Test simulations and the scope of the CTBT

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Annette Schaper, Peace Research Institute Frankfurt

The aim of the CTBT The Comprehensive Test Ban Treaty (CTBT) has always been a symbol for the end of the nuclear arms race. The freeze of the technical standard of nowaday's nuclear warheads, and the prevention of any future modernization or even invention of new kinds of nuclear weapons is the spririt of the CTBT. But is its effect only a political one, or does it also technically put an end to the invention and development of new kinds of nuclear explosives? This effect depends very much on the scope of the treaty which defines the technical line between what is forbidden and what is also allowed in the future. It determines very strongly how many loopholes will be left and how reliable the Treaty will be.

The test ban as a means to nuclear non-proliferation and disarmament

Two results are expected from the CTBT: an end to the qualitative arms race and the restrictions on the ability to develop further nuclear weapons in countries seeking nuclear status. Further nuclear ambitions are hoped to be capped both in the present nuclear weapon states (NWSs) as well as in all other states, especially India, Pakistan and Israel who are suspected of already possessing a nuclear arsenal. In contrast to nearly all other countries, these so-called "threshold states" have not committed themselves to the NPT and have not restricted their nuclear ambitions through multilaterally binding commitments. A CTBT would therefore be a means of achieving disarmament as well as non-proliferation.

The first phase of the development of nuclear weapons, the so-called nuclear weapons of the first generation which apply the effects of nuclear fission, can be accomplished without testing.1 Other experiments supplemented by computer simulations, which the treaty does not prohibit, are sufficient. Thus in countries suspected of nuclear proliferation such as Iraq or North Korea, development would be possible even under a test ban if other measures such as safeguards or export controls were not in effect. Also further developments such as the adaptation to the delivery systems, which could perhaps constitute the next phase in Pakistan or India would to a certain extent be possible. However, the option of demonstrating such new nuclear capability would not be permitted. The military planners would have no 100% certainty that their arsenal is effective in combat. Similarly, the possibility of making a political statement by means of a nuclear explosion would not be available to CTBT members. So in relation to the development of nuclear weapons of the first generation, restrictions of a political rather than a technical nature would apply.

Technical restrictions would have more effect at the next stage of development: the hydrogen bomb, which apart from using nuclear fission also employs the effects of nuclear fusion and which is also called the nuclear weapon of the second generation. In the hydrogen bomb, a nuclear warhead of the first generation functions as a trigger for a further, even greater release of energy, but it only works by applying much technical precision. Therefore it is necessary to have not only approximate knowledge of the technology concerning the simple nuclear fission warheads but also to understand the details involved. For this, substantial testing is mandatory whereby many parameters and variations of the trigger mechanism must be accurately measured, information which cannot be derived by other methods. A CTBT would thus effectively impair any further development in these countries. This would affect the three threshold states, India, Pakistan and Israel, for whom the next technical phase is precisely the development of the hydrogen bomb. It is not known whether those countries currently have such ambitions, but the option would no longer be open to them. The symbolic significance emanating from their membership in an international arms control treaty is primarily of political importance: by their signature they would have documented vis-à-vis the rest of the world the end of any further technical development. The possibility of using nuclear tests for political purposes would be denied for ever and the aim of arms control, nuclear non-proliferation, would have been recognised in the form of a treaty for the first time. States already in possession of the hydrogen bomb, i.e. the five NWSs, might wish to develop, miniaturise and adapt their weapons to modern delivery vehicles. Without testing, the ability to develop them would be substantially limited as a variety of technical influences interact and this complexity can only be partially simulated without sufficient measurement data. The more activities which can provide such measurement data are forbidden the more reliable will be the prevention of future modernisation.

The development of the nuclear weapons of the third generation can only be undertaken by those countries with previous substantial experience with the hydrogen bomb. For these novel and exotic systems, basic research is necessary which for instance measures the physical reactions of different materials under the extreme conditions of a nuclear explosion. Some aspects of this basic research are also possible without tests but it is quite impossible to develop nuclear weapons of the third generation for combat readiness without hundreds of nuclear tests so that a CTBT prevents such a qualitative arms race.

Stronger than the technical consequences of a test ban would be the political effect: the end of all nuclear testing and its consolidation with international law has been repeatedly called for and has become an important symbol for ending the qualitative arms race. This call for a test ban also implicitly contains demands for nuclear disarmament. Even if under a test ban further development and invention of ever newer nuclear weapons were technically possible, it would definitely be perceived as immoral, as a breach of the treaty's objective. Hence a treaty would constitute a twofold measure of disarmament: it would restrict technical possibilities and exert political pressure.

The scope: the core of the agreement

During the negotiations, a large number of technical activities that could or could not be of importance for the development of nuclear weapons have been under consideration.

In the first instance, the NWSs had negotiated a testing threshold among themselves although this is not compatible with the aim of a comprehensive test ban. But all were subject to strong pressure from their nuclear lobbies to preserve as many technical activities as possible, the USA were in favour of the narrowest limitation: Nuclear explosions releasing energy of only a few kilograms of TNT, also called 'hydronuclear tests',2 were still to be allowed. By contrast France insisted on a threshold of several hundred tons of TNT. The proposals of the other three countries lay in the middle. As a reaction to the protests against the French tests, the French suddenly changed their minds: on August 10, 1995, President Chirac announced that France would now support a ban of 'all nuclear explosions'. This was interpreted as a 'zero-option' which includes a ban on hydronuclear tests. One day later President Clinton agreed to the 'zero-option'3; Great Britain followed in September, Russia in March 1996. This change came as a surprise for observers, presumably the 'zero-option' would never have arisen if France had not been put under such pressure because of its tests and had not given rise to a domino-effect because of its initiative. Whether Chirac really meant a 'zero-option' with his announcement will never and presumably does not have to be clarified. The USA probably took their decision in favour of a 'zero-option' independently of the French based on a study by experts.4 They just happened to announce it later. This result is in any case more than observers dared to hope for at that time and it improved the treaty: if a higher threshold had remained, there would have been many gaps which would have simplified or even stimulated future modernisation.

It is to be regretted therefore that this result which was welcomed by all the negotiating parties is not specifically taken up in the present draft treaty. There is merely a reference in Article 1 to the fact that nuclear explosions shall be prohibited without defining this context more specifically.

Nevertheless the negotiating process is known whereby the last meaning of 'nuclear explosion' was that it meant every test, however small, and this can be quoted in the event of a future conflict. Elaboration of a definition would have involved innumerable further sessions, consultations, suspicions and conflicts. Experts would need to have been involved on both the technical and the international law aspects.

The absence of a more exact definition in the text of the treaty can be interpreted in various ways: ratification by the NWSs with their influential nuclear lobby is thereby simplified. The malicious minded might also suspect these states of wishing to keep open the possibility of small tests. The suggestion for a definition - although too late - ought not to be withheld: one can use an already existing definition of a nuclear weapon which is already internationally accepted, for example from the founding treaty of the WEU. Then one can write the definition that every release of nuclear energy by such a device, however small, constitutes a nuclear explosion. Hydronuclear tests would be included in this ban.5

China insisted up to the end on 'peaceful' nuclear explosions6 which were however, unacceptable for all the other negotiating parties, because 'peaceful' nuclear detonations cannot be distinguished from military ones and are useful also for military research. It looked as if this conflict would become a critical obstacle but a face-saving compromise for all parties was found: a review conference to meet every ten years can decide by consensus that a 'peaceful' nuclear explosion may be conducted upon application from a party to the treaty (Article VIII, review treaty). In this event, precautions would need to be taken to secure the solely peaceful use of this nuclear explosion. In practical terms this means: unless every state without abstention is in favour, no 'peaceful' nuclear detonation may take place. In other words, it will never happen. But the phrase 'peaceful nuclear explosion' is included in the treaty and the Chinese were thereby satisfied. This is criticised by certain purist observers who fear that this phrase could be used to justify the continued existence of nuclear research. It would however be easier to obtain permission for a 'peaceful nuclear explosion' if the objectionable phrase were not mentioned: to change the treaty requires agreement by a simple majority of members allowing abstentions, although here too one single veto suffices to reject the recommendation for a change. (Article VII, Changes to the treaty). There were further suggestions in relation to scope: Indonesia and India demanded a ban on all nuclear weapons testing, including those which did not involve explosions. In this category belong also activities necessary for the maintenance of existing arsenals - an unacceptable thought for the NWS. At one stage Indonesia wanted to prohibit a number of other experiments and activities which promote the development of nuclear weapons. This also included computer simulations and inertial confinement fusion (ICF). The latter is a branch of research which can be of use both in the development of advanced nuclear weapon concepts and in the research into civil fusion energy production. This is therefore a typical example of a civil military ambivalence which applies also to the other activities which Indonesia wanted to have banned. But ambivalent research is taking place in many industrialised countries. Non-nuclear states who are committed to solely civil use would never permit their activities to be banned so that those putting forward these very broad proposals withdrew them in order not to jeopardise further progress on the negotiations. The problem of ambivalence is, however, a serious one and research for civil purposes should be structured as openly as possible, as is normal in civil scientific activities. This allows it to be distinguished from similar research conducted for military purposes and therefore kept secret.

In fact in some NWSs, activities are planned which are not forbidden by the treaty and which in part could make one believe research is being undertaken into qualitatively new nuclear weapons: in this category are secret ICF research as well as computer simulations and maintenance activities in the USA and France, and in the USA a further development of testing sites for which in October 1995 a budget of $ 1.5 billion was appropriated. Also so-called 'subcritical tests' are planned in Nevada. A new modern ICF plant is also being constructed in France, also Russia plans reportedly an elaborate program for the maintenance of its arsenal. The suspicion from nonnuclear weapon states and critical observers is rising that in fact these technologies might be sufficient for the development of new warheads, and that the CTBT is being undermined.

A non-technical guideline for the evaluation of the scope

For a judgement whether a simulation technology or a related technical activity will be necessary also in future or wether it should not be pursued, the following criteria should be considered:

1. Potential for continuing the qualitative arms race: this criterion investigates whether the activity provides important contributions for new nuclear weapons .Experiments that offer the possibility of circumventing nuclear tests by enabling significant R&D for new and more modern nuclear weapons such as for nuclear weapons of the third generation would undermine the spirit of a CTBT and should be included in the ban. Another aspect is maintaining the expertise and attracting and training of new scientists in skills which would motivate them to work on new concepts instead of just maintening the existing one.

2. Reliability and safety: activities are still necessary for the maintenance of the existing arsenals. As long as no world-wide nuclear disarmament has been achieved, the possibility of servicing for the technical safety of existing warheads or adapting to new component standards must be maintained. A large number of tests has been devoted to this goal, and the test ban was only acceptable because other replacements for these tests are possible.

3. Horizontal proliferation potential: It must be avoided that the activity provides important aids to threshold countries, since another goal of a CTBT is stemming horizontal proliferation. If a threshold country that is not member of the NPT has no legal possibility of testing, another obstacle against proliferation is created. The technical requirements for developing new generations of nuclear weapons and for the acquisition of a first, simple design are not necessarily the same since for each of these goals different parts of the technology are to be explored.

4. Civil-military ambivalence: Can the experiment be confused with important civilian uses? This question is important with regard to nonproliferation. It is hardly possible to conduct experiments that also have a civilian use and to deny it to nonnuclear weapon states. But this might bear a proliferation potential.

5. Transparency and verification: This is of great importance in all arms control treaties. Verification has always technical as well as political aspects since there is always a certain degree of technical uncertainty that is also dependant on political processes, especially the degree of trust of the parties in each other. Untransparent acitivities that take place and that cause suspicion, but that cannot be verified as "harmless" undermine the confidence in the CTBT and the good will of delegations to cooperate in future arms control measures. Such activities can also serve as a pretexte for countries who are not willing to cooperate for other reasons as can now observed with India's behaviour in the Conference of Disarmament.

The U.S. Stockpile Stewardship

In the U.S., an ambitious and costly program is being implemented, the so-called Stockpile Stewardship and Management Program (SSMP).7 It aims at "maintaining confidence in the safety and reliability of the enduring U.S. nuclear weapon stockpile". It is estimated to cost $45 billion over the next ten years, and it will consist of the following principal components:

- The National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory, which will be the largest ICF facility on earth.
- The Dual Axis Radiographic Hydrotest Facility (DARHT) at the Los Alamos National Laboratory: a device that

will take 3-dimensional photographs of the implosion phase of an atomic bomb. Because plutonium is replaced in these bombs with an inert substitute, there is no nuclear chain reaction, which by common understanding is no nuclear explosion. It enables so-called "hydrodynamic tests".

- Sub-critical tests at the Nevada Test Site: underground explosions in which plutonium and uranium is shocked by conventional explosives. These tests are sub-nuclear, since they do not generate nuclear chain reactions that multiply above one.
- The Accelerated Strategic Computing Initiative (ASCI): a multi-sited computer research initiative aiming for 1,000-fold increases in computational speed and data storage. This will enable the refinement of supercomputer codes that simulate nuclear explosions in detail.

Also the Nevada test site is being maintained for which in October 1995 a budget of $ 1.5 billion was appropriated.

These activities are heavily contested, and opponents stress that the program will also enable the continuation of the arms race by conducting and stimulating the development of new warheads.8 The critics quote government papers that contain indeed formulations that are suitable for raising suspicion, including "prototype programs to provide possible future replacement warhead designs". Outside the U.S., e.g. in Germany, even a lot more confusion can be observed, large fractions of the public in many countries believe that also subcritical tests are in fact real nuclear tests undermining the CTBT. Rumors in the media even talk of new miniaturized warheads and rucksack bombs. This suspicion and confusion can even observed with some less informed parliamentarians who must soon ratify the CTBT.

In October 1997, an interesting and enlightning expert discussion on the SSMP took place in an electronic forum provided by MIT.9 The discussion started from a paper by Ray Kidder10 in which he suggests that the SSMP should concentrate on the ability of refabricating existing warheads but should refrain from experimenting with any new designs. It should be better to put it some modifications just now, but for the sole goal to make sure that refabrication will also be possible in a more distant future. But new designs that are not tested are less reliable and less safe that existing designs. The nuclear weapons labs on the contrary maintain that also the scientific and not only the technical skills are indispensible. John Holum (Director of the Arms Control and Disarmament Agency) has said that the U.S. has no intention or capability of designing new nuclear weapons with stockpile stewardship, yet Livermore and Los Alamos are currently in the process of a substantial redesign of the W88 (Trident II) warhead, which will lead to the building of a new prototype. In order to find out if this really undermines the spirit of the CTBT, it must be clarified if the purpose of this redesign just serves a better future guarantee of safety and reliability or if it is a training of scientific redesign abilities with the goal of better military capabilities.

Evaluation

Inertial Confinement Fusion (ICF), e.g. NIF

Inertial confinement fusion is an experimental technique which uses energy sources (lasers or particle beams) to produce a short-lived, extremely dense and highly energetic plasma11. Depending on the material used, ICF can produce nuclear fusion and/or nuclear fission reactions in the laboratory, and be used to measure the properties of materials under extreme conditions (pressure, temperature, radiation transport parameters)12. The physical principle of creating the plasma is very similar to that of hydrogen bombs: In both cases, a hollow cavity is heated to extremely high temperatures so that it is filled with black body radiation in the x-ray range, only the dimensions of the setups differ extremely. In hydrogen bombs, this is accomplished by detonating the primary, in ICF, high energy beams are directed through small holes of the (tiny) hollow cavity. Inside each cavity, the fusion material is placed. Its outer layer is heated and exploded due to the large energy density, and as a consequence, the inner part is compressed so that in the center, the extreme conditions necessary for fusion are achieved. Therefore, in physical terms, ICF can be illustrated as a "hydrogen bomb explosion in the laboratory scale". This sort of experiment is well suited to simulate the physical conditions in a nuclear explosion. The major purpose of the NIF facility is to attract skilled scientists and measure the various quantities that can be used in computer simulations. It is also possible to do research into various basic physical principles, e.g. the possible uses of new laser materials which can only be pumped involving extremely high energy densities, or equations of state for special materials under the conditions of a nuclear explosion. It is impossible, however, on the basis of these experiments to construct the new weapons themselves. ICF can also be used to test the effect of nuclear weapons radiation on military equipment.

ICF is technologically complex and very costly, and can only be mastered by the developed industrial nations. For less developed threshold countries such as Iran or North Korea, the technological hurdle is still prohibitively high and will remain so for several decades. A beginner programme is also not dependent upon the kinds of results provided by an ICF. The potential for horizontal proliferation is therefore rather marginal. There are various potential civilian uses for ICF, not all of them already realized, and some very unlikely to be ever achieved. The major civilian goal is energy supply by fusion reactors, others are simulation of the inner core of stars which is interesting for astrophysics, R&D on laboratory scale x-ray lasers, or space propulsion, the latter most unlikely to be ever realized. Because of the potential civilian uses for ICF, especially fusion reactors, also in the non-nuclear states Japan and Germany is a strong, purely civilian interest in ICF. The biggest difference between civilian and military applications is the transparancy of the activities. In the civilian area, especially in the non-nuclear states, all R&D takes place within a context of international cooperation and exchange, as is standard in science. In contrast, military research in the nuclear states is shrouded in secrecy. ICF is allowed under the CTBT and plays a major part in replacements of nuclear tests. Its is the most attractive piece of science for nuclear weapon physicists.

Hydrodynamic Experiments (HDE), e.g. DARHT

An experiment central to the development and maintenance of nuclear weapons are hydrodynamic experiments. They are tests of warheads in which the fissile material is replaced by a passive material (natural uranium or depleted uranium). All other components of the explosive device remain otherwise unaltered. The implosion and compression take place in exactly the same way, with the one difference that no chain reaction takes place as a result. The process is recorded precisely according to various methods, e.g. with X-ray flash cameras which provide a rapid sequence of pictures of the compression. HDE series can lead to the optimisation of a symmetrical and stable compression. In principle, this already suffices for the development of a nuclear weapon and guarantees that it will function. These experiments are therefore of enormous relevance to proliferation.

If one wants such experiments not only to guarantee the function of the weapon but also to determine its yield, then additional computer programs are needed which calculate the course of the chain reaction together with the release, distribution and diffusion of energy and expansion of the plasma. Writing such programs is very difficult, but with the help of publically accessible literature on several parameters such as cross sections of fission or opacities of hot plasmas, it is also possible for the determined proliferator to do so. In this case the HDE can be used to predict yields quite precisely. It is necessary to have this information if one wants to develop the primary of a hydrogen bomb. It is therefore possible to do some of the important work involved in building new explosive devices in this way. However, the development of new modernized hydrogen bombs is not possible, since even the effect of boosting cannot be investigated without creating a substantial nuclear yield. HDEs are of no use for weapons of third generation. In short, HDEs are relevant for horizontal and, in a limited degree, also for vertical proliferation.

HDEs are very useful for the test of the reliability of existing arsenals in the NWS, more precisely, the functioning of the detonators, the test of the precision of a simultaneous release of several high energy, short time pulses and thereby the achievement of a uniform and precise compression of the fissile material. This is also a test of the so-called one-point safety, which is the reduction of the probability of an accidental detonation by starting an unintened shock wave in the conventional explosive surrounding the fissile material.

For this reason, HDEs are necessary for safety and reliability although they have such a strong proliferation potential. Verification of such experiments would be very difficult if not impossible: Since large quantities of high explosives are detonated in the course of an HDE, it can only be exploded in the open, or in specially reinforced or underground buildings. Subsequent on-site inspections can in principle prove whether conventional explosions have taken place. Enhancing the probability of the detection of such activities in NNWSs is one of the goals in the ongoing IAEA reforms.

HDEs are forbidden to NNWS by the NPT, and the histories of several NNWS show that they have complied with this ban although no verification existed. The are allowed under the CTBT and necessary for safety and reliability experiments.

Modelling on Supercomputers, e.g. ASCI

Computer modelling is an important aspect of every nuclear weapons program. It allows, together with hydrodynamic experiments to replace underground tests completely for the development of simple (non-fusion) nuclear weapons. As is well known, the computers used in the Manhattan project were not up to the performance of even the cheapest modern PCs, but they were sufficient to produce a simple nuclear weapon. A simple PC would have done the job for the Iraqi scientists to build a nuclear weapon if they had developed a sufficiently precise computer model and their project had not been stopped beforehand. Of course all nuclear weapons laboratories have comprehensive modelling activities of all kinds and a large number of high-performance programs. Computer simulations also play an important role in the development of new kinds of nuclear weapons. The scientific work on the X-ray laser, for example, consisted largely of computer simulations. All such programs must be loaded with data which have for the most part been public for a long time. In part, the data must also be derived from theoretical calculations. If it cannot be tested experimentally, e.g. by means of nuclear tests or ICF, then there is a factor of uncertainty which sets limits to the further development of the nuclear weapon. But in sum, the relevance for horizontal as well as for vertical proliferation is very significant.

Computers and programming activities are characteristic of all scientific projects. Most of the programming methods and principles are universal and can be equally applied to civilian or military projects. The broad availability and further development of high-performance computers together with programming projects can hardly be stopped. It is also most unlikely that existing simulation programs in nuclear weapons states would be destroyed. Also verification of programming activities seems impossible.

Subcritical tests

Subcritical and hydronuclear tests are not the same. The latter are nuclear chain reactions produced by the use of proper warheads, and they are banned by the CTBT, thanks to the French initiative on a true zero yield scope. In the former the experimental structure is modified so that their value for nuclear weapons is doubtful.13 In a subcritical experiment, hardly any neutron multiplication can take place, and the amount of this nuclear energy is very marginal. Therefore, the heat and pressure that can be generated by these experiments are far below of those of real nuclear weapons, and extrapolations are limited. They would not allow any research on boosting effects, so the potential for modernization is probably near to zero.

Why should any subcritical tests take place if they are not of use in the development of the new nuclear weapons? The reason can be found in the influence of weapons research establishments for whom the existence and purpose of a whole industry is at stake. The doubtful activities should therefore be seen as a concession for frustrated physicists rather than as the attempt to contravene the objective of the treaty.

However, it is a pity that it is planned to conduct these tests underground for safety reasons.14 Since the treaty does not provide for any routine transparency measures on former test sites, the world will be dependant on good faith that indeed harmless subcritical and no banned hydronuclear explosions are being conducted. This good faith cannot be expected from all countries. A suspicion would be left that could undermine the nonproliferation regime because it would reduce the good will of some countries on whose cooperation we are dependant.

The most simple solution to the dilemma would be simply to close all former test sites as now are doing the recently much critized French and to allow only above ground experiments. This would make clear that no HNEs are taking place. Unfortunately this seems unlikely to happen in some other NWS at the time being. So the solution should have been that the Treaty provide for some transparency regime on former test sites to prove that no hydronuclear test or a small yield explosion is being conducted. This is unfortunately not foreseen. It is possible to imagine scenarios which could lead to complications: let us assume an underground test takes place in Nevada and that a party to the treaty suspects that it was in reality a small nuclear explosion, a hydronuclear test. Externally both appear the same. On photos for instance which could be produced as 'national technical means' these events would be indistinguishable. In this case an on-site inspection would be appropriate, an event that would be very embarrassing in this example for the Americans. If the treaty had provided for specific measures of transparency, this would become a routine event avoiding scandal.

Germany and Sweden had during an earlier phase also supported the prohibition of test preparation. This would have exposed certain suspicious activities on test sites at least to public doubt whether they represent a treaty violation. But since this proposal was not supported, in order to speed up the negotiations - as a demonstration of the readiness to compromise - this position was abandoned in early 1996 and in its place a high degree of transparency was demanded.15

It would be wise for the nuclear states to announce at a high diplomatic level that they have not planned the development of any new nuclear weapons, neither now nor in the future. Deutch said this at the press conference for the Nuclear Posture Review. Prior to that, new warheads were banned in the U.S. by legislation anyway. France has in August 1995 announced that no future developments are underway. It would therefore be easy to confirm this at a politically more binding level.16

1 On the ability of developing nuclear weapons without testing by beginning or more advanced proliferators respectively, see R. Garwin, Can a Proliferant State Acquire a Nuclear Weapons Stockpile Without Testing, in: M. McKinzie (Ed.): The Comprehensive Test Ban Treaty: Issues and Answers, Cornell University, Peace Studies Program, Occasional Papers, p. 11, June 1997; or A. Schaper, Un frein à la course aux arméments nucléaires (A break at the nuclear arms race, in French), in: , M. De Becker, H. Müller, A. Schaper (Ed.), Essais Nucléaires (Nuclear Tests), GRIP, Brussels 1996. C. Mark, Nuclear testing and potential proliferators, presentation at the PPNN 10th core group meeting, 8-10 November 1991; For details on individual nuclear weapon states and states outside the NPT see: E. Arnett, Implications for the comprehensive test ban for nuclear weapon programmes and decision making, in: E. Arnett (ed.), Nuclear Weapons After the Comprehensive Test Ban, SIPRI, Oxford 1996. See also the literature on hydronuclear testing and testing thresholds (Footnote 2)

2 For an overview on hydronuclear testing and other simulation technologies see JASON and the MITRE Corporation, Science Based Stockpile Stewardship, Report JRS-94-345, November 1994, an overview on this report is: R. L. Garwin, Stockpile Stewardship and the Nuclear Weapon Complexes, Pugwash Meeting No. 206, Moscow, 19-23 February 1995; R. Garwin, The Maintenance of Nuclear Weapon Stockpiles Without Nuclar Explosion Testing, 24th Pugwash Workshop on Nuclear Forces, London, September 22-24, 1995, Ray E. Kidder, The Utility of Hydronuclear and Other Tests for Stockpile Evalutation, Maintenance, and the Development of New Weapon Prototypes, March 30, 1995; Thomas B. Cochran, Christopher E. Paine, The Role of Hydronuclear Tests and Other Low-Yield Nuclear Explosions and Their status Under A Comprehensive Test Ban, NRDC Report, March 1995

3 The German understanding that the zero-option means no nuclear yield is reflected in Foreign Minister Kinkel's press declaration of August 12, 1995, commenting on Clinton's declaration of August 11.

4 JASON and the MITRE Corporation, Nuclear Testing, Summary and Conclusions, JSR-95-320, August 3, 1995

5 A. Schaper, The problem of definition: Just what is a nuclear weapon test?, in: Eric Arnett (ed.): Implementing the Comprehensive Test Ban, SIPRI Research Report No. 8, 1994

6 See Hu Side and Tian Dongfeng, Peaceful Nuclear Explosions and the Comprehensive Test Ban, in: Arms Control Collected Works, Program for Science and National Security Studies, Institute of Applied Physics and Computational Mathematics, Beijing 1995, p. 100

7 U.S. Department of Energy, Office of Defense Programs, The Stockpile Stewardship and Management Program, May 1995. The text can also be found on http://web.fie.com/htdoc/fed/doe/oor/any/text/any/st01.htm

8 Natural Recources Defense Council, End Run – The U.S. Governments's Plan for Designing Nuclear Weapons and Simulating Nuclear Explosions under the Comprehensive Test Ban Treaty, August 1997. The text can be found on: http://www.igc.apc.org/ndrc/ndrcpro/endrun/enrinx.html

9 A Debate About the Future of Weapons Science. Participants: David Dearborn, Phil Goldstone, Ray Kidder, and Arjun Makhijani, moderator: Hugh Gusterson. The complete documentation can be found at: http://stsfac.mit.edu /projects/sbss/.

10 Ray E. Kidder; Problems with stockpile stewardship, Nature vol. 386, 17 April 1997

11 A. Schaper, 'Arms Control at the Stage of Research 0and Development? The Case of Inertial Confinement Fusion', Science & Global Security, vol. 2, p. 279, 1991.

12 Equations which describe the relationship between pressure and temperature are called "equations of state".

13 Suzanne Jones, Subcritical experiments and the CTBT, Paper presented at the 8th International Summer Symposium on Science and World Affairs, Beijing, July 1996

14 It has been reasoned that the subcritical tests must be conducted underground because large amounts of conventional explosives and the scattering of nuclear materials are involved (Ch. Paine, at the Carnegie Conference on Nuclear Nonproliferation, Feburary 12-13, Washington DC). Yet it should be asked why this could not be conducted in a reinforced building.

15 Rebecca Johnson, Geneva Update, Disarmament Diplomacy, February 1996

16 It is also recommendable to wait for the ratification of the CTBT by the nuclear weapon states before asking for more pressure on them.