CHAPTER 10

SUMMING UP: QUESTIONS AND ANSWERS ON THE COMPREHENSIVE TEST BAN TREATY

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My experiences with the ratification of the Strategic Arms Reduction Treaty, the Threshold Test Ban Treaty, and the Conventional Armed Forces in Europe Treaty have led me to conclude that presenting technical issues early in the process greatly reduces their politicization during the ratification end game. This chapter summarizes the important issues that will be raised during the debate on ratification of the Comprehensive Test Ban Treaty. It uses a compact question and answer format to cover the following topics: I. Nuclear Proliferation, II. Nuclear Arms Control, III. Warhead Reliability and Yield for National Security, IV. Warhead Safety, V. Verification, and VI. The Verification-Compliance process. Each section begins with a statement of conclusions, followed by a set of relevant questions and answers.

I. NUCLEAR PROLIFERATION

Conclusions:

For 40 years, a Comprehensive Test Ban Treaty (CTBT) has been considered the quid pro quo by the 175 non-nuclear weapon states (NNWSs) for them to end their sovereign right to develop nuclear weapons. Without cooperation by the five nuclear weapon states (NWSs), the NNWSs will limit their participation in the International Atomic Energy Agency (IAEA) and in other non-proliferation arenas. The CTBT and the Nuclear Non-Proliferation Treaty (NPT) are forever politically linked in the global regime to prevent nuclear proliferation by creating a norm that outlaws nuclear weapons programs, by negating confidence in untested though unsophisticated weapons, and by preventing development of sophisticated fission and fusion weapons. In support of the nuclear non-proliferation regime, the NWSs have offered security assurances to the NNWSs outside the context of bloc alliances.

Question I.1: Comprehensive Test Ban Treaty/Nuclear Non-Proliferation Treaty Linkage

What language in the NPT, the Limited Test Ban Treaty (LTBT), and the Threshold Test Ban Treaty (TTBT) links a ban on nuclear testing and the NPT requirement that forbids NNWSs from establishing nuclear weapons programs?

Answer I.1:

> LTBT Preamble (1963): "Seeking to achieve the discontinuance of all test explosions of nuclear weapons for all time . . ."

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> NPT (1968) and TTBT (1974) Preambles: "Recalling the determination expressed by the Parties to the 1963 Treaty . . . to seek to achieve the discontinuance of all test explosions of nuclear weapons for all time and to continue negotiations to this end,"
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> TTBT Resolution of Ratification (September 1990): ". . . the United States shares a special responsibility with the Soviet Union to continue the bilateral Nuclear Testing Talks to achieve further limitations on nuclear testing, including the achievement of a verifiable comprehensive test ban."

Since progress on banning all nuclear tests had not been fulfilled by 1990, the LTBT States Parties convened an Amendment Conference at the United Nations (UN). The Mexican Working Paper of August 24, 1990 captured the views of many NNWS participants at the Conference on the linkage between the CTBT and the NPT:

> A comprehensive test ban treaty would make the single most important contribution toward strengthening and extending the international barriers against the proliferation of nuclear weapons . . . the continued testing of nuclear weapons by the nuclear-weapon States Parties to this Treaty would put the future of the Non-Proliferation Treaty beyond 1995 in grave doubt.

This consideration was the driving force at the LTBT Conference behind the final vote of 74 to 2 (the United States and United Kingdom against, with 19 abstentions) in January 1991 on the proposition that the "States Parties were of the view that further work needed to be undertaken. Accordingly, they agreed to . . . resuming the work of the Conference at an appropriate time." To a large extent the NWSs' promise of a CTBT was the factor that convinced the NNWSs in May 1995 to indefinitely extend the NPT—without dissent—and thus give up their sovereign right to develop nuclear weapons for all time. In order to strongly remind the NWSs of their CTBT promise, the 195 NPT States Parties adopted a set of objectives that politically committed them to conclude a CTBT "no later than 1996." In August 1995 France and the United States stated their intention to establish a "zero yield threshold" CTBT by seeking a complete ban on nuclear explosions. This strengthening of CTBT criteria clearly supports Article VI of the NPT, but the United States stated this commitment without linking it to the NPT. In September 1996, in a near unanimous vote of 158 to 3 (India, Bhutan, and Libya against), the UN General Assembly accepted the CTBT without amendment for signature. It is rare to find such a consonant momentum in global decision making on national security affairs. By December 1996 over 130 nations had signed the CTBT.

Question I.2: Comprehensive Test Ban Treaty/Nuclear Non-Proliferation Treaty World Norm

How will the CTBT and NPT affect the political will and internal debate of a state considering the option of starting a nuclear weapons program? How would the existence of a CTBT in force affect the responses of the world's states to a nuclear weapon test by either a CTBT Party or by a non-CTBT Party?

Answer I.2:

Without a CTBT, it will be difficult to sustain the NPT, which discriminates between the "haves" (the nuclear weapon states) and the "have-nots" (the non-nuclear weapon states). Without both a CTBT and an NPT, it will be difficult for some national leaders to restrain calls to establish a nuclear weapons and testing program. If a state cannot test the nuclear research products of its scientists, it will be less likely to allow the development of the weapons in the first place. A viable CTBT/NPT regime will strengthen international cooperation on proliferation by enhancing the IAEA, by enhancing export monitoring, and by supporting those who would foreclose the nuclear weapon option in their countries. In addition, the CTBT/NPT regime strengthens the political will of the states of the world to establish harsh sanctions against any States Party that established nuclear weapons and testing programs. States Parties that have signed the CTBT, but have not yet ratified the Treaty, are obligated by Article 18 of the Vienna Convention on the Law of Treaties to refrain from acts that would defeat a treaty's "object and purpose" in the interval between signature and entry into force. Clearly this constrains the signatories from testing nuclear weapons even if the CTBT has not entered into force.

Question I.3: Constraints on the Non-nuclear Weapon States

How does the CTBT constrain the technical nuclear capabilities of a non-nuclear weapon state?

Answer I.3:

A relatively unsophisticated, first-generation nuclear weapon can be developed without testing,[1] but a state would not know with certainty its reliability and yield. If a state wished to have reliable, compact nuclear weapons for deployment on missiles, it is generally believed that testing would be required to secure this as a viable military option. If a state cannot test such weapons, it would be much less likely to develop them.

In 1974 India tested a nuclear weapon, an act that greatly influenced the United States to tighten its nuclear export policies with the passage of the Nuclear Non-Proliferation Act of 1978. It is generally believed that three legally defined NNWSs (as defined in Article IX.3 of the NPT) have nuclear weapons (Israel, India, and Pakistan).

Most assume that it is necessary to test boosted primaries and hydrogen bombs to obtain a reliable, deliverable arsenal—in contrast to certain first-generation fission weapons. It would be easy to detect and identify tests of hydrogen bombs and of full-scale boosted primaries, since such tests would produce a yield greater than 1 kiloton TNT equivalent. Thus the CTBT greatly constrains the three de-facto NWSs and the NNWSs from developing hydrogen bombs.

Question I.4: Nuclear Weapon State Positive and Negative Security Assurances

What are the positive and negative security assurances offered by the nuclear weapon states in support of the 1995 NPT extension?

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[1] Eric Arnett, ed., *Nuclear Weapons After the Comprehensive Test Ban* (Oxford: SIPRI, Oxford University Press, 1996).

Answer I.4:

Positive Security Assurances: The five NWSs declared they "would have to act immediately through the [UN Security] Council to take measures to counter such aggression or remove the threat of aggression."[2] This type of unspecified action is not legally binding.

Negative Security Assurances: The five NWSs declared they would not use or threaten to use nuclear weapons against any NNWS party to the NPT except in the case of an attack (with conventional weapons or weapons of mass destruction) by that NNWS on the NWS or its allies "carried out or sustained . . . in alliance or association with a nuclear weapon-state."[3] Since this specific lack of action was promised as part of the NPT renewal process, it is generally believed to be legally binding in accordance with the 1996 decision by the International Court of Justice.

II. NUCLEAR ARMS CONTROL

Conclusions:

The CTBT is both a nonproliferation and an arms control treaty. The CTBT constrains the NWSs from augmenting their arsenals with further technical advances. For China, this means forgoing an advanced missile system equipped with multiple independently-targetable reentry vehicles (MIRVs). The United States and the Soviet Union conducted 85% of all nuclear tests, and thus have an advantage in residual knowledge over all other states on information obtained from tests. The collapse of Russia's nuclear infrastructure has produced a large U.S. lead in such residual knowledge.

Banning nuclear testing reduces tensions between the NWSs; by contrast, conducting nuclear tests raises tensions. Without a CTBT one can expect other NWSs to begin testing anew. A global ban on testing was negotiated in the context of reductions in the numbers of U.S. and Russian deployed nuclear weapons. Under START II, the United States will retain over 9000 warheads, with 3500 of them deployed and accountable.

Question II.1: Constraints on the Nuclear Weapon States

If the nuclear weapon states do not test nuclear weapons, how does this constrain their plans to modernize with new, untested warheads?

Answer II.1:

The U.S. force structure is adequate by almost any yardstick one can imagine when discussing possible missions; therefore the United States does not need to develop new types of nuclear weapons. By not being able to test, it is very unlikely that the NWSs will be able to develop and deploy new types of weapons, thus freezing the present levels of technology. For China, which has not yet deployed a viable, long-range MIRVed system, a CTBT would constrain such plans. If one NWS began to test, others would most likely follow.

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[2] G. Bunn and R. Timerbaev, "Security Assurances to Non-Nuclear Weapon States," *Program for Promoting Nuclear Non-Proliferation*, no. 7 (September 1996), University of Southampton, UK.

[3] Bunn and Timerbaev, "Security Assurances to Non-Nuclear Weapon States."

Question II.2: Past Tests by the Nuclear Weapon States

How much have the five nuclear weapon states tested in the past?

Answer II.2:

During 1962, the first year after the 1958-61 testing moratorium, nuclear testing reached its maximum rate, with the United States conducting 96 tests and the Soviet Union 79. The United States last tested nuclear weapons in 1992 (6 times) and the Soviet Union last tested in 1990 (once). The United States and the Soviet Union carried out 85% of all tests to date. Only the United States currently maintains its nuclear infrastructure with vigor. Listed below are the number and aggregate yields of nuclear tests by the five NWSs. India conducted one underground test in 1974 with a yield of 10 kilotons.

Table 10.1
Historical record of nuclear testing by the five nuclear weapon states

	Number of Tests	Percent of Total	Yield (of all atmospheric)	Yield (of all underground)	Yield (of all tests)
United States	1030	50.3	141	38	179
USSR	715	34.9	247	38	285
France	210	10.3	8	0.9	8.9
United Kingdom	45	2.2	10	4	14
China	45	2.2	21.9	1.5	23.4
Total	**2045**		**427.9**	**82.4**	**510.3**

Data shown in this table do not include the 1945 Hiroshima and Nagasaki explosions and the 1974 Indian explosion. Yields are given in units of megatons (million of tons) high explosive (TNT) equivalent.

Source: R. Norris and W. Arkin, "NRDC Nuclear Notebook: Known Nuclear Tests World Wide, 1945-1995," *Bulletin of the Atomic Scientists* 52 (May/June 1996): 61-63; and "Factfile," *Arms Control Today* 26 (August 1996): 38.

Question II.3: Relations between the Nuclear Weapon States under a Comprehensive Test Ban

How could a CTBT reduce contentiousness among the five nuclear weapon states?

Answer II.3:

One would expect that a permanent ban on nuclear tests would improve relations between the five NWSs by avoiding the following problems: (1) Since nuclear testing is in part a political act, testing by one NWS causes other NWS governments to respond politically, lest they appear to be weak to their own citizens. (2) Since nuclear testing is in part a technical act, it would be interpreted as a strengthening of the ability of one state to attack another. Therefore, if an NWS were to begin again to test nuclear weapons, the other NWSs would most likely resume their testing programs, for both political and technical reasons.

Question II.4: Nuclear Weapon State Nuclear Forces

In order to assess the military implications of the strategic balance between the five nuclear weapon states, what are their present and planned nuclear force structures?

Answer II.4:

Under present planning, the total number of nuclear weapons will drop from 1991 numbers of about 23,000 for the United States and about 38,000 for the Soviet Union to perhaps about 10,000 each under START II. The data below cover the weapons that can be launched on a moment's notice plus nondeployed nuclear weapons.

Table 10.2
Numbers of strategic, non-strategic, and non-deployed warheads comprising the nuclear forces of the United States, Russia, the United Kingdom, France, and China

	ICBM	SLBM	Bomber	Total Strategic	Non-Strategic	Reserve/ Inactive	Total
U.S. (9/90)	2450	5760	4508	12,718	7100	3400	23,000
U.S. (10/96)	2090	3264	3048	8402	1200	7100	17,000
U.S. (START I)	1400	3456	3000	7856	950	5000	14,000
U.S. (START II)	500	1680	1320	3500	950	5000	9,000
USSR (9/90)	6612	2804	1363	10,779	11,000	16,000	38,000
Russia (10/96)	3577	2272	820	6669	4400	9000	20,000
Russia (START I)	2960	1840	1000	5800	2750	5000	14,000
Russia (START II)	605	1696	800	3101	2750	5000	11,000
U.K. (1996)	0	160	0	160	100	n.a.	260
France (1996)	0	384	0	384	65	n.a.	449
China (1996)	7	12	0	19	376	n.a.	395

The notation "n.a." indicates that the data are not available to the author, or not yet determined. Totals for the U.S., USSR and Russia were rounded to the nearest 1000 to reflect uncertainty in the nonstrategic and reserve categories.

Source: R. Norris and W. Arkin, "NRDC Nuclear Notebook: U.S. Nuclear Weapons Stockpile, July 1996," *Bulletin of the Atomic Scientists* 52 (July/August 1996): 61-63; and "NRDC Nuclear Notebook: British, French, and Chinese Nuclear Forces," *Bulletin of the Atomic Scientists* 52 (November/December 1996): 64-67; J. Mendelsohn and C. Cerniello, "Factfile," *Arms Control Today* 26 (October 1966): 28-29; START Memoranda of Understanding; J. Cirincione (Henry L. Stimson Center), private communication; *The Military Balance 1994-1995*, published by Brassey's (UK) Ltd. for the International Institute of Strategic Studies, London, 1994; START Treaty, Senate Executive Report 102-5, September 18, 1992; and START II Treaty, Senate Executive Report 104-10, December 15, 1995.

The 1994 U.S. Nuclear Posture Review sets aside some 2500 "hedge" weapons to upload the Minuteman IIIs from one to three warheads, to upload the Trident SLBMs (submarine-launched ballistic missiles) from five to eight warheads, and to add warheads to the B-52H and B-1 bombers. In addition, the review states that the United States should maintain some 2,500 "inactive" weapons, which have their tritium removed but are intact and available for future deployment. Thus, the U.S. total under START II is over 9,000 warheads: 4450 deployed (or able to be deployed on short notice) and about 5000 that could be deployed after systems are modified to accept them in a period of a months to a few years.

III. WARHEAD RELIABILITY

Conclusions:

The JASON Study and the U.S. nuclear-weapon laboratory directors have certified that the U.S. stockpile is now reliable and safe. Both agree that the Stockpile Stewardship and Management Program should be able to maintain this status without nuclear testing. In the unlikely event that this is not true or does not continue to be true, the United States can withdraw from the CTBT under its "supreme national interest" clause.

This section first discusses the JASON Study conclusions, warhead designs in the present U.S. arsenal, and the historical contrast of the 1958-61 moratorium. The definition and analysis of warhead reliability is then examined, including the Department of Energy (DOE) warhead defect data and the critical, related issue of missile reliability. Of the missions to which the U.S. nuclear forces could be tasked, a first strike against another NWS requires the highest degree of weapon reliability.

Question III.1: The Technical Assessment of the JASON Study

What did the JASON Study conclude in 1995 on the necessity for further nuclear testing to maintain the U.S. nuclear deterrent?

Answer III.1:

For many years the JASON Group, composed of independent, senior, non-government scientists, has advised the U.S. Departments of Defense and Energy on technical aspects of national security issues. The unanimous report from the group of 14 prominent scientists, including four DOE weapon designers, concluded that (in brief): (1) The JASON Committee has high confidence in the safety, reliability, and performance margins of the present U.S. nuclear stockpile, which will continue to be needed for deterrence. (2) The United States can maintain the quality of its nuclear weapons with the Science-Based Stockpile Stewardship and Management Program, which does not include nuclear testing. (3) The range of performance margins of the weapons is adequate at this time, and changes should be made to a weapon type only under extreme circumstances. (4) Continued testing under 500 tons TNT equivalent would only marginally assure the quality of the weapons, and much less so than the Stockpile Stewardship Program. (5) Experiments with high explosives and fissionable material that do not reach criticality are useful in improving our understanding of the behavior of weapon materials. (6) In the past, problems that occurred were primarily the result of incomplete or inadequate design activities. The JASON Group is convinced that those problems have been corrected and that the weapon types in the enduring stockpile are safe and reliable in the context of explicit military requirements. (7) The above conclusions are consistent with the CTBT, recalling the fact that the United States has the option to withdraw under conditions of "supreme national interest."[4]

Question III.2: U.S. Nuclear Warheads in the Enduring Arsenal

What warheads will be in the "enduring" U.S. force structure after 2003, and what are the presently planned quantities, type, yield, date of introduction into the stockpile, and laboratory custodianship.

Answer III.2:

Table 10.3
Warhead designs comprising the U.S. arsenal after the year 2003.
Lead laboratories are Los Alamos National Laboratory (LANL)
and Lawrence Livermore National Laboratory (LLNL)

Design	Number	Type	Yield	Date Introduced in Arsenal	Lab with Custodianship
B61/4, B61/11	600	tactical bomb	170 kt	1980	LANL
B61/7	750	strategic bomb	300 kt	1986	LANL
B83	650	strategic bomb	1.2 Mt	1983	LLNL
W62	610	MM III (ICBM)	170 kt	1970	LANL
W76	3000	Trident C4 (SLBM)	100 kt	1979	LANL
W78	920	MM III (ICBM)	335 kt	1980	LANL
W80/1	1400	ALCM*	150 kt	1981	LANL
W80/0	350	SLCM*	150 kt	1984	LANL
W84	400	GLCM*	50 kt	1983	LLNL
W87	525	MX (ICBM)	300 kt	1986	LLNL
W88	400	Trident D5 (SLBM)	475 kt	1988	LANL

*The W80/1, W80/0, and W84 warheads were designed for deployment on air-launched cruise missiles (ALCMs), sea-launched cruise missiles (SLCMs), and ground-launched cruise missiles (GLCM), respectively.

Source: Norris and Arkin, "NRDC Nuclear Notebook: U.S. Nuclear Weapons Stockpile, July 1996."

Question III.3: 1958-61 Testing Moratorium: the Modernization Era

Were there large technical changes to then relatively new types of U.S. warheads during the 1958-61 testing moratorium? How is the situation different in 1997?

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[4] "Nuclear Testing," Jason Report #JSR-95-320, Mitre Corporation, McLean, VA (August 3, 1995).

Answer III.3:

Major, impressive changes were taking place in the U.S. nuclear arsenal when the moratorium of 1958 was established: (1) The hydrogen bomb technology was then relatively new (the first deliverable thermonuclear weapon was tested in 1954). Several years were required to deploy smaller hydrogen bombs. (2) The first boosted primaries were tested in 1955. (3) In 1955, compact, light warheads assembled with sealed pits and deployable on missiles required new designs providing for one-point safety.

In contrast to the 1958-61 moratorium, the United States now has had an additional 35 years and a total of 1000 tests to attain its present nuclear stockpile, which has not changed significantly in design for a number of years.

Question III.4: U.S. Department of Energy Definition of Reliability

What is DOE's definition of reliability for nuclear weapons?

Answer III.4:

"In general terms, reliability is defined as the ability of an item to perform a required function. Implicit in the above definition of 'required function' for one-shot devices, such as nuclear weapons, are the required conditions and duration of storage, transportation, and function. Also implicit in the above definition of 'ability' is the concept of successful performance. Successful performance for nuclear weapons is defined as detonation at the desired yield (or higher) at the target (i.e., desired burst height or desired delay time within the desired CEP [circular error probability]) through either the primary or any designed backup mode of operation."[5]

Question III.5: Reliability Tests

How reliable are U.S. nuclear weapons? Has the United States performed enough nuclear tests to prove that its warheads are, say, 90% reliable with 90% confidence?

Answer III.5:

There have not been enough performance nuclear tests to establish a statistical reliability value with great confidence for any specific warhead type in the enduring arsenal. For example, if ten performance tests were carried out and all were successful, there would still be a 30% chance that the weapon would be less than 90% reliable, and a 10% chance that it would be less than 80% reliable.[6]

In the years when the United States tested some 20 times per year only one or two tests were for reliability. Considering that the United States has had some 30-40 different warheads types, there has clearly not been sufficient nuclear reliability testing to quote a reliability value even with a medium level of confidence for a particular warhead type, and certainly not as a function of time for warheads deployed more than two years.

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[5] H. Zerriffi and A. Makhijani, "The Nuclear Smokescreen: Warhead Safety and Reliability and the Science-Based Stockpile Stewardship Program," Institute for Energy-Environmental Research, Takoma Park, MD (May 1996).

[6] S. Fetter, *Toward a Comprehensive Test Ban* (Cambridge, MA: Ballinger, 1988).

In general, non-explosive tests have been the most important way to determine the status of warheads. This is particularly true for warheads that have been in the stockpile for over two years.

Question III.6: Actionable Defect Types

What is the DOE record of "actionable defect types" associated with the safety and reliability problems for the U.S. weapon stockpile?

Answer III.6:

Since the Department of Energy has built over 50,000 warheads, the operational and maintenance record gives indications of possible future problems with warheads. According to DOE, an "actionable defect type (ADT) is defined as a defect type which reduces the reliability assessment for the nuclear weapon in which it occurs or which results in some action to remedy the defect type or prevent future occurrence of the defect type. Often a defect type is interdicted before enough information (sufficient number of occurrences) has been collected to indicate that the reliability should be reduced. Therefore, not all ADTs have an associated reliability reduction."[7]

In response to a freedom of information request, DOE stated that of the 164 ADTs, they had the following distribution of reduced reliability (ΔR): $0<\Delta R<1\%$ (112 ADTs); $1\%<\Delta R<5\%$ (37); $5\%<\Delta R<10\%$ (6), and $10\%<\Delta R<100\%$ (9).[8] However, DOE states that they cannot specify the absolute reliability R because DOE does not carry out sufficient nuclear tests to do this.

After looking at the ADT data, I have reached the following conclusions: (1) Older warheads that had generic problems have been retired. This was particularly true for the early warheads at the time of the 1958-61 moratorium. (2) Aging has not affected the safety of the warheads. The aging effects on reliability of current warheads were in the arming/firing/safeing, the parachute, the gas transfer, and the neutron generator systems. None of these problems needed nuclear testing to resolve them. (3) The primary is much more sensitive than the secondary. The problems with primaries have been design or production problems, which mostly show up within a few years of entrance into the stockpile. Generic problems have been solved over time and can be monitored in the future without nuclear testing. Under a finding that there is a threat to the "supreme national interest," the United States can always withdraw from the CTBT. (4) If one uses a realistic mission-oriented values for reliability and yield, aging is not likely to be a factor for the weapons over their lifetimes. If, to save money, one wishes to extend the lifetimes of the warheads from, say, 20 years to 40 years, then the weapons will have to be monitored closely. (5) Non-nuclear testing is far more cost effective than nuclear testing to determine the statistics of the fraction of the stockpile affected by a potential problem.

Question III.7: Missile Reliability

For U.S. nuclear weapon systems, do the missiles or warheads have the larger failure rate?

Answer III.7:

The reliability of a warhead is generally concluded to be greater than the reliability of a missile to arrive on target with good accuracy. If, for example, the reliability of a missile is 0.9

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[7] Zerriffi and Makhijani, "The Nuclear Smokescreen."

[8] Zerriffi and Makhijani, "The Nuclear Smokescreen."

and that of a warhead is 0.95, the missile would have twice the failure rate (F) of the warhead [F(missile) / F(warhead) = (1 - 0.9) / (1 - 0.95) = 0.1/0.05 = 2], producing twice as many missile failures as warhead failures. For the case of 97.5% warhead reliability and 0.9 missile reliability, the missile failure rate is four times that of the warheads. The lower bound of missile reliability used by the Congressional Budget Office was 0.8, a value that gives failure rate ratios twice as high as those quoted above.[9] The most significant improvement to the reliability of the entire weapon would be to increase missile reliability.

Question III.8: Competence of Weapon Designers

Assessments of the reliability and safety of nuclear weapons will often require judgment calls based on experience. How will the United States maintain the continuing competence of weapon designers under a CTBT?

Answer III.8:

It is widely expected that shifting the emphasis of the DOE's nuclear weapons program to non-testing, science-based methods will be very effective for the mature stockpile. Many new diagnostic tools such as the National Ignition Facility will be developed at the three weapons labs and at the Nevada Test Site. Supercomputers with thousands of times the present speed and memory will be used for three-dimensional simulations of nuclear explosions. Lastly, subcritical hydronuclear tests will allow the weapon designers continued opportunities to maintain their skills.

Question III.9: Performance Enhancements

Is it possible to enhance the reliability of aging primaries beyond their design lifetimes in order to save money?

Answer III.9:

By increasing the amount of tritium in the primary, extra boosting is obtained to further ensure that a very old primary could still trigger the associated secondary. In this way the reliability of older weapons can be enhanced to reduce the frequency of remanufacture, and thus save money.[10]

Question III.10: Purpose of Reliability

The United States will have approximately 3500 accountable strategic warheads under START II, and more than twice that number under START I. Consider four hypothetical scenarios: an attack against the United States by an NWS, an attack against the United States by an NNWS, a U.S. first strike against an NWS, and a U.S. first strike against an NNWS. Which scenario requires the highest level of reliability?

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[9] U.S. Congress, *Trident II Missiles: Capability, Costs, and Alternatives* (Washington, DC: Congressional Budget Office, July 1986).

[10] "Nuclear Testing," Jason Report #JSR-95-320.

Answer III.10:

The highest reliability requirement would be for a first strike against an NWS to minimize the response—a second strike. A U.S. retaliation to a first strike by an NWS would not have to be as reliable because many of the enemy silos would then be empty and because cities are soft targets. A U.S. first strike against an NNWS would not require very reliable weapons since the strategic targets are few and soft. Of course the United States has given negative security assurances that we would not launch first against an NNWS (except in a special case; see Answer I.4). A U.S. nuclear response to an NNWS attack would not require great reliability because the targets are soft and few and the launchers would be empty. Since nuclear weapons are meant to deter the actions of others, it is the perception of high reliability by other nations (and not the actual reliability) that deters nations. What is the most important purpose of reliability? It is ironic that the highest level of reliability needed would be for a first strike and not for a deterrent second strike.

IV. WARHEAD SAFETY

Conclusions:

U.S. and Soviet nuclear weapons have to date been very safe, as no one has been killed by nuclear yield from weapons accidents since 1945 in over one million nuclear-weapon-years of experience by the Americans and the Soviets. Since bombers no longer fly with nuclear weapons, the most dangerous cause of accidents has been removed. The cost per life saved of replacing existing warheads with new designs is many orders of magnitude higher than what is normally spent in medical practice or safety regulations. Officials from both the Reagan and Bush administrations have testified that potential safety problems were not severe enough to build new warheads and missiles. For these reasons, the issue of further testing for safety has disappeared from the CTBT debate.

Question IV.1: Accidents with Nuclear Weapons

What significant accidents have occurred involving U.S. nuclear weapons since World War II? Were there radioactive releases, and were people injured or killed from the radioactivity?

Answer IV.1:

According to the DOE there have been 32 accidents (31 prior to 1968 and one in 1980) involving U.S. nuclear weapons.[11] None of these resulted in a nuclear detonation or any nuclear yield despite severe stresses on the weapons. Only two accidents—at Palomares, Spain in 1966 and Thule, Greenland in 1968—released significant amounts of radioactivity. All but three of the 32 accidents involved aircraft, which no longer fly with nuclear weapons aboard. Of the three nonaircraft accidents, the accident at an igloo storage in Texas released little contamination and the two accidents with ICBMs released no radioactivity. No one has been killed by radiation exposure, and doses have not been significant over some one-million weapon years of American and Soviet nuclear weapon experience.

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[11] S. Drell and B. Peurifoy, "Technical Issues of a Nuclear Test Ban," *Annual Review of Nuclear and Particle Science* 44 (1994): 285-327.

Question IV.2: How Safe is Safe?

What is the DOE criteria for a "safe" nuclear weapon?

Answer IV.2:

DOE defines "safe" as the probability of less than a one-in-a-billion chance per warhead life of prematurely detonating with a yield of more than four pounds of TNT (nuclear equivalent) prior to launch under normal conditions and less than one-in-a-million per accident under abnormal conditions such as a fire or a crash. Two independent strong links, each with a failure rate of 1/1,000 in an accident, gives the one-in-a-million figure.[12] One link uses a read-only chip to arm the weapon and the other requires a zero gravity trajectory.

Question IV.3: Safety Features and Cost/Benefit Analysis of Safety

What features can be added to warheads to make them safe? What are the costs and benefits of replacing the U.S. stockpile with new, safer weapons?

Answer IV.3:

The three enhanced safety improvements that can be added to warheads in the enduring U.S. nuclear arsenal are: insensitive high explosives, fire-resistant pits and enhanced nuclear detonation safety (ENDS, which isolates electrical systems in an accident).[13] These, and many other of the 1990 Drell Nuclear Safety Report recommendations, have been implemented in some systems, such as the procedure for loading Trident missiles without warheads and only then emplacing the warheads.[14]

The Drell report did not take into account the costs of new warheads and missiles versus the potential health benefit from their recommendations. In 1992, W. Isard calculated that it would take about $200 million to save a (statistical) life if the United States were to modernize the arsenal with safer warheads and missiles.[15] This figure is about 1,000 times more costly to save a life than what is spent for some expensive medical procedures. During my tenure at the Senate Foreign Relations Committee, I was told by Los Alamos in 1992 that they estimated a comparable value of about $300 million to save a life. The Weapon Safety Value Assessment (WESVA) decision tool is used to estimate the probability and severity of various accident scenarios. Because the estimated cost/benefit ratios appeared very high, the Hatfield-Exon-Mitchell Act of 1992 required the President to carry out "an analysis of the costs and benefits of installing such [safety] feature or

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[12] S. Drell and B. Peurifoy, "Technical Issues of a Nuclear Test Ban."

[13] Drell and Peurifoy, "Technical Issues of a Nuclear Test Ban"; and R. Kidder, "Assessment of the Safety of U.S. Nuclear Weapons and Related Nuclear Test Requirements," Lawrence Livermore National Laboratory, Livermore, CA, UCRL-LR-107454 (July 26, 1991).

[14] U.S. Congress, House of Representatives, "Nuclear Weapons Safety: Report of the Panel on Nuclear Weapons Safety of the Committee on Armed Services," 101st Cong., 2nd sess., December 1990.

[15] W. Isard, "An Economic Analysis of the Costs and Benefits of Ending the U.S. Nuclear Testing Moratorium," *Economists Allied for Arms Reduction*, New York, 1992.

features in the warhead" before he could carry out nuclear tests on new warheads with enhanced safety features. This law did not set a dollar level for the cost/benefit ratio, it merely mandated that the calculations be done.

The Isard values may be too low in that they use the Fetter and von Hippel probability of 0.1 percent per year rate, which is based on the two large plutonium releases from accidents with U.S. aircraft.[16] I would agree with former Assistant Secretary of Energy Claytor, who argued that extrapolating from two aircraft accidents exaggerates the risks since our bombers no longer fly with nuclear weapons in peacetime. In addition, when one considers that no lives have been lost after a million weapon-years of American and Soviet experience, and that these warheads were less safe than the present ones, I believe that the $200 million cost per life saved is considerably too low.

Question IV.4: Military Views on Testing for Safety

How do the Navy and Air Force view the benefits of possible major safety modifications to U.S. warheads?

Answer IV.4:

Officials from both the Bush and Clinton Defense Departments have testified that potential safety problems were not severe enough to build new warheads and missiles.

Robert Barker, Assistant to the Secretary of Defense (Atomic Energy), before the Senate Armed Services Committee, Subcommittee on Strategic Forces and Nuclear Deterrence, March 27, 1992:

> The Air Force and Navy, in cooperation with the Office of the Secretary of Defense and the Department of Energy, evaluated the safety of all ballistic missiles that carry nuclear warheads. It was determined that there is not now sufficient evidence to warrant our changing either warheads or propellants.

Undersecretary of Defense John Deutch, before the House Armed Services Committee, Military Application of Nuclear Energy Panel, May 3, 1993:

> [A]s chairman of the Nuclear Weapons Council . . . I would think that we are not convinced that such safety improvement [i.e., adding insensitive high explosive to the Trident warheads and modifying the missile] would be worth the very considerable cost [of over three billion dollars].

Rear Admiral John T. Mitchell, Director, Strategic Systems Program Office, U.S. Navy, before the Senate Armed Services Committee, Subcommittee on Nuclear Deterrence, Arms Control and Defense Intelligence, May 11, 1993:

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[16] S. Fetter and F. von Hippel, "The Hazard from Plutonium Dispersal by Nuclear-warhead Accidents," *Science and Global Security* 2 (1990): 21-41.

> [W]e believe there would be no gain in safety in changing to insensitive high explosive [on the W88 warhead in the event of a third stage detonation of the Trident D-5 missile].

V. VERIFICATION

Conclusions:

The combination of the near real-time Primary Seismic Network, the Auxiliary Seismic Network of broad-band triple-axis seismographs, and regional seismic monitoring stations will be able to detect and identify fully-coupled nuclear explosions down to a yield of one kiloton TNT equivalent. In many geographical regions the detection threshold is considerably better than one kiloton, and global capabilities will improve with time. The CTBT verification regime can adapt to changing political conditions by focusing on areas where nuclear proliferation is suspected. Attempted clandestine testing by exploding at the one kiloton level in a cavity would only be attempted by a very technologically sophisticated state, since yield excursions, venting, detection by national technical means, and other issues arise.

Question V.1: Seismic Capabilities

What are the seismic capabilities of the Primary Network of 50 stations, the Auxiliary Network of 120 broad-band, three-component seismograph stations, and the regional networks?

Answer V.1:

Using all of the seismic capabilities available, nuclear explosions will be detected with high confidence (90% certainty) down to seismic magnitudes (m_b) of about 4. This magnitude corresponds to that of a tamped explosion of about 1 kiloton in hard rock. However, this assessment is too cautious in that it does not take into account the combination of teleseismic stations (more than 2200 km away) with the regional stations. By combining the capabilities of the Primary, Auxiliary, and regional networks (now available in many locations), one can improve the detection threshold to about 3 m_b, corresponding to a nuclear explosion with a yield of mere tenths of a kiloton. The more open process of CTBT monitoring by many nations should incorporate the supplemental data from regional seismographs to reduce the CTBT measuring threshold and improve the location determinations.

The teleseismic m_b level to identify an event as a nuclear weapon and not an earthquake is generally about 0.5 units higher than the detection threshold. Model calculations carried out at Sandia National Laboratory by Claassen show that the Primary Network of 50 stations should have a detection threshold range of 3.25 to 3.5 m_b in central Eurasia, and below 4 m_b for the remainder of the Earth (except for Antarctica and some southern islands, where it is 4.25 m_b).[17] Claassen required that three or more stations detect seismic P-wave (primus) arrivals with a 99% probability. This detection criterion was specifically used because it admits only a 1% probability in missed detection, as opposed to the more conventionally used 10% value. It should be noted

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[17] J.P. Claassen, "Performance Estimates of the CD Proposed International Seismic Monitoring System," *18th Annual Seismic Research Symposium on Monitoring a CTBT* (4-6 September 1996), *Environmental Research Papers*, No. 1195, pp. 676-84.

that in a recent study the detection threshold of regional seismic networks near the Nevada test site was about 2.4 m_b, about 1.5 units lower than that for the more distant teleseismic systems ($m_b = 4$) for now-known, previously undeclared nuclear explosions.[18] If there is a suspicious region, a neighboring state can place a regional seismograph close to the suspected region and the ability to monitor will improve. Finally, large chemical explosions are readily detectable since they are generally not spherical explosions, but rather ripple-fired in a linear array in order to greatly reduce costs for breaking rock and to reduce off-site damage. In order to lessen misunderstandings, there will be voluntary notifications of chemical explosions larger than 0.3 kilotons.

Question V.2: High Confidence and Deterrence

The error bars discussed above for threshold seismic values are usually quoted in terms of high confidence limits, with a confidence of 90%. What do these higher confidence levels mean in terms of the threshold levels for the detection of nuclear weapons and for psychological deterrence?

Answer V.2:

The U.S. Intelligence Community quotes higher threshold m_b values (larger yields) in order to claim "high confidence." One usually describes the limits of measurement, the error bars, as one standard deviation (σ), but for the case of "high confidence" one insists that some 90% of the events are discovered, which corresponds to two standard deviations. If the confidence level were lowered to about 50%, then the threshold level would be reduced by about 0.5 for regions with good seismic coverage and by 0.25 for regions with poorer coverage. It probably is useful to quote higher m_b thresholds with more certainty, since would-be cheaters would know that a 90% chance of identification corresponds to only a 10% probability of not being identified.

Question V.3: Cavities

How easy would it be for a nation to hide a nuclear explosion in a cavity?[19] What diameter cavity would be needed to decouple (muffle) a nuclear explosion of 1 or 30 kilotons? What are the technical risks for the covert tester?

Answer V.3:

There are very few data on decoupled tests in cavities; only one has been carried out with a yield greater than one kiloton. If a nuclear weapon is placed in a cavity of sufficient size, such that the blast pressure on the cavity wall is below the elastic limit of the surrounding media, the seismic signal strength can be reduced by a factor of about 7 at 20 Hz, and 70 at lower frequencies. (The Soviet test at Azgir had a reduction of only a factor of 10 in magnitude at low frequencies.) The cavity size necessary to obtain these decoupling factors has a radius of 20-25 meters per cube-root kiloton. Thus, a 30 kt explosion would need a cavity radius of 60-75 m (the size of a 25

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[18] C. Hennet, G.E. van der Vink, P.G. Richards, V.V. Adushkin, Y.F. Kopnichev, and R. Geary, "Multi-Use Seismic Stations Offer Strong Deterrent to Clandestine Nuclear Weapons Testing," *EOS,* 77 (July 30, 1996): 289.

[19] L. Sykes, in *Monitoring a Comprehensive Test Ban Treaty*, E. Husebye and A. Dainty, eds. (Boston: Kluwer Academic Publishers, 1996), pp. 247-93.

story building) to achieve full decoupling—an extraordinary engineering challenge when one considers the requirement for secrecy. Many experts have concluded that the higher frequencies of the decoupled signal would still be detectable and identifiable with regional seismographs. If a 1 kt weapon had an unexpected yield of 5 kt, which is quite possible for a new, clandestine program, it would require a cavity radius of 35-45 meters (diameter of 70-90 meters), a factor of 1.7 larger than for the 1 kt cavity (a volume 5 times greater).

The tester's problems would be further complicated by possible venting of radioactivity, which could be easily detected; 30% of Soviet tests vented and the United States had severe venting problems with its earliest tests.[20] In particular, it appears that smaller tests can be harder to contain than larger ones. The last four U.S. explosions that vented were from tests with yields of less than 20 kilotons. It is hypothesized that smaller explosions do not sufficiently glassify the cavity and also do not rebound sufficiently to close fractures with a stress cage. Thus, the smaller explosions, which one might think were easier to hide, are more likely to vent and could be detected by the release of radioactivity. For these same reasons, it is further hypothesized that partially decoupled tests would also be difficult to completely contain.

Other intelligence means, such as satellites and electronic intelligence gathering, can also gather evidence on brine pumping, excavation, equipment for monitoring tests, and other factors. Only a very technologically sophisticated nation could conduct that a clandestine test of a kiloton (or larger) that was decoupled to a degree that enabled the test to escape detection by seismic means and that did not have yield excursions and venting.

Question V.4: Infrasound, Hydroacoustics, Radionuclide, Electromagnetic Pulse, National Technical Means, and On-Site Inspection Monitoring

What monitoring technologies other than seismic exist to determine CTBT compliance?

Answer V.4:

The International Monitoring System will also incorporate 60 infrasound stations (global threshold detection of about 1 kiloton in the atmosphere), 11 hydroacoustic stations (global detection of much less than a kiloton in the ocean), and 80 radionuclide stations (global detection of less than 1 kiloton in the atmosphere, and capabilities to determine venting from underground explosions). In addition the United States presently monitors with satellites for optical electromagnetic pulse (EMP) and nuclear radiation signatures from nuclear weapon tests above the surface of the earth. In addition the national technical means (NTM) of satellite reconnaissance, human intelligence, and signals intelligence will combine synergistically to make the intelligence whole greater than the sum of its parts both to deter cheating and to enhance detection and identification.

States Parties can call for an on-site inspection (OSI) to examine the location of a suspicious event. If a nation were considering testing a nuclear weapon, it would have to be confident that it would have sufficient internal security to prevent knowledge of the test from being obtained by all these technologies and the intelligence community of any State Party to the CTBT. A 50% chance of detection of a sub-kiloton test might seem like weak monitoring to the CTBT States Parties, but it would seem like a risky endeavor to the cheating nation. On-site inspections are

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[20] Congress of the United States, Office of Technology Assessment, "Seismic Verification of Nuclear Testing Treaties," OTA-ISC-361, 1988; and "The Containment of Underground Nuclear Explosions," OTA-ISC-414, 1989.

useful for at least four reasons: OSIs can (1) catch cheating, (2) raise the cost of cheating, (3) deter cheating, and (4) confirm NTM data. A guilty nation probably would not allow an OSI to take place, but this refusal, coupled with other evidence, would indicate guilt.

VI. VERIFICATION-COMPLIANCE PROCESS

Conclusions

The definition of "effective verification," as defined by Paul Nitze of the Reagan administration and James Baker of the Bush administration, includes the criteria of military significance of potential violations and timely warning to overcome such military threats. By this definition, the CTBT is clearly verifiable. The CTBT States Parties have legal mechanisms to strongly sanction (as in the case of Iraq) those States Parties that violate the CTBT by conducting nuclear test explosions.

Question VI.1: Effective Verification

How much verification is enough? What was the definition of "effective verification" used by the Reagan and Bush administrations when establishing the criteria to determine the sufficiency of verification?

Answer VI.1:

In 1988 Ambassador Paul Nitze defined "effective verification" as follows:

> What do we mean by "effective" verification? We mean that we want to be sure that 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.[21]

In 1992 Secretary of State James Baker expanded the definition of "effective verification" to be:

> If the other side attempts to move beyond the limits of the Treaty in any militarily significant way, we would be able to detect such a violation well before it becomes a threat to national security so that we are able to respond. Additionally, the verification regime should enable us to detect patterns of marginal violations that do not present immediate risk to U.S. security. However, no verification regime can be expected to provide firm guarantees that all violations will be detected immediately.[22]

Nitze points out that verification cannot be expected to catch all forms of cheating, but that it must be good enough to detect a violation in time to allow the United States to make a military response before the violation becomes militarily significant. Baker echoes this definition, but points out

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[21] START Treaty, Senate Executive Report.

[22] START Treaty, Senate Executive Report.

that verification should also be able to determine patterns of marginal misbehavior. It makes logical sense to apply this same standard for the quality of verification to the CTBT.

Question VI.2: The Comprehensive Test Ban Treaty vs. the Threshold Test Ban Treaty

In what ways is it easier (and harder) to determine treaty compliance to the CTBT than the Threshold Test Ban Treaty (TTBT)?

Answer VI.2:

By quantifying a specific yield threshold in kilotons, one must be able to accurately determine the conversion from m_b units to kilotons. This was initially a difficult task at 150 kilotons for the TTBT. Since the CTBT does not have a limit in kilotons, the question is easier, since it is not What is the particular yield?, but rather, Was it a nuclear explosion? On the other hand, at levels less than a kiloton down to zero, the seismic monitoring becomes more difficult. At this point, the national technical means (NTM) of verification, using satellites, intercepts of phone calls, and other means, come into play.

Question VI.3: Threshold Test Ban Treaty Compliance

In 1990 the Administration reversed its finding that the Soviets had likely violated the TTBT. What were the 1990 and subsequent findings on this issue?

Answer VI.3:

The primary confusion on the TTBT compliance issues was caused by the (now) incorrect government estimate of the seismic bias factor, which takes into account the geological differences between the United States and former Soviet test sites. The U.S. test site in Nevada is on newer geological strata that better absorb the seismic waves, reducing the m_b values. On the other hand, the Soviet site in Kazakhstan is on older geological strata, which absorb much less seismic strength, giving larger m_b values. Thus, weapons with the same yield produce explosions with higher m_b values at the Soviet site than at the American site. This was interpreted as excessive Soviet yields beyond the 150 kiloton TTBT limit, with the charge that the Soviets had "likely" violated the TTBT. U.S. geophysicists had long predicted the "bias" difference between the sites would give a false reading in this manner. In 1988 the Joint Verification Experiment was carried out by using Corrtex measurements at the two sites. These measurements convinced the executive branch that the geophysicists were correct on the value of the bias between the two sites. Finally in 1990, the Bush administration reversed the former finding of a "likely" violation. This reversal allowed the TTBT to be ratified and entered into force, and the CTBT negotiations to begin.

Question VI.4: Comprehensive Test Ban Treaty Violation

If a CTBT States Party is suspected of having tested a nuclear weapon, what recourse do the other CTBT States Parties have? How would the international process move forward?

Answer VI.4:

The data from the International Monitoring System (IMS) and NTM data (consistent with international law—no data from spying) will be transferred to the International Data Center. These data are open to all States Parties, who individually must first come to their own conclusions on the meaning of the data as the IMS does not make compliance findings. Each States Party has the right to request an on-site inspection on the territory of the suspected nation. The Executive

Council of 51 nations must respond within 96 hours. At least 30 of the 51 members of the Council must vote affirmatively for the OSI to go forward. For the case of a possible violation of the CTBT, the Conference of all the States Parties will determine if a state is in noncompliance with the CTBT, and determine collective measures that are in conformity with international law. Alternatively, the Conference or the Executive Council may bring the issue, including relevant information and conclusions to the attention of the United Nations for resolution and action. As in the case of the 1991 Middle East War, the UN can impose harsh sanctions on a violator such as Iraq.

FURTHER READING

On the historical record on the ratification of arms control treaties, I recommend M. Krepon and D. Caldwell's excellent book, *The Politics of Arms Control Treaty Ratification* (New York: St. Martin's Press, 1991). For an excellent discussion of the negotiating record of the CTBT treaty terms, see R. Johnson, "The In-comprehensive Test Ban," *Bulletin of the Atomic Scientists,* 52 (November/December 1996): 30-35. For technical issues, I recommend S. Drell and B. Peurifoy, "Technical Issues of a Nuclear Test Ban," *Annual Review of Nuclear and Particle Science* 44 (1994): 285-327 and S. Fetter, *Toward a Comprehensive Test Ban* (Cambridge, MA: Ballinger, 1988).