# A Low-Threshold Nuclear Test Ban

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The testing of nuclear weapons is currently banned in all environments except underground by the Limited Test Ban Treaty of 1963. Furthermore, the signed but not yet ratified Threshold Test Ban Treaty of 1974 limits the yields of U.S. and Soviet underground tests to no more than 150 kilotons (kt).

Recently, the Soviet Union has dramatized, with an 18-month unilateral testing moratorium, its interest in banning *all* underground nuclear explosions. The Reagan Administration, supported by the Joint Chiefs of Staff and the nuclear weapons laboratories, has, however, flatly rejected the desirability of such a Comprehensive Test Ban (CTB) in the foreseeable future. A spokesman for the Administration has summarized its position on a CTB as follows:

> As long as we depend on nuclear weapons for our security, we must insure that those weapons are safe, secure, reliable and effective. This demands some level of underground nuclear testing as permitted by existing treaties.[1]

CTB opponents have also pointed to the importance of being able to use underground nuclear explosions to test the resistance of military systems to nuclear weapons effects.

Within the Congress, however, strong interest has been expressed in the possibility of lowering the yield limit on underground testing as far as verifiability by seismic means will allow. In August 1986, the U.S. House of Representatives voted an amendment (later dropped in Senate–House conference) which would have withheld funding for U.S. testing above 1 kiloton provided that the Soviet Union reciprocated and cooperated with the U.S. in establishing in-country seismic monitoring stations.[2] In May 1987, the House again attached this amendment to its version of the Fiscal Year 1988 Defense Authorization Bill while, in the Senate, a modified version of this

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[1] *The New York Times*, February 27, 1987, p. A-3.

[2] *Congressional Record*, August 8, 1986, p. H5754.

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amendment containing more detailed verification provisions and a small quota for tests up to 15 kilotons was introduced with bipartisan sponsorship.

In this article, we will explore the extent to which such a Low-Threshold Test Ban (LTTB) approach deals with the concerns that have been raised by the Reagan Administration.[3] We also will examine the possibility of allowing a small quota of tests at higher yields to deal with the concerns that have been raised about reliability.

Our discussion is based entirely on public information combined with insights derived from simple physics calculations. Although we have not had access to the secret literature on nuclear weapons design, we have been assured by several reviewers that none of our basic conclusions are invalidated by it. Our lack of access has given us one important advantage: the freedom to discuss publicly what we *do* know.

## *The Debate over Nuclear Testing*

For more than two decades, the most prominent arguments against a Comprehensive Test Ban centered on verification questions. These questions became particularly difficult after 1959, when CTB opponents showed that it was theoretically possible to muffle small nuclear explosions in large underground caverns[4]—a possibility that has subsequently been confirmed by experiment.[5] This meant that nonseismic means, such as satellite photography, would have to be depended upon to detect the preparations for such tests or in-country seismic monitoring would be required to detect their seismic vibrations. For many years, the Soviet Union was unwilling to permit in-country monitoring.

During the Carter Administration, however, the Soviet Union agreed, in principle, to allow the deployment of unmanned seismic monitoring stations

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[3] The idea of a low-threshold test ban has been discussed recently in several articles and reports that focus primarily on questions of verifiability. See Ray Kidder, *On the Degree of Verification Needed to Support a Comprehensive Test Ban* (Livermore, Calif.: Lawrence Livermore National Laboratory, December 1986), Report # UCRL 95155 Rev. 1; Jack Everden, Charles Archambeau, and E. Cranswick, "An Evaluation of Seismic Decoupling and Underground Nuclear Test Monitoring Using High-Frequency Seismic Data," *Review of Geophysics*, Vol. 24 (May 1986), pp. 143–215; and Paul Richards and Allan Lindh, "Toward a New Test Ban Regime," *Issues in Science and Technology*, March 1987, pp. 101–108.

[4] This history is reviewed in Glenn T. Seaborg, *Kennedy, Khrushchev, and the Test Ban* (Los Angeles: University of California Press, 1981), pp. 18–19.

[5] See, e.g., Everden, Archambeau, and Cranswick, "An Evaluation of Seismic Decoupling," p. 147.

within its borders. Then in July 1986, it allowed a private U.S. group to set up three manned seismic stations around the principal Soviet test site in Eastern Kazakhstan. Much analytical work has been done in assessing the potential capabilities of in-country seismic monitoring networks. There is now general agreement within the expert community that, given 25–30 carefully sited seismic stations within both the U.S. and U.S.S.R., even muffled nuclear explosions could be reliably detected and identified down to yields of a few kt,[6] and with the use of high-frequency seismometers, perhaps down to below 1 kt.[7]

As the ability to monitor testing limitations has improved, however, test-ban opponents have begun emphasizing various other reasons why the U.S. needs to continue testing. We discuss these reasons below under the headings of effectiveness, reliability, safety and security, and weapons effects. We begin with a discussion of effectiveness, because it relates to the need to develop new nuclear weapons, the primary purpose of underground testing today.

## *The Effectiveness of Nuclear Weapons*

Technical concepts for new types of nuclear weapons are usually developed at the nation's two nuclear weapons laboratories: the Lawrence Livermore National Laboratory in California and the Los Alamos National Laboratory in New Mexico. These technical concepts are then developed into weapons concepts by the weapons labs and the military, and finally into specific production programs for new nuclear weapons which are proposed to Congress. The weapons labs participate at each stage in this planning process and have also played a leading role in opposing limitations on nuclear testing.

The weapons laboratory perspective on the importance of the continued development of new nuclear weapons has been presented repeatedly to Congress during the past few years. An example is the following statement, taken from the 1985 Congressional testimony of C. Paul Robinson, then Principal Associate Director for National Security Programs at Los Alamos National Laboratory:

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[6] Willard J. Hannon, Lawrence Livermore National Laboratory, "Seismic Verification of a Comprehensive Test Ban," *Science*, January 18, 1985, p. 251.

[7] Everden, Archambeau, and Cranswick, "An Evaluation of Seismic Decoupling," p. 149.

> All our experience at Los Alamos convinces me that continued research, development, and testing of nuclear weapons is essential if the United States is to continue to rely on the nuclear deterrent as we know it, or any likely alternative. . . . a CTB . . . would prevent us from validating the development of weapons that would allow us to respond to new requirements such as those which may derive from the changes that are occurring in the targets we must hold at risk in the Soviet Union. These requirements might include using maneuvering reentry vehicles (MaRVs) to counter Soviet defenses; developing earth penetrating weapons to hold at risk extremely hard, buried targets (missile silos, deep underground facilities) and developing effective means to hold at risk mobile and imprecisely located targets. . . . To ensure that we could destroy buried or hardened Soviet $C^3$ [command, control, and communications] assets or missile silos, we need to know more about cratering, ground shock, source-region electromagnetic pulse, and other phenomena associated with nuclear explosions. To be able to hold at risk mobile Soviet weapons and support capabilities, we need to know more about the generation of microwave radiation by nuclear explosions.[8]

This excerpt refers to one "third-generation" weapons concept—the use of nuclear weapons to generate microwave radiation in order to destroy the electronics of mobile targets. Another third-generation concept often mentioned by testing advocates is a nuclear-explosion-pumped X-ray laser that could be used to attack ballistic missiles and satellites in space.

Statements such as Robinson's should not be misunderstood to mean that weapons scientists necessarily believe that nuclear weapons could be used successfully to fight and win wars. However, most proponents of new nuclear weapons *do* believe that the U.S. can best protect its own security and that of its allies by continuing to improve the U.S. arsenal of strategic counterforce weapons—weapons specifically designed to attack the Soviet nuclear arsenal and its command and control system.

There is an opposing view about the value of counterforce weapons, however, which sees the possession of counterforce weapons by the U.S. and U.S.S.R. as creating incentives both to strike first and not to wait to strike second. It is therefore argued that new counterforce weapons such as the earth-penetrating warhead and enhanced microwave warhead advocated by Robinson would be crisis-destabilizing and should not be developed. Nuclear weapons designed to destroy space targets are also seen as destabilizing as they too might be most effectively used by the side that strikes first.

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[8] C. Paul Robinson, in *Review of Arms Control and Disarmament Activities,* Hearings of the House Armed Services Committee, 1985, pp. 140–142.

Of course, the value that one assigns to the deterrent effects of U.S. counterforce capabilities relative to their crisis-destabilizing effects depends heavily upon one's assumptions concerning the psychology of the Soviet leadership. Official views on this question can also be found in Congressional testimony. For example, Richard L. Wagner, then Assistant to the Secretary of Defense for Atomic Energy, made the following statement in 1983 concerning the psychological impact of new nuclear weapons on the probability of war:

> What it comes down to in the end is to keep [the Soviets'] image of themselves inferior to their image of us, so that if a crisis comes they will have a gut feeling that they won't measure up against us. It is often said that Soviet leaders are conservative. They are when they feel inferior. . . . our job is to keep them feeling inferior and thus conservative. . . . I believe that our level of technology in itself, quite apart from exactly how it is built into fielded systems, affects their overall image of themselves and of us, and thus can have a significant deterrent effect. . . . By the [19]90s we'll need some really new technology to keep the image ratio in our favor. The technology of nuclear explosive design is an important part of our overall technological capability.[9]

This statement was unusual more for its bluntness than for the views expressed, which are widely held among government officials who believe in the strategic value of continuing efforts to refine nuclear weapons technology.

Test-ban advocates typically have a quite different view of the value of the continued development of new nuclear weapons. This view is that once a country obtains for itself even one-tenth of the high levels of survivable destructive power that the United States and Soviet Union both currently possess, it has bought for itself most of the deterrence that nuclear weapons can provide. Beyond this point, trying to give the nuclear threat more credibility is like a man who has filled up his house with dynamite continually inventing new triggering mechanisms to convince potential burglars that the house really will blow up if they break in. In this view, the nuclear weapons modernization process simply fosters a nuclear warfighting approach to deterrence which dehumanizes the other side, undermines diplomatic steps toward Soviet–American reconciliation, and weakens the ability of the U.S. and U.S.S.R. to persuade other nations not to develop nuclear weapons.

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[9] Richard L. Wagner in *Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1984,* Hearings before the U.S. House Committee on Armed Services (Washington, D.C.: U.S. Government Printing Office, 1983), p. 33.

Obviously, underlying the technical debate over the development of new nuclear weapons are considerations that are ordinarily labeled "political." In this article, we can only emphasize this fact before passing on to the issues relating to reliability, safety and security, and weapons effects. It should be kept in mind during the following discussion, however, that the importance assigned to these more technical issues also depends in large part on political considerations.

### *Temperatures and Yields*

Different yield ranges have varying importance for underground nuclear explosive tests bearing on reliability, safety and security, and weapons effects. In order to lay a basis for the understanding of these considerations, we digress here into a brief description of certain of the basic design features of nuclear weapons. The key points that will be made are that there are certain critical temperatures which must be achieved during different stages of a nuclear explosion and that it is difficult to achieve these critical temperatures below certain yield thresholds.

Modern strategic nuclear warheads release their energy in two main "stages." In the primary stage, most of the energy release is due to fission. Energy from this primary explosion then compresses and heats the fuel of the secondary stage to the point at which thermonuclear reactions are ignited. Typically, a considerable amount of additional fission energy is also released in the secondary stage.

In the primary stage, a mass containing a few kilograms of "fissile" (chain-reacting) plutonium-239 and/or uranium-235 is "imploded" into a denser configuration by surrounding chemical explosions. As the spacing between the nuclei in the imploding mass decreases, the probability increases that any free neutron traveling through the mass will be captured by a fissile nucleus, causing a fission and the release of 2–3 new neutrons. At some point, the capture probability rises through the threshold above which an exponential fission chain reaction can be sustained. In this domain, the compressed mass is termed "supercritical."

The total energy released by a fission chain reaction initiated in such a configuration is proportional to the number of fissions that occur before the pressures developed by the energy release reverse the implosion and return the density to a subcritical level. The time scale for the entire explosion is much less than a microsecond (a millionth of a second) with the energy release growing from tons to kilotons in the last one-hundredth of a microsecond.[10]

Although the complete fission of only about 60 grams of fissile material releases an amount of energy equal to that released by one thousand tons (i.e., one kiloton) of standard chemical explosive, even the lowest-yield fission warheads in the U.S. nuclear arsenal weigh tens of kilograms. Most of this weight is associated with the implosion system. Much of the refinement of fission explosives has been devoted to the reduction of this extra weight—or, conversely, to increasing the yield of an explosive with a given weight.

A major contribution to the increase of the yield-to-weight ratios of fission primaries has occurred through the introduction into the fissile core of a small quantity (probably a few grams) of deuterium-tritium (D-T) gas. The rapid increase in temperature during the fission explosion ignites the thermonuclear reaction ($D + T \rightarrow He^4 + n$), releasing a burst of high-energy neutrons (n) which give a final "boost" to the chain reaction just as expansion is causing the mass to become subcritical. Since a D-T fusion releases only one-tenth as much energy as a fission event, the fusion reactions make only a relatively minor direct contribution to the total energy of the explosion, but their neutrons make a large indirect contribution through the extra fissions they cause.

The D-T reaction rate becomes significant on the very short time scale involved in a fission explosion only when the temperature in the core becomes of the order of 100 million °K.[11] At these temperatures, the collisions of the deuterium and tritium nuclei become violent enough so that they can penetrate each other's electrostatic shields, allowing short-range nuclear reactions to take place. In order to achieve such a temperature, at least 1

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[10] In seven generations of fission, the total energy release can increase one-thousandfold. See, for example, Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed. (Washington, D.C.: U.S. Government Printing Office, 1977), p. 17. The length of time between fissions is roughly the average time of travel of the fission neutrons within the fissile material. After compression, the fissile material in the core of a nuclear explosive has a radius of only 2–3 cm. The time required for a typical fission neutron, with a kinetic energy of one million electron Volts, to travel 4 cm is about one one-thousandth of a microsecond.

[11] For a mole of D-T gas (4 grams) in a volume of 0.6 cc and at an ion temperature of 100 million °K, the reaction time constant is about 0.01 microsecond. At temperatures one tenth and five times as great, the reaction time constants are 10,000 and 0.1 times as long respectively. Reducing the volume (i.e., increasing the gas density) tenfold would reduce the reaction time constant by the same factor. See, for example, R.F. Post, "Controlled Fusion Research and High-Temperature Plasmas," *Annual Review of Nuclear Science*, Vol. 20 (1970), p. 518. We use the usual conversion from energy to temperature scales: 1 eV = 11,600 °K. The Kelvin and Centigrade temperature scales are the same except that 0 °K is at absolute-zero temperature (−273 °C).

percent of the material in the core must fission.[12] If we assume that the minimum amount of fissile material required to make a practical primary is 2 kg of weapon-grade plutonium,[13] the fission of 1 percent of this material would release about 0.4 kilotons of energy. This estimate of the minimum amount of fission energy release required in practice to reach the threshold for boosting is consistent with the statement by Theodore B. Taylor, a former weapons designer, that "[i]t is difficult to imagine militarily attractive boosted weapons with yields less than one kiloton or so."[14]

The thermonuclear reactions in the "secondary" are ignited by compression—apparently caused by the energy carried by the black-body X-rays radiated by the hot primary.[15] High efficiency in the conversion of fission energy into X-ray energy is therefore a key *desideratum* in a primary. This efficiency is a function of the primary's yield-to-weight ratio. In the approximation that the temperature of the core and surrounding implosion mechanism is uniform after the completion of the release of the energy in the primary, the fraction of the primary's energy going into X-rays increases rapidly with yield-to-weight ratio until it exceeds 50 percent at yield-to-weight ratios above about 0.1 kilotons/kg (see Figure 1).[16]

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[12] A fission releases approximately 200 MeV (million electron Volts) of energy, and the fissioning atoms contain almost 100 electrons each. Therefore, if the core material were fully ionized and in thermal equilibrium, the fission of 1 percent of the atoms would give each particle an energy of about 20,000 eV (electron Volts). Our assumption of complete ionization and our neglect of the energy absorbed in the ionization process make this a very rough result, since the initial average binding energy of the electrons is on the order of 10,000 eV.

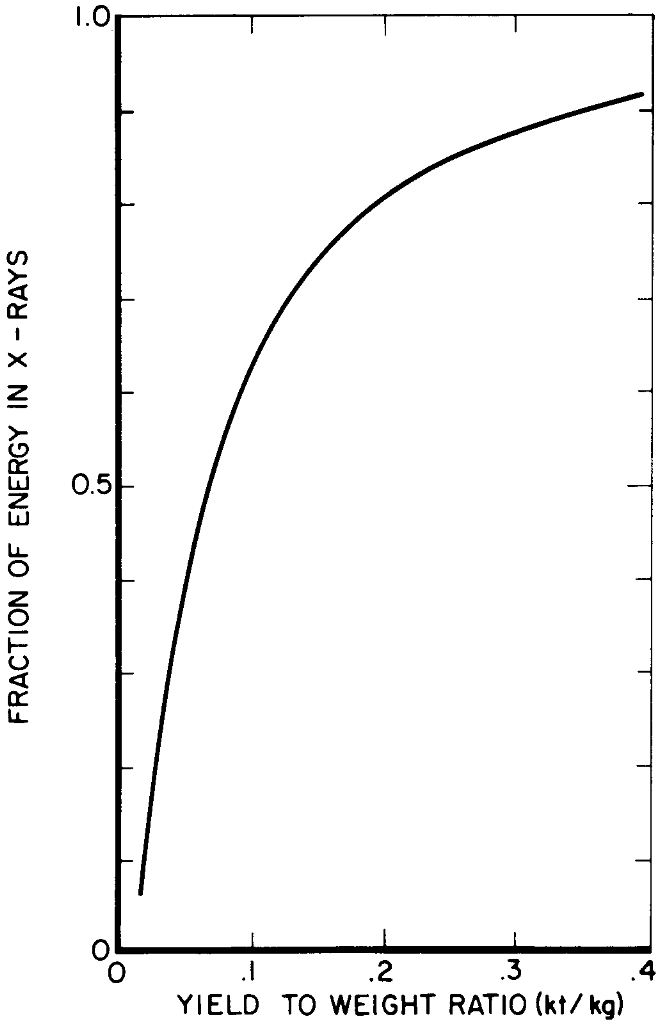
[13] The critical mass of weapon-grade plutonium at normal density and inside a thick neutron reflector is about 6 kg; see H.C. Paxton, *Los Alamos Critical-Mass Data* (Los Alamos, N.M.: Los Alamos Laboratory, 1975), Report #LA-3067-MS, Rev. p. 40. This was the amount of plutonium in the core of the Nagasaki bomb. (Leslie R. Groves, "Memorandum for the Secretary of War," July 18, 1945, reprinted as Appendix P in Martin J. Sherwin, *A World Destroyed* [New York: Alfred A. Knopf, 1975].) Subsequent design improvements resulted in dramatic reductions in the amount of fissile material required to make a fission explosive to a fraction of a critical mass ("frac crit"). See, for example, Hans A. Bethe, "Comments on the History of the H-Bomb," *Los Alamos Science*, Fall 1982, pp. 44–45.

[14] Theodore B. Taylor, "Nuclear Testing is a Pandora's Box," *Public Interest Report* (Federation of American Scientists), December 1986, p. 4.

[15] For a review of the available public information on this mechanism, see Alexander deVolpi, Gerald E. Marsh, Theodore A. Postol, and George S. Stanford, *Born Secret: The H-Bomb, the Progressive Case and National Security* (New York: Pergamon Press, 1981). The physics, as applied to inertial-confinement fusion, is reviewed in Thomas H. Johnson, "Inertial-Confinement Fusion: Review and Perspective," *Proceedings of the IEEE*, Vol. 72 (May 1984), pp. 548–594.

[16] The energy density in a black-body radiation field increases with temperature as $1.37*10^{13}*T^4$ joules/$m^3$. (T in keV, 1 keV = $11.6*10^6$ °K.) The kinetic portion of the energy density ($k_b*T/2$ per degree of freedom) of the completely ionized gas produced by the fissioning of the primary may be approximated by $7.2*10^{10}*T$ joules/kg, assuming an average of one gram-mole of (i.e.,

**Figure 1.** In a strategic nuclear weapon, the X-rays produced by a "primary" fission explosive carry the energy that causes the compression and heating of the thermonuclear fuel in the "secondary." This graph suggests that, in order to be efficient producers of X-rays, primaries would have to have yield-to-weight ratios of 0.1 kt/kg or greater. Such yield-to-weight ratios are achievable at about 10 kt. The graph shows, as a function of yield-to-weight ratio, the fraction of the energy released by a fission weapon that is in the form of X-rays. The residues of the explosive are assumed to be fully ionized and at a uniform temperature, and the X-ray radiation field inside the weapon casing is assumed to be in thermal equilibrium with these residues at the original bomb density of 2,500 kg/m$^3$.



Based on the yield-to-weight ratios of pure fission warheads, a primary with a yield-to-weight ratio of 0.1 kilotons per kilogram would weigh about 100 kg and have a yield of about 10 kt.[17] The fact that a significant portion of U.S. testing occurs in the yield range of 5–15 kilotons (see Figure 2)[18] suggests that U.S. strategic weapons have such "hot" primaries.

This gives us our second temperature-related point of nuclear yield. Note that both of these points relate to the performance of boosted primaries: the first, at about one kiloton, relates to the onset of thermonuclear reactions in the primary, and the second, at about ten kilotons, relates to the capability of the primary to ignite thermonuclear reactions in a high-yield secondary. (This does not mean that it is impossible for a thermonuclear explosive with a low-yield secondary to have a total yield lower than ten kilotons. The so-called "neutron bomb," which has a yield of about one kiloton, is an instance of such an explosive.)[19]

The fact that primaries account for a significant portion of the weight of all but the highest-yield modern thermonuclear warheads has made them a principal target for weight-reduction efforts. This probably accounts for the relatively high frequency with which they are tested. This may also be one reason why virtually all concern expressed about the reliability of U.S. nuclear weapons focuses on the primaries. This is certainly the message carried by the most explicit public statement to date on this subject from the weapons laboratories:

> It is by now no secret that the large majority of reliability problems discovered in the US stockpile over the years have involved the physical process known as boosting. . . . [L]aboratory experiments have been and continue to be incapable of accurately predicting the results of nuclear tests of boosted

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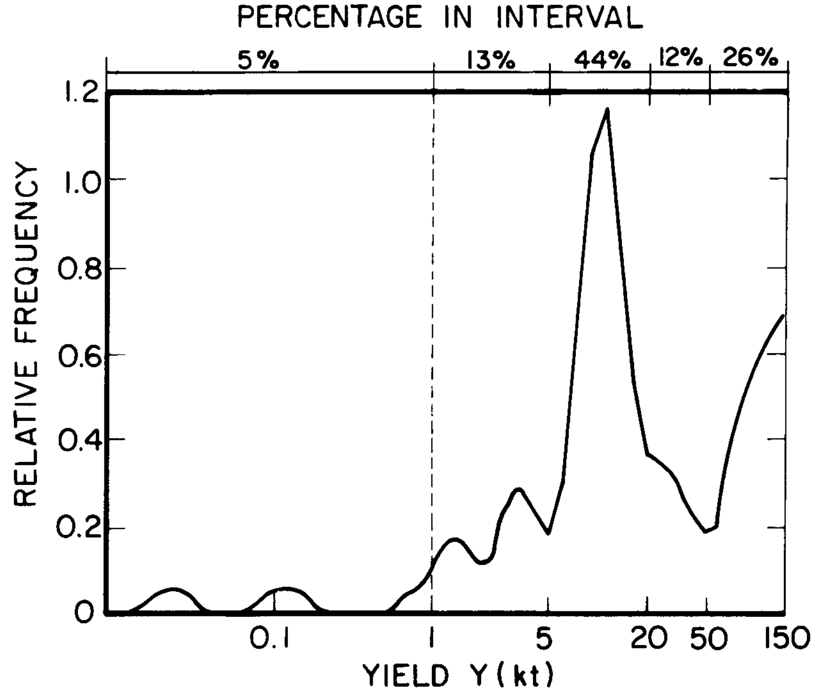
$6.0*10^{23}$) electrons per two grams of mass for the mixture of core, reflector, and chemical explosive. We adopt a warhead density of 2,500 kg/m$^3$, which is the approximate density of both the old W33 kiloton-range tactical warhead and the modern W79 kiloton-range enhanced-radiation warhead in the U.S. arsenal. (Thomas B. Cochran, William M. Arkin, and Milton M. Hoenig, *U.S. Nuclear Forces and Capabilities* [Cambridge, Mass.: Ballinger, 1984], pp. 47, 77.) Given this warhead density, the calculated energy densities are approximately equal when $T = 2.3$ keV and the total energy density is approximately $3*10^{11}$ joules/kg (0.08 kt/kg).

[17] Cochran et al., *U.S. Nuclear Forces and Capabilities,* p. 36.

[18] Ray E. Kidder, Lawrence Livermore National Laboratory, "Militarily Significant Nuclear Explosive Yields," in *Proceedings of the Department of Energy Sponsored Cavity Decoupling Workshop, Pajaro Dunes, CA, 29–31 July 1985* (Washington, D.C.: Department of Energy Report # CONF-850779), p. V-25.

[19] Cochran et al., *U.S. Nuclear Forces and Capabilities,* p. 28.

**Figure 2.** **This figure represents the yield distribution of U.S. tests for the period 1980–84. Equal areas under the curve correspond to equal relative frequencies of testing. The relatively high frequency of testing in the 5–15 kt yield range is probably mostly due to the tests of the fission "primaries" of thermonuclear weapons. The peak at higher yields reflects the influence of the U.S.–U.S.S.R. Threshold Test Ban Treaty, which constrains all U.S. and Soviet nuclear explosions to yields of not more than 150 kt.**



DISTRIBUTION OF U.S. EXPOSIVE YIELDS
(1980-1984)

devices. This is a fact of particular importance when those devices are used as triggers for thermonuclear weapons, where the permissible range of yields may be quite small.[20]

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20. Donald R. Westervelt, Los Alamos National Laboratory, "Nuclear Weapons: The Role of

### *Reliability*

Concerns raised about the possibility that U.S. nuclear weapons might become unreliable in the absence of testing played a key role in derailing President Carter's efforts to achieve a Comprehensive Test Ban.[21] The technical basis for this concern was immediately challenged in a letter to Carter from a former weapons laboratory director and two former weapon designers.[22] However, spokesmen for the weapons laboratories have continued to insist that reliability remains a real concern.

The most precise official statement of which we are aware regarding the use of nuclear weapons tests to maintain stockpile reliability is the following: "More than one third of all weapons designs introduced into the stockpile since 1958 have encountered reliability problems. Of these 75% were discovered and/or corrected as a result of nuclear testing."[23]

Several of these instances of reliability problems have been publicly discussed by Jack Rosengren, a former weapons designer, as evidence of the need for nuclear weapons testing to maintain confidence in the weapons stockpile.[24] Ray Kidder, another former weapons designer, has however reviewed the Rosengren study and concluded that:

> none of the examples cited . . . support[s] the thesis that nuclear explosive testing is necessary to maintain confidence in the reliability of the *existing* U.S. nuclear stockpile of *thoroughly tested* nuclear weapons. . . .[25]

Kidder's critique has elicited a rebuttal from Rosengren,[26] which Kidder has rebutted in turn.[27]

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Laboratory Tests," in *Symposium on the Comprehensive Test Ban: Problems and Prospects, Ottawa, Canada, October 23–25, 1986* (Canadian Institute for International Peace and Security and the Stockholm International Peace Research Institute); *Proceedings* forthcoming from Oxford University Press.

[21] Jimmy Carter, *Keeping Faith* (New York: Bantam Books, 1982), p. 229.

[22] Norris Bradbury, Richard Garwin, and Carson Mark, Letter to President Carter; reprinted in *Effects of a Comprehensive Test Ban Treaty on United States National Security Interests*, Hearings before the Panel on SALT and the CTB, House Committee on Armed Services (Washington, D.C.: U.S. Government Printing Office, 1978), p. 181.

[23] Paul Brown, Lawrence Livermore National Laboratory, *Energy and Technology Review*, September 1986, p. 13.

[24] Jack W. Rosengren, *Some Little-Publicized Difficulties with a Nuclear Freeze* (Marina Del Rey, Calif.: R&D Associates Report #RDA-TR-122116-001, 1983).

[25] Ray E. Kidder, *Evaluation of the 1983 Rosengren Report from the Standpoint of a Comprehensive Test Ban* (Lawrence Livermore National Laboratory, June 17, 1986), Report #UCID-20804. Emphasis in original.

[26] J.W. Rosengren, *Stockpile Reliability and Nuclear Test Bans: A Reply to a Critic's Comments* (Arlington, Va.: R&D Associates Report #RDA-TR-138522-001, 1986).

[27] Ray E. Kidder, *Stockpile Reliability and Nuclear Test Bans: Response to J.W. Rosengren's Defense of His 1983 Report* (Lawrence Livermore National Laboratory, 1987), Report # UCID-20990.

It is impossible for outside observers to come to a final conclusion on the reliability issue based on such fragments of the debate as have been declassified by the weapons labs. However, the following three key facts *have* been established.

1) Prohibitive numbers of nuclear tests would be required to maintain confidence in the continuing reliability of the stockpile with random nuclear tests. The principal way in which problems in the stockpile are detected and rectified today is by disassembly and inspection and by nonnuclear tests.
2) During the period 1970–85, only eight underground nuclear explosions were justified by the need to "correct defects in stockpiled weapons."[28] A comparable number were probably carried out to determine the seriousness of problems detected during routine disassembly and inspection. The resulting total of an average of about one reliability test per year should be compared with the average of a total of approximately 20 U.S. nuclear tests per year during this same period.
3) As has already been noted, almost all reliability problems concern the primary. Those who argue that reliability tests are required therefore only argue for tests up to the full yield of the primary—which we have concluded above is typically less than 15 kilotons for U.S. primaries. This may account for the willingness of former Livermore Director and Secretary of Defense Harold Brown in 1986 to endorse a threshold test ban with a yield limit at 5 kt.[29] It may also account for the statement in 1977 by Harold Agnew, then Director of the Los Alamos National Laboratory, that "I don't believe testing below say five or ten kilotons can do much to improve (as compared to maintaining) strategic posture. . . ."[30]

It would appear from the above discussion that a quota of about one test per year at a yield of about 5–15 kt could satisfy the concerns that have been raised about the need for reliability tests.[31]

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[28] Department of Defense/Arms Control and Disarmament Agency/Department of Energy, joint answer to a question for the record in *Nuclear Testing Issues,* Hearing before the Senate Armed Services Committee, April 29, 1986, p. 46.

[29] Harold Brown in *Implications of Abandoning SALT,* Hearing before the House Foreign Affairs Committee, April 15, 1986 (Washington, D.C.: U.S. Government Printing Office, 1986), p. 13.

[30] Harold Agnew, Letter to Representative Jack F. Kemp, April 19, 1977, reprinted in *Effects of a Comprehensive Test Ban Treaty,* p. 193.

[31] Recently Harold Brown has stated that "I can support an agreement to limit nuclear tests to a few a year at 10–15 kt and all others to 1–2 kt" (private communication to C.E. Paine, May 5, 1987).

It appears quite possible to us also that an independent review with full access to the relevant information would establish that even this small number of tests would be unnecessary or could be phased out within a few years if no new weapons designs were introduced into the weapons stockpile. Alternatively, a consensus could probably be achieved to forgo reliability tests if the U.S. were to abandon its emphasis on counterforce. A high degree of reliability is significant only to those who believe that it is possible to destroy thousands of military targets in the Soviet Union without inflicting unacceptable damage to the civilian population.[32]

### *Safety and Security*

Another technical reason given for continued testing is the need to improve safety and protection against unauthorized use.

With regard to safety, U.S. nuclear weapons are already designed to be "one-point safe"—i.e., not to explode with a significant nuclear yield even if a segment of the chemical explosives in the nuclear trigger is detonated by the penetration of a bullet or by fire. Current work on safety improvements is therefore focused on the much less serious problem of reducing the likelihood of dispersal of toxic plutonium as a result of the accidental detonation of the chemical high explosives. An important advance in this regard has been the introduction in new nuclear weapons of "insensitive high explosives" (IHE), which are much less subject to accidental explosions. The introduction of IHE into the U.S. arsenal was motivated primarily by the need to reduce the risks associated with the movements of airborne and land-mobile weapons.[33] Modern nuclear bombs containing IHE are now available at yields up to a few hundred kilotons and in the megaton range, and the

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[32] In a recent policy paper on "Nuclear Weapons Testing" (Policy Paper #5, January 1987, p. 29), the U.S. Department of Energy opposed a test ban on just these grounds:

> The U.S. and the Soviets have different target sets: the Soviets have invested heavily in hardening their targets while we have not. To hold those important Soviet assets at risk without unacceptably high levels of collateral damage, we must optimize the yield-to-weight ratio of our warheads. Because of this, nuclear testing appears to be more important to the U.S. than to the Soviet Union. Based on available evidence, we think that we rely more on high technology and on optimized warhead characteristics in our nuclear warhead design than do the Soviets. In a no-test environment, Soviet missile throw-weight and volume advantages could permit the Soviets to fall back on previously tested, heavier, and relatively simpler warhead designs which generally should be more reliable and rugged.

[33] Brown, *Energy and Technology Review.*

warheads of all U.S. cruise missiles and the Pershing II contain IHE. The warhead for the MX, which contains IHE, could be used on the Midgetman as well.[34]

In many cases where new warheads containing IHE have not been developed, there are institutional or technical reasons. Thus, for example, the Navy has elected not to put IHE in the warhead for its Trident II ballistic missile because warheads containing IHE are somewhat heavier and the substitution would therefore reduce either the range or number of warheads that can be carried by the missile. If the Navy changed its mind, the Trident II could use the same warhead as the MX. In the case of artillery shells, the problem is technical: since a larger volume of IHE is required to release a given amount of energy, the small diameter of artillery shells makes them difficult to convert. Finally, replacement warheads are not being developed for some tactical weapons that are being phased out in favor of precision-guided conventional weapons.[35]

Virtually all other safety improvements are focused on the mechanical and electrical designs of the triggering systems and can therefore be adequately tested without a significant nuclear explosion. One way in which this is done is by removing the fissile material from the primary and replacing it with non-fissile material such as U-238. The progression of the implosion is then followed with imbedded sensors and flash X-ray pictures. Even more sensitive tests are sometimes conducted by partially removing the chain-reacting material, leaving only enough so that the result is a nuclear explosion with a yield equivalent to the explosion of less than one kg of TNT. The production of neutrons from such a "zero-yield" nuclear test provides an extremely sensitive measure of the degree of compression that has been achieved by the chemical implosion. Such tests were used by the U.S. to explore safety problems during the 1958–61 U.S.–Soviet nuclear testing moratorium.[36]

The permissive action links (PALs) that are used to secure U.S. nuclear weapons from unauthorized use have already gone through several generations of improvements. The primary issue today is not further technical refinement but rather the fact that many weapons in the U.S. stockpile,

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[34] Cochran et al., *U.S. Nuclear Forces and Capabilities*, pp. 65, 79, 126, 133, 182, 200, 297.

[35] We would like to acknowledge useful discussions with Steve Fetter on questions relating to IHE.

[36] Robert N. Thorn and Donald R. Westervelt, *Hydronuclear Experiments* (Los Alamos National Laboratory Report # LA-10902-MS, 1987).

including the weapons on board ballistic missile submaries, still have no PALs at all.[37]

### *Nuclear Weapons Effects*

The final purpose for nuclear weapons tests is to examine the ability of military equipment—especially nuclear warheads—to withstand the effects of nearby nuclear explosions. For this purpose, the Limited Test Ban already imposes significant constraints on our ability to obtain further knowledge of such key nuclear weapons effects as the electromagnetic pulse from nuclear explosions in near space or on cratering by large surface-burst explosions. Much of the knowledge obtainable from underground tests can be gleaned from low-yield explosions, and therefore the need for effects tests is not a strong argument against an LTTB. For example, about the same radiation intensities can be achieved 40 meters from a one-kiloton test as 500 meters from a 150-kiloton test. For this reason, and because tests involving smaller-yield explosions are less expensive, most U.S. nuclear weapons effects tests are already conducted at quite low yields.[38] If a small number of 5–15 kt tests were allowed, they could be used for those few applications where a higher-temperature source is advantageous.

### *A Low Threshold with a Quota?*

Based on the above discussion, it appears that a Low-Threshold Test Ban would meet the concerns that have been raised with respect to the effects of a test ban on nuclear weapons safety and security and on our ability to collect information about nuclear weapons effects. The addition of a quota of about one test per year at a yield of 5–15 kt would allow the continuation of reliability tests at their previous rate. At the same time, an LTTB would achieve a large number of the objectives of a CTB by significantly constraining the development of new nuclear weapons.

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[37] Thomas Julian, "Nuclear Weapons Security and Control," in Paul Leventhal and Yona Alexander, eds., *Preventing Nuclear Terrorism* (Lexington, Mass.: Lexington Books, 1987), pp. 180–181.

[38] Robert S. Norris, Thomas B. Cochran, and William M. Arkin, *Known U.S. Nuclear Tests, July 1945 to 16 October 1986* (Natural Resources Defense Council Report # 86-2 [Rev. 1], Washington, D.C., 1986).

A strict 1-kt threshold test ban would prevent the development of new types of nuclear weapons with yields over a few kt.[39] To the extent that a small permitted quota of 10-kt tests were exploited for weapons development rather than reliability tests, some slow progress could also be made on the development of new weapons with yields up to perhaps 30 kt. Since the certification for deployment of even a modestly improved version of an already existing type of warhead currently typically requires about 10 tests, however, the development of qualitatively new weapons types would be greatly impeded.

A disadvantage of a Low-Threshold Test Ban relative to a CTB is that it would still allow the development of exotic new types of sub-kiloton weapons and the exploration of the underlying physics and technology that could be used to develop higher-yield weapons if the treaty limits were to break down. For this reason, some arms control experts advocate still more stringent limitations on nuclear weapons testing. Richard Garwin, for example, would only permit "explosive releases of nuclear energy" sufficiently small that they could safely take place "in permanently occupied above-ground buildings. . . ."[40] Gaining broad political acceptance of this position would, however, require either a higher profile and public credibility for non-seismic verification techniques or increased acceptance of the idea that little is to be gained militarily through testing at very small yield and that much is to be gained from the moral force of a complete test ban.

A final concern about a low-threshold treaty is that it would require a capability to verify the yields of small nuclear explosions with high accuracy and reliability. In the absence of adequate verification capabilities, a treaty could give rise to serious disputes over compliance. It would therefore be important to design and agree on appropriate in-country monitoring systems and associated constraints on test arrangements as part of any low-yield test ban treaty.[41]

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[39] Carson Mark in *Public Interest Report*, December 1986, p. 12.

[40] Richard Garwin in ibid., p. 13.

[41] The authors wish to acknowledge early contributions to this article by Dr. Josephine Stein.