The Role of Hydronuclear Tests
and
Other Low-Yield Nuclear Explosions
and
Their Status Under A Comprehensive Test Ban

by

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EXECUTIVE SUMMARY

The Conference on Disarmament (CD) in Geneva is currently negotiating a multilateral Comprehensive Test Ban Treaty (CTBT). The slow progress to date toward agreement on a final treaty text is undermining support for indefinite extension of the Nuclear Nonproliferation Treaty (NPT) at its 25-year review conference, scheduled to open in New York on April 17, 1995. Achieving a consensus on the scope of the nominally ''comprehensive'' ban is one of the most contentious issues awaiting resolution in the negotiations.

''Activities Not Prohibited''

In parallel discussions among the permanent five nuclear weapon state members of the UN Security Council (''Perm-5'' or ''P-5''), the U.S. government has proposed that so-called ''hydronuclear'' tests of nuclear weapon implosion systems with nuclear yields not exceeding four pounds (1.8 kg) of TNT equivalent should be treated as ''activities not prohibited'' by a treaty designed to ban nuclear test ''explosions.'' However, Russia and France are currently seeking to shield tests in the 10 to 200 ton range from inclusion in the CTB (i.e. tests with about 5,000 to 100,000 times greater yield). These tests indisputably constitute nuclear weapon test explosions. Nuclear yields of a few-to-tens of tons would be of significant value to a proliferant state, and would begin to be of value to a weapon state for nuclear weapons development. At nuclear yields of 100-200 tons, fusion phenomena can be investigated, allowing partial yield verification of the performance of new boosted-fission weapons, including new designs for the ''primary'' or triggering component of much more powerful two-stage thermonuclear weapons.

China's position is said to depend on whether the treaty is a genuine ''zero-yield'' test ban, or contains a tacit or explicit threshold at some level. If it does incorporate a threshold. China is said to favor tests at substantial yields, to compensate for China's perceived disadvantages in using low-yield and non-nuclear test data for supercomputer modeling of nuclear weapon performance at higher yields. Meanwhile, in the main body of the negotiations, China seeks to reserve the right to conduct so-called ''peaceful nuclear explosions,'' a position virtually without support among the other parties to the negotiations.

The approach of the U.S. and other governments has been to avoid further elaboration in the treaty text of the basic CTB obligation not to conduct a ''nuclear weapons test explosion. or any other nuclear explosion.'' Instead, the P-5 are seeking to negotiate a common understanding among themselves regarding ''activities not treaty prohibited.'' At the appropriate time, the Chairman of the Conference would read this common understanding into the negotiating record as the putatively ''authoritative'' interpretation of the test ban treaty's scope.

The exact legal status of such a joint statement, and its ultimate force and effect on other treaty parties. remain to be determined. If other parties to the negotiations object to the P-5 interpretation when it is read into the negotiating record, the interpretation cannot be considered legally binding on the parties to the treaty.

To date, the nuclear-weapon states remain far apart in their respective conceptions of allowable low-yield testing. Even if a common understanding could be reached, to avoid future verification difficulties and mutual suspicions of cheating, the conduct of such unregulated activities must somehow be readily distinguished from those included within the scope of the treaty. While continuing to protect the right to conduct hydronuclear and other low-yield tests, the current negotiating positions of the weapon states do not include solutions for any of these problems.

Hydronuclear Tests

Although no internationally accepted definition exists, hydronuclear tests are nuclear weapon tests, or high-explosive driven criticality experiments, limited to subcritical, or slightly supercritical neutron multiplication. As a consequence they can be designed to release negligible or at most very small amounts of fission energy. The prefix ''hydro'' means in this instance that the core of the nuclear device behaves like a fluid under compression by the chemical high explosive. Sufficient energy may be released to melt the core, but the nuclear energy released is insufficient for the core to heat to plasma temperatures and explode ''like a bomb.'' A narrower definition would limit the nuclear energy released to a level that would not perturb the mechanics of the chemical implosion. Thus, hydronuclear tests would typically be limited to total nuclear energy releases, or ''yields,'' of a few pounds or less of TNT equivalent.

There are several ways to modify a nuclear weapon to keep its yield within the hydronuclear regime. The rate of development of the chain reaction during a hydronuclear test can be assessed experimentally by measuring the gamma-rays and neutrons emanating from the fissioning material. The resulting data can be compared to the predictions generated by modeling the altered design using nuclear weapon design codes. Within the accuracy afforded by the experimental data, this comparison provides an independent measurement of the accuracy of portions of the weapon design codes. If confirmed or corrected by these experiments, the codes could then be employed with greater confidence to predict the behavior of the unaltered weapon.

Proliferation Risks

Full-scale nuclear testing is highly desirable for all but the lowest technology designs, not only to certify the yield of fully-engineered devices, but also to improve the predictive power of nuclear weapon design codes and to optimize weapon designs with respect to yield-to-weight and yield-to-volume. If full-scale testing is prohibited, hydronuclear tests *in theory* can serve a limited but useful role in the development of the full spectrum of *unboosted fission weapons*, including first generation nuclear weapons of the implosion type with yields in the 10 to 30 kiloton range, more sophisticated designs with yields of several hundred kilotons, and advanced micro-nuclear weapons that use small quantities of fissile material and have yields less than one kiloton.

In practice the utility of hydronuclear testing will strongly depend upon a host of other factors, including the availability of fissile materials to conduct hydronuclear tests, the availability of alternative means of obtaining the relevant information (including access to existing codes and historical test data), the sophistication of diagnostic tools needed for hydronuclear testing versus other techniques, the accuracy of alternative measurement techniques, the relative costs of the relevant experimental technologies, and whether the less accurate but independent measurements afforded by an *integrated* hydronuclear test are desired to enhance confidence in weapon code predictions and "reassure the boss."

Hydronuclear tests are useful for nuclear weapon development because they can be used to obtain an improved understanding of two key performance parameters of the weapon assembly system. The first is the optimum moment for initiating the chain reaction by an external neutron source. The second is the rate at which the nuclear chain reaction proceeds during the period between initiation of the chain reaction and the beginning of the explosive disassembly phase.

Assuming the hydrodynamics of assembling the fissile material into a supercritical mass have been mastered, prior to beginning hydronuclear tests the proliferant will already be assured of achieving a minimum ("fizzle") yield of at least 100 tons even if the weapon is initiated at the worst possible time, with the odds favoring significantly more yield. By providing data on the early supercritical stages of nuclear device performance, hydronuclear testing can provide a proliferant nuclear establishment with a stronger scientific basis for its estimate of the probability distribution for the yield of the device. Confidence in a proliferant's ability to achieve higher yields can be reinforced through the use of straightforward theoretical approximations that relate the fraction of material likely to be fissioned to the number of critical masses achieved through compression at the time explosive disassembly commences.

Despite having had access to weapon design codes, and to the results of hydrodynamic experiments and 194 nuclear test explosions conducted prior to November 1958, the record of extensive hydronuclear test activities at Los Alamos during the 1958-61 test moratorium reveals that the U.S. government appears to have conducted at least one hydronuclear test for development of a low-yield tactical nuclear warhead. Additional warhead safety and criticality experiments are known to have been conducted during the moratorium by the Lawrence Livermore National Laboratory, but the number, nuclear yield, and purpose of these tests remain classified to this day.

The Los Alamos record provides evidence of other potential benefits from hydronuclear testing that are less direct but nonetheless significant--improved equation-of-state data for fissile materials (important data for the physics models employed in nuclear design codes), and maintenance (or training) of a scientific cadre with expertise in nuclear test diagnostics. According to Russian sources, the USSR likewise conducted numerous implosion experiments with nuclear yields "under 100 kilograms" of TNT equivalent. When these tests occurred has not yet been disclosed.

On the other side of the ledger, it must be acknowledged that proliferators do not *require* hydronuclear tests to gain an initial fission weapons capability, or to improve this capability through a combination of *hydrodynamic* tests with non-fissile materials--to develop the required levels of implosion symmetry, peak compression, and initiation timing--and laboratory-scale experiments with pulse reactors or fast critical assemblies to "benchmark" neutronic codes.

Reliability Tests

In principle, hydronuclear tests could also be conducted to assess the performance of existing stockpile weapons, although this has not been the practice of the United States, and presumably other weapon states, that have had access to full-scale nuclear explosive tests. These test results would then serve as benchmarks against which future hydronuclear test results could be compared. Such tests would be one way of assessing the significance of unforeseen physical changes in the warheads that might be discovered later, or of assessing the impact of possible future safety-related modifications on performance.

The incremental value of hydronuclear testing for these purposes appears to be marginal at best. Any degradation of stockpiled weapons significant enough to be detected through hydronuclear testing would also be detectable by other means, primarily by periodic disassembly, visual inspection, and radiographic and other scanning techniques. As noted by experts at Lawrence Livermore National Laboratory, because of the "10 percent or worse" uncertainty in measuring the peak fission-neutron production rate achieved in a hydronuclear test, and the inherent complexities of using that measurement to predict the precise rate that would prevail at explosion time in the unmodified device, hydronuclear tests do not appear to offer the United States a decisive advantage over current non-nuclear explosive methods of maintaining weapon reliability.

Safety and "Render-Safe" Experiments

A safety criterion for U.S. nuclear weapons is that they be "one-point safe," meaning that the probability of producing a nuclear yield in excess of four pounds (1.8 kilograms) of TNT equivalent, due to the accidental detonation of the chemical high explosive at a single point, must be less than one per million. Other nuclear weapon states presumably utilize a similar criterion, albeit with perhaps higher permissible releases of nuclear energy. For the enduring U.S. stockpile, the one-point safety of an adequate number of fully-tested primary designs has already been established for the most likely--if not all foreseeable--accident geometries.

Whether a particular design meets its prescribed safety can be explored through computer modeling, but the phenomena involved are inherently three dimensional, and this makes calculation of the hydrodynamics extremely difficult. Historically, the United States has had difficulty predicting the results of one-point safety experiments, and thus the one-point safety of a given design was usually established by one or more underground field tests. Some of the 88 recently acknowledged U.S. safety tests are known to have exceeded the four pound safety criterion by tens or hundreds of tons, and it is likely that other tests exceeded the threshold by a lesser amount. This fact is of considerable relevance when considering the utility of hydronuclear tests for conducting so-called "render-safe" experiments--i.e. tests that would purport to demonstrate a capability for remote "disablement" of a prototype terrorist device through intentional one-point detonation. Given that these simple, unboosted designs are likely "one-point *unsafe*," it would be very difficult to use tests at a few pounds to verify methods for rendering these nuclear weapons safe, since it would be very difficult to ensure that such tests did not give several tons of yield.

If at some time in the future, a judgement were reached that a particular warhead type was not one-point safe as then deployed, changing the nuclear design and conducting additional tests would not be options under a bona fide CTB. Safety concerns, nevertheless, could be resolved by mechanical safing, by substituting a safer warhead type, or by altering the manner in which the warhead is handled, stored, and deployed.

Thresholds

To summarize what can be learned from tests at various low nuclear yields produced by chemical implosions of 50 to 100 lb TNT equivalent:

- at 0.05 kg or less, the one-point nuclear detonation safety of a boosted fission weapon can be assessed by the weapon states, although for some states with less developed computer modeling skills, this might involve a more expensive ''creep-up'' series of tests rather than a single test to avoid ''overshooting'' the maximum permissible yield;
- at 0.25 kg or less, some hydronuclear ''criticality experiments'' for fission weapon development can also be conducted, but the same caveat regarding ''overshooting'' applies;
- at yields under 1.8 kgs (4 lb), the U.S. proposed threshold for permitted experiments, additional safety tests, criticality experiments, and equation-of-state measurements can be conducted with a few kilograms of plutonium in a melted or vaporized state;
- at a few kg to a few hundred kg, the same set of phenomena can be more easily investigated, because of an improved nuclear signal-to-noise ratio and the greater margin for errors in projecting nuclear yield, thereby allowing fewer tests to be conducted to extract the desired data. There should be no debate that tests in this range constitute ''explosions'' in the common sense understanding of the term. In the P-5 discussions the U.K. is believed to be protecting tests at the low end of this range, reportedly on the order of 100 lbs (45 kg).
- nuclear yields of a few-to-tens of tons would be of significant value to a proliferant state for developing more advanced pure fission weapons with improved yield-to-weight ratios for delivery by missiles and tactical aircraft. Russia is currently seeking to protect this level of testing in discussions among the P-5.
- at nuclear yields of 100 - 200 tons, fusion phenomena can be investigated, allowing partial yield verification of the performance of new boosted-fission weapon designs. France has sought to protect this level for ''treaty compliant activities'' conducted by the weapons states.

Verification

While including hydronuclear tests in the CTBT poses a challenge to verification, this challenge is not qualitatively different from the problem of verifying a ban on the slightly larger, but still very low yield nuclear explosions that most parties to the negotiation agree should be covered by the treaty. Verification of all very low-yield events will depend primarily on other national technical means and the notion of ''societal verification,'' backed up by the codification in domestic law of the treaty's basic provisions as they apply to individuals, including criminal penalties for those found guilty of violating the provisions of such a statute. The CTBT should also include a provision that confers a protected international status upon those persons who have provided, or seek to provide, the Conference of State Parties or its Technical Secretariat with information concerning activities of a member state that may be in violation of the Treaty.

Because they result in vaporization and dispersion of toxic plutonium and small amounts of fission products, hydronuclear and other low yield tests are most likely to be conducted underground at existing test sites. The activity surrounding preparations for such tests will not always be easy to distinguish from preparations to carry out the larger explosions banned by the treaty, thereby requiring time-consuming negotiation of detailed provisions for cooperative verification of nuclear test activities at active test sites.

Under a treaty sanctioning low-yield tests, a State Party would have the latitude to use such tests--in addition to the wide range of non-nuclear test and computer modeling techniques already contemplated for exclusion from the agreement--to develop a variety of ''candidate'' nuclear warhead designs, which would be ready for full-scale testing whenever it or another country decided its supreme national interests required a resumption of testing.

If nonproliferation were truly to be taken seriously as the principal underpinning of the CTB, then all nuclear tests involving the use of fissile materials and high explosives or propellants, including hydronuclear tests, would be excluded, and a threat to supreme national interests would be the only sanctioned cause for withdrawal from a treaty of unqualified indefinite duration.

A Zero Yield Treaty

Since the marginal value of hydronuclear and other low yield tests for insuring the safety and reliability of existing stockpiled weapons is small in comparison to their associated verification complexities and proliferation risks, such tests should be explicitly banned under the CTBT.

A tightly written and/or interpreted CTB treaty could feasibly ban *any release of nuclear energy associated with the deliberate assembly or compression of fissile or fusion material by chemical high explosives or propellants.* Article I of the Treaty (as contained in the Australian ''Draft Treaty Elements'' of 30 March 1994) would thus be amended to read:

> 1. Each State Party undertakes not to carry out any nuclear weapon test explosion, any other nuclear explosion, or *any release of nuclear energy*

> *[exceeding X grams] caused by the deliberate assembly or compression of fissile or fusion material by means of chemical high explosive or propellants*, and to prohibit and prevent such explosions *or releases* at any place under its jurisdiction or control.

A number of governments, including Sweden, have also favored a broad ban on ''preparations'' to conduct nuclear tests. While a ban on ''preparations'' *per se* is likely to prove unworkable and unenforceable, Article I of the March 30 Australian draft text might usefully be modified to include a *prohibition on test site preparations to contain, or diagnose the characteristics of, a nuclear explosion.*

If the Basic Obligation were amended to bar [or limit] both hydronuclear tests and test site preparations, it might read as follows:

> 1. Each State Party undertakes--
>
> (a) not to carry out:
> (i) any nuclear weapon test explosion or any other nuclear explosion;
> (ii) *any release of nuclear energy [exceeding X grams] caused by the deliberate assembly or compression of fissile or fusion material by means of chemical high explosive or propellants*;
> (iii) *any test site preparations for containing, or diagnosing the characteristics of, such explosions or releases;* and
>
> (b) to prohibit and prevent such explosions, *releases, and preparations* at any place under its jurisdiction or control.

How Solid is the U.S. Commitment to a ''Comprehensive'' Test Ban?

A number of senior officials within the Joint Chiefs of Staff, the Office of the Secretary of Defense, and the Department of State are known to favor a low threshold treaty at 300 tonnes. They believe this level would provide the U.S. greater flexibility for modifying nuclear weapon designs, and would facilitate agreement among the P-5, but they are waiting to push for a change in the U.S. negotiating position until the pending NPT Review Conference has acted favorably on the U.S. proposal for unconditional, indefinite extension of the Nonproliferation Treaty.

On January 30, 1995, National Security Adviser Anthony Lake announced that the Clinton Administration was withdrawing its widely criticized proposal for an ''easy-out'' from the test ban treaty after ten years, and this decision was welcomed in some quarters as an indication of U.S. sincerity and dedication to the success of the CTB talks. Less attention has focused on the terms of the *quid-pro-quo* inside the U.S. government leading to the demise of the ''easy exit'' proposal, which ostensibly derived from Pentagon concerns that a future President might be reluctant to characterize future safety and reliability problems in the U.S. nuclear weapons stockpile as a threat to ''supreme national interests'' meriting withdrawal from the CTB. For assenting to deletion of the easy exit clause, the Department of Defense and Joint Chiefs of Staff received a public assurance that, in Lake's words, ''the President considers the maintenance of a safe and reliable nuclear stockpile to be a supreme national interest of the

United States.'' The secret quid-pro-quo involved in this decision was a White House pledge to the Joint Chiefs and the Secretary of Defense that they can *reopen* the question of the U.S. position on the test ban treaty threshold once the NPT Review and Extension Conference is out of the way.

While using the prospect of a CTB to lobby successfully to maintain a $1.6 billion annual budget for a program of ''science-based stockpile stewardship'' involving, at most, nuclear yields of less than four pounds, neither the Livermore nor Los Alamos nuclear weapon design laboratories are firmly committed to this approach, and some laboratory experts have been quietly proffering ''advice'' to senior officials in Washington that undermines the Clinton Administration's current position in the talks.

Given the slow progress of the CTB negotiations and the continuing reluctance of the nuclear weapon states to negotiate a genuinely comprehensive ban, the actions taken by the NPT 25 Year Review and Extension Conference may indeed be decisive in determining whether this objective long sought by the vast majority of states is finally achieved.

PREFACE

The Conference on Disarmament (CD) in Geneva is currently negotiating a Comprehensive Test Ban Treaty (CTBT). In parallel discussions among the declared nuclear weapon states--the permanent five members of the UN Security Council (''Perm-5'')--the U.S. government has proposed that tests of nuclear weapon implosion systems producing nuclear yields not exceeding four pounds (1.8 kg) of TNT equivalent--so-called ''hydronuclear tests''--should be treated as outside the scope of the treaty. However, several of the other nuclear weapon states are seeking to preserve their ability under the treaty to conduct tests on the order of 25 to 100,000 times greater yield. In this range, all but the smallest tests indisputably constitute nuclear explosions. The discussions on the CTB's scope have taken on special urgency in light of the April 1995 conference to review and extend the Nuclear Nonproliferation Treaty (NPT). Pursuant to Article Six of the NPT, the CTBT is widely held to be one of the arms race cessation measures that the nuclear weapon states pledged 25 years ago to negotiate ''at an early date.''

In the spring of 1994, the Department of Defense, based upon recommendations of the Los Alamos National Laboratory (LANL), urged that the United States proceed with a series of hydronuclear tests prior to completion of CTBT negotiations. The purpose would be to obtain, for each of the weapons to be retained in the ''enduring stockpile'' under a CTB, ''benchmarks'' of weapon performance that could ostensibly be compared with later hydronuclear tests to identify, assess, and correct potential reliability problems arising from aging of the stockpile. The technical utility of this proposal for diagnosing and fixing stockpile problems was challenged by other agencies, and by weapons scientists at the Lawrence Livermore National Laboratory (LLNL). As a result of these concerns, and the political sensitivity of conducting tests that could be construed as disrupting the current test moratorium prior to the NPT extension conference, a decision on whether to proceed with such tests has been deferred until Fiscal Year 1997.

Under a Department of Energy (DOE) contract, the JASON division of the MITRE Corp., a longstanding scientific advisory group to the Department of Defense and other agencies, was commissioned to conduct a 1994 summer study on ''Science-Based Stockpile Stewardship,'' including an analysis of whether the United States should seek to conduct hydronuclear tests prior to and under a CTB. In February, 1994, William J. Quirk of the Lawrence Livermore National Laboratory made a viewgraph presentation to a Cambridge, MA workshop on the future role of US nuclear weapons jointly sponsored by NRDC and the Defense and Arms Control Program of the MIT Center for International Studies [''How Necessary is Nuclear Testing for Proliferant Nations?,'' LLNL, Feb. 4, 1994]. In July 1994 NRDC provided the JASON panel with an analysis supporting our view that hydronuclear tests should be banned under the CTBT [Thomas B. Cochran and Christopher E. Paine, ''Hydronuclear Testing and the Comprehensive Test Ban: Memorandum to Participants, JASON 1994 Summer Study,'' NRDC, July 1, 1994]. In response, the Los Alamos National Laboratory (LANL) prepared a critique of the NRDC report for DOE [Richard K. Wallace, ''Hydronuclear Experiments as Related to the Comprehensive Test Ban Treaty,'' DOE/LANL, X-94-449(U), Draft, 5 August 1994].

On 29 August 1994, William J. Quirk produced an unclassified version of a paper he had provided to the JASONs, [''What Can Proliferants Learn from Low-Yield Nuclear Testing?'' LLNL, 29 August 1994]. On 30 September 1994, Quirk presented a briefing entitled, ''Value of Hydronuclear Testing,'' [view graphs]. In early November, Ray E. Kidder, LLNL (Ret.), provided a briefing to senior French nuclear weapons program officials entitled, ''Comments and Background Information Concerning The U.S. Nuclear Test Ban Readiness Program, Hydronuclear Tests, The National Ignition Facility, and U.S. Warhead Safety and Reliability, October 27, 1994,'' [reprinted as Appendix C in R.L. Garwin, R.E. Kidder, and C.E. Paine, ''A Report on Discussions Regarding the Need for Nuclear Test Explosions to Maintain French Nuclear Weapons Under a Comprehensive Test Ban,'' Paris, France, November 2-7, 1994, FAS/NRDC, Washington, D.C., January 1995.]

Subsequently, the DOE/LANL report was revised at least twice [revisions dated 5 October 1994 and 12 October 1994] but to our knowledge never publicly released by DOE. The NRDC report herein is a revision of our earlier report to the JASONs, taking into consideration the results of the JASON summer study, the DOE/LANL critique of our earlier report, the presentations by Quirk and Kidder, and our further reflections on the subject. The authors welcome comments and criticisms from the readers of this report, and are grateful to those who have commented to date.

I. Nuclear Weapon Types

In order to discuss which types of nuclear weapons require testing and the instances in which hydronuclear testing may be beneficial, it is useful to review the various types of warhead designs that are typically found in the arsenals of nuclear weapons states.[1] These can be categorized as either pure fission, boosted fission, or thermonuclear devices. The latter, also referred to as "fusion" or "hydrogen" weapons, are usually defined as nuclear weapons in which a significant portion of the release of energy occurs through nuclear fusion. In a strict sense, boosted fission weapons can be categorized as thermonuclear weapons since they utilize fusion materials. However, since the fusion reaction accounts for only a tiny fraction of the total yield of boosted fission weapons, they are often treated as a distinct weapon category.

Thermonuclear weapons (and even fission weapons) can be categorized as having one, or more than one, stage. Single stage pure fission designs are further characterized as being either of the gun-assembly or implosion type. The fissile core of an implosion type fission device can vary in sophistication from the low-technology *Trinity* type device--also called a "solid pack"-- first tested by the United States in 1945, to the more sophisticated "levitated pit" design used in modern fission warheads and the fission primaries of thermonuclear warheads.

A two-stage thermonuclear weapon has a fission or boosted fission primary, also called a "trigger," and a separate component called the secondary, both contained within a heavy casing. Very high yield thermonuclear devices may have a third stage--a "tertiary." In an efficient, modern staged device,--such as a long-range ballistic missile warhead--the primary is likely to be boosted to conserve on volume and weight. The secondary usually contains a composite of fusion and fissile materials, although it is possible to construct secondaries from purely fissile or fusion materials. The outer casing of a staged thermonuclear device can be made of some type of fissionable material--depleted, natural, or enriched uranium, or even thorium.

A. Gun-assembly Pure Fission Designs

The simplest weapon design is the pure fission gun-assembly device. Here two subcritical masses of fissile material at normal density are brought together to form a single "supercritical" mass (a "critical mass" is the minimum amount of material that can support a self-sustaining chain reaction). An explosive propellent is used to fire one of the subcritical masses down a "gun barrel" into the other. Plutonium cannot be used as the fissile material because the speed of assembly is too slow to preclude a high probability of "predetonation" from spontaneous neutron emission, thereby preventing the achievement of a yield in excess of a few tens of tons. Therefore, gun-assembly weapons are made with high-enriched uranium (HEU), typically, uranium enriched to more than 80 percent in the isotope U-235.

The relevant physics needed to construct a workable gun-assembly weapon is widely available in the open literature, as are most of the design details of *Little Boy*, the first U.S. gun-assembly weapon. It is notable that the design of *Little Boy* predated the use of computers. *Little*

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[1] We do not discuss here the full spectrum of possible designs. We omit, for example, a discussion of neutron warheads and various theoretical directed energy weapon designs.

Boy was not tested before it was used in warfare--at Hiroshima on August 6, 1945. Similarly, the six warhead arsenal of South Africa, since dismantled, was composed of gun-assembly type warheads considerably smaller than Little Boy, and none were explosively tested.[2]

The yield of a gun-assembly device is a function of the number of critical masses of the final HEU assembly, which in turn depends on several key parameters, including the enrichment of the uranium, the type and amount of tamper/reflector material that surrounds the assembled HEU, and the geometry of the final HEU and tamper/reflector assembly. It is public knowledge that the *Little Boy* design used 64 kilograms of about 80%-enriched uranium; the target uranium was housed within a thick tungsten carbide reflector/tamper surrounded by a much thicker steel tamper; the final supercritical assembly was on the order of 2.4 critical masses; and its yield was on the order of 15 kilotons. Any country can copy this design; or if a modified design is chosen, the number of critical masses of the final HEU/reflector assembly can be accurately estimated by conducting subcritical assembly measurements in the laboratory. Hence, there is no need for nuclear explosive testing to have high confidence of achieving a yield in the ten to twenty kiloton range. While hydronuclear testing can be used in developing gun-assembly designs, the marginal value of these tests is considerably less than the value of hydronuclear testing for implosion designs, for which predicting the number of assembled critical masses is more difficult.

Although the yield of a gun-type design can be predicted using modifications of commercially available nuclear hydrodynamic computer codes, there is no guarantee that the prediction would be closer than a factor of two unless one had good equation-of-state data and high confidence in the computer modeling. On the other hand, a simple equation relating the efficiency (i.e, the ratio of actual yield to the yield if all the fissile material were fissioned) to the number of critical masses can be derived from open sources, so computer modeling is not necessary to predict the yield of gun assembly weapons to within a factor of two or so.

B. "Solid-pack" Implosion Type Pure Fission Designs

In an implosion-type fission weapon a subcritical mass of fissile material is compressed by a chemical high explosive. The fissile material is typically either plutonium, or HEU, or a composite of the two. In the most straightforward design the core of fissile material is a solid sphere or cylinder, surrounded by a reflector/tamper, which in turn is surrounded by the chemical high explosive. A sphere has the smallest surface to volume ratio, and therefore the smallest neutron losses and smallest critical mass. Other geometries can be used where the diameter of the device must be kept small--to fit, for example, in an artillery shell. To obtain a given yield, considerably less fissile material is needed for an implosion weapon than for a gun-assembly device.

Similar to the gun-assembly device, the yield of a solid-pack implosion device is a function of several factors, including the number of critical masses of the final assembly and the timing of the initiation of the chain reaction. The number of critical masses depends in turn on

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[2] According to the Institute for Science and International Security (May 1994), the South African bomb was reportedly 25 inches in diameter and 6 feet long and weighed 2000 lb., while Little Boy was 28 inches in diameter, 10 feet long and weighed 9000 lb.

several other key parameters, including the size and enrichment of the fissile core, the type and amount of reflector/tamper material, and the geometry and density of the final assembly. Although the yield of the design can be predicted using modifications of commercially available nuclear hydrodynamic computer codes, accurately predicting the yield is somewhat more difficult than predicting the yield of a gun-assembly device.

On the other hand, the basic design concepts of *Fat Man* are publicly available, and any country can copy this design, as Russia did in 1949 using data obtained through espionage. As in the case of gun-type weapons, simple equations can be derived from open sources that relate efficiency to critical masses and amounts of fissile materials and chemical high explosives needed. Hence, if non-nuclear hydrodynamic testing techniques have demonstrated capabilities for rapidly compressing the fissile material to the required number of critical masses, and for initiating the chain reaction at an appropriate time, there is no technical need for full-scale nuclear explosive tests to provide high confidence of achieving a yield in the ten to twenty kiloton range.

Hydronuclear tests likewise are not needed for the development of such a design. Moreover, if a nation's nuclear weapons program were sufficiently advanced to be conducting useful hydronuclear tests, it is more likely that its nuclear weapons designs would be more sophisticated than this first generation solid-pack design. Therefore, a proliferant is more likely to employ hydronuclear testing in conjunction with levitated pit and hollow core designs--discussed next.

C. Levitated Pit and Hollow Core Designs

The levitated pit design is an implosion weapon where there is a gap between a "flying plate" and the fissile core. The fissile core is supported, or "levitated," in the center of the device. As described by Ted Taylor, if you want to drive a nail you do not rest the hammer on the nail and push; rather, you hit the nail with the hammer. The flying plate--in this case a thin metal shell--is analogous to the head of the hammer. Driven by the chemical high explosive, it gains momentum as it accelerates through the free space before striking the fissile core. By achieving greater compression, levitated pit designs can be lighter and use less fissile material to achieve the same yield, or alternatively achieve a greater yield for the same device weight.

The fissile core geometry may be solid, a hollow shell, or it may be a solid fissile core levitated within a fissile shell. The flying plate can serve as the reflector tamper, part of the reflector tamper, or, as in a hollow core design, it can itself be composed of the reflector and fissile material.

The relevant physics for basic levitated pit designs is available in the open literature. Imploding hemispheric and hemicylindric flying plate systems, without the fissile materials, are used commercially to shape metals and for conducting materials research. Relative to the solid-pack nuclear warhead designs, the physics and nonnuclear experiments required to verify levitated pit and levitated core designs are more complicated, and the possibility of error is greater. Without nuclear explosive testing one could still have confidence that a conservatively designed weapon would work, although one would have considerable uncertainty about its yield, and the design would not be optimal in terms of its yield-to-weight or yield-to-volume ratios.

The utility of hydronuclear testing to a program directed at developing these more sophisticated fission weapon designs is discussed in Section IV.

D. Fissile Material Requirements for Weapons

From a technical perspective, one must assemble two or more critical masses ("crits") of fissile material to obtain a sizeable explosion, on the order of 1 - 20 kt, the yield depending on the amount of material employed and the sophistication of the mechanism used to compress it. For example, the original implosion-type bomb that destroyed Nagasaki, *Fat Man*, produced a 21 kt explosion with 6.1 kg of weapon-grade plutonium.

The bare critical mass (M_c)of the relatively stable "delta-phase" weapon-grade plutonium metal used to make weapons is about 16 kg. However, under compression, the change to the denser "alpha-phase" occurs with only a modest input of energy, so the smaller critical mass value for alpha-phase plutonium can be used to compute national fissile material requirements for weapons. The M_c of alpha-phase plutonium at normal density is about 10 kg. Adding a moderate neutron reflector reduces the critical mass to about 5.5 kg. Since the critical mass of material needed to support a chain reaction is inversely proportional to the square of its density, a two-fold increase in the density of the reflected mass would allow the minimum "two crits" to be assembled using $2 \times (5.5/2^2) = 2.75$ kg of plutonium, for a yield of about one kiloton. Making the assumption that plutonium densities 3-4 times normal density can now be achieved in modern weapons designs with existing types of high explosives, pure fission weapons made with 2.75 kg of plutonium today could produce yields of 10 to 20 kilotons, or, in the extreme case, as little as 1 kg under high compression could produce about 1 kt.[3]

It follows that successful development of even higher energy density explosives, or some other compact mechanism for compressing fissile [or possibly fusion] material, would permit development of a new class of nuclear weapons requiring even less material, on the order of hundreds or even tens of grams. In theory, there is no lower limit on the minimum amount of material required to construct a nuclear explosive. What can actually be achieved along this line of development is limited only by available implosion technologies.[4] If a CTBT ends full-scale nuclear tests but allows continued low-yield nuclear experimentation with implosion systems, one might expect that the vast research capabilities of the weapon states will be focused on this last "legal" domain for investigation, particularly if some governments come to view compact micro-nuclear explosives with yields in the ton range as having significant military utility.

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[3] See T.B. Cochran and C.E. Paine, "The Amount of Plutonium and Highly-Enriched Uranium Needed for Pure Fission Nuclear Weapons," Natural Resources Defense Council, 22 August 1994, p. 4; and W.J. Broad, "A Smuggling Boom Brings Calls for Tighter Nuclear Safeguards; World Rules Are Outdated, A New Report Says," *New York Times*, 21 August 1994, p. 1.

[4] T.B. Taylor, "Nuclear Tests and Nuclear Weapons," in *Opaque Nuclear Proliferation: Methodological and Policy Implications*, a special issue of the *Journal of Strategic Studies*, Volume 13, No.3 (September, 1990), p. 180.

E. Boosted Fission and Other Single-stage Thermonuclear Designs

As noted above, by incorporating thermonuclear fuel, typically a mixture of deuterium and tritium gas (or lithium hydrides) directly into (or proximate to) the core of fissile material, the efficiency of the fission bomb can be greatly improved; that is, one can obtain a much higher yield from a given quantity of fissile material, or alternatively, the same yield from a much smaller quantity.

High-yield single-stage designs can be made very efficient without boosting. Boosting is most advantageous in lower yield single-stage weapons and in the primaries of multi-stage thermonuclear weapons. In a typical modern boosted fission primary, the rate at which the compressed plutonium or highly-enriched uranium undergoes fission is substantially increased (''boosted'') during the explosion phase by a burst of additional energetic neutrons from fusion reactions in a few grams of deuterium-tritium gas injected into the center of the core immediately prior to detonation. The boosted yield--typically, a few kilotons--can be five to ten times the unboosted yield. The quantity of high explosive and fissile material in a boosted device having a yield in the few kiloton range can be made sufficiently small to be made very safe from the standpoint of single-point asymmetric detonations; that is, the yield of a single-point detonation can be made extremely small (single-point safety tests are taken up in Section VI).

Boosted fission devices are likely to incorporate many of the features of levitated pit design; therefore, the utility of hydronuclear testing in developing boosted fission weapons devices would be similar to levitated pit and hollow core designs discussed above.

Since substantial DT burning does not take place until the energy release has reached a few hundred tons of TNT equivalent, and since in an actual weapon, the nuclear energy released causes an outward explosion of the fissile material prior to boosting, hydronuclear testing cannot provide high confidence that the boost phase of a nuclear device will operate as designed.

A recent analysis prepared by a DOE laboratory expert claims, ''[a] hydronuclear experiment could be used to assess changes that might occur due to aging or remanufacture of a device identical to one from a previous experiment...''[5] The utility of this application is considered, and on balance, rejected in Section V.

F. Staged Thermonuclear Designs

In a staged thermonuclear device, a fraction of the X-radiation from a fission or boosted fission primary is contained within a heavy metal case. The initial X-radiation from the primary heats up the inner surface of the casing turning it into an opaque plasma. Subsequent X-radiation from the primary is absorbed by the plasma surface and re-irradiated into the cavity. Some of the radiation trapped within this blackbody cavity, also called a ''hohlraum,'' is absorbed by the surface of the secondary component which heats up in a manner similar to the case. The radiation absorbed at the surface of the secondary causes the surface of the secondary to ablate, that is, to ''boil away.'' The reactive force from the ablation produces a rapid compression of

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[5] R.K. Wallace, "Hydronuclear Experiments as Related to the Comprehensive Test Ban Treaty," DOE/LANL, X-94-449(U), 5 August 1994, p. 10.

the secondary. The density of the secondary material, achieved by compression with radiation from a fission primary having a yield in the kiloton range, can be ten or more times greater than that achievable using chemical high explosives. Thus, the fission and fusion processes that take place in the secondary are generally much more efficient than those that take place in the primary.

Early thermonuclear primaries of the implosion type probably had thick tampers and high yields. Since the objective is to utilize the X-radiation from the primary, in modern weapons the heavy tamper has probably been replaced by a thin beryllium reflector. This modern pit, now considerably lighter, requires much less chemical high explosive to achieve the desired compression. The lack of a heavy tamper is partially offset by the fact that the radiation that escapes from the primary does not contribute to the disassembly of the primary core. The amount of high explosive needed can be reduced even further by boosting. Basic considerations of energy density and critical mass suggest that a typical modern thermonuclear primary might consist of a four kg plutonium core in the form of a spherical shell of 5 - 8 cm radius, a beryllium reflector and 40 kg, more or less, of high explosive.

In a multi-stage device the secondary can be made entirely of fusion or fissionable material, or typically both. The casing can be made of fissile material (enriched uranium) or fissionable material (enriched, natural or depleted uranium, or thorium), or in the case of early British thermonuclear designs and the Soviet 58 megaton bomb, lead bismuth.

Early conservative thermonuclear designs used heavy unboosted primaries with primary yields of a few hundred kilotons. Modern staged thermonuclear warheads use boosted fission primaries with primary yields on the order of a few to about 15 kilotons.[6]

A number of technologically advanced nations are believed to be capable of producing thermonuclear weapons without nuclear explosive tests or test data, but these are likely to be heavy single-stage devices, or possibly two-stage devices with heavy high-yield primaries. The United States and the Soviet Union produced workable, conservatively designed, multi-staged thermonuclear weapons before the advent of high speed computers. The first U.S. and Soviet tests of two-stage thermonuclear devices were both successful. The first British two-stage thermonuclear test demonstrated staging, in that the fissile material in the secondary fissioned, but the fusion materials apparently did not burn and therefore the desired yield was not achieved. Only after the third attempt did the British achieve a successful test of a two-stage thermonuclear device. France exploded its first two-stage thermonuclear device eight and a half years and 29 tests after its first atomic test, a delay that is only partly explained by the priority assigned to development of an operational lightweight boosted fission bomb (the AN 11) for delivery by the Mirage IV bomber.

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[6] This estimate of the likely range of U.S. primary yields is derived from the high relative frequency of tests in the 1-15 kt range given by R.E. Kidder, LLNL, in Proceedings of the Department of Energy Sponsored Cavity Decoupling Workshop, Pajaro Dunes, CA., 29-31 July 1985 (Washington, D.C.: DOE Report #850779) p. V-25; on Congressional testimony regarding yields required to evaluate weapon reliability, given in *Effects of a Comprehensive Test Ban Treaty on United States National Security Interests*, Hearings before the Panel on SALT and the CTB, HASC (USGPO: Washington, D.C., 1978), pp. 8 - 16; and our own calculations based on the published yield-to-weight ratio of about 0.1 kt/kg for two compact single stage fission weapons in the former stockpile (see the *NRDC Nuclear Weapons Databook, Vol. I*, p. 36).

China, on the other hand, successfully detonated a 3.3 megaton two-stage thermonuclear device on the first attempt, only 32 months and five tests after its first atomic test.[7] In light of this history, and given the vastly greater computing resources available today, and the unclassified advances in the scientific and engineering disciplines which bear on the design and fabrication of thermonuclear weapons, one is driven to the conclusion that a conservatively designed, staged thermonuclear design of high yield that was produced without testing would nevertheless represent a credible threat.[8] However, perfecting the design of an optimal yield-to-weight, two-stage thermonuclear design for long range missile delivery, with a yield of several hundred kilotons, has in the past required--and some would argue can only be achieved with--at least partial yield testing of the secondary component. This is one of the primary technical reasons why the CTB remains an important arms control measure.

Radiation implosion of the secondary and ignition of the fusion fuel of a modern staged high-yield thermonuclear weapon can be verified experimentally only with nuclear explosive testing beginning at around 10 - 20 kilotons.[9] Hydronuclear tests are of no value in this regard, since the energy of the radiation emitted from the primary is less than the energy released by the primary's chemical high explosive and is totally inadequate to compress the secondary.

II. Hydronuclear and Other Low Yield Tests

Hydronuclear tests are nuclear weapons tests, or high-explosive driven criticality experiments, limited to subcritical, or slightly supercritical neutron multiplication. As a consequence they can be designed to release negligible or at most very small amounts of fission energy. The prefix "hydro" means in this instance that the core of the nuclear device behaves like a fluid under compression by the chemical high explosive. Sufficient energy may be released to melt the core, but the nuclear energy released is insufficient for the core to heat to plasma temperatures and explode "like a bomb." A narrower definition would limit the nuclear energy released to a level that would not perturb the mechanics of the chemical implosion. Thus, hydronuclear tests would typically be limited to total nuclear energy releases, or "yields," of a few pounds or less of TNT equivalent.

There are four categories of interest for very low-yield nuclear weapon tests:

-- development of new or modified fission weapon designs;
-- reliability assessments of existing warhead designs;

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[7] R.S. Norris, et al., *Nuclear Weapons Databook, Vol.5, British French and Chinese Nuclear Weapons*, (Boulder, CO: Westview Press, 1994), p. 420.

[8] This possibility was first raised in an unclassified forum by William J. Quirk, in a viewgraph presentation entitled "How Necessary is Nuclear Testing for Proliferant Nations," Lawrence Livermore National Laboratory, February 4, 1994 (see Preface).

[9] J. D. Immele, "Some Issues on Thresholds and Verification," LLNL Nuclear Design Program, undated, unclassified memorandum, circa January, 1987. The existence of neutron bomb designs with yields in the vicinity of one kiloton and the Halite/Centurion experiments with large DT capsules indicate that radiation implosion and fusion fuel burning can be explored at lesser yields.

-- safety of new or existing nuclear warheads; and
-- explosive disassembly of prototype terrorist devices without producing significant nuclear yield (so-called "render-safe experiments").

With the nuclear yield reduced to a few kilograms of TNT equivalent or less, hydronuclear tests for warhead development are sometimes referred to as "criticality experiments." While involving virtually identical techniques, a *nuclear safety test* for warhead development is essentially the opposite of a *criticality experiment*. While the former seeks to verify that an *accidental* explosive *disassembly* of the weapon will occur *without* producing a significant nuclear yield, the latter seeks to verify that *deliberate* explosive *assembly* of the weapon *will lead* to production of a certain minimum significant yield. And therein lies the difficulty for those seeking to protect the option of conducting hydronuclear tests under a CTB while also using the treaty as a bulwark against proliferation.

Several means are available for reducing the yield of a hydronuclear test device to the desired level:

a) for weapon criticality experiments, the established method is to remove some of the fissile material in the core and replace it with non-fissile isotopes of the same or similar elements to preserve the geometry and compressional behavior of the core (e.g., U-235 components can be partially replaced by, or diluted with, depleted uranium (U-238), or weapon-grade plutonium can be replaced by U-238, or by plutonium with an isotopic concentration of ≥ 85% non-fissile Pu-242);

b) in principle, the hollow core of a normally "sealed-pit" weapon could be pressurized via the boost-gas channel with a neutron absorbing gas, allowing detonation of an actual weapon assembly system without first removing fissile material;

c) non-fissile materials, such as a dense gas or tiny metallic beads, could be inserted via the boost gas channel into the hollow core of a sealed pit weapon, to physically prevent full compression of the fissile material in a process similar to the mechanical safing of stockpile weapons; or

d) a weapon quantity of fissile material could be weakly compressed, by reducing the amount of chemical high-explosive surrounding it.

The rate of development of the chain reaction during the hydronuclear test can be measured experimentally by measuring the flux of gamma-rays and neutrons emanating from the fissioning material. The resulting data can be compared to the predictions generated by modeling the altered design using nuclear weapon design codes. Within the accuracy afforded by the experimental data, this comparison provides an independent measurement of the accuracy of portions of the weapon design codes. If confirmed or corrected by these experiments, the codes could then be employed with greater confidence to predict the behavior of the unaltered weapon (i.e. a weapon having a full complement of fissile material of the desired isotopic mix.)

To assess the reliability of stockpiled weapons under a CTB, some analysts propose that hydronuclear tests of existing stockpiled warhead designs be conducted soon, during the current test moratorium. These test results could then serve as performance "benchmarks," against which future hydronuclear test results could be compared, to gauge the effect of unforeseen physical changes or design defects in the warheads that might be discovered later.

In conducting a hydronuclear test to demonstrate weapon safety, the full complement of fissile material may or may not be included, depending on how well the safety design of the system is understood. The chemical high explosive is initiated at a single point, rather than simultaneously at multiple points, to demonstrate that the weapon will disassemble without producing more than a few pounds of nuclear yield if the chemical high explosive is detonated accidentally by penetration of a bullet or the shock wave of a sudden impact. The one-point nuclear detonation safety of current modern U.S. boosted-fission weapons, for example, can be confirmed by tests with nuclear yields of 1/10 of a pound or less. However, in developing boosted weapons, the U.S. experienced yields in such tests ranging into the tens of tons. Unboosted fission weapons require more fissile material, or more high explosive, to achieve the same yield as a boosted device. Thus, achieving one-point safety through inherent design characteristics--rather than mechanical means--is by no means assured for fission weapons that do not rely on the boosting principle.

III. Overview of U.S. and USSR Hydronuclear Experiments

In order to deliver large numbers of nuclear weapons at long range, first by bombers and then later by intercontinental ballistic missiles, the United States sought during the 1950s to reduce the size and weight of its nuclear weapons while simultaneously increasing their destructive power. By 1958 the U.S. nuclear weapons program had demonstrated two significant new concepts and began incorporating them into the nuclear weapons stockpile. The first of these was the two-stage thermonuclear weapon, in which a fission bomb is employed as the "primary stage" or trigger to ignite a much more powerful "secondary stage" utilizing both thermonuclear and fission reactions (for further details, see Section I). The first such "H-bomb" entered the U.S. stockpile in 1954. The fission primaries of these early thermonuclear weapons, however, did not differ significantly from the fission bombs already deployed, resulting in weapons that were large, heavy, relatively inefficient in their use of fissile material, and in need of mechanical safing mechanisms (to guard against an unintended nuclear yield in an accident) that were seen as impeding "reliability" in wartime.

Many of these deficiencies were addressed by the second new concept, the compact boosted-fission primary, first tested in 1955. In this design, the rate at which the compressed plutonium or highly-enriched uranium undergoes fission is greatly increased ("boosted") during the explosion phase by a burst of energetic neutrons from fusion reactions in a few grams of deuterium-tritium gas injected into the center of the core immediately prior to detonation (for more on boosting, see Section I).

The net result was a significant reduction in the size and weight of fission primaries, which in turn allowed the development of compact two-stage thermonuclear design technologies for ballistic and cruise missile warheads with high nuclear yield-to-weight ratios. An added benefit was thought to be the potential for "inherent safety." The use of less nuclear material and less powerful chemical high explosive mechanisms in theory implied less chance of accidentally assembling a supercritical mass.

However, a major concern with such compact "sealed pit" primaries was that the fissile material was now located in permanent proximity to the chemical high explosive, creating the possibility of accidental nuclear yield, while mechanical safing solutions were now "much more difficult and in some cases impossible, [and] somewhat incompatible with the [military] requirement for reduced size and weight."

> It thus became a major design objective to assure that even when the fissile material and high explosive components were fully assembled, there would be no nuclear yield if an accident resulted in detonation of the high explosive. Since such a detonation might start at any single point on or in the high explosive components, this design objective came to be known as "one-point safety....Both the available computers and physical models of that time were inadequate, and the safety of a particular design could only be established by a nuclear test.[[10]] If the design in question was safe, the nuclear yield of such a test [of a weapon initiated at a single point] would be essentially zero; but if it was not, the nuclear yield might be measured in tons of high explosive equivalent. *It was soon realized that the latter result might be avoided in an experiment by a sufficient reduction in the amount of fissile material* (emphasis added).[11]

By the time President Eisenhower suspended U.S. nuclear testing on 31 October 1958, the U.S. had conducted some 33 safety tests, many involving the new boosted weapon designs scheduled to enter the stockpile over the next few years. Subsequent analysis of the results of the final test series conducted just before the moratorium showed an unanticipated effect--that the safety behavior of a given design seemed to depend critically on the *location* of the particular point at which detonation of the high explosive was initiated. This meant that several of the systems then in or about to enter the stockpile might *not* be one-point safe.

To resolve this issue under the constraints of the moratorium, Los Alamos conducted a series of experiments on several of the fission primaries whose safety was in question. The tests

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[10] Authors footnote: This argument for conducting nuclear weapon safety tests is still being made today, only now the existing computer models for weapon safety analysis are deemed insufficient because even advanced *three*-dimensional codes are incapable of predicting the outcome of "*multi*-point detonations" in "*complex* accident geometries." Obviously, the "problem" of nuclear weapons safety, and the capacity of U.S. nuclear weapons scientists to explore it, are both virtually infinite. It is by no means obvious, however, that these issues *merit* further exploration, particularly to the extent of carving out a loophole in the CTB.

[11] R.N. Thorn and D.R. Westervelt, *Hydronuclear Experiments*, LA-10902-MS UC-2, Los Alamos National Laboratory, February 1987, p. 3.

began with a mass of fissile material so small that no nuclear reaction could occur, and successive firings used increased amounts in small increments until a subcritical, but multiplying nuclear reaction was detected. The nuclear energy release for such experiments was not to exceed one pound of TNT equivalent. If at the end of this sequence, the nuclear energy released exceeded a specified threshold, it could be reliably assessed that the weapon did not meet one-point safety requirements.[12]

During the 32-month moratorium, Los Alamos performed 35 of these "hydronuclear" (hydrodynamic-nuclear) experiments.[13] Not all the tests were conducted for the direct purpose of assessing the one-point safety of a given design. Some of the tests involved the use of the hydronuclear technique to "obtain *improved equation-of-state data for the fissile materials involved* (emphasis added)." Such data is critical for constructing the computer models used in nuclear weapons design. And at least one test involved a "criticality experiment . . . on a modified, unboosted weapon design," conducted in June 1961, near the end of the program. This experiment produced "four-tenths of a pound of fission energy," the highest by an order of magnitude of the entire Los Alamos series.

The weapon involved in this particular Los Alamos test has never been declassified, but the timing and description strongly point to the W-54, a low-yield tactical nuclear warhead which was developed and entered production during the nuclear test moratorium. "Early production" of the W-54 began on 28 April 1961.[14] It seems likely that, not knowing the ultimate duration of the moratorium, the "criticality experiment" was ordered to reassure military authorities that the yield of the weapon would meet their specifications. In the case of the low yield W-54, a hydronuclear test for this purpose appears reasonable. The inherent uncertainties in predicting the neutron multiplication rate for the actual weapon at the moment of maximum compression did not have the potential to propagate to very large differences in the final yield, as would have been the case for weapons designed to produce higher yields.

Soon after the moratorium ended, the 58.6 lb W-54 was tested at least twice above ground, with yields of 22 tons and 18 tons, and was widely used as the warhead for the "Davy Crockett" (a fratricidal, if not suicidal battlefield nuclear bazooka for the infantry), the Falcon air-to-air missile, and later in modified form for the man-portable Special Atomic Demolition Munition.[15] For the purposes of assessing the efficacy of hydronuclear criticality experiments

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[12] Today U.S. DOE Order 5610.11 (paragraph 6.k) defines a "nuclear detonation" as "an energy release through a nuclear process, during a period of time on the order of one microsecond, in an amount equivalent to the energy released by the detonation of four or more pounds of TNT." The United States has proposed that 4 pounds be the threshold for distinguishing treaty compliant nuclear tests from banned nuclear explosions.

[13] Thorn and Westervelt, *Hydronuclear Experiments*, p. 6. They note in passing that "a smaller number were conducted at the Nevada Test site by the Livermore laboratory." Nothing further is known about these Livermore tests, although their purpose was most likely safety-related.

[14] "Timetables of Weapons Events," Sandia National Laboratory, 22 September 1986, p. 81.

[15] R.S. Norris and T.B. Cochran, *U.S. Nuclear Tests, July 1945 to 31 December 1992*, NWD 94-1, Natural Resources Defense Council, Washington D.C., 1 February 1994, p. 35.

for weapons development, it would be interesting to know whether the yield predicted for the W-54 on the basis of hydronuclear testing accurately foreshadowed the results achieved in the full-scale nuclear explosive tests. One may presume that it did, at least to the extent that the hydronuclear test results do not appear to have prompted a delay in production of the W-54.

Thus, even though by 1958 the United States had developed weapon codes, and had already conducted numerous hydrodynamic experiments and 194 nuclear tests, it appears to have conducted at least one hydronuclear test for warhead development during the test moratorium. (For a brief account of what is known about very low-yield Soviet tests, see Section VI.)

IV. The Value of Hydronuclear Tests for Engineering Development of New or Modified Nuclear Warheads.

It is useful to think of the explosion of an unboosted, implosion-type fission device as comprising two phases: the assembly phase, during which fissile material is compressed; and the disassembly or explosion phase, during which the fissile material rapidly expands due to the large amount of energy released by the nuclear chain reaction. According to one Los Alamos scientist with experience in conducting hydronuclear tests, a proliferant or threshold state developing such a device "will be concerned mainly about getting four things right: hydrodynamics (the dynamics of materials in motion), neutronics (which, along with hydrodynamics, determines the criticality behavior of systems), initiation of the chain reaction at an appropriate time, and estimation of yield."[16]

The hydrodynamic behavior of the device during the assembly phase can be predicted by computer models and experimentally confirmed by hydrodynamic testing. The neutronics during the assembly phase can be calculated using publicly available data and computer codes that are the same as, or similar to, codes widely used by the commercial nuclear industry. Neutronic calculations using weapon-applicable versions of these codes can be "benchmarked" against laboratory-scale experiments using pulsed reactors and fast critical assemblies, and by conducting various neutron transport/shielding experiments. Computer modeling of the hydrodynamic and neutronic behavior of a weapon during the disassembly phase, which is important for accurate yield prediction, cannot be verified without nuclear testing, access to historical test data, or previously verified weapon codes.

As noted in a recent LANL report, "because the fission neutron production rate peaks at the time of average maximum core compression, knowing this time provides information on the optimal time to activate an external neutron generator to initiate an explosion."[17] Judging by early fission weapon designs, first generation proliferant devices are likely to be internally (self) initiated, and thus susceptible to exploding before the point of average peak compression (maximum criticality) has been reached. To achieve a bigger bang from the same amount of

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[16] D.R. Westervelt, "The Role of Laboratory Tests," in Jozef Goldblat and David Cox, eds., *Nuclear Weapon Tests: Prohibition or Limitation*, SIPRI (New York: Oxford University Press, 1988), p. 48.

[17] Richard K. Wallace, "Hydronuclear Experiments as Related to the Comprehensive Test Ban Treaty," DOE/LANL, X-94-449(u), Draft, 5 August 1994, p. 7.

material, or to reduce the amount of material required, a proliferant might want to use an external neutron source to achieve initiation closer to the optimal moment. Other benefits of external initiation include simpler development (neutron generators are an established dual-use technology with application in civil science and mineral exploration) and reduced weapon maintenance.

While information on the optimal time for activating an external neutron generator can be obtained ''using [non-nuclear] hydrodynamic experiments and calculations to determine the time history of the compression of the core,''[18] a proliferant might not have access to the sophisticated x-ray diagnostic and computer simulation capabilities needed for such work. Instead, a proliferant might seek to fix more precisely the point of maximum criticality by comparing the nuclear signals from hydronuclear experiments initiated at different times. More likely, hydronuclear test results would be used to *independently confirm* the optimum initiation timing indicated by prior hydrodynamic test results.

A second parameter that can be tentatively explored through hydronuclear testing is the rate at which the nuclear chain reaction proceeds during the assembly phase. The rate of fissioning can be calculated using the weapon codes that predict the hydrodynamic and neutronic behavior of the device; and as noted above, these codes can be ''benchmarked'' with hydrodynamic and other laboratory tests. In weapon criticality type hydronuclear tests, typically, the concentration of fissile material in the nuclear pit is reduced by substituting non-fissile isotopes, (e.g. U-238, Pu-242), in order to substantially reduce the yield of the device while minimizing changes to its hydrodynamic performance. The principal difficulty for a proliferator is that the neutron multiplication rate measured in a hydronuclear experiment with reduced fissile mass (or a modified implosion system) is completely different from that produced in a full-scale nuclear test. A recent paper by an LLNL weapon designer notes three reasons why the results of a hydronuclear test cannot be ''directly extrapolated'' to determine the neutron multiplication rate at the point of explosion for a full-scale device:

> First, the compromises in the design necessary to bring the neutron multiplication rate down to very low levels are often major and will distort the [fission] reaction rate. Second, the signals from a hydronuclear experiment are weak and difficult to measure. The high relative error [in measuring these signals] translates to much higher absolute errors at full yield. Third, the full fission reaction history is needed to know what the neutron multiplication rate will be when an actual weapon explodes, and the reaction history of a hydronuclear [test] is not the same as that for a [full-scale] nuclear weapon [test].[19]

While the relative uncertainty of a measurement of neutron multiplication rate as a function of time, derived from hydronuclear experiments, likely will be larger than the uncertainties in the extensive data (taken from alternative experimental sources) that is

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[18] William J. Quirk, "What Can Proliferants Learn from Low-Yield Nuclear Testing?," LLNL, 29 August 1994, p. 2.

[19] Ibid.

incorporated in the weapon codes, the value of the hydronuclear experiments lies in the fact that the output of neutrons and gamma rays as a function of time represents the *integrated output* of an experimental device that behaves in a manner similar to that of an actual weapon prior to disassembly. Thus, as noted previously, hydronuclear tests may still be useful in that these tests might indicate significant errors in the input data or computer coding, or might discover some major flaw in a design, and thereby provide a proliferant nuclear establishment with a stronger scientific basis for concluding that it has developed a device with the capability to produce a substantial minimum yield.

One cannot verify that the weapon codes accurately predict yield without verifying the accuracy of the computational modeling for the disassembly phase of the weapon. For this, one needs higher-yield testing or access to historical test data or nuclear test-calibrated codes. Therefore, full-scale nuclear testing is highly desirable for all but the lowest technology designs, not only to certify the yield of fully-engineered devices, but also to improve the predictive power of nuclear weapon design codes and to optimize weapon designs with respect to yield-to-weight and yield-to-volume. Lacking higher-yield test data, confidence in a proliferant's ability to achieve higher yields can be reinforced through the use of straightforward theoretical approximations that relate the fraction of material likely to be fissioned to the number of critical masses achieved through compression at the time explosive disassembly commences. Such approximations can narrow the yield uncertainty for unboosted devices to within a factor of two or so.

Other possible benefits from hydronuclear testing are less direct but nonetheless significant--improved data for the physics models employed in nuclear design codes, and maintenance (or training) of a scientific cadre with expertise in nuclear test diagnostics. As noted in an historical report of hydronuclear test activities at Los Alamos, not all the tests during the moratorium were conducted for the direct purpose of assessing the one-point safety of a given design. Some were designed to "obtain improved equation-of-state [EOS] data for the fissile materials involved." Historical data recently obtained from Russian sources indicates that several dozen similar tests with nuclear yields "less than 100 kg" were conducted for the same purpose by the Soviet Union.[20] Contrary to current official assertions that such tests are of little value for nuclear weapons development, the U.S. Defense Nuclear Agency (DNA) has recently concluded agreements with the Russian weapon laboratories to purchase the EOS data on nuclear weapon materials obtained from these very low-yield Soviet tests. In fact, such data is critical for anyone attempting to develop the computer models used in nuclear weapon design.

The Los Alamos report then describes another indirect benefit of the hydronuclear testing program:

> Even though the moratorium was less than a year old, much of the Los Alamos testing expertise had dispersed to other activities. A new team was assembled rapidly, however, and the program was

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[20] The source of this information is a recent private communication to one of the authors from a Russian nuclear weapons expert, who desires to remain anonymous until the Russian legal status of historical data regarding the USSR's test program has been clarified.

> supported across the Laboratory much as some of the earlier nuclear test operations had been. *One result of this effort was restoration of some of the capability that would be needed for the prompt resumption of underground nuclear testing* at NTS following the surprise abrogation of the moratorium by the Soviets (emphasis added).[21]

Of course, under a CTB that allowed hydronuclear tests, this beneficial effect on capabilities for full-scale nuclear testing would be legally available only to declared and non-NPT nuclear weapon states, possibly prompting charges of "hypocrisy" and "discrimination" from treaty parties bound by the stricter standards of the NPT. The cumulative corrosive effect of such a dynamic could be a gradual erosion in the will of the international community to strictly enforce the NPT's implied ban on experimental research activities that have nuclear weapons development as their "primary purpose."

On the other side of the ledger, it must be acknowledged that proliferators do not *require* hydronuclear tests to gain an initial fission weapons capability. Nor are such tests an irreducible requirement for making some improvements in this initial capability. Improvements can be achieved through a combination of *hydrodynamic* tests with non-fissile materials--to develop the required levels of implosion symmetry, peak compression, and initiation timing--and laboratory-scale experiments with pulse reactors or fast critical assemblies to "benchmark" neutronic codes. However, to make dramatic improvements in the yield-to-weight-ratio of its weapons for missile delivery, a proliferant either needs access to higher-yield nuclear test data on its designs, or to nuclear-test-calibrated computer codes that can model the performance of a device in its explosion phase.

In sum, hydronuclear testing, *in theory*, can serve a useful role in the development of the full spectrum of *unboosted fission weapons*, including first generation nuclear weapons of the implosion type with yields in the 10 to 30 kiloton range, more sophisticated designs with yields of several hundred kilotons, and advanced micro-nuclear weapons that use very small quantities of plutonium and have yields less than one kiloton. *In practice* the utility of hydronuclear testing will strongly depend upon a host of other factors, including the availability of fissile materials to conduct hydronuclear tests, the availability of alternative means of obtaining the relevant information (including access to existing codes and historical test data), the sophistication of diagnostic tools needed for hydronuclear testing versus other techniques, the accuracy of alternative measurement techniques, the relative costs of the relevant experimental technologies, and whether the less accurate but independent measurement afforded by an *integrated* hydronuclear test is desired to enhance confidence in weapon code predictions and to "reassure the boss."

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[21] Thorn and Westervelt, *Hydronuclear Experiments*, p. 6.

V. The Value of Hydronuclear Tests for Assessing Weapon Reliability.

In principle, hydronuclear tests could also be conducted to assess the performance of existing stockpile weapons, although this has not been the practice of the United States, and presumably other weapon states, that have had access to full-scale nuclear explosive tests.

> The idea would be to take a warhead out of storage or from the SLBM where it may have spent ten years, to reduce the criticality of the warhead by replacing the boost gas by dense gas under high pressure, and to fire the warhead not at one point, but in the normal way with all the detonators firing simultaneously. The assembly of the critical mass would then proceed in the microseconds normally allotted to it, but the plutonium or U-235 would not be allowed to reach as critical a configuration as in normal operation. In fact the neutron multiplication time, instead of being in the order of 0.01 microsecond might be only 0.1 microsecond, so that a lot fewer ''generations'' of neutrons are available before the metal ''bounces'' and the neutron reproduction factor falls below one.[22]

These test results would then serve as benchmarks against which future hydronuclear test results could be compared. Some experts believe that such tests would be a way of assessing the significance of unforeseen physical changes in the warheads that might be discovered later, or of assessing the impact of future safety-related modifications on performance.

The incremental value of hydronuclear testing for these purposes appears to be marginal at best. Any degradation of stockpiled weapons significant enough to be detected through hydronuclear testing would also be detectable by other means, primarily by periodic disassembly, visual inspection, and radiographic and other scanning techniques. Degradation of the electronic arming, safing and firing mechanisms can be evaluated by testing the components independent of the nuclear assembly system. Degradation of the high explosive can be evaluated independently, and through integrated hydrodynamic testing of the implosion system with surrogate non-fissile material. The surfaces of sealed pits can be inspected visually, and their interiors probed radiographically and ultrasonically, for signs of oxidation or cracking. If necessary, a statistically valid number of randomly selected units can be withdrawn from the stockpile, taken apart, the pits sectioned, and the interior surfaces given a detailed physical inspection for defects that could affect reliable performance.

Degradation of a significant fraction of a given warhead inventory near the end of the planned stockpile life (usually 20-25 years) would not be a serious cause for concern. The warhead type in question could be remanufactured on, or slightly ahead of, schedule to its original specifications, while accelerated aging experiments on intact weapons of the same type sought to identify the environmental exposure conditions leading to the earlier-than anticipated

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[22] Richard L. Garwin, "Stockpile Stewardship and the Nuclear Weapon Complexes," a paper prepared for Pugwash Meeting No. 206, 2nd Pugwash Workshop on the "Status and Future of the Nuclear Weapon Complexes of the FSU and U.S.," Moscow, 19-23 February 1995, p. 7.

degradation. These experiments would presumably help to define a storage regimen that could assure the full stockpile life for the remanufactured item.

Likewise, early-to-mid life deterioration in a small number of weapons of a given class would not give rise to serious concern, if continuing visual inspection and x-ray, ultrasonic, and other non-nuclear explosive diagnostic techniques provided a statistically valid basis for concluding that the degradation remained limited to a few weapons. If the deterioration was not so limited, and the aforementioned benchmark testing had been performed, hydronuclear testing of primaries randomly withdrawn from stockpile and modified to slow down the chain reaction (reduce alpha), could *in principle* be a timesaving and convenient, but also *costly* alternative method for assessing the impact of the degradation on weapon performance.

Whether or not such tests would offer an improvement in results commensurate with their cost is an open question, with the current answer being "probably not." According to Richard L. Garwin, one of the early designers of U.S. thermonuclear weapons and a longtime scientific consultant to the Los Alamos National Laboratory and U.S. government agencies, "the problem is that the mechanism of degrading criticality changes the implosion very much from the normal one, and reduces the sensitivity to all of those things one might like to measure, including the state of the surface of the plutonium, etc."[23]

Moreover, hydronuclear testing in this instance would not be *essential*, as similar data could be obtained through traditional inspection and hydrodynamic testing techniques. Computer codes would be used to model the effects on primary yield of any observed shortcomings in hydrodynamic performance. It is by no means clear to the authors why the results of a hydronuclear test of a largely inert primary would reveal more about the effects of degradation on performance than advanced hydrodynamic methods.

The primary relevance of hydronuclear testing appears to be limited to the implausible scenario of a *large number* of weapons in a given class showing signs of deterioration *relatively early* in their stockpile life, thereby calling into question the viability of remanufacture to original specifications. If the advocates of hydronuclear testing are to be believed, hydronuclear tests of the *modified* boosted weapon design would then be compared with the original benchmark results and a judgement made as to whether the modified primary should be "recertified" for use in the original warhead system, or an entirely different warhead substituted for the defective system. However, as noted by experts at the Lawrence Livermore National Laboratory, because of the "10 percent or worse" uncertainty in measuring the peak fission-neutron production rate achieved in a hydronuclear test, and the difficulties of using that result to predict the rate that would prevail at explosion time in the modified full-scale primary, hydronuclear tests do not appear to offer the United States a decisive advantage over current non-nuclear explosive methods of assuring weapon reliability.

In summary, the marginal utility of hydronuclear tests is limited to those instances in which sufficient information cannot be obtained through hydrodynamic and nondestructive testing techniques, but *can be obtained* through hydronuclear testing. The future utility of hydronuclear

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[23] Ibid.

tests for assessing weapon reliability and certifying modifications prior to remanufacture would seem to be limited to an implausible conjunction of circumstances:

> -- the warhead defect is in the nuclear assembly system (high explosive or fissile material);
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> -- the defect affects, or potentially affects, a significant fraction of a given class of weapons;
>
> -- reasonably careful regulation of the warhead storage environment will not arrest the degradation sufficiently to permit continued stockpiling, or prevent recurrence of the degradation following remanufacture;
>
> -- the defect appears relatively early in the warhead life cycle, effectively precluding remanufacture to original specifications;
>
> -- no backup warhead system previously certified by full-scale testing exists for the delivery system(s) involved.
>
> -- a sufficiently precise understanding of the effects of the defect, and/or the proposed fix, on the nuclear performance of the primary system *cannot* be obtained through hydrodynamic testing alone.
>
> -- a sufficiently precise understanding of the effects of the defect, and/or the proposed fix, on the nuclear performance of the primary system *can* be obtained through hydronuclear testing.

VI. Nuclear Safety and Render-Safe Assessments of Nuclear Weapons.

A safety criterion for U.S. nuclear weapons is that they be "one-point safe," meaning that the probability of producing a nuclear yield in excess of four pounds (1.8 kilograms) of TNT equivalent, due to the accidental detonation of the chemical high explosive at a single point, must be less than one per million. Other nuclear weapon states presumably utilize a similar criterion, albeit with perhaps higher permissible releases of nuclear energy. For the enduring U.S. stockpile, the one-point safety of an adequate number of fully-tested primary designs has already been established for most, if not all foreseeable accident geometries. Given an adequate supply of fissile materials and technical expertise, any proliferant or undeclared nuclear weapon state can perform safety experiments.

Whether a particular design meets its prescribed safety can be explored through computer modeling, but the phenomena involved are inherently three dimensional, and this makes calculation of the hydrodynamics exceedingly difficult. Historically, the United States has had difficulty predicting the results of one-point safety experiments, and thus the one-point safety of a given design was usually established by one or more underground field tests. This fact is of considerable relevance when considering the utility of hydronuclear tests for conducting so-called "render-safe" experiments--i.e. tests that would purport to demonstrate a capability for remote "disablement" of a prototype terrorist device through intentional one-point detonation. In the view of an LLNL scientist with expertise on the design of proliferant devices, these designs are "probably one-point unsafe," and it would be "very difficult to use tests at a few pounds to verify the means of rendering [these] nuclear weapons safe, since it would be very difficult to ensure that such tests did not give tons of yield." The four pound limit "would greatly limit experiments;" a 10 ton yield limit is needed "to get the best information from such tests."[24]

In 1994 the U.S. DOE acknowledged that from 16 July 1945 to 23 September 1992, the United States had conducted 1149 discrete nuclear device detonations, which the department counts as 1054 "nuclear tests."[25] Of these 88 were one-point safety tests. In addition, we estimate that an additional 50 "hydronuclear experiments" (not counted above as discrete device detonations) were conducted during the 1958-61 moratorium, for a total of about 140 low-yield safety tests. Some of the acknowledged 88 one-point safety tests are known to have exceeded the 4 pound safety criterion. In some cases they yielded tens or even hundreds of tons.

Russia has yet to publish a definitive accounting of all its nuclear tests, but a Russian nuclear weapons scientist recently supplied the following updated, but still approximate breakdown of the former Soviet Union's nuclear test program. The USSR conducted a total of approximately 1100 discrete nuclear device detonations. Of these, "nearly 1000" produced yields "greater than one ton." In line with the TTBT protocol defining a test as one or more explosions occurring within a circle having a radius of 1 km and within 0.1 of a second, Russia now counts these 1000 discrete device detonations as 718 "nuclear tests." In addition, the USSR conducted "about 100" discrete device detonations with yields at or below 1 ton, of which "about 10" involved nuclear experiments between 100 kg and one ton, and "about 90" involved "hydronuclear experiments" under 100 kilograms (220 lb). Of these 100 additional tests, about "30-40" were conducted for one-point safety, and the remainder for the purpose of improving equation-of-state data for fissile materials.[26]

On the one hand, modern boosted fission primaries use so little fissile material that they approach inherent one-point safety--that is, even if a high explosive detonation is accidentally initiated at a single point, the resulting asymmetric compression of the fissile material will release very little nuclear energy. On the other hand, first generation proliferant implosion devices are likely to contain such large amounts of fissile material that they are not susceptible to being made inherently safe by design, and thus require safing by mechanical means. However, hydronuclear testing for safety might well be relevant to the development of advanced unboosted fission weapons incorporating levitated cores, beryllium reflectors, or hollow core thin-shell designs that

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[24] William J. Quirk, "Value of Hydronuclear Testing," (briefing charts) LLNL, 15 November 1994, p. 11.

[25] DOE Order 5610.11 (paragraph 6.k) defines a "nuclear detonation" as "an energy release through a nuclear process, during a period of time on the order of one microsecond, in an amount equivalent to the energy released by the detonation of four or more pounds of TNT." A "nuclear test" is defined in the Threshold Test Ban Treaty Protocol as either a single underground nuclear explosion conducted at a test site, or two or more underground nuclear explosions conducted within an area delineated by a circle having a diameter of two kilometers and conducted within a total period of time not to exceed 0.1 second. Multiple devices emplaced in the same shaft and fired within 0.1 seconds are referred to as a "string of pearls."

[26] NRDC interview with senior Russian nuclear weapons scientist, February 1995.

use relatively small amounts of fissile material.[27] As noted elsewhere in this report, hydronuclear testing in general appears most useful for development of a class of unboosted pure fission weapons that is now barely represented in the U.S. nuclear arsenal, but of considerable interest to proliferators.

Under a CTB regime, the only weapons that will be retained in the U.S. stockpile are those that have already been fully tested and demonstrated to be one-point safe. While rare, there have been recent instances--such as the W79 artillery shell and the W88 D5 missile warheads--in which three dimensional computer analyses indicated that a design, or the way in which it is deployed, appeared less safe under certain accident scenarios than had previously been believed. If at some time in the future, a judgement were reached that a particular warhead type was unsafe as then deployed, changing the nuclear design and conducting additional tests would not be options under a CTB. Safety concerns, nevertheless, could be resolved by mechanical safing, by substituting a safer warhead type, or by altering the manner in which the warhead is handled, stored, and deployed.

VII. Proposed Thresholds for Tests to be Permitted Under a CTBT.

In discussions among the Permanent Five members of the UN Security Council (P-5), the United States reportedly favors excluding from the treaty tests having nuclear yields of four pounds (1.8 kg) or less of TNT equivalent.[28] The narrow technical justification for this position is that the nuclear energy released in such a test is insufficient to "turn around" or significantly perturb the rapid inward motion ("implosion") and rebound of the fissile material propelled by detonation of the surrounding chemical high explosive. In a hydronuclear test, the fissile material flies apart before it fissions sufficiently to cause an "explosion."

For reasons that have not been stated publicly, the United Kingdom is understood to favor a higher threshold, reportedly on the order of 100 pounds (45 kg). At this level, the nuclear signals from the test would be somewhat easier to detect, as the nuclear energy released would equal or exceed that released by the chemical high explosive in a modern nuclear weapon. But a release of nuclear energy on this scale can scarcely be characterized as *not* constituting an "explosion" in the common sense appreciation of that term. For example, a 1995 terrorist attack in Tel Aviv that destroyed a bus and killed 22 people, reportedly involved 10 kilograms (22 lb) of high explosive, less than a quarter of the U.K.'s proposed threshold amount for permitted nuclear tests.

A possible cost rationale for the U.K.'s position can be inferred from the recent analysis prepared by LANL for the U.S. Department of Energy:

> the type and quality of technical information obtained from experiments between a few pounds and several hundred pounds of

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[27] For more detail on the amounts of fissile material required for implosion weapons at various levels of technology, see Section 1.D.

[28] S. Drell, et al., "Science-Based Stockpile Stewardship," JSR-94-345, JASON (McLean, VA, The MITRE Corporation: 10 August 1994), footnote, p. 5.

> HE-equivalent nuclear energy release is very similar. The nuclear energy released at these levels has little effect on the hydrodynamic implosion. Energy release closer to a ton is needed before the nuclear energy significantly perturbs the implosion physics and causes an "explosion." *The main advantage of performing experiments at a few hundred pounds, rather than a few pounds, is that States would need fewer tests to reach the required level of neutron generation [without accidentally exceeding the limit], rather than the several expensive tests needed to gradually approach a few pounds* (emphasis added).[29]

Russia, on the other hand, reportedly is seeking a threshold of 10 *tons* or more, with some Russian officials arguing in favor of hundreds of tons, on the grounds that an even larger margin is needed to protect against the possibility that calculations could be in error by a fraction of a microsecond (in a rapidly multiplying change reaction in a sufficiently dense mass of material, a tenth of a microsecond can be roughly the difference between one kilogram of nuclear explosive yield and one kiloton.) A very low limit on the nuclear energy released by such tests favors the weapon-states having either the greatest scientific expertise--to avoid errors--or the greatest available resources, to permit gradual buildup (and expenditure) of fissile material in the device through repeated testing to minimize the risk of "overshooting" and incurring a treaty violation.[30] However, at *ten tons* yield, the fission weapon or primary is well into its explosive "disassembly" phase, in which virtually all of its nuclear yield is produced. Data extracted from tests at this level "would be of very substantial value to a proliferator in checking and correcting computer codes, reducing yield uncertainty, verifying performance, and reassuring 'the boss'."[31] Such tests would also begin to be of value for weapons development to nuclear-weapon states. Livermore's Quirk observes:

> Some information can be gained from testing at a few tons that cannot be gained at significantly lower yields or with non-nuclear testing. To optimize a device [i.e., improve its yield-to-weight ratio], it is very useful to have a code that will accurately predict

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[29] Wallace, "Hydronuclear Experiments as Related to the Comprehensive Test Ban Treaty," p. 8.

[30] During a discussion of low-yield testing thresholds held in Beijing in June 1993, Prof. Hu Side, Director of China's principal nuclear weapons laboratory, the Academy of Engineering Physics (Ninth Academy), observed, "At 10 kg, one can do one-point safety, but [it] needs a certain skill. Sometimes one can get several dozen tons when one is wanting to stay below 10 kg." At the same meeting in June, 1993, Chen Xueyin, a senior weapon scientist with the Ninth Academy, observed that he had seen "published reports of 100 ton yields for [U.S.] one-point safety tests." Ray E. Kidder of LLNL responded by noting that "those tests were conducted in the absence of a moratorium, when it was unnecessary to stay below any limit. So this [shooting at 100 tons] was more economical of fissile material than to use several shots in a 'creep up' approach." See "The Comprehensive Test Ban: Views from the Chinese Nuclear Weapon Laboratories - A Report on Recent Discussions in Beijing, June 1-4, 1993, NWD 93-2, NRDC, Washington D.C., June 1993, p. 6.

[31] R.E. Kidder, LLNL (Ret.),"Nuclear Tests and Nuclear Yields," 27 October 1994, Appendix C-1, in *Report on FAS-NRDC Discussions in Paris Regarding the Necessity of Nuclear Tests for Maintaining A Reliable French Nuclear Force under a Comprehensive Test Ban, November 2-7, 1994*, Washington, D.C. December 1994.

> yield. Such codes are major undertakings. Since they have no civil uses, these codes are not openly available. It would take many scientists several years to write such a code, and without nuclear test data it is very difficult to verify such a code....It would probably be possible to obtain useful data for model validation with yields of a few tons, though a test at a few hundred tons would be easier to interpret.
>
> A proliferant would find it easier to perform and interpret tests at a few tons than a few pounds. The device would be closer to its final configuration. The signals from the experiment would be far easier to measure. Fewer tests would be required to creep up on a yield limit. Such tests might also be preferable because a yield of a few tons would be more impressive to military and political leaders than a test of a few pounds. They would also give information on the plutonium EOS [equation-of-state] that would not be easy to obtain in a laboratory.[32]

To summarize what can be learned from tests at various low nuclear yields:

-- at less than 0.05 kg, the one-point nuclear detonation safety of a boosted fission weapon can be assessed by the weapon states, although for some states with less developed computer modeling skills, this might involve a more expensive "creep-up" series of tests rather than a single test to avoid "overshooting" the maximum permissible yield;

-- at yields less than 0.25 kg, some hydronuclear "criticality experiments" for fission weapon development can also be conducted, but the same caveat regarding "overshooting" applies;

-- at yields under 1.8 kg (4 lb), the U.S. proposed threshold for permitted experiments, additional safety tests, criticality experiments, and equation-of-state measurements can be conducted with a few kilograms of plutonium in a melted or vaporized state;

-- at a few kg to a few hundred kg, the same set of phenomena can be more easily investigated, because of an improved nuclear signal-to-noise ratio and the greater margin for errors in projecting nuclear yield, thereby allowing fewer tests to be conducted to extract the desired data. There should be no debate that tests in this range constitute "explosions" in the common sense understanding of the term. In the CTBT negotiations the U.K. is seeking to protect tests in this range.

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[32] Quirk, "What Can Proliferants Learn from Low-Yield Nuclear Testing?," p. 2.

-- nuclear yields of a few-to-tens of tons would be of significant value to a proliferant state for developing more advanced pure fission weapons with improved yield-to-weight ratios for delivery by missiles and tactical aircraft. Russia is currently seeking to protect this level of testing in discussions among the P-5.

-- at nuclear yields of 100 - 200 tons, fusion phenomena can be investigated, allowing partial yield verification of the performance of new boosted-fission weapon designs. France has sought thus far to protect this level for "activities not treaty-prohibited" that may be conducted by the nuclear weapon states, and by any other state not otherwise bound by its non-weapon state status under the NPT.

The public position of the U.S. government on the "scope" issue was summarized by National Security Adviser Anthony Lake on 30 January 1995 as follows:

> One of the most complicated and challenging issues in the CTB negotiations is the question of what kinds of experiments and other stockpile stewardship activities will be permitted under the treaty--what our negotiators call "treaty compliant activities." The U.S. position with regard to these activities is determined on the basis of three criteria:
>
> - The CTB Treaty must be comprehensive and promote our vital national interest in curbing the further proliferation of nuclear weapons;
> - The CTB Treaty must not prohibit activities required to maintain the safety and reliability of our nuclear stockpile; and
> - The CTB Treaty must be signed by all declared nuclear states and as many other nations as possible.
>
> As the negotiations proceed, the United States will continue to review its position on this issue to ensure it meets these criteria.[33]

Quite clearly, these "criteria" are sufficiently vague, disparate, and flexible to accommodate virtually any outcome to the negotiations. Lake could have taken the opportunity afforded by the gathering of some 250 nonproliferation experts from around the globe to announce an unambiguous U.S. position on the scope issue that would indisputably "promote our vital interest in curbing the further proliferation of nuclear weapons." Instead, his three criteria are discouraging evidence that even internally, the U.S. government has not resolved the scope issue. They may in fact presage a step backward from the current U.S. position--that nuclear

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[33] Anthony Lake, "A Year of Decision: Arms Control and Nonproliferation in 1995," Remarks at the Carnegie Endowment For World Peace, 30 January 1995 (prepared text) p. 10.

weapon tests with nuclear energy releases exceeding four pounds should be banned--to proposals floated early in the Administration for a "CTB" beginning with a low-threshold treaty among the weapon states at a few hundred tons to a kiloton. For example, given the desire of Russia and France to continue tests at nuclear yields of tens or hundreds of tons, the third criterion could be read as a mandate for a "greatest common denominator" settlement of the scope issue.

Considerable attention and approval has been focused on the Clinton Administration's decision to withdraw its proposal for an "easy exit" from the treaty ten years after it enters into force. However, the right of withdrawal was already fully protected by a supreme national interest clause in the draft text. In the context of the impending conference to consider indefinite extension of the NPT, an effective ten year term for the CTB had immediately been tagged as a provocative "nonstarter" by arms control specialists inside and outside of the government, months before it was finally tabled in Geneva. That did not keep the Clinton Administration from presenting it in August 1994, and one wonders whether this was done solely for the purpose of reaping political credit for withdrawing it later on.

Less attention has been focused on the terms of the quid-pro-quo inside the U.S. government leading to this decision. The "easy exit" provision was ostensibly motivated by Pentagon concerns that a future President might well be reluctant to characterize future safety and reliability problems in the U.S. nuclear weapons stockpile as a threat to "supreme national interests" meriting withdrawal from the CTB. For assenting to deletion of the easy exit clause, the Department of Defense and Joint Chiefs of Staff received an assurance that, in Lake's words, "the President considers the maintenance of a safe and reliable nuclear stockpile to be a supreme national interest of the United States."[34] This statement not only took back with one hand what had just been given with the other, but it confused a declining *tool* of U.S. defense strategy--the nuclear weapons stockpile--with the "supreme national interests" this strategy is designed to serve. "Safe" and "reliable" nuclear weapons *per se* do not constitute supreme national interests of the United States. Preventing the proliferation and use of nuclear weapons, and coercion arising from another country's threat to use nuclear weapons, *are* supreme national interests. Overblown efforts to hedge against the future occurrence of safety and reliability problems in the U.S. nuclear stockpile have precious little to do with achieving these objectives. and may in fact hinder them.

VIII. The Value of Hydronuclear and Low Yield Tests in Specific Countries

The value of hydronuclear testing to a given weapon state (declared or undeclared) under a CTB regime depends upon a number of factors, including the maturity of the state's nuclear weapons program and the extent to which full yield tests have already been conducted by, or their results disseminated to, the state in question. In this section we examine the situation in the principal countries of interest, namely those that now have nuclear warheads.

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[34] Ibid.

A. U.S., Russia, U.K., France and China

The nuclear weapons programs in these five declared nuclear weapons states are mature. All have deployed a variety of nuclear designs, including modern two-stage thermonuclear weapons. All have extensive nuclear test archival data.

Country	Devices Detonated	Counted as ''Tests''
United States	1149[35]	1054 (24 with U.K.)
Russia	~1100[36]	718
France	204+?	204
United Kingdom	45	45 (24 with U.S.)
China	41+	41

All nuclear weapon states have sophisticated design codes that have been normalized against their respective tests, although data from partial yield tests under one kiloton may vary significantly among these states.[37] These calibrated codes can be used to model accurately the performance of pure fission devices during the disassembly phase, which cannot be accessed empirically via hydronuclear or other tests under a few tons. These codes may not model adequately the boost-phase of boosted designs, or the performance of thermonuclear secondaries, particularly if the designs differ significantly from previously tested designs.

Under a CTB regime in which low yield or hydronuclear testing is permitted, these tests could be used to provide data for certifying the performance of new unboosted fission devices. How useful this data will be in a given instance depends on the particulars of the design and the amount of nuclear energy release effectively allowed under the test ban regime. A key determinant of ''significance'' for any low-yield test is whether meaningful data from the explosion phase of the weapon can be extracted at the permitted yield level. For the current generation of weapon designs in the arsenals of the weapons states, if permissible yields are effectively constrained to a few pounds, the additional information obtained seems unlikely to improve significantly upon the data that can be obtained by using hydrodynamic and other above-ground experiments. The data from these tests can provide the input for calculating nuclear performance, using proven computer codes calibrated by previous nuclear explosive tests.

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[35] Includes 95 discrete device detonations that are not counted by DOE as separate tests under the TTBT protocol. For further explanation, see Section VI.

[36] Includes approximately 200-250 discrete device detonations that are not counted as separate tests under the TTBT protocol; and about 100 device detonations (including single-point safety tests) with yields under one ton that are not counted by Russia as nuclear tests.

[37] French defense officials, for example, believe that France is behind the United States in its ability to extrapolate yields from the results of subkiloton tests, because they believe the United States has conducted more low-yield tests expressly for the purpose of improving its yield prediction capabilities under a test ban. See R. L. Garwin, R. E. Kidder, and C.E. Paine, ''A Report on Discussions Regarding the Need for Nuclear Text Explosions to Maintain French Nuclear Weapons Under a Comprehensive Test Ban,'' Paris, France, November 2-7, 1994, FAS/NRDC, Washington, D.C., January 1995, pp. 10-13.

On the other hand, almost all experts agree that if the allowed yield threshold is increased to 10 tons, clearly outside of the hydronuclear regime, weapon design data of importance to an advanced nuclear weapon state can be extracted from a test. In between a few kilograms and a few tons is a gray area, in which the onset of the explosion phase--and hence the importance of the test for weapon development--depends on nuclear diagnostic and design details--such as the amounts of high explosive and fissile material, the average peak compression achieved by the implosion, and the time resolution of experimental measurements--that affect the yield level at which weapon scientists can record and interpret significant data on the explosion phase.

Tests of a few tons yield could provide important data in some instances to an experienced nuclear weapons state. For instance, Edward Teller observed as follows in an October 1991 speech at West Point:

> We have no experience in making a fission bomb with some 5-ton equivalent high explosive yield, perhaps weighing 100 pounds, and we will not know how useful it will be in warfare--in killing tanks, for instance--until we learn how to make it and use it.[38]

If the goal were to develop a new class of high-compression, micro nuclear weapons utilizing sub-kilogram quantities of fission or fusion materials, hydronuclear testing could prove to be of particular relevance (for more on low fissile material designs, see Section I.D - "Fissile Material Requirements for Weapons").

Apart from the potential direct benefits for nuclear weapon design, a program of hydronuclear or larger low-yield tests could be used by the weapon states to maintain test sites and some of the technical expertise needed for prompt resumption of full-scale underground nuclear testing following the abrogation of the CTB by one or more states.

Regarding the utility of hydronuclear tests to the United States, an August 1994 report by a high-level scientific advisory group to the Defense and Energy Departments concluded:

> Since hydronuclear tests would be potentially more valuable to proliferants seeking to check computer predictions for more advanced designs using less fissile materials and with smaller weights and volumes that could be more readily delivered, it would be in our national interests to forego them.
>
> ....The very limited added value [beyond that provided by advanced hydrodynamic testing techniques] of hydronuclear tests that provide for a brief glimpse in to the very early stages of criticality have to be weighed against costs, and against the impact of continuing an underground testing program at the Nevada test

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[38] As quoted in Garwin, "Stockpile Stewardship and Nuclear Weapon Complexes," p. 6.

> site on U.S. non-proliferation goals. On balance we oppose hydronuclear testing.[39]

B. Israel

Israel has nuclear weapons and is presumed to have deployed compact fission weapons boosted with DT and/or lithium hydrides. Israel may have tested such a device at low yield on 22 September 1979 in the South Atlantic. The evidence is indicative, but not conclusive, that this event was a nuclear test.[40] Israel may also have conducted a series of secret hydronuclear and other low-yield tests.[41] This is well within its capability, and these could have easily gone undetected. Israel may have obtained through espionage or other means the designs of U.S. and/or French nuclear weapons and/or calibrated warhead design codes. It is widely believed that Israeli scientists were present at French nuclear tests in the Sahara during the early 1960's, and the two countries may have shared nuclear weapons design and test data. Israeli scientists have had close professional contact with scientists at the U.S. nuclear weapon laboratories in the field of nuclear technology and related sciences, and Israeli scientists have participated in the fusion

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[39] Drell, et al., "Science-Based Stockpile Stewardship," pp. 4, 19. However, in a footnote the panel added the following revealing caveat:

> "The arguments leading to this conclusion [not to pursue hydronuclear tests]. . . .are based on the assumption that the U.S. will continue to advance our broad, if still quantitatively incomplete, understanding of implosions of the primary stage of a weapon up to pre-boost criticality. These advances in understanding will come from improvements in the weapons codes and diagnostics of above-ground hydrotests that we are recommending in this report as part of the SBSS [Science-Based Stockpile Stewardship] program. Together with the other components of SBSS identified here, they should provide for adequate safety and reliability of the stockpile for the foreseeable future. Although we see no need for hydronuclear testing in the near term, the consequences of going as long as 10 years without underground tests are difficult to fully anticipate. Depending on what we learn from the proposed SBSS program, together with future strategic and political developments in the post-Cold War world, the U.S. may find it necessary to review its obligation under a CTBT under a "supreme interest" clause. Should that circumstance arise, it will most likely call for consideration of much higher yield nuclear testing than at the 2-4 lb level of TNT equivalent yield now being considered for "zero-yield" [more precisely, "zero-*net*-yield"] nuclear tests [p.4-5]."

[40] A White House panel convened soon after the event concluded that the VELA sighting "contains sufficient internal inconsistency to cast serious doubt whether that signal originated from a nuclear explosion or in fact from any light source not in the proximity of the VELA satellite." However, recent scholarship has shown that key technical and military intelligence data was withheld from the White House panel, and the U.S. intelligence community now refers to the "flash" as "Event 747," indicating that the intelligence community ultimately resolved the ambiguity in favor of classifying it as a nuclear explosion. A recent unclassified review of the Vela episode is contained in Johannes Fritze, "A Fallible Scientific Advisory Process: The September 22, 1979 Vela Incident," (unpublished manuscript) Princeton University, 12 May 1992.

[41] The well-known investigative journalist, Seymour M. Hersh, citing "well-placed Israeli sources," reports that "physicists and technicians at Dimona conducted at least one successful low-yield nuclear test sometime in the mid-1960s at an underground cavern near the Israeli-Egyptian border in the Negev desert....The test was said to have shaken parts of the Sinai." *The Samson Option: Israel's Nuclear Arsenal and American Foreign Policy* (New York: Random House, 1991), p. 131. A 1967 Associated Press dispatch from Beirut relayed a report from a Beirut newspaper that "Israeli scientists trained in the United States exploded an underground atomic device in the Negev desert late last year" [i.e. 1966]. The newspaper said "the blast occurred in a chamber 2,600 feet underground." "Israel Exploded A-Bomb," *Las Vegas Review Journal*, 27 February 1967.

physics, laser isotope separation, and chemical high explosive research programs of these laboratories.[42]

Since Israel has had limited or no full-scale nuclear testing experience, hydronuclear tests and other low yield nuclear explosions might well have benefited Israel relatively more than other states having such experience. These benefits could include increased confidence in the accuracy of weapon design codes, optimized initiation timing, and a reduced concern that there may be serious unrecognized design flaws in weapon designs proposed for stockpiling. On this point, Theodore B. Taylor, who contributed to the designs of both the largest and smallest pure fission weapons ever produced for the U.S. arsenal, has observed:

> Extremely low yield nuclear tests typically are more stringent tests of the overall behavior of the weapon assembly system than tests of the nominal weapon itself, since imperfections in the system have more effects on tests at very low yield than at high yield. It is for this reason that such tests can be useful to countries with considerable experience of nuclear weapons. But they can be even more useful to countries starting nuclear weapon development, if they want to test without being noticed.[43]

C. India and Pakistan

India has exploded a nuclear device, which it termed a "Peaceful Nuclear Explosion," in 1974. Both India and Pakistan are believed to have nuclear weapons, or components that can be quickly assembled into workable weapons. There is no public evidence to suggest that either country has developed a thermonuclear capability at this time. However, Director of Central Intelligence William Webster told a Senate Committee in May 1989 that there were indications that India was building a hydrogen bomb.[44] Hydronuclear tests would assist India and Pakistan in incorporating levitated pit and hollow core technologies in their fission weapon designs. Given the high degree of tension between India and Pakistan, there are ample incentives for both to improve their respective nuclear weapon capabilities, including warhead designs that would permit deployment of intermediate range ballistic missiles. Hydronuclear testing would be especially useful if either or both countries decided under a CTB to pursue the development of compact low-yield nuclear weapons for tactical use, because for a low yield device the relative hydronuclear measurement errors propagate to smaller absolute errors when estimating the actual yield.

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[42] U.S. General Accounting Office, *Nuclear Proliferation: Major Weaknesses in Foreign Visitor Controls at Weapons Laboratories*, GAO/RCED-89-31, October 1988, pp. 25-26.

[43] Taylor, "Nuclear Tests and Nuclear Weapons," p.177.

[44] Indian scientists have published papers in areas directly relevant to thermonuclear weapons, such as the opacities of high temperature, high Z plasmas, equations-of-state for metals in the very high temperature range, 14 MeV neutron transport, tritium production, and methods for separation of lithium isotopes. See Mark Gorwitz, "The Indian Nuclear Experience: An Annotated Bibliography," (xerox monograph) Los Angeles, June 1994.

IX. Verification.

While including hydronuclear tests among the tests banned under a CTBT poses a challenge to verification, this challenge is not qualitatively different from the problem of verifying other very low yield nuclear explosions, e.g. decoupled nuclear explosions with yields below about one kiloton and coupled explosions below about 100 tons. Unless very dense networks of stations are deployed to detect the regional phases of the seismic waves produced by such events, these tests cannot readily be detected and identified seismically, but are universally understood to be "nuclear test explosions" falling within the scope of the treaty. Even if a seismic signature is registered for such a small explosion, seismological techniques will be of only modest help in discriminating it from the vast background clutter of mining and other industrial explosions that occur daily worldwide.

While including hydronuclear tests within the scope of the treaty adds to the verification burden, tacitly conferring a license to conduct them would seem to entail even greater verification difficulties. The term "hydronuclear" is a "term of art"--it has no commonly understood definition. Absent specific agreement, the United States might elect to observe a limit of four pounds of fission energy release in its hydronuclear weapon tests, while other countries, such as the U.K., might observe a limit of 100 pounds (i.e. equivalent to the largest amount of energy typically released by the chemical explosive used to create the "implosion" in a modern weapon primary). Still other countries, such as Russia, might argue that hydronuclear tests are really "safety tests," and for that purpose they need a limit of at least 10 tons,[45] in order to protect against the real possibility that the complex calculations required to predict the "accidental" yield are in error.

A very low limit on the nuclear energy released by such tests favors the weapon-states having either the greatest expertise, or the greatest available resources, thereby permitting gradual buildup of fissile material in the device through repeated testing to minimize the risk of "overshooting" and incurring a treaty violation. Some observers suggest that a hydronuclear testing regime might require an accidental overshoot provision similar to the so-called "whoops clause" in the Threshold Test Ban Treaty that made allowances for "unintended breaches" of the 150 kiloton treaty limit.

Moreover, because they result in vaporization and dispersion of toxic plutonium and small amounts of fission products, hydronuclear tests are most likely to be conducted underground at existing test sites. The activity surrounding preparations for such tests might not always be easy to distinguish from preparations to carry out the larger explosions banned by the treaty, thereby requiring complex provisions for cooperative verification of nuclear test activities at the site.

Since hydronuclear and other low yield tests would most likely be conducted underground at test sites, the question of whether or not to conduct them overlaps another issue which has

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[45] One senior Russian nuclear weapon scientist has recently expressed this view. See the "Report on the Sixth International Workshop on the CTB and Nuclear Warhead Elimination," sponsored jointly by the Natural Resources Defense Council, Federation of American Scientists, and the Moscow Physical-Technical Institute, Washington, D.C. December 15-17, 1993, p. 11.

arisen during the negotiations--the question of regulating or banning ''test preparations,'' possibly in conjunction with a requirement to close existing test sites and refrain from establishing new sites.

Both Russia and the United States have made known their intention to keep their respective nuclear test sites open. In the case of the United States, the nuclear weapons program for the current fiscal year (beginning October 1, 1994) includes the expenditure of $196 million to maintain the capability to conduct ''a minimal test program within six months'' and a ''full test program'' within 2-3 years. For Fiscal Year 1996, the Clinton Administration is requesting $182 million to ''maintain the Nevada Test Site in a state of readiness to conduct an underground nuclear test within 3 years, if necessary.''[46] A number of governments, including Sweden, favor a broad ban on ''preparations'' to conduct nuclear tests. While a ban on ''preparations'' *per se* is likely to prove unworkable and unenforceable, Article I of the March 30, 1994 Australian draft text might usefully be modified to include a *prohibition on field preparations to contain, or recover data from, a nuclear explosion.* Thus amended, the Basic Obligation would now read:

> 1. Each State Party undertakes not to carry out any nuclear weapon test explosion or any other nuclear explosion, or any field preparations for containing or extracting data from, such explosions, and to prohibit and prevent such explosions and preparations at any place under its jurisdiction or control.

Under a treaty exempting hydronuclear or possibly larger low-yield tests, any state party to the treaty not otherwise bound by NPT obligations would have the legal latitude to use low-yield tests--in addition to the wide range of non-nuclear test and simulation techniques already contemplated for exclusion under the agreement--to help prepare a variety of ''candidate'' nuclear warhead designs, which would be ready for full-scale testing whenever a country decided its supreme national interests were threatened. If nonproliferation were truly to be taken seriously as a principle underpinning of the CTB, then all nuclear tests involving fissile or fusion materials and high explosives, including hydronuclear tests, would be banned, and a threat to supreme national interests would be the only sanctioned cause for withdrawal from a treaty of indefinite duration.

If the Basic Obligation were amended to bar both hydronuclear tests and test site preparations, it might read as follows:

> 1. Each State Party undertakes--
>
> (a) not to carry out:
> (i) any nuclear weapon test explosion or any other nuclear explosion;

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[46] Department of Energy *FY 1996 Congressional Budget Request: Budget Highlights*, Chief Financial Officer, February 1995, p. 78, and Vol. 1, *Atomic Energy Defense Activities*, p. 45.

(ii) *any release of nuclear fission [or fusion]*[47] *energy [exceeding X grams] caused by the deliberate assembly or compression of fissile [or fusion] material by means of chemical high explosives or propellants*;
(iii) *any test site preparations for containing, or extracting data from, such explosions or releases;* and

(b) to prohibit and prevent such explosions, *releases, and preparations* at any place under its jurisdiction or control.

CONCLUSION

The principal nuclear weapon design concepts are generally known. The basic physical principles related to nuclear chain reaction, efficient implosion techniques by high explosive means, fission boosting, radiation coupling, and thermonuclear burn are widely available in the open literature. Most of the basic physics parameters, such as nuclear cross sections, and equations-of-state, as well as computer codes for high explosive detonics, nuclear chain reactions, radiation transport, and thermonuclear burn, are also available in the open literature.

Early, low-technology fission and thermonuclear warheads were designed without the benefit of high speed computers. Today's computer-aided design and manufacture (CAD/CAM) techniques greatly facilitate yield prediction and optimization for weapon designs of all types. Most of the warheads in the U.S. stockpile were designed using computers roughly equivalent to today's personal computers. The desktop computers of the next decade are likely to approach the speed and storage capacity of current mainframe supercomputers. A few unclassified fission weapon design codes have been written by researchers outside of the nuclear weapons laboratories, but these codes have not been calibrated against archival nuclear test data.

Full-scale nuclear testing is highly desirable for all but the lowest technology designs to provide confidence in the computer calculations, to better predict yields, and to optimize the designs with respect to yield-to-weight and yield-to volume. If full-scale nuclear testing is prohibited, hydronuclear tests, *in theory*, can serve a useful role in the development of the full spectrum of unboosted fission weapons, including first generation nuclear weapons of the implosion type with yields in the 10 to 30 kiloton range, more sophisticated pure fission designs with yields of hundreds of kilotons, and advanced micro-nuclear weapons with yields of 5 to 500 tons. *In practice*, the utility of hydronuclear testing for this purpose strongly depends upon a host of other factors, including the relative scarcity of fissile materials to conduct hydronuclear tests, the availability of alternative means of obtaining the relevant information (including existing codes and historical test data), the sophistication of diagnostic tools needed for hydronuclear

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[47] The inclusion of fusion energy releases in the prohibition would bar the kinds of demanding tests of spherical layered chemical implosion system symmetry using D-T gas mixtures (or solid mixtures of deuterides or deuteride-tritides of metals) that the Russian --and perhaps the U.S. – nuclear weapons laboratories are known to have conducted. Such Russian "Gasdynamic ICF" (GICF) experiments have reportedly achieved a maximum 14 MeV neutron yield of 4×10^{13} in a system of 375 mm HE radius, that is, about two orders of magnitude below the ignition threshold. See Research Institute of Technical Physics. *The III-rd Zababakhin's Scientific Readings*, (abstract of reports), Dalnaya Dacha, Chelyabinsk Region, Ural, USSR, January 14-17, 1992, Chelyabinsk-70, 1991, p. 24.

testing, the accuracy of alternative measurement techniques, the relative costs of the relevant experimental technologies, and whether independent but less accurate hydronuclear measurements are desired to enhance one's confidence in weapon code predictions.

Hydronuclear tests can be used to obtain an improved understanding of two key performance parameters of the weapon assembly system. The first is the optimum moment for initiating the chain reaction by an external neutron source. The second is the rate at which the nuclear chain reaction proceeds during the period between initiation of the chain reaction and the beginning of the explosive disassembly phase.

Hydronuclear tests can also be used to confirm the inherent one-point detonation safety of modern boosted fission designs against the possibility of providing a nuclear yield in an accident. However, it is difficult to predict the yield of such disassembly experiments for new weapon designs, or for terrorist devices of uncertain design, particularly if the weapon does not involve boosting, which allows the use of smaller quantities of fissile material, lighter tampers, and less high explosive to attain a given yield, all of which contribute to the inherent nuclear safety of the design.

Other potential benefits from hydronuclear testing are less direct but nonetheless significant--improved equation-of-state data for fissile materials, and maintenance (or training) of a scientific cadre with expertise in nuclear test diagnostics. Since hydronuclear tests do not generate sufficient yield to create the conditions for significant fusion of deuterium and tritium in the core, such tests do not provide a reliable means of extrapolating the performance of new boosted fission weapons, boosted thermonuclear primaries, or thermonuclear secondaries.

In negotiating the CTBT the current strategy of the United States and other governments is not to define in the treaty what constitutes a nuclear test explosion, and to employ a joint statement of the P-5 weapon states to establish a definitive interpretation of ''activities not treaty-prohibited'' in accordance with some as yet undefined threshold for nuclear energy release. Nuclear yields of a few-to-tens of tons would be of significant value to a proliferant state, and would begin to be of value to a weapon state for nuclear weapons development. At nuclear yields of 100-200 tons, fusion phenomena can be investigated, allowing partial yield verification of the performance of new boosted fission weapon designs. Russia and France are currently seeking to shield tests in the 10-200 ton range from inclusion in the CTB.

To burnish its nonproliferation leadership credentials in preparation for the April 1995 conference on NPT extension, the Clinton Administration has made some adjustments in its negotiating positions--principally withdrawal of a dysfunctional proposal for ''easy exit'' from the CTB after ten years--with the goal of diverting attention from the continuing reluctance of the nuclear weapon-states, including important elements of the U.S. national security establishment, to accept the limitations that would be imposed by a genuine CTB. Given the current lack of progress in the CTB negotiations, and the tepid and divided approach of the weapon states toward completing the treaty, the non-weapon state parties to the NPT may well have cause to worry about what will happen to the goal of completing the CTB *after* the NPT extension has been achieved.

A program of hydronuclear or low-yield nuclear testing by any or all of the nuclear weapon states will likely encourage undeclared weapon states, and perhaps other nations as well, to conduct similar tests at yields that may or may not conform to an informally agreed threshold. All these states will then have acquired a license under the ''CTBT'' to design *and test* a variety of new modern fission weapons, thereby undermining the purpose of the treaty.

Nuclear test sites of declared nuclear powers may be maintained, in part, to facilitate the conduct of hydronuclear tests. In the United States these tests would likely be conducted at the Los Alamos National Laboratory or the Nevada Test Site. If hydronuclear tests are conducted at the respective nuclear test sites, which may be necessary for safety reasons, such tests will make verification of the CTBT increasingly difficult. Since the marginal value of hydronuclear tests to insure the safety and reliability of existing stockpiled weapons is less than their importance to the development of fission weapons by proliferant nations, they should be explicitly banned under the CTBT.

A tightly written and/or interpreted CTB treaty could feasibly ban *any release of nuclear energy associated with the assembly or compression of fissile or fusion material by chemical high explosives or propellants.* This provision would deny access by all the States Parties to the ''hydronuclear regime'' of weapon physics, which affords an improved understanding of several important performance parameters of fission weapons.

Failing achievement of a zero yield treaty, it is of the utmost importance that any nuclear test activity ''not treaty prohibited'' be limited to nuclear energy releases of a few pounds or less, well below the threshold for exploration of the explosion phase of nuclear weapons.

APPENDIX

The Legal Status of Hydronuclear Tests: Are They Within the Domain of Nuclear Weapon Tests Regulated by the "Hatfield-Exon-Mitchell" Amendment?

Whether or not a future CTBT bans hydronuclear tests in the U.S., if they are conducted underground, they are governed by the restrictions of Sec. 507 (the "Hatfield-Exon-Mitchell Amendment") of the Energy and Water Development Appropriation Act of 1992, P.L. 102-377, 106 Stat. 1343 (1992).

According to this statute:

> "[Sec. 507 (f)] **No underground test of nuclear weapons** may be conducted by the United States after September 30, 1996, unless a foreign state conducts a nuclear test after this date, at which time the prohibition on United States nuclear testing is lifted." (emphasis added)
>
> Sec. 507(b) provides that "**no underground test of a nuclear weapon** may be conducted by the United States after September 30, 1992, and before July 1, 1993," and after the latter date Sec. 507(c) permits "**an underground test of a nuclear weapon**" only if, among other conditions, the President has submitted an annual report specifically identifying the permitted purpose of such test. (emphasis added)

The provisions of Sec. 507 clearly govern *all* underground tests of nuclear weapons, because the statute does not specify, or otherwise imply the existence of, a yield threshold below which underground tests would be exempted from the statute. There is little room for argument that, irrespective of whether the tests are for the purpose of weapons safety or weapon development, the items that have historically being subjected to hydronuclear tests are ***nuclear weapons*** or modified versions or prototypes of such weapons. However, because some may be tempted to argue that hydronuclear tests involve "nuclear explosive devices" rather than "nuclear weapons," it is necessary to emphasize the fact that the Hatfield-Exon-Mitchell Amendment uses the terms "nuclear weapon" and "nuclear explosive device" interchangeably.

Sec. 507(a) of the statute makes funds available "for conducting ***a test of a nuclear explosive device*** only if the conduct of that test is permitted in accordance with the provisions of this section." Sec. 507(e)(1)(A) likewise establishes the overall domain of tests covered by the statute by imposing a general standard that "only those ***nuclear explosive devices*** in which modern safety features have been installed...may be tested." Thus tests of both nuclear "nuclear explosive devices" and "weapons" are covered by the statute.

Another line of argument has been to suggest that hydronuclear tests of nuclear weapons are not "nuclear weapons test explosions." Both legally and practically, if fissionable or fusion materials are removed from a nuclear weapon to lower its yield, the test of such a device is still recognized as a ***nuclear weapons test*** that must meet the limitations imposed by Limited Test Ban Treaty, the Threshold Test Ban Treaty, and the Peaceful Nuclear Explosions Treaty. By the same token, if additional fissile material is removed, or if the chemical high explosive is detonated asymmetrically, on what basis can one conclude that the event is no longer a ***nuclear weapon*** test, even if is given the more descriptive name, "hydronuclear experiment?"

Since the Limited Test Ban Treaty was signed on 5 August 1963, DOE has acknowledged conducting 51 very low yield tests for one-point safety, and all were conducted in compliance with the terms of the LTBT prohibiting a "nuclear weapon test explosion, or any other nuclear explosion," in any environment save underground. If a hydronuclear or safety test is a nuclear weapons test when conducted in the atmosphere, space, or underwater, why would it cease to be a nuclear weapons test when conducted underground?

There is no legal basis for concluding that a hydronuclear test conducted today should not be regarded as a "nuclear weapons test" falling within the scope of the Hatfield-Exon-Mitchell restriction. The DOE Office of General Counsel has (speciously) cited the existence of DOE internal orders--characterizing a nuclear explosive as having a nuclear energy release equal to or exceeding the amount released by the detonation of four or more pounds of TNT[1]--as evidence of a general public understanding that was shared by Congress when it debated and approved Sec. 507. However, these orders are nowhere referenced in the statute or even referred to in the legislative history.

The only references to very low-yield safety testing during the debate were made by Senators Pell and Kennedy. Pell merely noted that "the U.S. criteria for safety is to virtually eliminate the possibility of an accident releasing a nuclear yield of more than the equivalent of four pounds of high explosive." His comment reveals nothing about the intended scope of Sec. 507.

Kennedy noted that concerns about accidental detonation "can be resolved with safety tests with an explosive power equivalent to a few pounds or less of TNT. Such tests need not be limited under a comprehensive test ban, because they are extremely small and would be almost impossible to verify." This statement has likewise been cited by the DOE as evidence of Congressional intent to exclude hydronuclear tests of four pounds or less from the scope of the Hatfield-Exon-Mitchell amendment's restrictions. We believe this interpretation is erroneous:

-- First, Kennedy's statement addressed the possible *scope of a future CTB*, not the scope of the legislative prohibition then under consideration;

-- Second, while Senator Kennedy was a supporter of the amendment and a longstanding supporter of a Comprehensive Test Ban, he did not participate in the Senate negotiations leading to the historic

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[1] DOE Order 5610.10. "Nuclear Explosive and Weapons Safety Program," defines a "nuclear explosive" as "any assembly containing fissionable and/or fusionable materials and main charge high explosive parts or propellants capable of producing a nuclear detonation," and DOE Order 5610.11 "Nuclear Explosive Safety," defines a "nuclear detonation" as "an energy release through a nuclear process, during the period of time on the order of one microsecond, in an amount equivalent to the energy release by the detonation of four or more pounds of TNT."

compromise amendment, nor did he engage in floor debate on the amendment other than to deliver a prepared statement.

-- Third, Kennedy's statement was simply an incontestable statement of fact, not intent-- "such [hydronuclear] tests [for safety] need not be limited under a CTB." Then again, they could be limited. Kennedy did not address the question of whether he or anyone else believed such tests *should be* limited, as he was seeking to appeal, not to the supporters of a CTB in the Senate, but rather to its opponents and their ostensible concerns about weapon safety.

To place Kennedy's remarks in context, later in his statement he remarked,

> "We must avoid allowing safety testing to be the Trojan horse that defeats a comprehensive test ban. For forty years, the Department of Energy and the Pentagon have assured the American people that U.S. nuclear weapons are safe. But now that all other reasons for conducting nuclear tests have been swept away by the end of the cold war, they suddenly want us to believe that our most modern weapons are not safe."[2]

Thus a fair reading of Kennedy's statement would be that he personally did not feel that further testing for safety was warranted, but for those Senators that did, a CTB could be negotiated that accommodated very low-yield one-point safety tests. In other words, Kennedy's remarks would seem to have no bearing on the question of the intended scope of Sec. 507.

Section 507(d)(1)(B) required the President to submit a report to Congress containing a "plan for achieving a multilateral comprehensive ban on the testing of nuclear weapons on or before September 30, 1996." President Clinton has already gone on record that, in the view of the Executive Branch, this report requires "a plan...leading to a **total cessation of tests in 1996.**"[3] Likewise, in its budget submission for FY 1994, the Department of Energy stated, "**the law requires that all nuclear testing end on September 30, 1996.**"[4] Thus, Section 507(f) prohibits all U.S. underground testing, with no specified or implied exemption for hydronuclear tests, after September 30, 1996 and provides only a single exception: the detonation of a nuclear test by another country after that date.

The DOE Office of General Counsel (DOE/OGC) has seized on Sec. 507(f) to argue that Congress could not have intended to include hydronuclear tests within the scope of Sec. 507 because doing so would lead to an "absurd or futile result" that legal precedent admonishes us to avoid when construing the meaning of legislation. DOE/OGC argues that if Section 507 were read to preclude a test of a device capable of producing a yield of less than four pounds of TNT

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[2] *Cong. Record*, August 3, 1992, S11195.

[3] *Cong. Record* (Senate) Feb. 16, 1993, p. S1513, (emphasis added).

[4] Department of Energy, *FY 1994 Congressional Budget Request*, Assistant Secretary for Defense Programs, Key Activity Summary, Weapons Testing, p. 77.

equivalent, it would then follow that a foreign state's conduct of such a test would result in the lifting of any and all prohibitions on U.S. testing after September 30, 1996. This line of reasoning leads to the presumptively ''absurd'' result that a foreign hydronuclear test with a nuclear yield equivalent to ''0.001 pound of TNT'' could have the effect of terminating all controls on U.S. testing under Section 507, and the conclusion that Congress could never have intended to construct such a trap-door under its own restrictions on full-scale U.S. testing.

Clearly, Congress did not intend that inherently unpredictable events occurring after September 30, 1996 would have, indeed *could* have, any bearing on defining Executive Branch obligations under Sec.507 *before* that date. And yet that is precisely the structure of the DOE/OGC's argument. In reality, whether or not a foreign country tests after September 30, 1996 is irrelevant to a consideration of what kinds of tests may or may not be limited prior to that date, because the entire statute is devoted to establishing a program to restrict tests and encourage completion of CTB negotiations *before that date.*

The DOE/OGC goes on to argue that it would be more in keeping with Congressional intent if U.S. underground testing were permitted to resume only if a foreign test conducted a ''significant'' test--significance in this instance being defined by DOE's internal orders (cited previously) that establish four pounds as the threshold for a 'nuclear detonation' controlled by the statute. This line of reasoning is momentarily appealing, but only until one recognizes that the same alleged ''absurd or futile results'' would logically ensue from a 5 pound, 100 pound, or 10 ton foreign detonation that *meets* DOE's criteria for a nuclear explosive test falling *within* the limitations imposed by the statute.

Moreover, the mechanism for making the determination that a foreign nation had indeed tested was not specified in the statute, so it is by no means clear that the normal workings of government would automatically lead to the self-nullifying result predicted by DOE/OGC. For example, the President, even if possessing knowledge of say, an Israeli hydronuclear test, might not provide such knowledge to the Congress or the public. What, then, would serve to trigger the legal termination of the restriction?

In reality, the likelihood of obtaining the feared ''absurd or futile'' outcome is not nearly as great as suggested by the DOE/OGC analysis. Under Section 507, Congress simultaneously required the President to report annually on ''a plan for achieving a multilateral comprehensive ban on the testing of nuclear weapons on or before September 30, 1996.'' Clearly, Congress intended a CTB Treaty *to be in place by that date* that would provide a mutually agreed international framework for making the determination that a ''foreign state'' had indeed conducted a ''nuclear weapon test'' that merited the lifting the statutory prohibition on U.S. nuclear testing. Alternatively, Senate ratification of a CTB could well be accompanied by Congressional repeal of Sec. 507, in which case the scenario postulated by the DOE/OGC would not even arise.

In sum, the ''avoiding a futile result'' argument is a very thin reed on which to support a permissive construction of Congressional intent to exclude hydronuclear tests from the restrictions imposed by the Hatfield-Exon-Mitchell amendment.