The Wayback Machine - https://web.archive.org/web/20020416022431/http://www.armscontrol.org:80/…

Home About ACA Employment Become A Member Internships Subscribe To ACT Contact Us

ARMS CONTROL ASSOCIATION

Search GO

Arms Control Today
Current Issue
Archived Issues
Subscribe
Submissions & Letters
Advertising
Subject Resources
Country Resources
Fact Sheets
Treaties
ACA Events
Links

Register for Arms Control Association email updates

Join List

Arms Control Today

November/December 1997

Printer Friendly

# The Future of Nuclear Weapons Without Nuclear Testing

**Richard L. Garwin**

*Sidebar: The Technology of Nuclear Weapons* In assessing the contribution of the Comprehensive Test Ban (CTB) Treaty to U.S. security, there are three fundamental technical questions involving nuclear weapons themselves that must be addressed. First, will the United States be able to retain confidence in the safety and reliability of its existing arsenal of nuclear weapons under the treaty? Second, to what extent will the treaty constrain the development of new types of nuclear weapons by the United States and other nuclear-weapon states? And third, how much will the treaty contribute to preventing the further proliferation of nuclear weapons?

Article I of the CTB Treaty obligates the parties "not to carry out any nuclear weapon test explosion or any other nuclear explosion" and "to prohibit and prevent any such nuclear explosions at any place under its jurisdiction or control." The negotiating history makes clear that in banning nuclear explosions the treaty permits *no yield* from nuclear explosions—not 1 kiloton, not 1 kilogram, not 1 milligram of yield, but zero yield. This provision applies to both fission and fusion explosions.

The treaty, however, is less clear about what constitutes a "nuclear explosion." The Clinton administration's article-by-article analysis, which accompanied the formal submission of the treaty to the Senate for its advice and consent to ratification, said the United States decided that a formal definition of "nuclear explosion" was "unnecessary and would be problematic." The document then lists "illustrative" examples of activities that are not prohibited by the treaty, including hydrodynamic experiments that might involve sub-critical amounts of fissile materials, inertial confinement fusion (ICF) experiments, experiments using pulsed-power facilities and the operation of nuclear power or research reactors. Despite these qualifications, the intent of the treaty is clearly to preclude any prompt (explosive) release of fission or fusion energy that could be used as or lead to a nuclear weapon.

Given the U.S. interpretation of the basic obligation of the CTB Treaty, the treaty will have the following impact on the future of nuclear weapons:

- Available experience demonstrates that, under the CTB Treaty, nuclear-weapon states will be able to maintain their nuclear weapon stockpiles safely and reliably for at least several decades, by means of appropriate programs of inspection, analysis and remanufacture. Each nuclear-weapon state may accomplish this by putting different emphasis on full funding of the mechanisms that it has used in the past, on a U.S.-style science-based Stockpile Stewardship and Management Program (SSMP) or on periodic automatic remanufacture.
- The nuclear-weapon states will be unable to develop radically new designs of nuclear weapons, such as the nuclear explosion-pumped X-ray laser.
- Any state will be prevented from acquiring new-design, two-stage thermonuclear weapons in which it could have much confidence. Although a state might design and even build new weapons within its existing range of experience, it would not have full confidence in their performance or reliability.
- A non-nuclear-weapon state could with reasonable confidence clandestinely build, under a CTB Treaty but in violation of its nuclear Non-Proliferation Treaty (NPT) obligations, a "gun barrel"-design weapon using uranium-235 (U-235), and with greater difficulty and somewhat less confidence could reproduce a first-generation implosion-type weapon using weapon-grade fissile materials. (In some cases, a competent non-state group might also be capable of such a design if it had access to fissile material.) Somewhat greater uncertainty and difficulty would be associated with the use of plutonium from the reprocessing

of commercial, reactor-grade spent fuel. Increasing uncertainty would be associated with more advanced implosion systems that use less fissile material than the original solid-sphere design.

- Still greater uncertainty would be incurred if a non-nuclear-weapon state designed and produced "boosted" fission weapons without testing, and very little confidence would be associated with two-stage thermonuclear weapons that had never been tested.

### Nuclear-Weapon State Activities

A CTB Treaty is only that—a ban on nuclear explosions of any yield exceeding zero; it is not a treaty by which nuclear-weapon states agree to give up their nuclear weapons, reduce their numbers or even stop their development. In the area of weapons development, activities that would be permitted under the CTB Treaty could include stockpile maintenance and refabrication; product improvement of existing weapons (for example, increased yield-to-weight ratio, safety and reliability or maintenance and remanufacture); or even the introduction of entirely new types of weapons, such as nuclear explosion-pumped X-ray laser or other nuclear weapon-powered, directed-energy weapons which were under development as part of the Strategic Defense Initiative (SDI) in the 1980s. One must understand what efforts may legally be conducted by a nuclear-weapon state under a CTB Treaty in pursuit of these objectives and how successful they are likely to be in producing reliable weapons. Even though a nuclear-weapon state may *desire* to continue its nuclear weapon development programs across the board, its ability to do so will be strongly limited by CTB Treaty constraints, and the activities of the state will actually probably be limited to the maintenance, including refabrication, of its existing weapon types since confidence in the reliability of the stockpile will be an overriding consideration in a non-testing environment.

### Activities By Non-Weapon States

Non-nuclear-weapon states party to the NPT are already committed not to build or otherwise obtain nuclear weapons or other nuclear explosives. Consequently, for them the CTB Treaty entails no new obligations. When the treaty enters into force, its International Monitoring System will provide augmented capability to verify that no nuclear explosion has occurred anywhere on territory under the control of that state.

Almost all of the world's states oppose the spread of nuclear weapons to additional countries or to non-state entities, and some states believed to have nuclear weapons or components ready to be assembled (such as Israel and Pakistan, which are not NPT parties) have not seen it in their interest to conduct an explosive test despite the fact that they have not accepted any legal prohibition on their right to do so. India, which is also not a party to the NPT, conducted a nuclear explosion underground in 1974 and has stated that it will not become party to the CTB Treaty, so it will be under no legal obligation not to test. It is very unlikely, however, that these undeclared nuclear-weapon states will find it easier to test now that the nations of the world have demonstrated their overwhelming support for the CTB Treaty.

In discussing the acquisition of nuclear weapons by additional states, we must avoid placing too much reliance on history. For example, if we were trying to understand the progress of a state toward the acquisition of advanced telecommunications capabilities, it would be ludicrous to expend much effort in monitoring its production of vacuum tubes. For ordinary communications it is now both more effective and simpler to use solid-state (transistor-based) electronic devices, and it would be a great mistake to imagine that such capability could emerge only after a state passed through a phase of competence in the production and widespread use of vacuum tubes.

The same argument applies to nuclear weapons. In the 52 years since the detonation of the first nuclear devices, great progress has been achieved in various fields of basic physics relevant to advanced nuclear weaponry, in computer modeling to which there is now general access, and in enhanced experimental techniques and technology for reliable implementation of various sophisticated nuclear weapon principles. Many other aspects of technology which can be important for nuclear weapons proliferation have evolved over the half century, in particular the widespread use of nuclear reactors for the production of electrical power—each of which produces some hundreds of kilograms of weapon-usable, if not weapon-grade, plutonium per year.<**1**>

Furthermore, a hundred or more metric tons of weapon-grade plutonium have been produced by the United States and Russia, and tens of tons of weapons plutonium have already been declared excess by the United States. On each side, at least 50 tons of plutonium from weapons is expected to be declared excess by the year 2003 as a result of START I and START II reductions; and there is already more than 100 tons of separated reactor-grade plutonium from commercial reprocessing of spent fuel from power reactors and more than 1,000 tons of reactor plutonium is present in spent fuel worldwide. In addition, some 2,000 tons of highly enriched uranium (HEU)—much of it enriched to 85 percent to 95 percent uranium-235 (U-235)—has been built into the U.S. and Russian weapon stockpiles or produced for use in reactors for propulsion of ships or submarines, some of which is suitable for use in nuclear weapons. With the evolution and spread of technology and the enormous amount of weapons material in the world (in comparison with the 6 kilograms of plutonium or 60 kilograms of HEU used in the first two nuclear devices exploded in 1945), constraints on the spread of nuclear weapons are more legal and political than technical, although the NPT's barriers against the transfer of weapon-usable material are extremely important.

The world's first two nuclear weapons typify two approaches to constructing an explosive device:

- Gun-barrel assembly, in which two sub-critical masses of fissile material are brought together in some milliseconds by ordinary propellant such as is used to propel artillery shells;
- Implosion assembly, in which a high explosive with similar energy content to a propellant, but with a much higher speed of reaction (detonation), is used to compress fissile materials to exceed a critical mass at higher density in a time measured in microseconds rather than milliseconds.

While it is possible to produce implosion-type weapons without a nuclear explosion test, real organizations of real people would not have much confidence in a stockpile of such untested weapons. Anyone seeing the unclassified pictures of mangled steel tubes that were supposed to be uniformly imploded by early attempts at implosion designs begins to get a feeling for the problems inherent in an indigenous nuclear weapons program. The implosion test work soon graduated to "pin shots," in which multiple, small wires make contact with an advancing metal surface, or to other schemes for diagnosing the motion of material that microseconds earlier was a rigid solid.

Only in the past few years has it been generally recognized that nuclear weapons can be made from reactor-grade plutonium. According to the 1994 study by the National Academy of Sciences' Committee on International Security and Arms Control (CISAC), despite the additional problems posed by reactor-grade plutonium in weapons use (for example, higher neutron background, more highly penetrating gamma rays and increased heat evolution), "In short, it would be quite possible for a potential proliferator to make a nuclear explosive from reactor-grade plutonium using a simple design that would be assured of having a yield in the range of one to a few kilotons, and more using an advanced design."<2> But the fact that there are no national nuclear weapon stockpiles built of reactor-grade plutonium does mean that no tried-and-true design exists to be stolen or copied, and the amount of material constituting a critical mass would depend on the specific reactor-grade plutonium available.

## Nuclear Explosions and Weapon Tests

In an unconstrained testing environment (before the signing of the CTB Treaty), nuclear explosions were carried out with the following wide range of objectives:

- Development of new models of nuclear weapons;
- Production verification of a developed design;
- Proof of concept of some new weapon idea;
- Demonstration of performance under marginal conditions;
- Demonstration of "one-point" safety;
- Development of nuclear explosives optimized for peaceful applications (PNEs);
- Study and demonstration of PNE effects;
- Use of PNEs for non-military applications;
- Study of weapon effects;
- Obtaining physics data related to weapon design;
- Non-weapon basic physics; and
- The use of two nuclear explosives in war.

From this list, it can be seen that not every nuclear explosion is a specifically dedicated test of a nuclear weapon. A significant number of explosions were carried out for peaceful applications or for basic research. However, most explosions were either related primarily to military programs or information relevant to military applications could have been and presumably was obtained from alleged or actual peaceful nuclear explosions.

The United States typically used some six nuclear explosion tests in the development of each new model of nuclear weapon, while France reportedly used some 22 per model.<3>The study of a new concept such as the X-ray laser would include all the aspects of traditional nuclear weapon functions, as well as essentially new design physics research and validation.

As for weapon physics, nuclear explosion tests have been used to measure the properties of materials in the relevant ranges of pressure and temperature that cannot be reached by high explosives (so-called equation-of-state tests), although these ranges are now accessible in part (at very small physical scale) by laser-driven X-ray sources. As for non-weapon physics, explosion tests might address questions such as the existence of metallic hydrogen, the properties of metals like iron when squeezed to 10 times their normal density, ICF physics and nuclear physics under high neutron flux.

For the nuclear-weapon states, most of the maintenance of stockpile weapons has always been done without nuclear explosion testing. A few tests have had the purpose of learning whether weapons would work in marginal conditions not tested during the design phase (for instance, very old tritium fill or extremely cold conditions). In the absence of nuclear testing, one would need either to avoid such conditions or, to the extent necessary, obtain confidence by scientific analysis and non-nuclear testing.

## Non-Nuclear Explosive Techniques

In the non-explosion testing realm, a whole panoply of techniques has been created both for weapon development and for stockpile monitoring and maintenance. First, there are the various quality-control methods used largely in production to verify that the materials used in fabrication (or refabrication) are up to standard. To the extent an individual component can be fully tested (for example, the detonators for the high explosive), full confidence is readily attainable. The high explosive itself is tested separately before fabrication and after. A bar can be cut from the fabricated material and its detonation velocity and other characteristics compared with the standard. Similarly, fabricated metal parts (such as pressure vessels) can be tested separately. Even the performance of a nuclear weapon in flight can be simulated by dropping a bomb or launching a missile with an inert warhead, so that the "weapon" itself goes through the entire stockpile-to-target sequence as a real weapon would, right up to the point of firing the high explosive. High-fidelity telemetry can be used or some of the warheads or bombs can be recovered, rather than being allowed to impact, in order to verify that unexpected problems have not intervened.

In the development of nuclear weapons, a lot of effort is placed on pin shots and other means of determining the performance of the nuclear "pit" itself—that is, the fissile material which is surrounded by a metal shell to constitute the sealed pit, which is "driven" by high explosives. The designer wants to determine the position vs. time of the inner surface of the plutonium shell, and this is measured by the use of numerous fine "pins," or metal contacts, which record the time of arrival of the shock wave. Laser imaging of the inner surface of the imploding pit is also used. These techniques can be useful to ensure that the high explosive in a weapon in storage as well as the high explosive for remanufacture is within original production specifications.

If actual plutonium needs to be used in experiments, the experiments can be done at reduced scale so that of the approximately three neutrons generated from each fission, less than one remains within the assembly to cause further fission and the system will be sub-critical with no nuclear energy release. Because of the toxicity of plutonium arising from its natural radioactivity, such sub-critical experiments must either be done underground (as was recently undertaken by the Department of Energy (DOE) at the Nevada Test Site and, apparently, by Russia at its Novaya Zemlya test facility) or, alternatively, experiments involving tens or even hundreds of pounds of high explosive could well be done above ground in rugged steel containment vessels. In either case, steps could be taken to avoid suspicion that the experiments were actually low-yield nuclear tests. In the two 1997 sub-critical tests in Nevada, special techniques (with a sensitivity below 1 milligram of high-explosive yield) were used to provide "transparency," and reported, as expected, no fission energy release.

Many modern nuclear weapons have boosted primaries, which to work properly require the achievement of the design conditions for the boost gas and the fissile material. Uncontrolled mixing under high-explosive impact between them must be avoided, and such mixing may depend upon the surface condition of the plutonium. To detect deterioration not visible on static radiographs, some of the pits, taken at random from the stockpile, can be cut open and inspected by microscope. In addition, so-called hydrotesting (in which inert material is used) or subscale experiments (in which criticality is not achieved) can allow the boost gas and the metal to be brought to the stage that in a larger assembly, or with the correct material, would lead to a nuclear chain reaction.

Flash radiography by pulsed X-ray systems permits observation of the interior of such hydrotests and is a primary tool of the nuclear weapon establishments in every nuclear-weapon state. Because flash radiography plays such an important role, it will be upgraded in the United States by providing a smaller source for the X-rays (and thus better resolution in the photographs) and by allowing multiple temporal and/or spatial views of the imploding assembly. The new Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility at Los Alamos National Laboratory and the Advanced Hydrotest Facility (AHF) at Lawrence Livermore National Laboratory will move in this direction, with DARHT providing two spatial and two temporal views, while the AHF might provide four to six. Such measurements provide information in addition to that from static, high-resolution radiography and other measurements of the pits in storage, either without disassembly of the weapon or among the weapons disassembled each year for careful inspection under the stockpile stewardship program.

The U.S. nuclear weapon laboratory facilities are to be very substantially improved as part of DOE's stewardship efforts, within a budget that for the next five years is expected to average around $4.5 billion per year for the program. However, only a portion of the very expensive and controversial National Ignition Facility (NIF), for example, is coupled directly to the stockpile stewardship task, and much of that portion has more to do with maintaining expertise and developing capabilities that would be useful in case the CTB regime collapsed than with maintaining the enduring stockpile of the nine existing weapon designs safely and reliably for the indefinite future.

The primary emphasis for stockpile maintenance should be placed on the disassembly and inspection program, under which 11 of each type of weapon in the stockpile are brought back annually for detailed inspection and disassembly.<**4**>The entire system is radiographed and inspected in fine detail. It is disassembled and each part tested for function.

In some cases, the high explosive is removed and the detonators and explosive tested. Every element of the nuclear weapon—except the nuclear physics package—can be tested to detect any degradation, although not every element can be tested in the assembled system. Some of the elements are destroyed by testing and must be replaced. In routine stockpile maintenance, there is a replacement of "limited-life components" such as batteries and tritium reservoirs. In the future, every element of the nuclear weapon will have to be regarded as a limited-life component, to be replaced either on some schedule or on some indication of change.

Even the nuclear components are not inert, and over the years there have been problems with chemical reaction caused by volatile components in the high explosive. In some instances, these problems have been solved by replacement of components that would certainly not affect the operation of the weapon (according to analysis and certification by the nuclear weapon laboratories), but in other cases remanufacture of critical elements has been required.

A key component of the maintenance of a safe and reliable stockpile is therefore the ability to remanufacture every element of the nuclear weapon or to certifiably substitute some other component for an existing one. In addition to the elements in the direct line of operation—from detonation of the high explosive to implosion of the primary, to criticality, to heating of the contained boost gas, to fission chain explosion, to full boosting, to full primary yield, to emission of large amounts of energy as radiation from the primary, to transfer of energy to the secondary, to implosion of the secondary, and to thermonuclear reaction and explosion of the secondary—there are many other required functions, with some 4,000 parts in a typical weapon. Some of these are the arming, firing and fuzing chain, while others simply have to do with the safe transport and carriage of the weapon itself. Most of these can be tested either non-destructively or destructively; and indeed, they can be substituted by modern, state-of-the-art elements that can be thoroughly tested for function and that can be proven with complete confidence to have no impact on the nuclear explosion itself. Nevertheless, a high degree of conservatism is necessary in the maintenance of such weapons, and, ultimately, expertise is required to certify that a substitution of even one of these non-critical elements will have no effect on the nuclear explosion.

Undue emphasis on new facilities to the detriment of the direct task of stockpile maintenance can actually present a hazard to the principal objective. New facilities compete for funds and qualified people with the "less exciting" work of actually maintaining the enduring stockpile. Nuclear-weapon states would do well to ensure that the tools and conditions afforded to those engaged in this task are upgraded modestly, and that resources are not diverted excessively to new tools that may not be so directly relevant.

The United States has, in its Stockpile Stewardship and Management Program, adopted a very aggressive program for the maintenance of its nuclear arsenal and its nuclear expertise. This program involves a range of activities such as the Accelerated Strategic Computing Initiative, greater involvement of weapon designers with the detailed results of the stockpile surveillance program, and the building and operation of major new facilities for improved experimental observation of aspects of nuclear weaponry without nuclear explosion testing. These activities primarily support the second of six safeguards set forth by President Clinton in his September 22 "Letter of Transmittal" of the CTB Treaty to the Senate (the maintenance of modern nuclear laboratory facilities and programs). Thus, a large part of the stewardship program has the goal of maintaining nuclear weapon expertise and the weapon establishment's ability to design, test, manufacture and certify new nuclear weapons if the CTB Treaty era should come to an end.

The great demand for computer modeling and for much of the experimental "simulation" systems (for example, hydrodynamic testing with flash radiography) comes from the desire to be able to investigate the effects of flaws that may be found in a stockpiled weapon. Examples of such flaws are corrosion, warping of metallic and non-metallic elements, and the opening of assembly joints—all problems that may occur within the primary or secondary and the acceptability of which cannot be tested by weapon detonation under the CTB Treaty.

The nuclear weapons that are now in the U.S. inventory were designed with computers far less powerful than the multi-teraflop systems (capable of a trillion arithmetic operations per second) that will be available in the SSMP era. In the earliest days of nuclear weaponry, computational capability was so minimal that only systems of one-dimensional spherical or cylindrical symmetry could be considered and diagnostic systems were also extremely limited. With the evolution of computers and electronics, it became possible to consider systems of axial symmetry (such as an American football), which have some advantages in packaging and safety. While a fine-scale computation might have 1,000 points along the radius of a spherical system; to do the same job in a system of axial symmetry might require a thousand points in each coordinate, or a million points altogether. Simply cycling through all those points means that the computation is at least a thousand times longer for this two-dimensional case than for the one-dimensional case. There seems no great benefit in designing weapons without axial symmetry; however, if there is a flaw in a two-dimensional weapon, the computation becomes three-dimensional. A full three-dimensional computation would then require a further increase in points by a factor of 1,000 and a growth in computing capability by a factor of 1,000 or more to handle it.

On the experimental side, for a spherical system any orientation of an X-ray picture (or the equivalent) would suffice to confirm that the assembly in reality moves as predicted, while for a two-dimensional system one would need specific views. For a three-dimensional system much more information would have to be gathered, as in the case of the CAT [Computer-Assisted Topography] scan for medical diagnostic purposes.

But computation does not make a weapon work that would not otherwise have functioned, nor would simulation or static diagnostics make it work. Moreover, a weapon that would have worked when it was put into the stockpile will assuredly not work after 10,000 years, when a good fraction of the plutonium will have decayed. Nor is it likely to work after 100 years, even if the tritium (with a half-life of 12.3 years) is replenished on schedule. Clearly, if nuclear weapons are to be maintained reliably and safely for a long time, it will be necessary to remanufacture them or their components. Some components will need to be replaced after 20 years; some after 40 years. The U.S. stockpile surveillance program will need to detect flaws in the weapons that are earliest to fail, or the stewardship program will need to provide the understanding to predict the component life so that remanufacturing can begin in time. A major benefit from these programs is the reduction in the size of the maintenance manufacturing complex below that required to replace the inventory of a given type of weapon or component in response to the discovery of an obvious flaw.

## Custodianship

A nation might instead choose to maintain a safe and reliable stockpile by what has been termed "custodianship," where the nuclear and other critical components of weapons would be routinely replaced on a predetermined schedule, even if there was no evidence requiring it, rather than science-based stewardship, where refabrication would only take place when there was specific evidence requiring it.<**5**>Under the stewardship approach, the United States might permit somewhat-deteriorated weapons to remain in the stockpile, in view of the SSMP-based confidence that performance would be degraded by no more than 5 percent on average—just to take an arbitrary number.

Automatic replacement of components on a fixed schedule is a reasonable approach if it can be afforded and if strong management prevents changing the design or process of the untestable parts; indeed, scheduled remanufacture may be less costly than the alternative. Of course, the combination of remanufacture within initial specifications together with understanding and computation would provide still more assurance of reliability and safety.

With these general approaches, each of the five nuclear-weapon states should be able to maintain its retained arsenal of nuclear weapons reliably and safely by measures appropriate to those particular weapons. One way for a nation to take steps that actually imperil the safety and reliability of its stockpile would be to make changes in the design or processes by which the untestable items are fabricated. Changing materials or processes and then relying on extensive computation in order to show the equivalence (or improvement) seems a lot riskier, and with potential benefits that are not worth the risk. A case in point is the substitution of cast plutonium for the rolled metal that has conventionally been used.

### Fission and Fusion Experiments

As the U.S. article-by-article analysis of the CTB Treaty recognizes, the definition of a "zero-yield" fission explosion presents some difficulties. For example, a nominal 1,000-megawatt (electric) nuclear power reactor fissions 1 ton of heavy nuclei per year, corresponding to an equivalent energy release of some 17 megatons of high explosive. In 1 millisecond (which might be deemed to separate an explosive regime from a steady regime), the fission energy produced by the reactor corresponds to that of 500 grams of high explosive, or 0.5 gram for a 1-microsecond interval. But, the fission energy release from the power reactor is not an explosion because it operates in a steady state. Some research reactors, however, have a very substantial and short-duration energy release.

Even more complicated are the issues raised by the ICF program, which is aimed at the utilization of fusion energy as a source of electric power. The article-by-article analysis states:

Concerning ICF, the U.S. statement made at the 1975 NPT Review Conference established that energy sources "involving nuclear reactions initiated in millimeter-sized pellets of fissionable and/or fusionable material by lasers or by energetic beams of particles, in which the energy releases, while extremely rapid, are designed to be and will be non-destructively contained within a suitable vessel" do not constitute "a nuclear explosive device within the meaning of the NPT...." Thus, such energy releases at the planned National Ignition Facility, as well as at existing facilities such as the NOVA laser facility, are not considered nuclear explosions and are not prohibited by the Treaty.

The $1.3 billion NIF will deliver more than a megajoule of laser energy to a small enclosure, where the radiation implodes a small composite pellet containing deuterium and tritium to densities and temperature so that it will burn explosively. It is hoped that in these experiments as much as 100 megajoules of fusion energy will be released (the equivalent of 25 kilograms of high explosive). In the hoped-for evolution of commercial ICF, a pellet energy of 10 tons of high-explosive equivalent (consuming 0.1 gram of deuterium and tritium) would need to be released every 10 seconds (or 0.1 ton every 0.1 second) within a confinement chamber in order to power the million-kilowatt (electric) generators of a typical modern power plant. Both the CTB Treaty and the NPT permit nuclear-weapon and non-nuclear-weapon states to pursue these activities. But it remains to be seen how much promise there actually is to this approach to commercial fusion energy.

A 0.1-ton or even a 10-ton fusion energy release is not a useful military tool if it requires a laser facility the size of a football field to produce it. But visionaries have long been fascinated by the fact that the actual energy invested in the pellet to produce

10 tons of energy could be only 1 percent of that release, despite the enormous facilities and gross energy investment required.

Is it possible to militarize such a system and in some way make a transportable ICF system? Is it possible to "stage" from the megajoule investment and hoped-for 100-megajoule burn, to invest that energy to implode a secondary pellet and a tertiary pellet and so on to a city-destroying hydrogen bomb or even one useful on the battlefield? It is hard to imagine a more wasteful investment for a country, whether a nuclear-weapon state or not. Moreover, the CTB Treaty would soon limit this progression in the unlikely event that some way could be found to implement it.

High-explosive materials are repositories of energy which are reasonably well matched to moving and even modestly compressing fissionable materials such as plutonium or U-235. However, a self-sustaining chain reaction in a plutonium sphere initially 5 millimeters in diameter, compressed sufficiently to be critical despite its tiny mass of about 1 gram, would require compression to about 100 times normal metal density, and the pressure required for such compression is far above the detonation pressure of high explosives. In particular, the mechanical energy of compression within the initial 5-millimeter-diameter sphere would be about 10 megajoules (within the initial 0.06 cubic centimeter volume), or 25,000 times the energy density of high explosives. To bring an even smaller pellet to criticality (say 0.1 gram rather than 1 gram) by cold compression would require *less* energy—about 1 megajoule instead of 10 megajoules—but still exceeding the energy density of high explosive by about the same factor.

Paradoxically, the smaller the amount of fissionable material, the smaller the energy of compression to make it critical. Fortunately for the success of efforts against proliferation of nuclear weaponry, this enormous gap between the pressure of high explosive and that required for micro-fission appears never to have been bridged, and there seems to be no interest in the United States, at least, in pursuing such an approach.

If a 1-gram pellet of plutonium could be burned at 10 percent efficiency, it would yield about 1.7 tons of high explosive-equivalent energy, which could be contained in a relatively modest steel vessel. Larger amounts of plutonium (with larger potential energy releases) would require less compression but more total compression energy. The above estimates assume that the plutonium can be compressed without heating and thus requiring more energy for compression. Laser beams in a super-NIF might be used for some compression, and according to the U.S. 1975 statement, such a confined energy release would not be banned by the CTB Treaty and to any state party to the NPT. What is the possibility that an energy source for compression could be small enough and cheap enough to make such a micro-fission system into some kind of radiation weapon? The energy content of high explosives can be converted with good efficiency into the energy of electrical currents and magnetic fields, and the magnetic fields can produce pressures much greater than those of the high explosive itself. Furthermore, magnetic fields can deliver energy to pellets or gas regions moving much faster than the detonation speed in high explosives, as evidenced in so-called Z-pinch pulsed-power machines at Sandia National Laboratories. In this facility, electrical energy from the power line (it could be derived instead from high explosives) is transformed by a large machine into a very hot region of plasma that in turn can implode pellets by use of the thermal X-rays at a temperature of 300 electron-volts or more. Perhaps the machine to concentrate the current can be made smaller and lighter. In this way one might implode an ICF pellet (or, with much more difficulty, a millimeter-scale fissionable pellet) to obtain a nuclear yield that might have some apparent military use.

While contained energy releases from pellets imploded by lasers, particle beams or pulsed-power systems are not prohibited by the CTB Treaty, it is easy to see that this is not a universal permission for the use of such "drivers." For instance, the relatively gentle high-explosive drive to render critical a near-critical multi-kilogram shell of plutonium could, in principle, be replaced by a larger amount of explosives driving a system that converts the explosive energy to magnetic fields that would actually push on the metal shells. If the nuclear energy release is not contained by a special vessel, such a release must be counted as a nuclear explosion. But, even if contained, this approach involves more than a millimeter-sized pellet, and is hence not exempted from the ban on all nuclear explosions.

It is also clear that a U.S. proposal of the 1970s to use thermonuclear explosives in underground caverns to heat steam for nuclear power generation is similarly banned by the CTB Treaty. Two 50-kiloton hydrogen bombs per day would be required to replace the nuclear reactor for a typical power plant. More recently, a Russian group has analyzed the possibility of a massive steel above-ground vessel with special provisions to contain repeated nuclear explosions with yields of 10 kilotons to 30 kilotons, but these also would not be permitted by the treaty. Any such "peaceful uses" program is banned by the treaty unless the concept is approved by consensus at one of the 10-year review conferences provided for in the CTB Treaty, and the treaty is subsequently amended by "a positive vote of a majority of all the States Parties with no State Party casting a negative vote." This is an extremely unlikely development given the general recognition that the permission of peaceful uses would constitute an enormous loophole for weapons development.

## Hydronuclear Tests

More relevant to weapon design in the nuclear-weapon states are so-called "hydronuclear" experiments and sub-critical experiments. Hydronuclear refers to a system in which the material flow is described by hydrodynamic equations, as in the assembly and compression of fissile material by the use of high explosives accompanied by a limited nuclear chain reaction. During the 1958-1961 testing moratorium, the United States conducted more than 40 hydronuclear experiments, some in shallow wells at Los Alamos National Laboratory and some at the Nevada Test Site.

During the 1958-1961 moratorium, an upper limit of 2 kilograms of high-explosive equivalent was established for the permissible fission yield of a hydronuclear experiment. This was related to one of the criteria that the United States formally set for the safety of its nuclear weapons: Given a detonation initiated at the worst single point in the high-explosive system, the likelihood of a fission-energy release exceeding 2 kilograms of high explosive must be less than one in a million. This relates to the accident scenarios for nuclear weapons involve the detonation of the high explosive at one point—by a rifle bullet or a fragment from an explosion.

To determine which U.S. designs were one-point safe, and to take corrective measures for those that were not, was the primary purpose of the hydronuclear experiments, which ultimately involved the actual firing of a primary by one-point detonation at the point determined by theory or experiment to be that giving greatest criticality. Because such one-point detonation could, in principle, give a considerable yield in the range of tons or hundreds of tons of high explosive, a series of experiments was conducted with gradually increasing amounts of fissile material (or of high explosive). A design found not to be inherently one-point safe might be rendered one-point safe, in a reversible fashion, by inserting in the hollow of the fissile pit some material that could be extracted when the weapon was activated. Its presence would prevent the imploding plutonium shell from reaching a small enough radius to become critical. Once a design has been demonstrated to be one-point safe, such experiments never have to be repeated on that weapon design. Consequently, banning hydronuclear tests is compatible with the U.S. commitment to retain the safety of the existing nuclear weapon stockpile, the safety of which has been demonstrated.

It had been suggested that hydronuclear tests can add significantly to confidence that remanufactured weapons (for example, pits that needed to be refabricated because of distortion of the metal) will perform within the same yield range as the original weapon. Clearly, a full-yield test of a remanufactured weapon would give such evidence, but to remain within the hydronuclear range for a symmetrical firing of the explosive would require a very big change in the configuration; either the amount of explosive would have to be significantly reduced or a hollow pit would need to be filled with a dense gas. In either case, the so-called JASON group of consultants to DOE concluded that thenecessary modifications would have to be so great that hydronuclear tests would add little to stockpile confidence.<**6**>

The fact that hydronuclear tests are not permitted under the CTB Treaty does not adversely affect the safety or reliability of the U.S. stockpile. Moreover, they have no value to nuclear-weapon states in developing new designs or to non-nuclear-weapon states in developing an initial capability. Nevertheless, it would be desirable to verify that these tests are not being performed by other states either clandestinely or under the guise of permitted activities. In this regard, it would be helpful for all permitted nuclear activities to be conducted above ground and subject to some degree of transparency to assure other parties of compliance with the treaty.

## Hydrodynamic Tests

In contrast to hydronuclear tests, "hydrodynamic" tests of weapon configurations produce no nuclear yield and are not prohibited by the CTB Treaty. However, these tests are forbidden to non-nuclear-weapon states by the NPT because they clearly relate to a weapons program, which these states are prohibited from conducting.

Because such hydrodynamic tests may involve kilograms of plutonium, they cannot be done in the atmosphere under current standards; as proposed they should be done in a containment vessel, above ground.

Other sub-critical "dynamic" experiments may involve masses of fissile material andconfigurations that have no chance at all of criticality, such as explosively driven equation-of-state experiments.<**7**>To provide greatest assurance of compliance with the CTB Treaty, such experiments—which are not prohibited by the treaty—also should be done above ground in steel containment vessels. If experiments involving plutonium or other fissionable material are nevertheless to take place underground, the planning should include positions into which interested states could agree to put their measuring equipment to ensure that there is no neutron or gamma ray output from the test.

### Stemming Nuclear Proliferation

The CTB Treaty will greatly impede qualitative vertical proliferation—that is, the introduction of new types of thermonuclear weapons or weapons using significantly modified designs into the arsenals of the nuclear-weapon states—because the inherent uncertainty in untested new designs makes them poor substitutes for existing types in which there is high confidence. It also will have a significant effect on horizontal proliferation, in limiting the choice of configuration to those that might be imagined reasonably sure of performance—the U-235 gun-barrel weapon that was used at Hiroshima or a primitive implosion device using either U-235 or plutonium. For a weapon utilizing plutonium, even the use of some supposedly sure-fire configuration would not provide a great deal of confidence without a nuclear explosion test, and to reach for weapons with substantially smaller fissile content (allowing therefore more weapons for a given stock of fissile material) would raise the question as to whether any one of the weapons would work.

At the same time, there are already many techniques available to the nuclear-weapon states to confirm that existing tested weapons are safe and can be counted on with high confidence to perform reliably. By identifying potential aging problems, the affected weapons or components can be refabricated or replaced. While this capability raises the question whether such techniques can be used to design substantially new weapons, examination of the requirements for such designs and the inherent limitations of the techniques indicate that the process of developing new designs cannot be carried very far with high confidence in the absence of additional testing. With its existing arsenal of highly reliable weapons, it would appear most unlikely that the United States would attempt to substitute such designs despite its substantial advantage in these non-nuclear-explosive techniques. Such an effort should prove even more difficult for the other nuclear-weapon states with less sophisticated facilities and virtually impossible for non-nuclear-weapon states with little experience to build on as well as lack of facilities.

The largest non-proliferation influence of the CTB Treaty, however, is political. As the nuclear-weapon states see it in their national security interest to reduce the number of nuclear weapons held by others, they need the support of the other members of the NPT in order to preserve and universalize the non-proliferation regime. They will not retain that support if they continue nuclear test explosions. There seems no way in which one of the nuclear-weapon states could continue to test without provoking the others to do the same, and thereby imperil the NPT regime. Above all, a universal CTB Treaty would put the might and will of the nuclear-weapon states on the side of the other NPT adherents, and this could lead to a strong reaction against a state outside the NPT building nuclear weapons or, in particular, conducting a nuclear test explosion.

### NOTES

**1.** Pure plutonium-239 (Pu-239) is the plutonium isotope of choice for making nuclear weapons, in view of its high fission cross section; long half-life, and hence, modest heat evolution; negligibly small spontaneous neutron emission; and lack of penetrating gamma radiation. The plutonium weapons in the U.S. stockpile are made of 94 percent Pu-239 and about 6 percent Pu-240—so-called weapons-grade plutonium. The plutonium that could be extracted from fully irradiated spent uranium fuel in the normal fuel cycle of the world's 400-some light-water or heavy water reactors contains some 60 percent to 65 percent Pu-239, with most of the remainder being Pu-240. [**Back**]

**2.** Committee on International Security and Arms Control, National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, Washington, DC: National Academy Press, January 1994, pp. 32-33. [**Back**]

**3.** Robert S. Norris, "French and Chinese Nuclear Weapon Testing," *Security Dialogue*, Vol. 27(1), 1996, pp. 39-54. [**Back**]

**4.** Formerly, inspections were conducted every two years; the magic number, 11, is chosen to provide 70 percent probability of detecting a flaw that affects 10 percent of the weapons in the stockpile. [**Back**]

**5.** Jonathan I. Katz, "Curatorship, not Stewardship," *Bulletin of the Atomic Scientists*, November/December 1995, pp. 3, 72. [**Back**]

**6.** "Nuclear Testing—Summary and Conclusions," JASON Report JSR-95-320, August 3, 1995. [**Back**]

**7.** E. N. Avrorin, B. V. Litvinov, V. A. Simonenko, "Nuclear Explosive Experiments for Matter Property Study: Results and Opportunities," Zababhakin Scientific Talks, Physics of Explosion, Shock and Detonation Waves, Russian Federal Nuclear Center—All Russian Scientific Research Institute of Technical Physics, Snezhinsk, Russia, August 1995. [**Back**]

---

Richard L. Garwin is Phillip D. Reed Senior Fellow for Science and Technology at the Council on Foreign Relations in New York, and Fellow Emeritus of the Thomas J. Watson Research Center of the IBM Corporation. He has served as a consultant to the Los Alamos National Laboratory on nuclear weapons.

1726 M Street, NW; Washington, DC; 20036;
Tel: (202) 463-8270; Fax: (202) 463-8273