclear release that conceivably could have taken place. The detection thresholds for the Russian test site are among the best in the world. Hence, a crucial question is: were the yields of those experiments, assuming any nuclear energy was released, of military significance?

U.S. CTBT Monitoring Goal and Nuclear Yields of Military Significance

In 1999, Fred Eimer stated that by Presidential directive an effective verification system "should be capable of identifying and attributing with high confidence evasively conducted nuclear explosions of about a few kilotons yield in broad areas of the globe." A kiloton (kt), now defined as a trillion calories, is the energy release of about1000 tons of TNT. What weapons might be developed without testing and what constitutes yields of military significance? The Hiroshima U-235 bomb was not tested prior to its use in 1945. Other countries could develop a similar first-generation weapon without testing but its weight would be large and its yield uncertain.

In Senate testimony in 1999, Garwin stated, "Without nuclear tests of substantial yield, it is difficult to build compact and light fission weapons and essentially impossible to have any confidence in a large-yield two-stage thermonuclear weapon or hydrogen bomb . . . Can one be certain that a nation has not tested in the vast range between zero and the magnitude of test that would be required to gain significant confidence in an approach to thermonuclear weaponry—say, 10 kilotons? No, but the utility of such tests to a weapons program has been thoroughly explored and found to be minimal." He stated that the 1995 report of the JASON study "refers to a nuclear weapon test that would involve full yield of the fission primary and some ignition of the thermonuclear secondary, and that such tests, to be useful, would 'generate nuclear yields in excess of approximately 10 kilotons.'" He also said, "A proliferant country might well want to acquire fission weapons of 5 kiloton yield . . ." Thus, the U.S. verification goal of a few kilotons, if fulfilled, would identify such tests with confidence.

Kidder showed a histogram of the frequency of U.S. tests as a function of yield from 1980 through 1984 in the *FAS Public Interest Report* for Sept. 1985. Its most prominent peak occurs between 7 and 20 kt, indicative of the high military significance of testing at those yields. About 5% of U.S. tests, mostly effects tests, were at yields below 1 kt, indicative of their low priority. The yields of past Russian tests have a pronounced peak near 20 kt.

Claims about Evasive Nuclear Testing during Senate Debate

On October 8, 1999, Senator Lott cited many reasons for opposing the CTBT. On verification he said, "We know, however, that it is possible to conduct a nuclear test with the intention of evading systems designed to detect the explosion's telltale seismic signature. This can be done through a technique known as 'decoupling,' whereby a nuclear test is conducted in a large underground cavity, thus muffling the test's seismic evidence. In a speech to the Council on Foreign Relations last year, Dr. Larry Turnbull, Chief Scientist of the Intelligence Community's Arms Control Intelligence Staff, said,

> The decoupling scenario is credible for many countries for at least two reasons: First, the worldwide mining and petroleum literature indicates that construction of large cavities in both hard rock and salt is feasible, with costs that would be relatively small compared to those required for the production of materials for a nuclear device; second, literature and symposia indicate that containment of particulate and gaseous debris is feasible in both salt and hard rock.

So not only is this 'decoupling' judged to be 'credible' by the Intelligence Community, but, according to Dr. Turnbull, the technique can reduce a nuclear test's seismic signature by up to a factor of 70. This means a 70-kiloton test can be made to look like a 1-kiloton test, which the CTBT monitoring system will not be able to detect."

Senator Helms made similar remarks about a 60 kt test. He said, "Every country of concern to the U.S.—every one of them—is capable of decoupling its nuclear explosions. North Korea, China, and Russia will all be able to conduct significant testing without detection by our country." Several Senators claimed that the Russians were conducting decoupled tests in a large granite cave on Novaya Zemlya. Lott cited James Woolsey, Clinton's first Director of Central Intelligence, "I do not believe that the zero level is verifiable. Not only because it is so low, but partially because of the capability a country has that is willing to cheat on such a treaty, of decoupling its nuclear tests by setting them off in caverns or caves and the like." None of these claims was challenged during the Senate debate.

Joint Statement by Scientific Societies on CTBT. These claims are in stark contrast to a joint public statement issued by the American Geophysical Union and the Seismological Society of America on October 6,1999. Their document, in preparation for a year, stated, "One of the biggest challenges to monitoring the CTBT is the possibility that testing could be successfully hidden by conducting nuclear explosions in an evasive manner. The concern is partly based on U.S. and Russian experiments which have demonstrated that seismic signals can be muffled, or decoupled, for a nuclear explosion detonated in a large underground cavity. The decoupling scenario, however, as well as other evasion scenarios, demand extraordinary technical expertise and the likelihood of detection is high. AGU and SSA believe that such technical scenarios are credible only for nations with extensive practical testing experience and only for yields of at most a few kilotons. Furthermore, no nation could rely upon successfully concealing a program of nuclear testing, even at low yields." It also stated the two societies "are confident that the combined worldwide monitoring resources will meet the verification goals of the CTBT."

Is Russia Conducting Clandestine Nuclear Tests?

The allegations in the *Post* that Russia may have carried out two nuclear explosions in September 1999 are the latest of about a dozen similar reports since 1996. Most of these were front page stories by Bill Gertz, the National Security Correspondent for the *Washington Times*. On October 12, 1999, he gave the dates and location of the two suspected Russian tests as September 8 and 23 at Novaya Zemlya. He said U.S. intelligence agencies suspect that site was used for small nuclear explosions and that a small test was conducted by China on June 12. Gertz also stated, "U.S. intelligence agencies are now saying that 'you can have militarily significant developments below the detection threshold.'"

Seismic stations of the International Monitoring System have been complete for several years for a broad area of northern Europe including Novaya Zemlya. Norwegian seismologists operate a Threshold Monitoring System by which they compute the seismic magnitude, mb, for which an event is likely to be detected from that test site as a function of time. On September 23, 1999, one of the dates that Gertz cited, no seismic event was detected from that area. The threshold of detection for that date was exceedingly good, mb 1.84. If an explosion occurred on that day, its yield must have been less than about one ton (0.001 kt) if it was well-coupled (tamped), i.e. no attempt was made to muffle its seismic waves. It is unlikely that its yield was greater than about 15 tons if it was fully decoupled in a large, deep cavity in hard rock. Salt, an easier earth material for the clandestine construction of a large cavity, is not present at the test site. Nuclear explosions with yields of 1 to 15 tons are tiny and rare and are far below the threshold of boosting a fission device. Hence, Russia could not learn anything from such a test that it could not gain from a permitted sub-critical test.

Thus, if U.S. intelligence agencies claim they cannot verify possible tests at Novaya Zemlya, then either they are not aware how good seismic capabilities are or they are referring to events that had yields no larger than 1 to 15 tons on September 23 and somewhat larger at other times. Detection thresholds are likely to improve now that data from the Russian seismic station Amderma, the closest to the test site, have become available. Within Novaya Zemlya the rate of seismic activity is low, comparable to that of much of the eastern U.S., and chemical explosions are rare. These factors contribute to the verifiability of compliance with the CTBT for Novaya Zemlya.

While granite is present at a few places on Novaya Zemlya, it does not occur on the test site itself. Caves are typically too shallow to contain even very small nuclear explosions. Those that are large and deep are typically filled with water and would be difficult, if not impossible, to pump dry. Explosions in either a water-filled cave or cavity are well coupled, not muffled. Hence, claims of evasive nuclear testing in a large granite cave at Novaya Zemlya are likely wrong.

Small Earthquakes Alleged to be Nuclear Explosions. Gertz quoted U.S. officials that small seismic events on January 13, 1996 and August 16, 1997 were suspicious nuclear explosions at the Russian test site. I discussed evidence that those two were very small earthquakes in the *F.A.S. Public Interest Report* for November 1997. Had the two been well-coupled nuclear explosions, their yields would have been about 4 and 50 tons, again very tiny explosions. Seismic events near Novaya Zemlya in 1986, 1992 and 1995 were claimed by some DoD officials to be either suspicious or unidentifiable. A strong consensus now exists that they were small earthquakes.

The seismic event of August 16, 1997 occurred as President Clinton was about to submit the CTBT to the Senate. The seeming inability of the U.S. to identify it positively as an explosion, earthquake, or something else were front-page stories in the media. Within hours of the event, however, the Data Center of the IMS placed it well offshore. Analyses done in the next few weeks by seismologists in the U.S., Norway, France, and the U.K. identified it as a small earthquake in the Kara Sea. Nevertheless, at a press conference two months after the seismic event, Robert Bell of the National Security Council stated that activity at the Russian test site on August 14 was similar to that associated with the past conduct of nuclear tests, that we had sent out a plane but that nothing was found. He claimed that the seismic event two days later was of ambiguous origin. Thus, the U.S. was at odds with three of its NATO allies, each of whom maintains a strong capability in seismic monitoring and analysis.

What happened can be put together from information in the media and scientific data in the public domain. The Russians conducted a sub-critical experiment at their test site on August 14, which was observed by the U.S. Two days later, a small earthquake occurred but was initially located by the U.S. Government using only two seismic stations in southern Scandinavia. Someone keyed in the location of a past nuclear test as that of the poorly located seismic event. In a front-page story "U.S. Officials Acted Hastily in Nuclear Test Accusation" on October 20, 1997, R. Jeffrey Smith of the *Washington Post* stated that a high-priority alert issued by the CIA on Aug. 18, 1997 "said that Russia probably had conducted a nuclear test two days earlier on an island near the Arctic Circle." He reported that Harold Smith, Assistant to the Secretary of Defense, said that other scientists at the Pentagon shared his belief that the initial CIA report was wrong. "We now know that they would have been well advised to wait" until they had more data and could reach an accurate conclusion. Jeffrey Smith quoted my colleague Paul Richards, "Not only was there a mistake made, but there was no effort to retract it."

A CIA press release of November 4, 1997 states, "a seismic event occurred on August 16, 1997, in the Kara Sea. That seismic event was almost certainly not associated with the activities at Novaya Zemlya and was not nuclear. However, from the seismic data, experts cannot say with certainty whether the Kara Sea event was an explosion or an earthquake." It could not have been of volcanic origin since such activity has not occurred in that region for 300 million years. A chemical explosion in the Kara Sea would have generated a large peak in seismic spectra, which was not observed. Hence, while the CIA concluded the seismic event occurred in the Kara Sea, it neither admitted it had made a rush judgment nor that the event was, in fact, a small earthquake.

In his *Post* article Smith also stated, "The Russian ambassador was summoned to hear a strong complaint at the State Department, and the senior U.S. diplomat in Moscow issued a similar demarche at the Foreign Ministry there." In 1999 a senior Russian scientist involved with nuclear monitoring told me that had the accusations about this event occurred during the height of the Cold War, they would have resulted in a serious escalation of tensions between our two countries. The mis-handling of the analysis of the seismic event of 1997 is quite important, since failure to correct those procedures and either replace or strongly reprimand key personnel who were involved, undoubtedly resulted in the same team misinforming Senators and their staffs in 1999.

Decoupled Nuclear Testing

A Historical Perspective. Many scenarios for clandestine testing have been proposed and analyzed in the 45 years a CTBT has been under consideration. Many, such as testing near the times of earthquakes or in dry media like sand and gravel, do not work for yields of a few kilotons. The decoupling concept has been of great contention for 40 years. Extreme opinions range from it being a credible method to cheat for many countries at yields of military significance using cavities in either salt or hard rock to claims for decoupling being the last refuge of scoundrels. I argue below that it is not credible using cavities in hard rock at significant yields, that it is only feasible using cavities in thick salt formations for countries like Russia with vast testing experience but that those events can be monitored at yields of a few kilotons and larger.

Within only a year of its development, Teller and Latter presented the decoupling concept as a well-developed and well-tested hypothesis. Their claim that nuclear explosions as large as 300 kt could be detonated in huge underground cavities so that their seismic waves were like those of a 1 kt explosion was a major factor in the U.S. decision to seek only a limited test ban treaty in 1963. As a result, testing by the U.S.S.R. and the U.S. went underground after 1963. In 1960, Teller and Latter stated before Congress that by inserting heat-absorbing materials like carbon into an underground cavity that the decoupling factor, DF, could be increased to 2000. (DF is the ratio of the long-period seismic amplitude of a tamped explosion to that of a decoupled event of the same yield.) Very small nuclear explosions in Nevada showed that such additional decoupling could not be obtained. Estimates of DF cf 300 claimed in 1960 were later reduced to 70.

Teller also stated that it was his hunch that further developments may continue to go in the direction of concealment rather than detection. In the same hearings Hans Bethe said, "that the next round ought to go to the detection rather than to the concealment." In his memoirs James Killian, Eisenhower's first science advisor, stated "Teller wished to make a dramatic demonstration of the possibilities of cheating, and this was it . . . The big-hole technique proved to be much more difficult than expected by its advocates . . . It was a bizarre concept, contrived as part of a campaign to oppose any test ban . . . We should have strengthened the campaign for a test ban by making clear when an apparent technical question is not really technical." The decoupling concept reached its zenith in 1960. Detection improved dramatically over the next 40 years. One would not know this, however, from many of the statements made in the recent Senate debate.

Since decoupling has been claimed to be a relatively easy method for evading a CTBT for more than 40 years, it is surprising how few decoupled tests were conducted and how little data exists on the subject. The U.S., Britain and the U.S.S.R. conducted a few chemical explosions in mined cavities to test the concept in general but at yields of only several tons. Two decoupled nuclear explosions were conducted in cavities in salt that were created by much larger tamped nuclear explosions—the U.S. Sterling test of 0.38 kt of 1966 and a partially decoupled Soviet explosion of 8 to 10 kt in 1976. In 1985 the U.S. detonated the tiny 0.02 kt Millyard nuclear explosion in a cavity in soft rock. While much is claimed about the ease of conducting decoupled nuclear tests in mined cavities in either salt or hard rock, no experiments of that type are known. There is no indication that the U.S.S.R. has conducted a fully-decoupled nuclear explosion.

How Decoupling Works and the Need for Containment. Only a few percent of the energy of even a well-coupled underground nuclear explosion is radiated as seismic waves. The rest goes into either vaporizing or permanently deforming rock. For full decoupling, a cavity must be created that is large enough that the surrounding rock remains in the elastic regime. Then most of the explosive energy goes into heating and pressurizing the gas in the cavity. Since rocks are weak in tension, a large compressive overburden stress is needed to ensure that material near the cavity wall is not subjected to tensional stresses from either the step in pressure of the explosion or its shock wave that could result in blowout of radioactive gases, collapse of the cavity and disturbances at the earth's surface. The step in pressure is large, typically 50 to 100 times atmospheric pressure, and the peak shock wave pressure several times greater. Thus, a minimum depth is needed to contain a nuclear test. For a spherical cavity and full decoupling, Latter concluded that the step in pressure must be less than half of the overburden pressure. The cavity volume needed for full decoupling is then proportional to the yield divided by the depth.

Dealing with decoupled testing involves expertise from a wide variety of disciplines—the physics of nuclear explosions, their containment, construction and stability of large underground cavities, stresses in the earth's crust, the properties of rocks and their distribution in countries of concern, and seismic monitoring. A knowledge of all of these is needed by an evader who hopes to foil the following verification gauntlet: construct a huge stable cavity at depth and dispose of its contents in secret, ensure the containment of bomb-produced isotopes, avoid making a detectable displacement or disruption of the surface, have a high probability of not being detected, and perhaps reuse the cavity for other tests. Since much specialized equipment has been used in nuclear tests, a potential evader must obtain sufficient diagnostic information yet use a minimum of such equipment to avoid detection. The U.S.S.R. and the U.S. acquired much technical know-how about containment of underground tests in their hundreds of past nuclear explosions, including tests that inadvertently vented. Countries with little or no underground testing experience are unlikely to undertake decoupled tests. Hence, I focus mainly on possibilities of decoupled testing by Russia.

Testing in Cavities in Salt. Thick sequences of salt offer the possibility of conducting decoupled nuclear tests with yields larger than a kiloton. Salt is one of the few geological materials in which cavities created by tamped nuclear explosions may remain standing for months to years. Massive salt deposits, especially salt domes, often do not contain major joints and faults that could serve as passageways for radionuclides to reach the surface. Its solubility allows salt to be mined hydraulically by drilling a well into it, injecting water to make a brine and pumping that liquid back to the surface. Mining of other geologic materials at depth requires creating shafts and tunnels, blasting, and the disposal of large amounts of rock. The disposal of brine may be easier, although huge quantities of salt dumped into a river or lake can be detected in minute quantities. Large cavities have been formed hydraulically in salt either to mine salt or to store petroleum and various wastes. The largest cavities in salt and their depths are greater than those in hard rock.

Salt, however, has disadvantages for the construction of large cavities for nuclear testing. It is much less common than hard rock. Significant deposits of salt are not even present in North Korea, South Africa, Scandinavia and many other areas of ancient rocks. Hydraulic mining of salt requires about seven times as much water as the volume of the cavity. Arid regions—including most of Algeria, Iran, Libya, Pakistan and western China—lack sufficient water for the formation of large cavities by hydraulic mining. None of the methods of mining salt require the use of chemical explosives. The near absence of earthquakes and chemical explosions in salt deposits makes identification of even small seismic events from them immediately suspect.

Salt is one of the few geological materials that becomes ductile at shallow depths in the earth's crust. Figure 1 shows the narrow stability range for a cavity in salt.

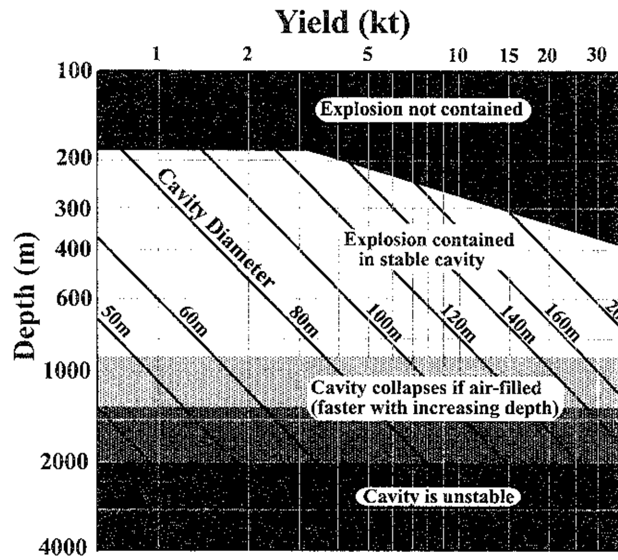

Figure 1 Stability range for a cavity in salt. Depth range (logarithmic scale) is bounded at shallow end by need for containment and at deep end by need to keep a cavity open long enough to permit decoupled nuclear testing. An air-filled or evacuated cavity, which is required for decoupling, is stable only at depths less than about 1000 meters. Vertical lines indicate yield; diagonal lines denote minimum cavity diameters required for full decoupling. After Davis and Sykes, 1999.

It is bounded at shallow depth by the need for containment. U.S. policy prior to the CTBT was to detonate even small nuclear explosions deeper than about 600 feet (183 meters, m) and those larger than 3 kt deeper than 122 meters times the cube root of the yield. Those depths are labeled "Explosion not contained" in Figure 1. A Soviet explosion in salt in 1966 of 1.1 kt at a depth of 165 m formed a water-filled crater at the surface, which is visible on unclassified SPOT satellite images. Cavities in salt have been constructed at depths as great as 2000 m but they are filled with brine, oil, or high-pressure gas, which support about half of the stress on the walls of the cavity. Air-filled cavities are not stable at depths greater than about 1000 m. Many examples exist of the collapse or severe deformation of deep cavities in salt that were either evacuated or depressurized. The U.S.S.R. created 15 cavities at a depth of 1100 m in salt near the mouth of the Volga River. They were not filled fast enough with their intended storage product, gas-condensates, and all of them collapsed.

Figure 2 from the 1988 OTA report "Seismic Verification of Nuclear Testing Treaties", shows that a cavity to fully decouple a 5-kt explosion in salt at a depth of 820 m would have to be large enough to contain the Statue of

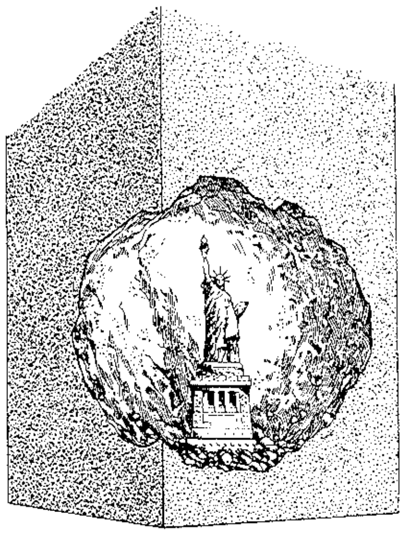

Figure 2 To fully decouple a 5-kt nuclear explosion in salt at a depth of 820 meters, a spherical cavity with a radius of at least 43 meters would be required, large enough to contain the Statue of Liberty and its pedestal. A larger cavity is required at a shallower depth. Source: Office of Technology Assessment, 1988.

Liberty and its pedestal. Figure 1 indicates that a larger cavity is needed to contain a fully-decoupled explosion of a given yield as cavity depth decreases, i.e. twice the volume is needed at 410 m compared to that at 820 m. Hence, containment and cavity stability severely limit the depths of cavities in salt that might be used for significant decoupled testing. Many salt deposits are either too deep or not thick enough for that purpose.

Possibilities of Russian Decoupled Testing in Salt. Only a few percent of Russia contains salt deposits. Many are not thick enough to be suitable for the construction of cavities for decoupled tests of a few kilotons and larger, including most of the extensive bedded salt layers north of Lake Baikal. Nearly all thick salt deposits in Russia are located in areas where seismic waves propagate efficiently, making explosions in them easier to detect. Many of the thick salt deposits of the U.S.S.R., including most in areas of poorer wave propagation, are located in separate countries—Kazakhstan, Tadjikistan and Ukraine.

Because the Soviet Union tested a number of peaceful nuclear explosions in salt, it was often assumed that the Russians know much more than we do about decoupling and that they would use that knowledge to cheat. When extensive data about them were published, however, it was evident that the U.S.S.R. had conducted only one decoupled nuclear test. It was an 8 to 10 kt partially-decoupled explosion in a salt cavity in 1976 formed by a tamped explosion of 64 kt near Azgir, Kazakhstan. That explosion of mb 4.06 was recorded by many seismic stations, some at large distances. Since its yield was more than 20 times that of Sterling, its data are the best for calibrating identification capabilities for decoupled events of military significance. The U.S.S.R. also detonated 6 nuclear explosions with yields of only 0.01 to 0.5 kt in a water-filled cavity in salt created by another tamped explosion. Those 6 were not decoupled explosions as some had suspected but were well coupled. All were detected outside the U.S.S.R. and would be better recorded today. Hence, Russian experience with decoupled nuclear explosions is very limited.

Tamped nuclear explosions in salt of yield, Y, create cavities that are suitable only for full-decoupled tests of about 5% of Y. Hence, we know the sites of all cavities in salt that may remain standing in the U.S.S.R. from previous explosions that conceivably could be used for decoupled tests of $Y > 0.1$ kt. The 7 largest cavities, which might be suitable for tests of 1 to 4 kt, are located in an arid part of Kazakhstan where they can be readily monitored; none are situated in Russia. Hence, if Russia wanted to conduct a decoupled test of military significance in salt, it would have to construct a cavity by solution or conventional mining, with the knowledge that no country is known to have conducted a decoupled nuclear explosion in a cavity created by either of those methods.

The decoupling factor, DF, for the 0.38 kt Sterling test in salt was about 70 at low frequencies but was less than 20 at high frequencies. The availability of seismic data today that were not available 10 years ago from Russia, Central Asia, China and Mongolia permits monitoring of Russian salt deposits using higher-frequency waves. The seismic magnitudes, mb, of such tests are computed for a value of 70 and for what likely is a more realistic value today of 20. The two smallest well-coupled explosions in the water-filled cavity at Azgir are used as a measure of detectability of events in salt. Their mb's of 2.8 and 3.0 correspond to fully-decoupled explosions of 2 and 3 kt for DF = 70 and 0.4 and 0.7 kt for DF = 20. Three other data sets indicate that a capability of about mb 3 is obtainable for thick salt deposits of Russia. Threshold magnitudes give values close to 3.0. Well-coupled chemical explosions with yields of 25 and 100 tons were detonated in eastern Kazakhstan. One of 25-tons and mb about 3.1 was detected in Alaska. Two explosions of 100 tons and mb about3.6 were detected in Alaska, Australia and central Africa.

Hence, a combination of seismic data from IMS and other stations, focusing on seismic events in thick salt deposits, and careful satellite surveillance of them should provide a capability to verify compliance of the CTBT by Russia for decoupled explosions in salt of a few kilotons and larger for the worse scenario, a decoupling factor of 70, and less than 1 kt for DF = 20.

Testing in Cavities in Hard Rock. The feasibility of decoupled testing at militarily-significant yields in hard rock is of prime importance since it, unlike salt, occurs widely. Nuclear testing in cavities in hard rocks presents four very serious difficulties: 1) no decoupled nuclear tests in them are known; 2) containment and cavity stability are very uncertain; 3) decoupling factors obtained for chemical explosions in them are smaller than those for salt, and 4) existing cavities in hard rock are not suitable for decoupled explosions larger than about 1.5 kt.

Hard rocks typically contain major imperfections—joints and faults—with a spacing of meters to tens of meters. Thus, information from small, decoupled chemical explosions in hard rock cannot be scaled up by the factor of 1000 in cavity volume that would be needed for a test of military significance. Joints and faults also are likely routes for the transport of bomb-produced isotopes to the surface. More Soviet than U.S. tests leaked radioactive products that were detected outside their borders. This can be attributed to the fact that most Soviet tests were conducted in hard rock while few U.S. tests were. Several small U.S. tests in hard rock vented radioactive products. The last major leakage, in 1970, led to a formal review by a Containment Evaluation Panel for each subsequent U.S. test.

J. E. Carothers, a former head of the Containment Panel, spoke on the feasibility of decoupled testing at Princeton in 1992. He stated that the creation of a cavity in hard rock to fully decouple 20 kt would be an unprecedented engineering accomplishment, would be very expensive, joints would present major containment problems, the Containment Panel likely would not approve such a nuclear test, and that he would not go into such a cavity even wearing a hard-hat. The U. S. detonated 1 kt of chemical explosives underground at the Nevada Test Site in 1993. Two chemical tracers were added to the explosive package. These, like bomb-produced xenon and argon, can be detected in exceedingly minute quantities. The two tracers were detected at the surface along faults for months after the explosion. Thus, containment is a serious problem for large cavities in hard rock, even for countries with decades of testing experience.

Leith and Glover (1993) list 10 of the world's largest cavities in hard rock. However, five of them, including an underground skating rink in Norway at a depth of only 25 to 50 meters, are far too shallow for contained nuclear tests. Depths are not available for two others.

The depths of the remaining three, which were constructed for hydro-power, are less than 350 m, far shallower than the 820 m used by OTA for Figure 2. Using the criterion in Figure 1, the volumes and depths limit fully-decoupled tests to yields of about 1.5 kt for those three cavities. Nevertheless, their highly non-spherical shapes indicate that their shortest dimensions (25 to 28 m) may be struck by strong enough shock waves to promote escape of isotopes along cracks and joints. Evasive testing using a cavity like one of those likely would be detected by radionuclide monitoring unless its yield was restricted to a small faction of a kiloton, i.e. far below that of the U.S. verification goal.

Many deep mines experience rock bursts, mining-induced earthquakes associated with the creation of underground openings, which kill many miners per year. They indicate that stability of a cavity becomes more serious in hard rock as depth increases.

Claims that Decoupled Testing is Possible at Significant Yields. In 1993, William Leith of the U.S. Geological Survey circulated a figure called "The Liberty Scale" (shown here as Figure 3). It is based on data of Leith and Glover (1993) and was used by Turnbull in an unclassified talk on evasion scenarios that could utilize mines. Its use is an attempt to discredit conclusions about decoupling in the 1988 OTA report. Its units are "Liberties," i.e. multiples of the 5 kt of Figure 2. "The Liberty Scale" focuses overwhelmingly on volumes of underground spaces with little regard for containment and does not take in account that a larger cavity volume is needed as its depth is decreased. Figure 3 appears to indicate that fully decoupled tests of up to 15 kt may be possible in large cavities with unsupported spans in hard rock, a factor of 10 larger than my estimates based on their data. One of the figures used by Turnbull titled "Known Evasively Conducted Nuclear Explosions in Mines" lists two Soviet explosions. While both were conducted in mines, they were not decoupled experiments. One on the Kola peninsula in 1972 of 2 kt, which was well recorded, was

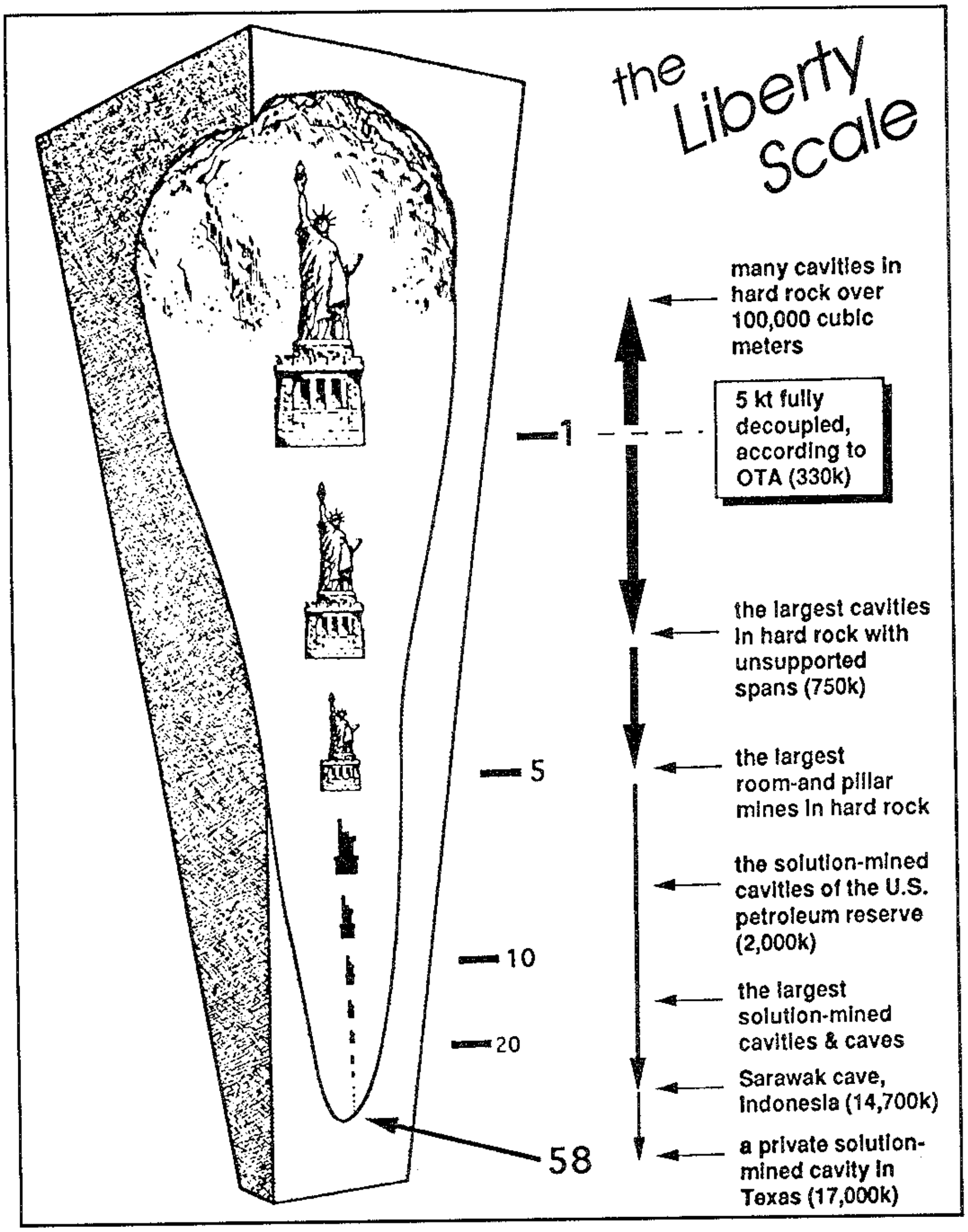

Figure 3 *The Liberty Scale of Leith (1993), which attempts to portray cavities suitable for decoupling opportunities worldwide.*

used to fracture ore. The other in the Ukraine in September 1979 of 0.3 kt and mb 3.3 was used to suppress methane in a coal mine. It was detected by a seismic array in Norway and would be recorded better today.

One of the largest structures in Figure 3 is the Sarawak cave, which is open to the atmosphere. It, like many other large holes in the ground, including the Grand Canyon, do not meet U.S. containment standards. Collapse frequently follows removal of too many support pillars, a likely consequence of a nuclear detonation in a room and pillar mine. Cavities in salt are used to store the U.S. petroleum reserve but are situated at about half the depth of that assumed in Figure 2. When oil in them is withdrawn, it is usually replaced by seawater for better cavity support. One of those cavities, which is saucer-shaped, was originally filled with liquefied gas. While its volume did not change appreciably over 30 years, it lost pressure and was abandoned. This loss of containment probably resulted from the caprock above having been fractured by stresses created by the formation of the highly non-spherical cavity. Containment is probably the most important issue for decoupled explosions in non-spherical cavities.

Verification Capabilities for Other Countries

The seismic component of the International Monitoring System was designed to detect seismic events of mb 4.0 or larger worldwide. It is meeting that goal now for all but a few isolated regions in the southern oceans. It is largely complete for areas north of about 25 degrees N. New stations are being installed in the southern hemisphere and near the equator, which should complete coverage worldwide at or better than the design level. For regions of efficient seismic wave transmission and no decoupling mb 4 corresponds to a yield of about 0.2 to 0.5 kt for explosions in hard rock and those below the water table. These areas include much of Russia, Scandinavia, North Korea, India, eastern South America, Australia and South Africa. For areas of poorer seismic wave transmission and no decoupling mb 4 corresponds to yields of about 0.8 to a few kilotons.

The seismic component of the IMS is at present more advanced in providing global coverage than its other technologies—underwater sound (hydroacoustic), infrasound and radionuclide sampling. Those three will provide additional capabilities for monitoring small nuclear explosions conducted in the oceans and the atmosphere, which are banned by the Limited Test Ban Treaty of 1963. Once those three networks are in operation that they will more than meet the U.S. verification goal. Radionuclide sampling also can detect underground tests that vent.

Seismic capabilities are now much better than mb 4 for areas north of 25 N including countries of special concern to the U.S. such as Russia, China, Pakistan, Algeria, Iraq, Iran, Libya and North Korea. A seismic array in South Korea detects very small events in North Korea. Capabilities to monitor India and Pakistan will improve once planned seismic stations are installed in Oman, Sri Lanka and other islands in the Indian Ocean. India does not permit IMS stations to operate on its territory. Its doing so would augment capabilities for southern Asia.

Data from many high-quality seismic stations that are not part of the IMS are becoming available over the internet in near real time. For example, a network of such stations in Kazakhstan provides very sensitive coverage for it and for adjacent parts of Siberia and western China. Likewise, the Nilore, Pakistan, seismic station, which is not part of the IMS, provided the most sensitive capability for the nearby Indian nuclear tests in May 1998. India and Russia furnished satellite images of the first Pakistani test the same month. Modern seismic networks that now exist in many Mediterranean and Middle Eastern countries provide capabilities for verifying compliance with the CTBT that are much better than that of the IMS alone. Most of the countries of concern to the U.S. in terms of nuclear proliferation are situated there. The trend is clear—more data will be accessible over the internet during the next few years, perhaps from thousands of stations. Those seismic data also have multiple uses—evaluation of earthquake and volcano hazards, CTBT verification, and studies of the interior of the earth.

While a country may use noise levels at IMS stations to calculate the yield of an explosion that likely would not be identified using IMS data alone, the existence of many additional stations, some unknown to them, would necessitate greater caution if they contemplate clandestine testing. Congress would shoot our intelligence capabilities in the foot if it cut off U.S. funding for the IMS. Several countries may drop out of their participation in data exchange if that occurred. Dr. Ralph Alewine, director of the nuclear treaty program office of DoD, stated recently "We're buying into a big system at 25 cents on the dollar, and this provides us data we couldn't get otherwise."

Summary

Many of the claims about lack of verifiability of the CTBT are either false or very exaggerated, especially for evasive nuclear testing. While muffled, i.e. decoupled, testing has been debated for more than 40 years, data on it is very limited. No decoupled nuclear explosions are known to have been conducted by any country in cavities in hard rock or ones in salt created by either hydraulic or traditional methods of mining. Making a huge stable cavity at depth, removing its contents, detonating a nuclear explosion in it, ensuring containment, and avoiding detection at all of those steps is a daunting process even for Russia and the U.S. with their vast testing experience. Even Russia is unlikely to avoid detection at one or more of these steps for decoupled explosions of a few kilotons in cavities in salt. Cavity stability and containment of bomb-produced isotopes likely limit decoupled testing in hard rocks to the sub-kiloton level.

Turnbull's assertion that the decoupling scenario is credible for many countries and that containment of particulate and gaseous debris is feasible in both salt and hard rock is false for nuclear tests of military significance—those of a few kilotons and larger. A combination of data from the IMS, supplementary stations and other U.S. intelligence assets should be capable of monitoring the CTBT with confidence at those yields. Claims that decoupled explosions of 60 and 70 kt would not be detected are hugely exaggerated.

Major emphasis needs to be given to convincing more Senators to vote for the CTBT. One strategy would be for small teams to meet with the staff of key individual Senators either this Fall or early in 2001. Each team might include an expert on verification, one on stockpile reliability, and another to address the overall benefits of the Treaty to national security. They would make the case that the Treaty is verifiable and that a wise stewardship program will ensure the reliability of the stockpile. They need to devote attention to the overall benefits of the Treaty—slowing the proliferation of nuclear weapons, preventing Russia and China from developing and deploying new advanced nuclear arms and retaining the U.S. lead in nuclear weapons. The U.S. has stated that we have no military requirements for new atomic weapons. India and Pakistan are more likely to sign the Treaty if the U.S. and China ratify it; otherwise they are more likely to test again. Under a CTBT regime, pressures will be greater on potential proliferators not to test than in the absence of a Treaty. Several senators stated during the CTBT debate that we need only the Non-Proliferation Treaty (NPT), not a CTBT. Nevertheless, many other nations ratified the indefinite extension of the NPT given the assurance that the nuclear weapons states would negotiate a halt to testing in 1996.

A review of verification and stockpile issues could help the ratification process if it were conducted in a thoughtful and timely manner. OTA, if it still existed, would have been an excellent lead agency. It may be possible to identify a mechanism for a problem-solving review after the Fall elections through either Congressional hearings in early 2001 or Executive leadership by NSC or OSTP. U.S. verification requirements understandably should be more stringent for Russia than for Paraguay. Monitoring a small country like North Korea, which lacks testing experience and salt deposits and where seismic waves propagate efficiently, is not difficult. Generalities about global capabilities are not appropriate. We must insist that the CIA and other U.S. agencies present detailed evasion scenarios for a variety of countries and define yields of military significance for each of them and then have those findings reviewed independently.

Some suggest re-negotiating the CTBT to permit nuclear explosions up to a certain threshold. This is a bad idea, not only because it necessitates negotiations with the 154 other nations who signed the Treaty, but also because a low-yield threshold of say 0.1 to 1 kt would raise suspicions that larger decoupled explosions were being conducted. A threshold of 10 kt would permit the testing of new thermonuclear weapons, one of the main things a CTBT seeks to prevent.

To improve verification the U.S., Russia and China could take steps to make sub-critical tests more transparent, such as conducting them above ground in containment vessels or allowing monitoring stations on their test sites. One powerful new technology, radar interferometry, can detect surface displacements at the sub-centimeter level. It has the potential to detect surface displacements generated by the formation of a buried source like a large cavity.

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