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The Comprehensive Test Ban Treaty: Issues and Answers

Matthew McKinzie
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Cornell University

OCCASIONAL PAPERS

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Matthew McKinzie, ed.

The Peace Studies Program was established at Cornell in 1970 as an interdisciplinary program concerned with problems of peace and war, arms control and disarmament, and more generally, instances of collective violence. Its broad objectives are to support graduate and post-doctoral study, research, teaching and cross-campus interactions in these fields.

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PREFACE

After decades of effort a Comprehensive Test Ban Treaty (CTBT) was finally approved by the United Nations General Assembly in October 1996. President Clinton, in signing the Treaty on behalf of the United States, called it "the longest-sought, hardest-fought prize in arms control." The Treaty prohibits all signatories from conducting any nuclear explosive test, or permitting such a test to be performed on territories under their control, and it establishes an international monitoring system to verify compliance. Any state party can request an on-site inspection in a member state to resolve compliance issues, and the Treaty empowers member states to act in concert against violators. It represents a significant—perhaps the most significant—step in the long process of building an international regime against the further proliferation of nuclear weapons or the development of new types of nuclear weapons.

For the treaty to enter in force, however, it must be ratified by a large number of named countries with nuclear capabilities (military or civil), including, of course, the United States. The U.S. Senate will be asked to give its consent to the CTBT, based on the treaty's expected impact on international security and U.S. national security. Much is at stake: ratification will bind the United States more tightly to the international nonproliferation regime, while failure to ratify would signal a significant weakening of that regime. The Senate will consider the effect of the treaty on nuclear proliferation and U.S. military capabilities, especially nuclear capability, and the potential for effective verification of treaty compliance. Its deliberations should be informed and supported by a public debate on these issues, a debate that can only occur if information on technical and political aspects of the treaty is widely available.

The Peace Studies Program of Cornell University sponsored a workshop in Ithaca on October 11-13, 1996 to discuss issues surrounding congressional ratification of the CTBT. The workshop was organized by Matthew McKinzie, with the help of Judith Reppy and the Advisory Council to the Peace Studies Program's Project on Technology and Security: Richard Garwin, Kurt Gottfried, Lisbeth Gronlund, George Lewis, Herbert Lin, Peter Stein, Jeremiah Sullivan, Zellman Warhaft, and David Wright. Participants in the workshop came from a variety of backgrounds, including the U.S. Arms Control and Disarmament Agency, the Department of Energy, the Department of Defense, the Central Intelligence Agency, non-governmental organizations, and universities. A list of workshop participants and their affiliations can be found in Appendix 3. Commissioned papers discussed the political context for the treaty, the technical challenges and capabilities relevant to the verification regime, and the impact of the treaty on nuclear proliferation and international security. These papers have been revised in light of the discussion at the workshop and are reproduced in this Peace Studies Occasional Paper, along with an Executive Summary and several appendices. It is our hope that they will provide a useful and accessible source of information to the public debate on treaty ratification.

We wish to thank all the participants for their thoughtful contributions to the workshop discussion. Elaine Scott and Sandra Kisner of the Peace Studies Program staff provided the essential administrative support with their usual efficiency and good humor; it is no exaggeration to say that without their help the Program could not function. Funding for the workshop came from the John D. and Catherine T. MacArthur Foundation's institutional training grant to the Peace Studies Program.

EXECUTIVE SUMMARY

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BACKGROUND

On 24 September 1996 President Clinton signed the Comprehensive Test Ban Treaty (CTBT) during a ceremony at the United Nations, describing this achievement as "the longest-sought, hardest-fought prize in arms control." As of May 1997, more than three-quarters of the world's states have signed the Comprehensive Test Ban, including the other four declared nuclear powers: Russia, China, France, and the United Kingdom. The United States is one of the 44 states that must ratify the CTBT before it may enter into force. This collection of papers has been published to inform Senate decision-making on advice and consent to ratify the Comprehensive Test Ban Treaty.

The Comprehensive Test Ban Treaty establishes a universal norm against nuclear testing and an effective means to monitor compliance, and it aligns the nuclear powers with the vast majority of non-nuclear weapon states against proliferation. More specifically, it prohibits states from conducting any nuclear explosive test, or permitting such a test to be performed on territories under their control. The CTBT establishes an international monitoring system to monitor all terrestrial testing environments—globally and in near-real time—for evidence of a nuclear explosion. Any state party can request an on-site inspection in a member state to resolve compliance issues based on data produced from this monitoring system, supplemented by intelligence derived from the national technical means of states parties. In conformity with international law, the Comprehensive Test Ban empowers member states to act in concert against Treaty violators.

By strengthening the nuclear non-proliferation regime and arresting the development of new types of weapons by the other nuclear powers, the CTBT strengthens U.S. national security. The Comprehensive Test Ban accomplishes these U.S. objectives verifiably. Through the Department of Energy Stockpile Stewardship and Management Program, the benefits of the CTBT are compatible with the U.S. objective of maintaining the safety and reliability of the enduring U.S. nuclear deterrent.

ACHIEVING U.S. NON-PROLIFERATION AND ARMS CONTROL OBJECTIVES

The demise of the Soviet Union and substantial reductions in Cold War arsenals have shifted attention to the security threats posed by proliferation of nuclear weapons. Three U.S. objectives were achieved by the successful negotiation of the CTBT: a further barrier to horizontal proliferation is now in place; high confidence in the deployment of new types of nuclear weapons by the recognized nuclear weapon states is now very difficult, if not impossible; and the regime of legally binding treaty constraints is strengthened.

A nuclear explosive test is the most important experiment in the development of nuclear weapons. A single test can confirm impressive gains in capabilities; even a few tests are of considerable value to a proliferant state. The ability of additional states to acquire nuclear weapons is increasing with the enormous expansion in the number of individuals able to access computers and model complex physical systems; with the spread of nuclear reactors for research and the production of electric power; and with the accumulation of plutonium and highly-enriched uranium from spent reactor fuel and disassembled weapons. By ending nuclear testing, the Comprehensive Test Ban Treaty creates a significant obstacle to the confident acquisition of nuclear weapons. Without the possibility of testing, the nuclear weapon design choices for a proliferant state are limited to a configuration in which performance uncertainties would be minimized, i.e., crude fission weapons similar to the original U.S. designs of more than 50 years ago. Acquisition of thermonuclear weapons is thereby denied. Confident deployment of boosted fission weapons—designs that conserve fissile material and permit enhanced yield-to-weight ratios—is also heavily compromised. Without explosive testing, high confidence in even crude fission weapons is not attainable, thus planting critical reservations in the minds of potential military users.

The Comprehensive Test Ban Treaty is a significant disarmament measure. It enhances deterrent stability as the United States and Russia reduce their nuclear capabilities unilaterally and in accordance with the Intermediate-Range Nuclear Forces Treaty and the Strategic Arms Reduction Treaties. The "zero-yield" scope of the CTBT blocks development of new weapons by Russia, China, France, the United Kingdom, and the United States across the full spectrum of use: tactical, theater, and strategic. Confidence in significant modifications to existing weapon designs is critically dependent on the ability to confirm such modifications through testing. The decision of the nuclear powers to sign the CTBT represents their judgment that global security, and their own national interests, are better served by foregoing further options to develop and field new types of nuclear weapons.

The nuclear non-proliferation regime of legally binding treaty constraints and export controls, of which the Nuclear Non-Proliferation Treaty (NPT) is the foundation, remains a crucial factor holding in check the further spread of nuclear weapons. Failure to negotiate a CTBT would have risked unraveling this regime, as the achievement of a comprehensive test ban has been a central tenet of the NPT since its inception. For the non-nuclear weapon states the CTBT is a gauge of progress in nuclear disarmament, a quid-pro-quo for giving up their sovereign right to develop nuclear weapons. For the United States the political benefits of the CTBT are enormous: it aligns the nuclear powers with the vast majority of non-nuclear weapon states, allowing the United States to assume a leadership role against any proliferant state. Such a state clearly risks sanctions and more severe international response in the face of the now strengthened non-proliferation regime.

MAINTAINING THE U.S. NUCLEAR DETERRENT

The nuclear arsenal of the United States is currently safe and reliable. The U.S. Department of Energy Stockpile Stewardship and Management Program (SSMP) represents an integrated set of capabilities designed to produce high confidence in the future safety and reliability of the U.S. nuclear weapons stockpile without nuclear testing or stockpile modernization. Under the U.S. test moratorium in place since 1993, future confidence in the safety and reliability of U.S. nuclear weapons is being based on the legacy of past testing, enhanced stockpile monitoring and assessment, and on the capability to remanufacture weapons as needed, buttressed by improvements in predictive weapons science. A successful SSMP makes the continued reliance of the United States on nuclear deterrence for its security compatible with ratification of the Comprehensive Test Ban Treaty. The general reasons supporting this conclusion are primarily technical, but also concern the present security environment.

Technically, an SSMP has the potential to succeed today based on improvements in computer technology that are critical to further achievements in modeling and on evidence that weapons scientists and engineers can simulate some nuclear weapons phenomena in hydrodynamic and high-energy-density facilities. Politically, the international security environment in the present and likely future allows the United States to depend on its existing types of nuclear weapons. Should the security environment deteriorate so that new types of nuclear weapons are required, or should unforseen problems arise in the enduring nuclear arsenal which require testing to repair, the United States has emphasized its freedom to withdraw from the CTBT under the "supreme national interest" clause within six months of stating its intent to do so.

MONITORING THE COMPREHENSIVE TEST BAN TREATY

During the negotiating process for the Comprehensive Test Ban Treaty, the United States sought and achieved a monitoring regime that will provide effective verification. The CTBT International Monitoring System (IMS), combined with the national technical means of states parties, will insure that significant nuclear explosive tests conducted in violation of the Treaty will be detected, identified, and attributable to a source. The basic U.S. monitoring criteria is that a nuclear test with a yield of "a few kilotons, evasively tested" will be detected with high confidence. With coordinated effort between specialists who have worked on test ban monitoring and specialists who have worked on earthquake monitoring, the IMS will be able to meet these U.S. monitoring goals.

The IMS approach to monitoring the CTBT uses the strategy of roughly homogeneous global coverage. Monitoring stations of the international regime will continuously sample potential testing environments: seismic monitoring for the detection of underground tests, hydroacoustic monitoring for undersea tests, infrasound monitoring for atmospheric tests, and radionuclide monitoring to obtain trace evidence of a nuclear explosion releasing radioactivity into the atmosphere. Data produced from these monitoring stations will be relayed to the CTBT International Data Center, processed, and released to CTBT states parties. The CTBT provides for confidence-building measures and consultation and clarification procedures to aid in the diplomatic resolution of a problematic event, in addition to the possibility of seeking an on-site inspection. The permitted use of data derived from National Technical Means (NTM) to request an on-site inspection represents a monitoring strategy complementary to the global IMS coverage, one in which the United States can direct its national intelligence assets to regions of concern. The IMS and NTM taken as a whole present a formidable challenge to would-be evaders.

ENTRY INTO FORCE

The Comprehensive Test Ban Treaty text specifically names 44 states now possessing significant civilian and/or military nuclear capabilities that must ratify the treaty before it can enter into force. Of these 44 states, India, Pakistan and North Korea have not signed the CTBT as of May 1997. India strongly opposed the final text of the CTBT during the close of the negotiations, and sought to block its transmission to the United Nations General Assembly. The past year has seen three Indian governments: Inder Kumar Gujral, the current Prime Minister, was Foreign Minister during the Test Ban negotiations and a proponent of India's opposition to the CTBT. Pakistan's stated policy is not to sign the CTBT unless India does.

If the Comprehensive Test Ban Treaty has not entered into force by 24 September 1999, a majority of those states that have by then ratified the CTBT may convene a Conference of States. Under Article XIV, ¶2 of the Comprehensive Test Ban Treaty, this Conference "shall consider and decide by consensus what measures consistent with international law may be undertaken to accelerate the ratification process in order to facilitate the early entry into force of this Treaty."

CONCLUSIONS

Over the past 51 years, a total of 2,046 explosive nuclear tests were conducted by the United States, the Soviet Union, the United Kingdom, France, China, and India, releasing the energy equivalent of over *one-half billion* tons of chemical high explosives; during this period a nuclear test occurred on average once every nine days. The end of the Cold War brought about fundamental, positive changes in the global security environment in accord with principal foreign policy objectives long sought by the United States. These changes are reflected in the record of nuclear testing since the disintegration of the Soviet Union: a consensus among the nuclear powers at the close of the 20th century has ended the era of nuclear explosive testing begun during the second World War. A verifiable treaty banning all explosive testing of nuclear weapons, universally in force, will cement this hard-won consensus, preserving it and strengthening it as the world community of states strives for a more peaceful future. Ratification by the United States is essential for the momentum of the Comprehensive Test Ban Treaty to continue to entry-into-force, an outcome that now and in the future will increase U.S. national security.

CHAPTER 1

REMARKS ON THE COMPREHENSIVE TEST BAN TREATY AND NUCLEAR NON-PROLIFERATION

The Honorable Lawrence Scheinman, Assistant Director
United States Arms Control and Disarmament Agency*

The Comprehensive Test Ban Treaty (CTBT) should be seen in the broader context of a long history of international efforts to establish a regime of international peace and security and to move towards the goal of an eventually denuclearized world. The relationship between a comprehensive test ban and the Nuclear Non-Proliferation Treaty (NPT) of 1968 is both straightforward and uncontrovertible. Achievement of a treaty banning nuclear tests has been a central tenet of the NPT since its inception. That linkage is spelled out in the Preamble of the Nuclear Non-Proliferation Treaty of 1968, which recalls "the determination expressed by the Parties to the 1963 Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water...to seek to achieve the discontinuance of all test explosions of nuclear weapons for all times and to continue negotiations to this end." Even earlier, the genesis of the CTBT traces to the 1954 appeal of Prime Minister Nehru for the termination of nuclear weapons testing. That appeal has been invoked by the current government of India in justification of its refusal to participate in the treaty, which—despite its endorsement by the United Nations General Assembly—India believes does not go far enough toward the intended goal of nuclear disarmament. India argues that the CTBT does not effectively eliminate the possibilities for qualitative development, upgrading, and improvement of nuclear weapons by the acknowledged nuclear weapon states—in short, that it leaves the nuclear weapon state hegemony intact. I will return to this issue momentarily.

The dates 1954 and 1963 are not the only benchmarks along the way to the present. Between 1958 and 1961 the United States, United Kingdom and Soviet Union engaged in discussions on how to monitor a comprehensive test ban and did so against the backdrop of a testing moratorium. In the 1970s two further partial measures were agreed upon—the Threshold Test Ban Treaty and the Peaceful Nuclear Explosions Treaty—which put additional constraints on nuclear testing. The 1980s also saw the beginning of a process of nuclear arms control and disarmament of which the CTBT is the latest significant addition. Between the mid 1980s and today we have agreement and implementation of the Intermediate-Range Nuclear Forces (INF) accord, which eliminated all intermediate and shorter range nuclear missiles that had been threatening to create a new instability in Europe; negotiation and ratification of the Strategic Arms Reduction Treaty I (START I; implementation of which is moving along at a smart pace—e.g., we are about two years ahead of schedule on silo elimination); the negotiation and U.S. ratification of START II (which is designed to achieve further deep reductions in strategic nuclear forces and enhance strategic stability by eliminating destabilizing weapon systems); and significant unilateral steps by the two major nuclear states to withdraw and dismantle thousands of tactical nuclear weapons. For the United

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*This paper represents the personal views of the author and does not necessarily reflect the views of the United States Government or any agency of that government.

States this includes not only the reduction of non-strategic nuclear force warheads, but also the placing of fissile material excess to national defense needs under International Atomic Energy Agency (IAEA) safeguards. The United States has already placed 12 metric tons of excess highly enriched uranium and plutonium under IAEA safeguards at Department of Energy facilities, and just last month announced that it would submit an additional 26 metric tons of excess fissile material to IAEA inspection during the next three years.

Throughout this forty-year period, the objective of achieving a comprehensive test ban treaty has been the *centerpiece* of the international security dialogue; and, as already mentioned, for the past twenty-five years it has figured prominently in the Nuclear Non-Proliferation Treaty as a gauge of progress in nuclear arms control and disarmament. In their first review of treaty performance in 1975, parties to the NPT asserted that "the conclusion of a treaty banning all nuclear weapons tests is one of the most important measures to halt the nuclear arms race," and expressed the hope that the nuclear weapon states party to the Treaty would take the lead in reaching an early solution of the technical and political difficulties on this issue.

Disgruntlement over the lack of progress toward nuclear disarmament, in particular the failure to move forward on a nuclear test ban, caused a breakdown in efforts to produce an agreed final document to the 1980 NPT Review Conference. The year 1985 saw the achievement of a consensus final document, but even in that review, Article VI, the arms control and disarmament article of the NPT, was the most acrimoniously debated issue with much of the discussion targeted on the priority to be accorded a comprehensive test ban. As one participant/observer put it, "the demand was repeatedly heard that the nuclear states get on with the job of reducing their nuclear arsenals and...with negotiation of a comprehensive ban on nuclear testing."

The fourth review conference held in 1990 also hit a deadlock over a test ban. Non-aligned countries recommended that the conference "deplore" that despite the end of the Cold War the appeals contained in United Nations (UN) General Assembly resolutions since 1981 for a moratorium on nuclear weapon testing pending conclusion of a comprehensive test ban treaty "have gone completely unanswered by two of the nuclear weapon states parties to the treaty." The non-aligned countries further sought a conference declaration that "continued testing of nuclear weapons by the nuclear-weapon States Parties to th(e) Treaty would put the future of the Non-Proliferation Treaty beyond 1995 in grave doubt."

In the critically important 1995 NPT Review and Extension conference, which bore the awesome responsibility for determining "whether the Treaty shall continue in force indefinitely, or shall be extended for an additional fixed period or periods," cessation of the nuclear arms race and nuclear disarmament including a comprehensive test ban were yet again central points of concern and contention. Once more a consensus final document was precluded by differences regarding progress on nuclear arms control and disarmament. (As the United States representative on Main Committee One that dealt with arms control and disarmament issues, I can attest to the intensity of feelings of many on this issue.) The parties to the NPT extended the treaty indefinitely, but in doing so set down in the form of a decision paper on principles and objectives for nuclear nonproliferation and disarmament an agenda of issues considered important to future efforts to implement and sustain the NPT. Chief among these was a reaffirmation of commitment by the nuclear weapon state parties to Article VI of the treaty, and in particular to the completion of a comprehensive test ban treaty "no later than 1996." Notably, CTBT was the *only* nuclear disarmament measure in the Principles and Objectives decision for which the parties stipulated a specific time frame for achievement.

It is to be regretted that a treaty so sought after and so central to the widely shared objective of sustained and tangible progress on nuclear arms control and disarmament—a treaty referred to by President Clinton in his recent UN General Assembly address as the "longest sought, hardest fought for prize in arms control history"—fell short of universal acclamation and support. While it is gratifying that 59 of the 60 Conference on Disarmament (CD) members voted for the treaty in New York, it is sadly ironic, to say the least, that the country which first initiated the movement to achieve a comprehensive end to nuclear testing—India—chose first to block consensus on the treaty draft in Geneva, and then to vote against the Australian-sponsored resolution endorsing the treaty and calling for its opening for signature at the earliest possible date.

India offered a number of reasons why it could not endorse and support the CTBT. From the point of view of my contribution to this publication, several stand out and deserve comment; other equally important questions are taken up in Chapter 3 by my colleague Pierce Corden. One argument is that the CTBT is not a serious disarmament measure but essentially only an additive nonproliferation treaty. To the contrary we believe that CTBT is *both* an arms control *and* a nonproliferation measure *as well as* being an essential prerequisite for nuclear disarmament. President Clinton expressed this in a straightforward manner in his recent UN address in asserting that the treaty "will help to prevent the nuclear powers from developing more advanced and more dangerous weapons. It will limit the ability of other states to acquire such devices themselves. It points us toward a century in which the roles and risks of nuclear weapons can be further reduced, and ultimately eliminated." Let me briefly elaborate on these points.

CTBT is an *arms control* measure because it freezes the technological level of the stockpiles of the existing nuclear weapon and threshold states. By completely banning "any nuclear weapon test explosion or other nuclear explosion," the CTBT will constrain the nuclear weapon states and other parties from developing and deploying advanced new types of nuclear weapons. Despite the sophistication of the U.S. stockpile stewardship program, few, if any really believe that *genuinely* new designs can be produced and deployed without explosive testing. This *appears* to preclude the development of new miniaturized battlefield weapons and weapons that rely on special effects such as microwaves or enhanced radiation. This constitutes a major constraint on nuclear weapon state capabilities and is a meaningful step toward nuclear disarmament. To the counter-argument that "subcritical" experiments are not banned by the CTBT, the answer is that these experiments, by their very nature, will not produce a nuclear yield. They are designed to help maintain the safety and reliability of our existing weapons and not for the development and qualitative improvement of weapons, objectives that India in fact sought. Even if computer modeling and subcritical experiments provide information that theoretically could be of value in a weapon development program, developing new kinds of weapons that can be confidently relied upon for deterrence or war-fighting is really not a tenable proposition in the absence of testing. Concluding this point, while the treaty will effectively constrain the development and qualitative improvement of nuclear weapons and end the development of advanced new types of nuclear weapons, it cannot eliminate the nuclear capabilities that some states now possess, and is not intended to. State motivations and means for developing a nuclear arsenal will need to be addressed in successive arms control steps.

The CTBT is a *nonproliferation* measure because it puts pressure on all states, not just signatories and ratifiers, to avoid nuclear testing. This does not necessarily prevent new nuclear states from arising, but it does mean that any new states will be unable to develop their weapons beyond the most primitive levels achievable without testing. Without testing it will be much more difficult than otherwise to make a weapon small enough to affix to a missile or to deploy on an aircraft. The CTBT serves as an added constraint to the Nuclear Non-Proliferation Treaty in closing off the nuclear option to a would-be proliferator. At the risk of being proven wrong by the behavior of a contrarian state, I would go a step further and say that the very act of the international community in giving overwhelming support for opening the CTBT to signature last month created a sort of instant norm against nuclear testing, a norm that poses an enormous political dilemma for any state—including the weapon states—contemplating testing. To argue that CTBT is a nonproliferation measure in this sense is in no way inconsistent with the proposition that the treaty is genuinely an arms control treaty as well.

As for my third point, the CTBT, as it stands today, is a necessary if not a necessarily sufficient condition for nuclear disarmament. *It is, in other words, an essential prerequisite for nuclear disarmament.* It is a building block toward a more secure and stable future in which the process of nuclear disarmament can continue. Development of new weapons must be brought to a halt in an effectively verifiable way before the states that currently rely on nuclear deterrence can feel safe in reducing their own arsenals to very low levels and ultimately zero.

There is a counter argument that to be meaningful a CTBT should signal a sea change in the perceptions of nuclear weapon states about their nuclear weapons *now*; that the CTBT should engage firm and immediate nuclear disarmament undertakings. This ties in to India's call for the establishing of an ad hoc committee on nuclear disarmament in the Conference on Disarmament for the purpose of carrying on negotiations on a phased program of nuclear disarmament and for the elimination of nuclear weapons within a timebound framework. In this view, a CTBT does not contribute to the process of nuclear disarmament *unless* the nuclear weapon states commit *now* to eliminate their nuclear weapons by a specific date. Most states, including the United States, contend that we should all strive toward the goal of global elimination of nuclear weapons but that achieving that important goal would be challenging and complex and realistically attainable only through a step by step process. The CTBT needs to be seen as a key step toward that goal, a step that was now feasible, but that our reach would exceed our grasp were we to link endorsement of a CTBT to a timebound framework of nuclear disarmament.

Let me take this point a little further. Disarmament on demand, or timetable disarmament, is not a workable proposition—rather, it is political grandstanding that blocks out consideration of whether and to what extent the political and security environment in which disarmament is to take place is conducive to such measures. We live today, and will for some time to come, in a period of transition between a world anchored on two relatively well-disciplined superpower alliances which defined the international security order, and a future that is unknown and difficult to map with confidence, and which is more likely than not to be characterized by forms of complex multi-polarity in which local, regional and transnationalist forces weigh heavily.

Building down one security order requires a commensurate building up of alternative orders if stability is to be safeguarded. The goal of ultimate elimination of nuclear weapons must take these considerations into account. What is critically important at this stage is to engage in a process that moves us inexorably toward that goal, but avoids the error of generating expectations that cannot be met, feeding the flames of disillusionment and frustration, and reinforcing those who would argue against changing the nuclear status quo.

What we said during the run up to the 1995 NPT Review and Extension conference, namely that indefinite extension of the NPT offered the best chance to establish and consolidate a stable strategic environment that would facilitate further progress on arms control, applies as well to the CTBT. Both of these treaties are critically important to creating conditions in which we can strive continually toward the goal of a world free of nuclear weapons. Both ran the risk of being encumbered with supplementary and in some cases extraneous demands which could have weakened or even crippled them. Both, fortunately, averted being undermined.

I already mentioned some of the other building blocks that, together with treaties like the CTBT and NPT, move us further down the road of nuclear arms control and disarmament—INF, the START treaties, the unilateral measures undertaken by the United States and Russia with respect to the protection and disposal of dismantled nuclear warheads and the fissile material that they contain. Much, much, more remains to be done. Using the benchmark of the 1995 NPT Extension Conference decisions, it may be noted that along with the completion of a CTBT "no later than 1996" the then 178 parties to the Treaty called for early conclusion of negotiations on a convention banning the production of fissile material for nuclear weapons or other explosives, and systematic and progressive efforts to reduce nuclear weapons globally with the ultimate goal of their elimination. A fissile material cut-off treaty has been a long-sought arms control objective of the international community. Like the CTBT it was first introduced by Prime Minister Nehru. With the end of the Cold War, the erosion of the disciplines of the Cold War alliances, the resurfacing of long-suppressed regional animosities, and increasing recognition that these emerging trends pose a growing threat to international security and of nuclear proliferation, a new impetus emerged for a fissile cut-off treaty. The CD took a consensus decision in March, 1995 to pursue negotiations by establishing a negotiating mandate and an ad hoc committee, but this initiative fell on hard times as first Pakistan and then India persuaded other non-aligned states to delay the start up of negotiations on cut-off until nuclear disarmament is addressed in the CD. With the CTBT no longer dominating the attention and energies of the CD, the United States will urge the CD to take up the challenge of producing a text for consideration by its membership and adding yet another building block to the edifice of nuclear arms control and disarmament.

In so far as the admonition for the weapon states to make systematic and progressive efforts to reduce nuclear weapons globally, President Clinton reaffirmed in his UN speech the 1994 Clinton-Yeltsin summit commitment to discuss the possibilities for further cuts in their nuclear arsenals once Russia ratifies START II as the United States already has done; to limit and monitor nuclear warheads and materials, and to make deep reductions irreversible. It goes without saying that the bilateral efforts of the two leading nuclear weapon states must soon be joined by the other three if the call for global reductions is to be answered. To this growing list of actions and undertakings should be added the recent adherence by the United States, France, and the United Kingdom to the protocols of the South Pacific Nuclear Free Zone and by the United States, France, the United Kingdom, and China to the protocols of the African Nuclear Weapon Free Zone, the result of which is to substantially increase the land mass now nuclear-weapon free, and to strengthen the negative security assurances which are so valued by non-nuclear weapon states party to these zonal treaties.

What is crucially important about the CTBT is that with its completion and opening for signature the process of nuclear arms control and disarmament has taken a significant step forward, reinforcing the indefinitely extended NPT, fulfilling a mandate of the parties to that treaty that the long-awaited CTBT be concluded in 1996, and opening the way to the pursuit of further nuclear arms control and disarmament efforts. The CTBT shows more clearly than perhaps any other treaty that nonproliferation, arms control and disarmament are intimately connected. Progress must be made on all three fronts simultaneously if the ultimate objective of a nuclear weapon free world is to be achieved. Without a successfully concluded CTBT, without an indefinitely extended NPT, the prognosis for further progress in nuclear arms control would have been dim indeed. Their endorsement by the overwhelming majority of states of the international system establishes the basis

for working with renewed optimism toward establishing a safer and more secure future world order in which, eventually, over time and in the context of changing political and structural conditions, nuclear weapons will become anachronisms.

CHAPTER 2

THE COMPREHENSIVE TEST BAN TREATY FROM A GLOBAL PERSPECTIVE*

Annette Schaper
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INTRODUCTION

For over half a century nuclear weapons have been developed and tested. Over that time they have been continuously modernized, miniaturized and adapted to new delivery systems; new strategies and new technologies have mutually promoted each other; and more sophisticated concepts have given rise to new development programs and ever more comprehensive test series. Examples of advanced concepts are multiple warheads, neutron weapons, and, as attempted in U.S. President Reagan's Strategic Defense Initiative, even space-based nuclear-driven X-ray lasers, microwave weapons, and particle beam weapons—the so-called nuclear weapons of the third generation. The most important experiment in the development of atomic weapons is the nuclear explosion called a "test." A total of 2046 "tests" and two uses in combat have been recorded to date. The 2048th and probably last nuclear explosion was conducted by China on 29 July 1996.

For decades there have been repeated attempts to negotiate a treaty for the final ban of all nuclear tests, but the mistrust during the Cold War was always too strong and the goodwill too weak. Now the Comprehensive Test Ban Treaty (CTBT) seems to be within reach: in September 1996, after two and a half years of negotiations in the Conference on Disarmament (CD), the United Nations General Assembly adopted for signature a treaty text by an overwhelming majority.[1] The document comprises 88 pages of treaty text, a protocol, and appendices. This laboriously-developed treaty is, however, in danger of never entering into force because of the likely non-participation of India. Yet negotiations have already established a norm against testing, as was demonstrated by the strong protests against the French test series in 1995 and 1996. In the first 11 days after opening for signature, a total of 111 nations signed the treaty, thereby reinforcing this norm. A large number of ratifications might be expected during the next year, which will legally oblige the ratifying countries not to test, even if the treaty is not yet in force.

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*An earlier version of this paper has been published in German language as: "Der Umfassende Teststoppvertrag: kurz vor dem Ziel—der Gescheitert?" ["The Comprehensive Test Ban Treaty in Reach of a Breakthrough—or a Failure?"], *HSFK-Standpunkte* no. 7 (August 1, 1996). This earlier version has been translated into English by Victoria Brooks.

[1] 126-Power draft resolution, United Nations document A/50/L.78.

THE CHRONOLOGY OF THE NEGOTIATIONS

Early on, attempts were made to negotiate a test ban treaty, but these were only partially successful.[2] In 1963 the United States, the Soviet Union, and Great Britain concluded the Limited Test Ban Treaty, which prohibited tests in the atmosphere, in space, and under water and only allowed them underground; the intention was above all to prevent environmental contamination in the atmosphere. In 1974 and 1976 there followed the Threshold Test Ban Treaty (TTBT) and Peaceful Nuclear Explosion Treaty between the United States and the Soviet Union, which prohibit all military and peaceful explosions above a threshold of 150 kilotons of TNT. The explosive energy of 150 kilotons TNT is still, however, equivalent to 150,000 tons of conventional explosives. In the preamble to the Non-Proliferation Treaty (NPT) of 1968, the state parties declared their determination to work towards a permanent ban of all test explosives of nuclear weapons. In spring 1995 the Review and Extension Conference of the NPT took place at which there was agreement on the Principles and Objectives of future review conferences; these emphasize disarmament and specifically describe the test ban as a disarmament measure. There was even a deadline set: not later than 1996. After the end of the East-West conflict international pressure became so strong that Gorbachev announced a Soviet test moratorium in 1991, which was joined in 1992 by France and, under pressure from Congress, the United States. As a result Great Britain was also unable to perform further tests because it was dependent upon American test sites. China alone undertook no voluntary commitment.

After the Clinton Administration announced that the United States would actively seek a test ban, the Geneva Conference on Disarmament was given a negotiating mandate at the beginning of 1994. The reaction to the resumption of the French testing in the summer of 1995 showed impressively how strong international pressure had now become. Protests against these six tests exceeded everything which one was accustomed to in the years during which more than 2000 explosions had taken place.[3] Even China, which—in contrast to France— had never announced a moratorium, suddenly became a target of world-wide criticism. Times have changed: because of public awareness, testing moratoria cannot easily be revoked, and the CTBT negotiations are designed to seal what has almost become reality.

At the end of June 1996, a final draft treaty had been worked out between the now 61 members of the Geneva Conference on Disarmament.[4] The draft had found almost full agreement in

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[2] On the history of test ban debates see: S. Fetter, *Toward A Comprehensive Test Ban* (Ballinger: Cambridge, MA, 1988); and J. Goldblat and D. Cox (eds.), *Nuclear Weapon Tests—Prohibition or Limitation?* (SIPRI, Oxford University Press: Oxford, 1988).

[3] On the background of French nuclear testing see: A. Schaper and H. Müller (eds.), *Fatale Versuche—Zur Wiederaufnahme der französischen Kernwaffentests* [*Fatal Experiments—the Resumption of French Nuclear Testing*] (Holos Verlag: Bonn, 1995).

[4] The developments in the CD have been described in great detail and accuracy by Rebecca Johnson in the *Acronym Reports* and the periodicals *Nuclear Proliferation News* (4/15/94-12/15/95) and *Disarmament Diplomacy* (1996-), Sean Howard (ed.), published by Dfax (Farndon House Information Trust: Bradford, UK) on behalf of the ACRONYM Consortium, available on the World Wide Web at http://csf.colorado.edu/dfax.

the CD, but India, acting alone, blocked the necessary consensus on submitting the draft text to the United Nations General Assembly. India claimed it would not block the agreement under one condition: namely that it was not put under pressure by the clause on entry into force, which explicitly requires India's ratification of the treaty. But the clause was sustained. This blockage was circumvented by a group of the treaty's "Friends" led by Australia, who took it to the General Assembly where it was adopted by a majority of 158 votes, with 3 against and 5 abstentions. This result, however, could damage the future credibility of the CD as the sole multilateral negotiating forum on disarmament issues. A total of 111 nations have signed the treaty in the first 11 days since it was open for signature.

THE TEST BAN AS A MEANS TO NUCLEAR NON-PROLIFERATION AND DISARMAMENT

Two results are expected from a test ban: an end to the qualitative arms race by the nuclear weapon states and restrictions on the ability to develop nuclear weapons in countries seeking nuclear status. Further nuclear ambitions are denied both to the present nuclear weapon states (NWSs) as well as to 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 crudely apply the effects of nuclear fission, can be accomplished without testing.[5] 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 adaptation to delivery systems, which could perhaps constitute the next stage of nuclear weapons acquisition in Pakistan or India, would to a certain extent be possible without testing. The option of demonstrating such new nuclear capability would, however, not be permitted. Military planners would not have 100% certainty that their arsenal would be 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

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[5] On the ability of beginning or more advanced proliferators to develop nuclear weapons without testing, see: Richard L. Garwin, "Can a Proliferant State Acquire a Nuclear Weapons Stockpile Without Testing," Chapter 6 of this publication; A. Schaper, "Un frein à la course aux arméments nucléaires" ("A break at the nuclear arms race"), in M. De Becker, H. Müller, and A. Schaper (eds.), *Essais Nucléaires (Nuclear Tests)* (GRIP: Brussels, 1996); and 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 Nuclear Non-Proliferation Treaty see: E. Arnett, "Implications of the comprehensive test ban for nuclear weapon programmes and decision making," in E. Arnett (ed.), *Nuclear Weapons After the Comprehensive Test Ban* (SIPRI, Oxford University Press: Oxford, 1996). See also the literature on hydronuclear testing and testing thresholds cited in reference 11, below.

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, is 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 only works with the application of utmost 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 because many parameters and variations of the trigger mechanism must be accurately measured—information that cannot be derived by other methods. A CTBT would thus effectively impair any further development in countries that do not possess the hydrogen bomb. 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 forever and the aim of arms control, nuclear non-proliferation, would be recognized in the form of a treaty for the first time by these states. States already in possession of the hydrogen bomb, i.e., the five NWSs, might wish to develop, miniaturize and adapt their weapons to modern delivery vehicles. Without testing, these developments would be substantially limited, because a variety of technical influences interact producing a complexity that can only be partially simulated without sufficient measurement data. The greater the number of activities providing such measurement data that are forbidden, the more reliable will be the prevention of future modernization.

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 within 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 new 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.

SURVEY: THE DIFFERING INTERESTS OF THOSE INVOLVED

The non-nuclear weapon states (NNWSs), which as a result of joining the NPT have given up all ambition concerning nuclear arms, are interested both in disarmament and non-proliferation.

In contrast to the NPT, the CTBT is not supposed to distinguish between two groups having differing rights and obligations: those with nuclear arms and those without. The Principles and Objectives are defined in the treaty as non-discriminatory and universal. As a result of the CTBT, discrimination is reduced and the importance of nuclear weapons further diminished, as the CTBT places new obligations primarily on the NWSs and the non-members of the NPT but not on those countries without nuclear arms.

The situation for the NWSs is different:[6] for the sake of the treaty, they would have to give up rights formerly taken for granted. Their interests are twofold. On the one hand they want finally to integrate the three threshold countries into the regime, thus strengthening nuclear non-proliferation; on the other hand, they want to curtail their own rights as little as possible; that is, not to accentuate the disarmament issue. These divergent interests became evident repeatedly during the negotiations: the scope of the ban was to be defined as narrowly as possible, leaving the aims in the preamble non-committal and vague.

Following the end of the Cold War, neither the United States nor Russia are still interested in confrontation between the blocs. Instead their main aim focuses on curtailing uncontrolled nuclear development in China and those states outside the non-proliferation regime, especially India. This is an interest of both states, and has lead the United States to propose and conclude negotiations successfully with the co-operation and substantial support of Russia. The old conflict of interests was hardly of any importance during the negotiations. It became obvious that the United States was dominant, but this position was not challenged by Russia. The same interest, namely to restrict the ability of these states to develop nuclear weapons, was shared by most NNWS taking part in the negotiations both from the Western and Eastern groups, as well as the Non-aligned states.

For the United States, public pressure and the influence of the pro-disarmament lobby is also important.[7] The test ban has for a long time been one of the most important symbols for nuclear disarmament. This symbolic significance was intensified in 1995 by the agreement on the Principles and Objectives of the implementation of the NPT-treaty, in which the test ban was specifically mentioned as a means of disarmament, and a deadline was laid down for 1996. This created international pressure apart from the domestic pressure in the United States. A failure of the test ban negotiations would have crucially undermined the importance of the Principles and Objectives, and thus the entire non-proliferation regime. The United States, however, is definitely interested in the strengthening of this regime. Hence it has devoted great efforts to avoid failure at the CD negotiations. This is not contrary to Russian interests, which concentrated on avoiding

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[6] A collection of views by analysts from the NWSs, states of concern, and states outside the NPT is given by *Nuclear Weapons After the Comprehensive Test Ban*.

[7] Examples from among the many contributions to the testing debate are: R.E. Kidder, *Maintaining the U.S. Stockpile of Nuclear Weapons During a Low-Threshold or Comprehensive Test Ban* (Lawrence Livermore National Laboratory Report UCRL-53820: Livermore, October 1987); *Toward a Comprehensive Nuclear Warhead Test Ban* (Report of the International Foundation: Washington, DC, January 1991); D. Fenstermacher, "The Effects of Nuclear Test-ban Regimes on Third-generation-weapons Innovation," *Science and Global Security* 1, no. 3-4 (1990), p. 187; F. von Hippel, H.A. Feiveson, and C.E. Paine, "A Low-Threshold Nuclear Test Ban," *International Security* 12, no. 2 (Fall 1987), pp. 135-51.

unnecessary conflicts. Russia has, however, no comparable domestic pressure for disarmament. It is far more interested in binding India into a treaty than pursuing disarmament.

Although the United States by no means would have supported a failure of the negotiations, it also has to satisfy the influential domestic nuclear arms lobby and to leave some technical options open. The strength of this influence was already in evidence when the Limited Test Ban Treaty (LTBT) was negotiated in 1963. Its original aim was to ban all explosions, not only those in the atmosphere as was later agreed on. Among the reasons for this failure was the influence of the inventor of the hydrogen bomb, Edward Teller, who supported further testing, claiming he was close to developing a nuclear weapon without radioactive fallout. Over 30 years later, Teller continued to advocate "peaceful nuclear explosions" during the time that the CTBT was under negotiation. The American nuclear weapons research laboratories and arms industry employ professional lobbying firms to influence members of Congress. At the CD negotiations on the CTBT the United States, along with the four other nuclear powers, aimed at downplaying the disarmament issue. The Russian nuclear lobby even proposed "peaceful nuclear explosions," but was not supported by their government.[8] At times the Americans demanded the possibility of conducting some tests in ten years time to comply with demands from some members of Congress.

Early in the negotiations, France was relatively uncooperative and insisted on a very narrow scope for the treaty. This would have left open many technical opportunities for further development of nuclear weapons. France changed its position after the strong protests against its renewed nuclear tests. Surprised by the extent of these protests and confronted with the reality of the altered public opinion, France became interested in improving its reputation, and from summer 1995 onwards became very co-operative.

The situation for Great Britain is different. It was forced to participate in the American test moratorium, having no testing sites of its own. Great Britain is not interested in limiting its options; rather it would prefer to keep them open.

China, an important target of other states, is confronted with massive international pressure; its prime aim, however, is to restrict India's possibilities of development. Simultaneously Beijing is striving for regional hegemony and a consolidation of its status as a nuclear weapon power. China is the only nuclear weapon state not to have participated in the test moratorium of the others. Its reasoning was that it had tested less than the others and had to compensate for their head start. For a long time it demanded the possibility of "peaceful nuclear explosions." This can also be explained by the existence of an influential domestic lobby. Chinese nuclear physicists were substantially supported by their Russian colleagues, who had not been successful at convincing their government with their studies and recommendations concerning peaceful nuclear explosions. China's position is characterized by the idea of competition. It frequently states that it will only take part in nuclear disarmament when the United States and Russia have reduced to a comparable level. The Chinese have, however, developed a strong interest in arms control. They clearly are trying to acquire a more influential role in ongoing nuclear arms control and non-proliferation activities and negotiations.[9]

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[8] This was apparent at the 3rd Pugwash Workshop on "The Future of the Nuclear Weapon Complexes of Russia and the USA" (Moscow, 25-26 March 1996).

[9] An indicator is the strengthened Chinese efforts to train arms control analysts and to educate them through international academic contacts. See, for example, the collection of Chinese articles

The NWSs are defensive concerning nuclear disarmament and offensive with respect to non-proliferation. The position of the threshold states is the reverse, although in differing degrees and especially with different motives. They too would have to give up options and privileges, and they are put under pressure by many states to subscribe to nuclear non-proliferation.

As compensation for signing the CTBT, India especially is insisting on concrete measures towards nuclear disarmament. In its view a simple consolidation of the status quo in times where test moratoria can in reality not be reversed is not enough. Like many other states, India is doubtful whether a test ban can really stop the qualitative nuclear arms race. During the negotiations it always pleaded for disarmament, and tried to lead the non-aligned states and bring them onto its side. It made more extreme demands than all other states, however, especially by insisting upon a definite time frame for nuclear disarmament. In this respect it was relatively isolated, as this demand was deemed both unrealistic and counter-productive. India's more moderate position, discussed below, was, however, shared by many participants.

India has always demanded a test ban and nuclear disarmament, but has refused to join the NPT, which it perceives as too discriminatory. The NPT, however, does include a commitment to disarmament by the NWSs. As a non-member of the NPT, India has no support in international law for its demands concerning nuclear disarmament, so it has a much stronger interest compared to the members of the NPT in including a disarmament clause in the CTBT. India's problem is primarily the discrimination within the non-proliferation regime. In disarmament it sees a possibility of reducing this problem.

It is, however, also conceivable that India was not interested in successfully finishing this round of negotiations. With its arguments on discrimination and disarmament it can put the blame on the others. Furthermore, it remains doubtful whether India really wants nuclear disarmament. India's foremost interest has always been regional hegemony, an interest that is supported by its political elite. Domestically, pressure is being exerted to undertake some nuclear tests to demonstrate that it is a nuclear weapon power.[10] Since it is obvious that India's extreme demands for a timeframe for complete nuclear disarmament are unacceptable to those in possession of nuclear arms, an irreconcilable conflict was foreseeable. It must be assumed that India was seeking to provoke precisely this conflict for rejecting a treaty that it had demanded for years.

Pakistan also is driven by political motives. Above all it does not want to be outdone by India. It also calls for India's membership, and like India emphasizes the disarmament issue. Probably it would only join a treaty if India did as well.

Israel has above all regional security interests, which means that it wishes to preserve the present status quo. This status quo is characterized by ambiguity: possession of nuclear weapons is neither admitted nor is it denied. Presumably Israel is not interested in conducting tests now, as was also the case in the past, and can also give up such an option. However, it is equally unlikely to support a verification process that would provide outsiders more detailed knowledge about its technical and military capabilities.

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on technical aspects of arms control: *Arms Control Collected Works*, Program for Science and National Security Studies, (Institute of Applied Physics and Computational Mathematics, Beijing, 1995).

[10] See for example: Brahmah Chellaney, "If pushed over Test Ban Pact, India could really 'Go Nuclear'," *International Herald Tribune*, 7-8 September 1996.

THE PREAMBLE: DIFFERING CONCEPTS FOR THE AIM OF THE TREATY

During the Cold War, preambles to arms control treaties at times incorporated far-reaching demands. "Comprehensive Disarmament" is mentioned in the LTBT, the Threshold Test Ban Treaty, and the Seabed Treaty. When these treaties were negotiated, no one expected a definite obligation for action to arise from them. This has changed, however, since the Principles and Objections for nuclear non-proliferation and disarmament were introduced at the NPT review conference. Far-reaching demands for disarmament have developed an authority that was noticeable during the test ban negotiations. Now the negotiating parties fear they could be called upon to fulfil those obligations. The preamble expresses the original intention: does the treaty cover disarmament or non-proliferation or is it just about a ban on nuclear explosions and nothing else, with the "accidental" effect of also curbing the arms race?

The differing views on the treaty's objectives become particularly transparent when comparing the text proposed by disarmament proponents and that in the current version of the treaty. In January 1996, India suggested a text that runs as follows: "Stressing the fact that the main aim of the treaty is the end of qualitative improvements in and developments of nuclear weapons systems..." This reflects the interest of all those for whom the disarmament element is important, and it was accordingly supported above all by the non-aligned states. This is the objective of a CTBT, according to the traditional view over several decades. The draft, by contrast, now talks not of an "end" to qualitative improvements but only of a "constraint." There is also no talk of an overall objective; the text now reads that a test ban and a "constraint" are "effective means towards nuclear disarmament and non-proliferation;" in other words, disarmament is a secondary effect.

This text clearly reflects the interest of the nuclear powers to de-emphasize as far as possible the disarmament element. It would have been possible without difficulty to have offered compromise language, with the result that India would not have had the argument that none of its views were considered.

> Excerpt from the preamble:
> Recognising that the cessation of all nuclear weapon test explosions and all other nuclear explosions, by constraining the development and qualitative improvement of nuclear weapons and ending the development of advanced new types of nuclear weapons, constitutes an effective measure of nuclear disarmament and non-proliferation in all its aspects, (CD/NTB/WP.Rev.1, June 28, 1996)

By contrast with the text of the preamble, India's most radical demand for a timetable for complete nuclear disarmament, which it also wished to see reflected in the preamble, found less support. This was above all because no one believed the NWSs would agree, but also because many members of the NPT feared that the significance of this treaty could be impaired by a competitive treaty.

THE SCOPE: THE CORE OF THE AGREEMENT

The preamble contains predominantly political objectives; the scope limits, on the other hand, the remaining technical possibilities. A large number of technical activities can be of importance for the development of nuclear weapons. Suggestions of what should be permitted and what disallowed therefore varied considerably.

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 United States was in favor of the narrowest limitation: nuclear explosions releasing energy of only a few kilograms of TNT, also called "hydronuclear tests,"[11] 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";[12] 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 if its initiative had not given rise to a domino-effect. Whether Chirac really meant a "zero-option" with his announcement will never be known and presumably does not have to be clarified. The United States probably took its decision in favor of a "zero-option" independently of the French, based on a study by experts.[13] 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 that would have simplified or even stimulated future modernization.

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 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, con-

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[11] For an overview on hydronuclear testing and other simulation technologies see: 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; and *Science Based Stockpile Stewardship*, JASON Report JRS-94-345, MITRE Corporation, McLean, VA, November 1994. (An overview of this report is given by R.L. Garwin in "Stockpile Stewardship and the Nuclear Weapon Complexes," Pugwash Meeting No. 206, Moscow, 19-23 February 1995.); Ray E. Kidder, "The Utility of Hydronuclear and Other Tests for Stockpile Evaluation, Maintenance, and the Development of New Weapon Prototypes," (unpublished) March 30, 1995; Thomas B. Cochran and 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.

[12] 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.

[13] *Nuclear Testing, Summary and Conclusions*, JASON Report JSR-95-320, MITRE Corporation, McLean, VA, August 3, 1995.

sultations, 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 the existing definition of a nuclear weapon, which is now internationally accepted, for example from the founding treaty of the Western European Union. 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.[14]

> Article I: Basic Obligations
> 1. Each State Party undertakes not to carry out any nuclear weapon test explosion or any other nuclear explosion, and to prohibit and prevent any such nuclear explosion at any place under its jurisdiction or control.
>
> 2. Each State Party undertakes, furthermore, to refrain from causing, encouraging, or in any way participating in the carrying out of any nuclear weapon test explosion or any other nuclear explosion. (CD/NTB/WP.330/Rev.1, June 28, 1996)

China insisted up to the end on "peaceful" nuclear explosions,[15] which were, however, unacceptable to all the other negotiating parties because "peaceful" nuclear detonations cannot be distinguished from military ones, and are also useful 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 that unless every state, without abstention, is in favor, 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 therefore the Chinese were satisfied. This is criticized 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 that did not involve explosions. In this category also belong activities necessary for the maintenance of existing arsenals—an unacceptable thought for

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[14] Schaper, "The problem of definition: Just what is a nuclear weapon test?"

[15] See Hu Side and Tian Dongfeng, "Peaceful Nuclear Explosions and the Comprehensive Test Ban," in *Arms Control Collected Works*, p. 100.

the NWSs. At one stage Indonesia wanted to prohibit a number of other experiments and activities that promote the development of nuclear weapons, including computer simulations and inertial confinement fusion (ICF). The latter is a branch of research that can be of use both in the development of advanced nuclear weapon concepts and for research on civil fusion energy production.[16] This is therefore a typical example of a civil-military ambiguity which applies also to the other activities that Indonesia wanted to have banned. But ambivalent research is taking place in many industrialized countries. Non-nuclear states who are committed to solely civil use would never permit their activities to be banned. Therefore those putting forward these very broad proposals withdrew them in order not to jeopardize 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 that are not forbidden by the treaty and that 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 United States and France, and in the United States a further development of testing sites for which a budget of $1.5 billion was appropriated in October 1995. Also so-called "subcritical tests," to be conducted in Nevada, are military experiments of limited use in the development of new nuclear weapons. These experiments have been postponed as a precautionary measure from 1996 to 1997 in order not to endanger the CTBT. Subcritical and hydronuclear tests are not the same. The latter are nuclear chain reactions produced by the use of proper warheads; in the former the experimental structure is modified so that their value for nuclear weapons is doubtful.[17] In a subcritical experiment, hardly any neutron multiplication can take place, and the amount of this nuclear energy is very marginal. They would not allow any extrapolation for research on boosting effects, so the potential for modernization is probably near to zero. Based on the definition suggested above, the hydronuclear tests would be prohibited but subcritical tests not, in line with the present intention.

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. It would, however, 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. Then Undersecretary of Defense, John Deutch said this at the press conference for the Nuclear Posture Review. Prior to that, new warheads were banned in the United States by legislation anyway. France in August 1995 announced that no future developments were underway. It would therefore be easy to confirm this at a politically more binding level.

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[16] A. Schaper, "Arms Control at the Stage of Research and Development? The Case of Inertial Confinement Fusion," *Science & Global Security* 2 (1991), p. 279.

[17] Frank von Hippel and Suzanne Jones, "Take a hard look at subcritical tests," *Bulletin of the Atomic Scientists* 52, no.6 (November/December 1996), p. 44.

It is a pity that these tests will be conducted underground for safety reasons.[18] Since the treaty does not provide for any routine transparency measures on former test sites, the world will be dependent on good faith that indeed harmless subcritical and no hydronuclear explosions are being conducted. This good faith cannot be expected from all countries. A suspicion will be left that could undermine the non-proliferation regime because it would reduce the good will of some countries. The simplest solution to the dilemma would be simply to close all former test sites (as the French are now doing) and to allow only above-ground experiments. This would make clear that no hydronuclear explosions are taking place. Unfortunately this seems unlikely to happen for the time being; on the contrary, the U.S. Department of Energy allocated $1.5 billions for maintenance of the Nevada test site in October 1995. The solution to this problem should have been for the Treaty to provide for some transparency regime on former test sites to prove that no hydronuclear test or small yield explosions were being conducted. This was unfortunately not foreseen. It is possible to imagine scenarios that 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. In photographs 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 of the CTBT negotiations, supported the prohibition of test preparations. This would have publicly exposed certain suspicious activities on test sites as potential treaty violations. But this proposal was not supported in order to speed up the negotiations and as a demonstration of a readiness to compromise, and it was abandoned last winter and in its place a high degree of transparency was demanded.[19]

THE ORGANIZATION

The Comprehensive Test Ban Treaty Organisation (CTBTO) is to be established in Vienna to give effect to the treaty. It will organize an annual conference of the treaty states and will have an executive council comprising 51 members and a technical secretariat, which will control a so-called International Data Center (IDC). The executive council, empowered to convene further conferences, has as its most important function to decide how to proceed in cases of suspected or actual treaty contravention. There will be permanent as well as rotating membership, the composition of which was of course subject to tough negotiations. As soon as a sufficient number of countries have signed the treaty, a preparatory commission will be set up to establish the CTBTO.

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[18] 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 (Chris Paine, *Carnegie Conference on Nuclear Nonproliferation*, February 12-13, Washington, DC). Yet it should be asked why this could not be conducted in a reinforced building.

[19] See reports by R. Johnson in *Acronym Reports*, *Nuclear Proliferation News*, and *Disarmament Diplomacy*.

VERIFICATION

For the last 20 years, regular conferences of experts concerned with the verification of a test ban have taken place in Geneva. This long preparation was worthwhile; voluminous and well-considered proposals were there negotiated so that it is now possible to set up a technical system quickly.[20] Earth, water, or air might be the test environment and so have to be monitored. The most important method for detecting and identifying underground tests is seismology, which registers and locates earth tremors and distinguishes them from natural earthquakes. For this purpose a world-wide network, the International Monitoring System, is to be set up.

To verify explosions in the atmosphere, infrasound stations and radionuclide measurement are used. Explosions in the oceans can be verified by hydroacoustic stations; that is, by special microphones. The plans foresee 50 primary seismic stations, which will transmit continuous data to the IDC, and 119 supplementary stations, which will register and store data so that they can be called up on demand. Eighty stations and 16 analytical laboratories are planned for radionuclide measuring; for infrasound there will be 59 stations; and for hydroacoustic ones 11 stations (this is sufficient because sound in certain layers under water carries for thousands of kilometers).

The data are to be collected in the IDC, processed, and distributed from there to the member states. In unprocessed form these data comprise hundreds of megabytes per day—an impossible volume to deal with for individual states without additional expenditure in cash, equipment and experts. Views have differed as to what extent the IDC should take on additional functions, namely to characterize, analyze and select data, allowing the member states to better evaluate them based on a condensed and prepared report. The greater the extent of such services, the easier it would be for those states not so technically experienced to form an opinion in doubtful cases and to participate in the decision-making process concerning the consequences. The United States was of the view, however, that each state should prepare its own analysis, with the justification that otherwise the IDC would take responsibility away from the member states and make verification decisions for them. Germany, on the other hand, was a proponent on behalf of the less-developed countries and supported the opposite regime: it was absurd to duplicate the effort for which the IDC was best suited. The result was a compromise: in case of need the member states can obtain all services required, although in part they will have to pay for them.

The International Monitoring System is sufficient to verify a threshold test ban treaty with a low threshold of approximately 1 kiloton. For a comprehensive test ban one would need further measures, such as mechanisms to clarify cases of doubt, on-site inspections, requirements for openness, and so-called national technical means (NTM), which can range from satellite monitoring to spying. Spying is an unpronounceable word at international negotiations, and satellite images are also an unsolved problem. The best spy satellites are owned by the United States and reach a resolution of 10 cm. In addition to optical imagery, satellite technologies capable of detecting nuclear explosions include X-ray, gamma-ray, neutron and electromagnetic pulse detectors, and thermal and radar imagery. The Chinese tests were always forecast by the United States. China, which does not possess satellite technology at this level, had argued in vain for satellites as

[20] H.-P. Harjes, "Global Seismic Network Assessment for Teleseismic Detection of Underground Nuclear Explosions," *Journal of Geophysics* [*Zeitschrift für Geophysik*] 57 (1985), pp.1-13; Congress of the United States, Office of Technology Assessment, "Seismic Verification of Nuclear Testing Treaties," Washington, DC, May, 1988.

a further element of the International Monitoring System. A Chinese proposal suggested three ways to establish this system. Firstly, to make an agreement with the appropriate States Parties to utilize their current NTM capabilities; secondly to mount CTBT monitoring equipments on States Parties' future launches; and lastly to procure a network of satellites dedicated to CTBT monitoring. China was not willing to accept NTM as the reason for on-site inspections. The United States holds a monopoly with this technology and is suspected by some states to misuse it, e.g., in the case of the non-verifiable claim in spring 1996 that India was preparing a nuclear test.

The use of NTM is a principle of arms control contained in other treaties and which should not be given up. For someone potentially violating the treaty, NTM represent the greatest uncertainty and are therefore the best deterrent. China was finally persuaded to accept the draft with provisions on use of NTM.

In the case of on-site inspections there were also conflicting interests. On the one hand, they should act as a deterrent, but on the other hand, many countries objected to opening up their affairs; above all China, Israel, India and Pakistan. A number of complicated details were negotiated, such as the height and execution of flights over a suspicious area, permitting and forbidding on-site measurements, or the length of the inspection report. But the most important questions were: what, when and how fast are on-site inspections triggered? Some states initially wanted laborious consultations and clarifying discussions. This would have complicated or impeded proof because some effects only last a few days, especially local aftershocks and the local venting of rapidly-decaying radioactive noble gases. There were also arguments about many complicated variations of the decision-making process: should the inspection take place automatically unless the executive council explicitly forbade it (red light), could it only take place after it had been explicitly permitted (green light), or should one accept a mixture, and all of this requiring what majorities and under what conditions? Agreement was reached after much effort on three pages of treaty text solely on the decision-making process. Agreement of the voting majority about on-site inspections was reached only in August 1996: 30 out of the 51 executive council members must vote in favor in order to let an inspection go forward.

ENTRY INTO FORCE

Efforts to reach agreement on the proposed treaty text within the planned time frame failed above all because of a conflict about entry into force (EIF), an issue that escalated towards the end of the negotiations. This conflict was about the goal of the treaty as well. The many different suggestions about when the treaty should enter into force, e.g., when all states with nuclear capability have ratified it, or all CD members, or a list of states plus a certain number of further countries—these initially concealed the aim of most NWSs, which then became very clear in the final stages of negotiation: the treaty should enter into force only when the three threshold countries, India, Pakistan and Israel, have ratified it. The underlying argument in favor of this clause was that it would put India especially under such pressure that it would be forced to adopt the treaty. The opposing position feared that just one of these countries, especially India, could prevent the treaty from entering into force. As a solution it was suggested that a conference of the treaty members could take place at a later date to validate the treaty without India or other states. This was categorically rejected by Great Britain, Russia, and China. It appears that the United States did not forcefully help Britain and the other two to back away from this rigid position. Such a position is logical if the main interest in a test ban treaty concerns only non-proliferation: better to have no treaty than one in which the non-proliferation component, namely membership of the states outside the NPT, is too weak. States, however, whose interest relates to nuclear disarmament negotiated in vain for a way out of the EIF impasse.

India has announced that it is not able to sign the treaty as it now stands on paper: none of its demands had been taken into account and not one concession had been made. So the prospects that the treaty will ever enter into force are worse than dim. India has successfully refused to become a member of the NPT for more than 25 years in spite of massive international pressure. An overwhelming majority at home supports the refusal to sign the CTBT. The treaty cannot therefore enter into force, if Indian ratification is a precondition.

Instead of a conference with the authority to allow the treaty to enter into force at a later point in time, a conference is now proposed to "examine" how "the ratification process can be accelerated in compliance with international law." It has already received the nickname "hand-wringing conference," as it has no other authority.

Excerpt from Article XIV: Entry into force
1. This Treaty shall enter into force 180 days after the date of deposit of the instruments of ratification by all States listed in Annex 2 to this Treaty, but in no case earlier than two years after its opening for signature.

2. If this Treaty has not entered into force three years after the date of the anniversary of its opening for signature, the Depository shall convene a Conference of the States that have already deposited their instruments of ratification on the request of a majority of those States. That Conference shall examine the extent to which the requirement set out in paragraph 1 has been met and shall consider and decide by consensus what measures consistent with international law may be undertaken to accelerate the ratification process in order to facilitate the early entry into force of this Treaty....

List of states pursuant to Article XIV

Algeria,* Argentina,* Australia,* Austria,* Bangladesh,* Belgium,* Brazil,* Bulgaria,* Canada,* Chile,* China,* Colombia,* Democratic People's Republic of Korea, Egypt,* Finland,* France,* Germany,* Hungary,* India, Indonesia,* Iran* (Islamic Republic of), Israel,* Italy,* Japan,* Mexico,* Netherlands,* Norway,* Pakistan, Peru,* Poland,* Romania,* Republic of Korea,* Russian Federation,* Slovakia,* South Africa,* Spain,* Sweden,* Switzerland,* Turkey,* Ukraine,* United Kingdom of Great Britain and Northern Ireland,* United States of America,* Vietnam,* Zaire.*
(*have signed as of February 1997)

The NWSs made the mistake of granting no single concession to India, not even, for example, in suggestions on the wording of the preamble, which would have been welcomed by all other parties to the negotiations. India's declaration that it was not in a position to sign or even ratify a treaty that had been entirely dictated to it and reflected none of its demands was easy to understand. This mistake is the more difficult to comprehend because a concession would have robbed India of an important argument. Its adopted role of disarmer would have appeared less credible, and the hypocritical nature of its position would have become more clear. If one takes the view that concessions would have had no purpose because India would not have signed the CTBT anyway, it is illogical on the other hand to believe that India could have been forced to sign by international pressure.

FUTURE PROSPECTS

The overwhelming support for the CTBT is evident, and its substance, especially the scope, is more profound than many observers dared to hope for only a year ago. It can be expected that over time the number of signatures will increase. Even if India and Pakistan abstain, thereby blocking entry into force, the treaty has already achieved a practical effect. Testing is now politically impossible; verification will be implemented, although the instrument of on-site inspections will not be used. The treaty will also have an effect on India: in case India does test it would isolate itself in an extreme manner, and thus it is most unlikely that it dares to risk such political damage to itself.

The non-proliferation regime is also strengthened because the Principles and Objectives of the NPT reviews have been confirmed and thereby stabilized. Both the goals of non-proliferation and nuclear disarmament have been symbolically reconfirmed by the international community.

The next task on the non-proliferation agenda is the Fissile Material Cut-Off Convention. Similar to the CTBT, the Cut-Off is prescribed in the Principles and Objectives, and a failure would be damaging to the non-proliferation regime. As the spirit of the CTBT is the end of the qualitative arms race, so the Cut-Off should be meant as an important symbol of the end of the quantitative arms race. It also will have both elements: a non-proliferation and a disarmament component. Inevitably, the experiences from the CTBT negotiations will influence the Cut-Off. The difficulties with the CTBT resulted from the different weight attributed to the two aspects by the different parties: India made disarmament claims, which are currently exaggerated and is not prepared to accept the aim of non-proliferation. The NWSs, on the other hand, gave too little support to the aim of disarmament and attempted frequently to retain as many options as possible and to impose their interests. Many states gained the impression that their influence was minimal. India suffered the experience that its demands were not taken up at all, even those that were not hypocritical but sensible and constructive. On the other hand, it is placed under pressure to accept a treaty that it has not been able to influence. A lesson that India will draw from the test ban is in future to hold back right from the start from participation and thereby from the pressure of the negotiating parties. A lesson the NWSs will draw is that serious commitments will be necessary in order to gain the support of the states outside the NPT.

CHAPTER 3

THE COMPREHENSIVE NUCLEAR TEST-BAN TREATY
THE UNITED STATES PERSPECTIVE

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This paper seeks to provide an overview of the negotiating objectives of the United States in the three years of effort in the Conference on Disarmament that produced the text of the Comprehensive Nuclear Test-Ban Treaty (the CTBT), opened for signature in New York on September 24, 1996. Further, the paper seeks to show how those objectives were achieved by the outcome of the negotiation: what the Treaty specifies in its text including the annexes, its Protocol and the annexes to the Protocol (all of which are integral parts of the Treaty), and in what it does not specify.

UNITED STATES OBJECTIVES

In making the decision during the middle of 1993 to pursue a comprehensive test ban, the United States began from a benefit-risk analysis that weighed the advantages and disadvantages of further nuclear testing against the advantages and disadvantages of a binding, multilateral and verifiable commitment to stop all further nuclear explosions. This decision was made in the context of a rather different international environment from that which existed when the United States had last engaged in CTBT negotiations from 1977 to 1980.

First, in 1992 the Congress had directed the United States, by the Hatfield-Exon-Mitchell legislation, to stop all testing by September 30, 1996, provided no other state tested after that date, and to engage in negotiations in order to achieve a CTBT by then. The legislation allowed that the United States could conduct up to 15 nuclear tests (of which three would be for the United Kingdom) prior to September 30, 1996, pursuant to an executive branch determination that such tests were required solely for the purpose of establishing enduring arrangements to maintain the existing weapons stockpile safely and reliably.

Second, the demise of the USSR and the emergence of a greater focus on security threats arising from the further proliferation of nuclear explosive capabilities helped recast the previously governing East-West competition into a more global and general context. The impact that a CTBT could have in constraining the emergence of such threats was thus an important consideration.

Third, the successes achieved by the Treaty on Conventional Armed Forces in Europe (CFE) in greatly reducing the levels of conventional weapons in Europe—tanks, armored combat vehicles, artillery, attack aircraft and helicopters—and by the first Strategic Arms Reduction Treaty (START I) in providing the framework for deep reductions in strategic nuclear forces con-

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*The views expressed herein are those of the author, and do not necessarily represent those of the United States Government.

tributed to reducing the military requirements for technical improvements to the existing types of U.S. nuclear weapons.

Fourth, the forthcoming Review and Extension Conference of the nuclear Non-Proliferation Treaty (NPT), scheduled for 1995, had engendered careful analyses of the potential positive contribution a CTB Treaty could make to securing agreement by the parties to the NPT to its permanent extension. This contribution is twofold—both the CTBT's direct constraint on the acquisition of nuclear weapon capabilities, and its concrete fulfillment of the implicit long-standing "bargain" in the NPT in which especially the nuclear weapon states take meaningful steps toward the objective of nuclear disarmament in return for the renunciation of nuclear weapons by non-nuclear weapon states.

Thus the decision to propose that a CTBT be negotiated was based on a "yes" to the benefit side of the benefit-risk assessment for supporting the following U.S. arms control and non-proliferation security objectives:

(a) to constrain the spread of nuclear weapon capabilities.

By removing the possibility of carrying out test explosions of nuclear devices, the CTBT should strengthen the international regime of legally binding treaty constraints on nuclear weapons. The CTBT will affect both so-called "horizontal" proliferation, i.e., the spread of nuclear weapon capabilities to states that have not acquired them, and so-called "vertical" proliferation, i.e., the further development of those capabilities by states already possessing them. Both objectives were foreseen early on in the U.S. assessment. The dividing line between "horizontal" and "vertical" tends to be blurry, in a technical sense, because of the existence of untested nuclear weapon capabilities on the part of so-called threshold states (in the case of India, a once-tested capability). Nevertheless, these two poles of proliferation capture the envelope of constraints that a CTBT establishes. In the U.S. view the CTBT will make the further spread of weapon capabilities at the lower end of the spectrum ("horizontal" proliferation) much more difficult, while it will rule out the confident development of advanced new types of nuclear weapons ("vertical" proliferation).

(b) not to prevent the maintenance of safety and reliability in the deterrent capabilities of existing U.S. weapons.

Although there have been times over the past five decades when testing ceased or proceeded at a very low rate—immediately after World War II and at the end of the 1950s during the Eisenhower test moratorium—the actual test explosions of nuclear devices were considered by many experts not only to be an integral part of the overall technical base for maintaining U.S. nuclear weapon capabilities, but an indispensable part. Thus the benefit-risk assessments, and the decision to forego this component of its capability, were for the United States understandably difficult, and contributed, as will be discussed below, to the U.S. approach to the scope and duration of the Treaty.

(c) to provide for effective verification, especially in areas where attempts to evade the CTBT could contribute to the emergence of threats to the United States.

Meeting this objective takes into account the disparities in risk presented by the potential parties to the CTBT: the 185 or so states of the international community. Some clearly pose no risk at all, by virtue of their size or location, their basic military capabilities, their lack of access to nuclear weapons materials, or their firm policy against acquiring nuclear weapons. Others can pose a serious challenge, either—in the event the present relatively benign international environment were to take a turn for the worse—by virtue of their latent capabilities, or because of their current, problematic stance in the global community. Also taken into account are the developments in remote sensing science and technology, the ability to establish international monitoring capabilities and to obtain on-site access, and the capabilities that the United States can draw on unilaterally—its national technical means of verification.

ACHIEVING THE U.S. OBJECTIVES FOR THE CTBT

The following discussion develops how the Treaty regime meets the three objectives outlined above.

(a) to constrain the spread of nuclear weapon capabilities.

The CTBT that emerged from the Geneva negotiations in the Conference on Disarmament is some ninety pages of text. Essentially all of it consists of provisions that support and implement Article I on "Basic Obligations." In two brief sentences, Article I prohibits, anywhere, "any nuclear weapon test explosion, or any other nuclear explosion," and binds parties "to refrain from causing, encouraging or in any way participating in the carrying out of any nuclear weapon test explosion or any other nuclear explosion."

Of first importance, the CTBT will bind the five established nuclear weapon states (frequently termed the P-5 because the United States, UK, France, Russia and China are also the permanent members of the United Nations (UN) Security Council. Setting aside the 1974 nuclear explosion by India, these five states carried out over the last half-century some two thousand nuclear tests among them, whether described as for weapons purposes or as for peaceful purposes. Although China sought through most of the negotiation to restrict the scope in such a way that nuclear explosions for peaceful purposes ("PNEs") would not be banned, in the end it settled for a recognition, in the article providing for review of the Treaty, that in the future the parties could if they so desired amend the Treaty to make provision to carry out "PNEs." (Of course, the parties in any case are free to amend the Treaty.) Active pursuit of this possibility is generally believed to be unlikely, and it would in any case require a consensus of parties in attendance at the review, thus guaranteeing that such an amendment could be prevented by any one state. The United States, as well as Japan and Canada, among others, could be expected to take a negative view of such an amendment.

Thus the Treaty recognizes that exploding any nuclear device, however its purpose is advertised, conveys military benefits to the testing state because nuclear explosive technology is inherently, in current jargon, "dual-purpose." In this way, the CTBT preserves and extends the U.S. position on what must be recognized as technical reality for a meaningful limitation on testing. This position is embodied in the identical 150 kiloton yield limitations on underground explosions in the 1974 Threshold Test Ban Treaty and the 1976 Peaceful Nuclear Explosions Treaty. In turn, these treaties were already based on the prohibition of any nuclear explosion, regardless of its stated purpose, in the named environments contained in the 1963 Limited Test Ban Treaty (LTBT): the atmosphere, outer space and under water.

The scope of the CTBT, which is otherwise identical with the LTBT in the physical activities it prohibits, completes the LTBT by extending its coverage from the three named environments to the only remaining environment—underground. Article I makes no mention of environments, and thus there is no possibility of even a theoretical loophole arising from a claim that some other environment existed. Nuclear explosions are prohibited anywhere and everywhere. The only mention of location occurs in the additional obligation placed on a party "to prohibit and prevent" nuclear explosions "at any place under its jurisdiction or control." Here the obligation is dependent on a legal consideration: states can only "prohibit and prevent" where they have jurisdiction or control. But parties may not test anywhere, whether or not they have jurisdiction or control.

The impact on the established nuclear weapons states is significant. Because these states are at more advanced stages of technical development, further modifications to their existing weapons designs would be critically dependent on the ability to confirm them through nuclear tests. Thus so-called "third generation" developments in technologies such as x-ray lasers or the production of high-power microwaves will essentially be frozen, as would be further yield-to-weight, configuration, or miniaturizing improvements. The willingness of two of the five nuclear weapon states to proceed with programs of tests in an international climate of strong criticism, even after the adoption of the program of action in the decision document on principles and objectives for nuclear non-proliferation and disarmament of the May 1995 NPT Review and Extension Conference, which called for completion of the CTBT no later than 1996, is perhaps further evidence of the fact that the CTBT has significant value for nuclear arms control and disarmament.

The decision by all five nuclear weapon states to sign the CTBT represents the judgment that global security, and their own national interests, are better served by foregoing any further options to develop and field new types of nuclear weapons. As discussed above, the post-Cold War situation in international relations has contributed significantly to making this judgment the governing one. Moreover, as President Clinton pointed out in his September 24 address to the United Nations General Assembly, signing the CTBT and stopping all nuclear explosions establishes a strong international norm against further testing by any state, even before the Treaty formally enters into force. As states refrain from testing, it may be expected that this norm will be self-reinforcing, and that any state going against it will risk considerable international criticism and condemnation.

Because all nuclear explosions are prohibited, from zero to infinity in terms of yield (practically, for the United States, the United Kingdom, and the Russian Federation, from zero to 150 kilotons; and for France and China, who are not parties to the LTBT, for all environments and attainable yields), the impact spans the spectrum of capabilities, from tactical (concepts of "mini-nukes" and "micro-nukes" involving very low yield weapons are explored from time to time; applications include artillery, land-mines, and naval engagements) through theater to strategic (bombs, missile and anti-missile warheads). It is difficult to assess the value of the CTBT in terms of specific, quantitative balances, as can be applied in the case of agreements such as the INF (Intermediate-Range Nuclear Forces) Treaty and START. However, the CTBT is clearly a strong "plus" for U.S. security. Potentially threatening new developments, across the range of applications but especially in the strategic area, are blocked to other states, the nuclear weapon and "threshold" states in particular.

In considering the impact of the CTBT on the "horizontal" dimension, it is important to note the very positive decision of Israel to sign the Treaty, and the more problematic announcements of India that it will not sign, and of Pakistan that it will not sign until India does. To make its full contribution to constraining the "horizontal" spread of nuclear weapon capabilities, and indeed to make formal entry into force a reality, the CTBT will need both India and Pakistan as Treaty parties. The controversial entry-into-force provision, sought so adamantly by China and

Russia and requiring 44 states with nuclear capabilities (including nuclear reactors) as original parties, and notably including the three "threshold" states, is a testament to the importance states place on the potential value of nuclear tests to those threshold states. (North Korea is another state required as an original party, as is Iran, which signed the Treaty on September 24.) The Indian reaction to this provision, couched primarily in terms of a complaint that the provision constitutes an imposition on its sovereignty, is perhaps another testament to the potential value of tests to threshold states.

But even now, well before entry into force can take place (a minimum of two years after opening for signature is specified, which should ensure appropriate preparations for verification and implementation), the overwhelming vote in the United Nations General Assembly on September 10, 1996 of 158 for adoption of the Treaty, with only three "no's" (India, Bhutan and Libya) and five abstentions, shows that the norm against further testing is already well established. The impressive list of signatories includes the P-5, Iran, Israel, Egypt, Morocco, Indonesia, and Brazil, with a steadily increasing total of 140 as of February 1, 1997. This overwhelming support should serve as a moderating influence on the potential threat from countries in South Asia to engage in nuclear testing, as the international community continues to seek a resolution of the underlying conflicts there that contributed to India's refusal to accept the Treaty.

In support of U.S. non-proliferation objectives, the CTBT should yield significant benefits. It is useful to consider the relative benefits that a test can confer on a state having a less-advanced nuclear capability. If our experience with China is any indicator, a single test can confirm rather impressive gains in capability. China has conducted fewer than 50 tests, yet it is credited with thermonuclear weapon capabilities, as well as the possession of very high yield missile warheads. An examination of some of the arguments made by India, in particular the allusion to the need to preserve "options" with the implicit corollary that a single test is an insufficient guarantor of an open option, also points to the conclusion that even a few tests would have considerable value in advancing the capabilities of threshold states.

Thus simple comparisons between the effect of a CTBT on the United States, with over 1000 completed tests in its program, and its effect on a threshold state may be misleading—in particular in dealing with the arguments that "the U.S. can continue developments using simulation" and that "threshold states don't need to test because they can rely on untested weapons." It may be that the CTBT will prove more beneficial to the United States through a disproportionately large impact in threshold contexts, as against its impact on the established nuclear weapon states. Moreover, the context may be more a matter of politics and psychology than one resulting from an assessment of technical factors. Although the bomb detonated over Hiroshima in 1945 had not been subjected to a nuclear explosive test (much other experimental work on materials and components had certainly taken place), the decision to employ it was taken under the pressures of a global conflict and of the presumed need for a large-scale invasion of Japan, and with the advice of a wartime gathering of Nobel-laureate physicists with essentially unlimited resources at their disposition. Today states may be hesitant, and military leaders even more so, to put their faith in all but the most rudimentary untested weapons.

At a more general level of global politics and international relations, the willingness of the P-5—including the United States—to stop their testing should have a powerful impact: the CTBT constitutes a positive response to those for whom nuclear weapons represent both a symbolic and a real division of states into camps of the haves and the have-nots. This response has figured in debate and diplomacy at least since the LTBT was signed (its Article I notes the pledge of the parties to seek to achieve a permanent ban on all nuclear test explosions). It is incorporated into the dynamics of implementing the NPT (by its preambular recollection of the LTBT pledge, and of course its Article VI, and by the fortunes and misfortunes of the various NPT review conferences). For such reasons the CTBT emerged as the first item in the NPT Review and Extension Conference's program of action for nuclear non-proliferation and disarmament cited above. The opening for signature of the CTBT is a very substantial fulfillment of that objective.

Failure to conclude the CTBT could have disrupted the smooth implementation of the NPT, despite the decision to extend it indefinitely. The Extension Conference established an expanded process for further substantive review, including a series of preparatory meetings beginning in 1997. The absence of a CTBT would not have helped that review process. It is even conceivable that failure to achieve the CTBT could have led non-nuclear weapon states to reconsider their adherence to the NPT, with adverse consequences for the NPT regime.

As noted above, the CTBT will require India and Pakistan to deposit their instruments of ratification before it can enter into force. Thus the United States and the international community more generally will need to do some creative thinking, in the first instance to address India's difficulties with the Treaty. India's anxieties about discrimination are not well founded. The ban on explosions applies equally to any party, although the relative impact of the CTBT depends on where a state is on the evolutionary ladder of technical capabilities. But this impact is difficult to quantify. While it is true that the Treaty does not spell out a detailed plan or provide a road map for future steps to achieve complete nuclear disarmament within a time-bound framework, at the same time the history of the CTBT makes it very clear that the international community rightly values it as a necessary step in the nuclear disarmament process. It is a step that should create its own dynamic for further steps in that process. Finally, it is simply not the case that India's sovereignty is damaged by the entry into force provision, although India will need to face the expectation of many states that it give appropriate consideration to engaging in a positive exercise of its sovereignty by signing the Treaty.

(b) not to prevent the maintenance of safety and reliability in the deterrent capabilities of existing U.S. nuclear weapons.

Specific aspects of the U.S. program of activities designed to ensure the safety and reliability of the deterrent capabilities of the U.S. nuclear weapons stockpile are addressed in more detail in other chapters of this publication. What needs to be pointed out here is that this program, referred to as the Stockpile Stewardship and Management Program, was envisaged from the outset as a domestic effort in parallel with but essentially distinct from the CTBT and its negotiation. In other words, once a decision was made that the United States would forego the possibility of further testing for any purpose, including purposes related to stockpile maintenance, then it became a matter of ensuring that the terms of the treaty *not* prevent the stewardship program from proceeding.

As the negotiation of the CTBT proceeded in the Conference on Disarmament, two aspects of the original approach envisaged by the United States as it related to stockpile maintenance required further consideration. The first was a specific provision for withdrawal at the ten-year mark after the Treaty's entry into force, and the second was a proposal that very low-yield nuclear tests, termed "hydronuclear experiments," not be covered by the scope of the prohibition on nuclear explosions.

Moreover, other negotiating partners introduced proposals for additional constraints, going beyond the ban on nuclear explosions, that were subject to the negotiating process but, ultimately, not incorporated in the final text. These included broadening the scope to include a ban on non-nuclear-explosive activities, and mothballing or shutting down existing nuclear testing sites.

The United States had always proposed that the duration of the CTBT be unlimited, i.e., that the Treaty should be permanent and enduring. However, the United States initially sought the right to a single opportunity to withdraw from the Treaty, ten years after its entry into force, without the necessity of citing reasons of supreme national interest. Withdrawal for other reasons would have provided a way to address possible problems in maintenance of the existing stockpile without citing reasons of supreme national interest. The United States found no support for this provision from our negotiating partners, and in January 1995 the United States decided that it could drop it and accept simply the usual withdrawal provision in an arms control agreement—one that specifies that states may withdraw for reasons of supreme national interest. In taking this step, the United States made clear that maintenance of the existing nuclear weapon stockpile would be considered a supreme national interest. Thus serious difficulties in ensuring maintenance of existing nuclear weapons deemed essential to U.S. security, difficulties that were judged to require further testing to resolve, would be grounds for withdrawal to enable such testing.

On the question of hydronuclear experiments, the initial U.S. approach was also reassessed as the negotiations proceeded. On the one hand, it was clear that many states were not prepared to support such an exception, for activities close to zero yield, from an otherwise comprehensive test ban. On the other hand some, including Indonesia and India, sought to broaden the scope of the prohibition beyond nuclear explosions to include non-nuclear experimental activities, such as hydrodynamic experiments (of which sub-critical experiments may be considered a subset), or even mathematical simulations of nuclear tests. After intensive reassessment in the summer of 1995, it became clear that the United States could, with diligence in pursuing the stockpile stewardship program, dispense with the option of hydronuclear experiments, however one might understand them in terms of an upper bound on their yield, and pursue a true zero-yield ban on all nuclear explosions. The work of the JASON group of scientific advisers to the Departments of Energy and Defense was critical in pointing the way to this outcome of the reassessment of hydronuclear experiments.

With regard to the proposals to broaden the scope of the CTBT to include non-nuclear-explosive activities, including even mathematical analyses, the key to understanding why various such prohibitions were not considered wise lies in the relative role of such activities in maintenance and in new weapon development. Despite the claims of India and others that simulation techniques have advanced to the point where new weapons can reliably be developed and deployed, the United States views the ban on nuclear explosions as putting a halt to the reliable development of advanced new nuclear weapons, i.e., that it halts "vertical" proliferation. Put another way, the United States would not wish to consider any ideas not actually put to the test by a nuclear explosion for stockpiling in new weapons. (Paradoxically, in the case of less advanced states, simulation capabilities might more easily be applied to less sophisticated designs in an attempt to assess correctly their performance.) Moreover, it was recognized that prohibitions on simulations were unverifiable without a degree of intrusive inspections that no one would accept.

It became clear that the only realistic dividing line between activities prohibited by the CTBT and activities not so prohibited was that between nuclear explosions—of any yield down to zero—and other activities of a non-nuclear-explosive nature. And it should be evident that for the established nuclear weapon states these activities are mainly useful for maintenance and for preserving the capability to resume testing should this become necessary, not for the fielding of new weapons.

(c) to provide for effective verification, especially in areas where attempts to evade the CTBT could contribute to the emergence of threats to the United States.

As with the issue of non-interference with maintenance of the U.S. stockpile, other chapters in this publication address verification in more depth. For the CTBT, the task of verification will mean, hopefully, ensuring the absence of nuclear explosions, or, if necessary, the discovery of Treaty parties attempting to evade the prohibition of nuclear explosions.

There are a number of technologies that can monitor for the absence or occurrence of a nuclear explosion. Some are direct and instantaneous, such as the remote observation of the light flash from an explosion in the atmosphere. Others are somewhat less direct but still relatively prompt, such as the detection of seismic waves from an underground explosion. Others provide information, such as the detection of radioactive byproducts of the explosion, that has an unmistakable association with a nuclear explosion. These techniques take more time to work; other verification means, such as on-site inspections, are typically even more delayed in when they produce useful results.

Many monitoring techniques are encumbered by the possibility of interference from other sources—both natural sources, such as earthquakes, and man-made sources, such as the seismic signals resulting from the detonation of large quantities of conventional explosives in mining operations. Thus the verification system has the added task of separating out these potentially interfering sources and avoiding false alarms. Ideally, the system should detect, identify, and attribute the source of a nuclear explosion.

It should be recalled that for over thirty years the United States has used its own assets to verify the Limited Test Ban Treaty. Its use of national technical means and other resources has been sufficient to provide effective verification of that Treaty in the three environments that it governs. To support their effective verification, the bilateral 1974 Threshold Test Ban Treaty and 1976 Peaceful Nuclear Explosions Treaty can utilize the additional components of information exchange, the possibility of close-in seismic measurements, and the possibility of the measurement of yields of explosions by personnel of the other Party at the site of the explosion.

The verification regime for the CTBT was developed with a recognition of both the actual and potential capabilities of remote sensing technologies—the Treaty provides explicitly for four: seismic, hydroacoustic, low-frequency sound detection (infrasound), and radionuclide—to monitor for explosions, and of the potential capabilities of on-site inspections. However, there is a need to balance the reach of any real-world verification regime against the acceptability of intrusion into facilities that might be sensitive for reasons unconnected with CTBT verification. Other obvious factors are cost and negotiability. The benefit-risk assessments for the United States, taking such factors into account, as well as the potential for evasion and the consequences for U.S. security of a successful program of clandestine testing, were made throughout the three years of the negotiation. The regime that emerged from the negotiation should provide a considerable capability for ensuring that parties are in compliance with the Treaty.

It is important to note that for the first time in a global treaty there is an explicit recognition of the role that national technical means (NTM) can play in the Treaty's verification. Paragraph 5 of Article IV of the Treaty states: "For the purposes of this Treaty, no State Party shall be precluded from using information obtained by national technical means of verification in a manner consistent with generally recognized principles of international law, including that of respect for the sovereignty of States." This recognition was sought by the United States to help ensure that it would not encounter difficulties if it sought to pursue a compliance concern engendered by NTM-based information.

Within the Treaty itself, its two longest articles (Article II on the organization, and Article IV on verification), together with the entire protocol specifying the International Monitoring System with its International Data Center, procedures for carrying out an on-site inspection, and confidence-building measures, are devoted to ensuring that parties are in compliance with the Treaty.

The Treaty provides a basis for global verification, including in areas not subject to national jurisdiction or control. Because the United States has a greater degree of interest in verification in specific parts of the world, it can add to this global capability by directing its national assets to optimize its overall monitoring capabilities, pursuant to its own decisions on more and less important verification requirements.

The combination of (a) U.S. national capabilities; (b) the Treaty's provisions for generating information from the four systems of remote sensors of the International Monitoring System, and from the confidence-building measures concerning conventional explosions; (c) the provisions for consultation and clarification both bilaterally and multilaterally, if an ambiguous event requires resolution; and (d) the provisions for carrying out on-site inspections, also to resolve cases of ambiguity, in aggregate represent a rather robust verification capability. In general terms, the combined capabilities should give a very high probability of confirming that a nuclear explosion has taken place in the tens-of-kilotons range, with a high probability at yields somewhat less, in some areas to below the kiloton level. At the lower yield levels, evidence of a suspicious event from remote sensing and national capabilities that was not persuasive in resolving an ambiguity as to whether or not the event was a nuclear explosion would likely lead to a request for an on-site inspection.

The aggregate U.S. capabilities, as well as the aggregate capabilities of other states, should also provide a strong deterrent against attempts to evade the ban on nuclear explosions. The capabilities of sensing systems taper off gradually, in terms of yield level detected, rather than coming to a sharp demarcation point. At lower yield levels, therefore, a potential evader will have some uncertainty as to the capabilities that can be brought to bear against an attempt to cheat at a given yield level, both those of the Treaty organization, and national technical means of verification. At the same time a potential evader will have to estimate how much it would gain from very low-yield test attempts.

Moreover, any potential evader will subject itself to the risk of exposure from non-quantifiable elements of national technical means, as well as information that can be brought to bear in pursuing the processes of consultation and clarification provided for by the Treaty. The potential evader, if discovered, cannot calculate the range of consequences to itself, for example of sanctions imposed by the United Nations Security Council, for a violation of its solemn obligation not to conduct a nuclear explosion. The experience of Iraq after the Gulf War, at least in part as a result of its violation of its NPT obligations, should be salutary in this regard.

CONCLUSION

This paper has sought to provide a brief overview of how the principal U.S. objectives for the CTBT are satisfied by the document that President Clinton signed on September 24, 1996, as the first leader to do so after the Treaty was opened for signature. Over 80 other states also signed the Treaty during the first week after it was opened for signature. Prospects are good that over the next two years ways will be discovered to bring the Treaty into force by September 24, 1998, thus fully implementing these objectives as a permanent contribution to a more secure and stable world.

CHAPTER 4

IMPLICATIONS OF THE COMPREHENSIVE TEST BAN TREATY FOR THE UNITED STATES STOCKPILE STEWARDSHIP AND MANAGEMENT PROGRAM

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The Comprehensive Test Ban Treaty (CTBT) and the Stockpile Stewardship and Management Program (SSMP) are part of a national strategy to address and reduce the nuclear dangers in the world. They are but two components of an overall U.S. strategy that seeks to reduce the spread of nuclear weapons, reduce the number of nuclear weapons worldwide, inhibit the development of new nuclear weapons, and maintain the U.S. deterrent. Although many of the components of this strategy are related to each other—like the Nuclear Non-Proliferation Treaty extension calling for a CTBT by 1996, or the Senate's advice and consent to ratify the second Strategic Arms Reduction Treaty (START II) calling for the maintenance of the nuclear deterrent and the ability to resume nuclear testing—each is also a stand-alone initiative with its own focus and key objectives.

The CTBT has a 40-year history, and the development of a program to maintain the U.S. deterrent without nuclear testing (or at very low yields) can be traced back over a decade. However, for the purpose of this paper, the focus is on the "zero-"yield CTBT, as articulated by President Clinton and recently opened for signature in Geneva, and on the current version of stockpile stewardship, the DOE Stockpile Stewardship and Management Program, which had its genesis some three years ago. It is important to understand that these specific initiatives were developed hand-in-hand, with neither one being a simple cause or effect of the other. Both initiatives required an assessment of U.S. post-Cold War nuclear posture requirements and an evaluation of U.S. nuclear safety and reliability requirements in the new security environment. Both also had to be consistent with the requirement for the smaller, safer, cheaper nuclear enterprise needed to support a smaller post-Cold War stockpile within an environment of budget constraints. Also key to both the CTBT and the SSMP was the question of whether or not a technical program could be developed that would give reasonable promise of being able to maintain the U.S. nuclear deterrent without the benefit of nuclear testing.

The Hatfield-Exon-Mitchell Amendment to the Energy and Water Development Appropriation Act for Fiscal Year 1993 (which was enacted into law as P.L. 102-377 on October 2, 1992) was the key milestone in setting the United States firmly on the path of maintaining its nuclear deterrent without nuclear testing. Prior to this law, studies and reports on maintaining the deterrent without testing had been called for, but this act established an actual moratorium on nuclear testing, during which a plan to upgrade the safety and reliability of the stockpile was to be developed. The law then authorized limited nuclear testing for the purpose of upgrading the stockpile

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* This paper presents the personal views of the author and does not necessarily reflect the views of the United States Government, the University of California or the Lawrence Livermore National Laboratory.

according to the plan that was submitted to Congress. The law allowed up to fifteen tests over three and one-half years, with twelve tests allowed for safety improvements and three for reliability testing. Finally, the law specified that the United States would conduct no nuclear testing after September 30, 1996, unless another nation tested after that date. This legislative action focused the U.S. nuclear enterprise—the Department of Energy (DOE), the Department of Defense (DOD), and the nuclear weapons laboratories—on the concrete steps that had to be taken to prepare the nuclear stockpile for a potential CTBT.

After an extensive review of the safety and reliability of the U.S. nuclear stockpile, as called for under Hatfield-Exon-Mitchell, the President decided to forego testing for safety improvements or reliability and to continue the U.S. moratorium so long as no other nation tested. In his radio address of July 3, 1993, the President stated: "After a thorough review, we have determined that the nuclear weapons in the United States arsenal are safe and reliable. Additional nuclear tests could help us prepare for a CTBT and provide some additional improvements in safety and reliability. However, these benefits would be outweighed by the price we would pay in conducting those tests now through undercutting our nonproliferation goals." Furthermore, the President established the mandate for what was to become the stockpile stewardship program: "To assure that our nuclear deterrent remains unquestionable under a test ban, we will explore other means of maintaining our confidence in the safety and reliability and performance of our weapons." The "other means" is today the Stockpile Stewardship and Management Program.

Concurrent with the President's public announcement of his intent to continue the testing moratorium and to seek other means of maintaining the U.S. stockpile, the President issued a Presidential Decision Directive that directed the DOE and the nuclear weapons laboratories to establish a science-based stockpile stewardship program.

The Congress followed the President's lead in the National Defense Authorization Act of 1994 (P.L. 103-160) with the requirement that the "Secretary of Energy shall establish a stewardship program to ensure the preservation of the core intellectual and technical competencies of the United States in nuclear weapons, including weapons design, system integration, manufacturing, security, use control, reliability assessment, and certification." This legislation also outlined the program elements of the stewardship program, which broadly included advanced computational capabilities, increased experimental programs, and new facility construction projects.

The DOD's Nuclear Posture Review, an element of an overall post-Cold War assessment of the nation's defense posture and strategy, also played a key role in shaping the CTBT and the SSMP. It set the overall strategy for the U.S. nuclear deterrent and established nuclear weapons requirements for the DOE's nuclear weapons program. These requirements included: (1) maintaining U.S. nuclear weapon capabilities; (2) demonstrating the capability to refabricate and certify weapons in the enduring stockpile; (3) maintaining the capability to design, fabricate, and certify new weapons for the enduring stockpile; (4) assuring the nuclear weapons science and technology base; and (5) ensuring an upload hedge for tritium production. Although many see the CTBT as a nuclear disarmament agenda, it is clear that the Nuclear Posture Review, as well as the legislation and administration directives leading up to it, are not a "going out of business" strategy. Rather, the U.S. strategy regarding a CTBT is based upon a belief that we can maintain an adequate deterrent without nuclear testing. In fact, the promise of a successful stockpile stewardship program is generally recognized as a precondition for the United States agreeing to a CTBT.

During 1994 and 1995, the nuclear weapons labs, in partnership with the DOE and DOD, developed the scope and strategy for a stewardship and management program that would be able to provide high confidence in the safety and reliability of the U.S. nuclear stockpile without nuclear testing or stockpile modernization. After extensive administration review, the President announced on August 11, 1995, his decision to seek a "zero" yield CTBT based in large part on the assurance he had received from "the Secretary of Energy and the directors of our nuclear weapons laboratories that we can meet the challenge of maintaining our nuclear deterrent under a CTBT through a science-based stockpile stewardship program without nuclear testing." On September 24, 1996, the President signed the CTBT, which had been opened for signature at the United Nations that day.

In making the decision to pursue a "zero" yield CTBT, the President recognized that there was no guarantee that the stewardship program would be successful. Therefore, he also established safeguards to assure that the U.S. nuclear deterrent would remain viable in an uncertain future. These safeguards include (1) the science-based stockpile stewardship program, (2) the maintenance of modern laboratory facilities and programs in theoretical and exploratory nuclear technology, (3) the basic capability to resume nuclear testing, (4) improved treaty monitoring capabilities, (5) a broad range of intelligence gathering and analytic capabilities, and (6) being prepared to withdraw from the CTBT under the standard "supreme national interest" clause in order to conduct whatever testing might be required to ensure high confidence in the safety and reliability of U.S. nuclear weapons.

The development of consensus on a CTBT strategy and the Stockpile Stewardship and Management Program, which resulted in the United States signing the CTBT, was almost exclusively an internal administration activity. Congress was not a significant part of this consensus. Other than getting the process going in 1992 with the temporary nuclear test moratorium, Congress was not part of the decision to extend the moratorium or the process to define the scope of the CTBT. In fact, most of the Congressional record over the last two to three years indicates serious concerns on the part of Congress, especially the majority party in 1994 and 1995, about the direction the administration was going. For example, Congress criticized the administration's underfunding of the stewardship program and added funds in both 1994 and 1995. Congress authorized expenditures to prepare for hydronuclear experiments while the administration chose to delay a decision on such tests. Congress repeatedly called for enhanced test readiness relative to the degree of test readiness supported by the administration.

This lack of consensus between the administration and Congress is critically important today because the Senate must now provide advice and its consent to the CTBT before the treaty becomes legally binding to the United States, and both houses must support the CTBT and the stockpile stewardship program over the next decade if the stewardship program is to be successful. The President has acknowledged that sustained financial support and commitment will be required on the part of Congress to ensure the success of the Stockpile Stewardship and Management Program.

At a minimum, the arguments that were laid out and debated within the administration in reaching its consensus will have to be laid out before Congress. The arguments on how safe is safe enough, how much reliability do we need, and how we can achieve these levels of safety and reliability without nuclear testing will have to be reengaged. Ultimately Congress will have to have confidence in our ability to maintain the nation's nuclear deterrent without nuclear testing if it is to support a CTBT.

Confidence is a subjective and often fragile quantity. Even with nuclear testing, nuclear weapons were never tested in a statistically significant number. Our confidence in the safety and reliability of the stockpile rested on our confidence in the judgment of the scientists and engineers who maintained the stockpile, and much of this confidence resulted from their experience and the lessons learned in nuclear testing. Through nuclear testing, these experts learned how subtle changes in a weapon design could lead to significant problems in the weapon's performance. The technical challenge in the science-based stockpile stewardship program is to maintain this confidence, and to maintain it in a smaller, less diverse nuclear stockpile without nuclear testing or modernization.

In the past, overall confidence was provided in part by the robustness of a larger, more diverse stockpile, kept relatively young through modernization, and with a program of numerical simulations and non-nuclear experiments leading to a significant nuclear testing program. For the future, we will have a smaller, less robust stockpile that will age without modernization, and we will not be able to rely on nuclear testing as a means of resolving questions about safety or reliability. Confidence will depend on our predicative capability, which will rely on advanced computational techniques (with computing capabilities a thousand times more powerful than those of today's computers), advanced experimental techniques to provide data on the properties of weapons materials and components, and non-nuclear experiments to validate aspects of nuclear weapons performance or operation.

Without the advances proposed in the SSMP, our confidence in the stockpile will inevitability decline. It is the judgment of the current stewards of the stockpile that we will lose our confidence in the stockpile in a decade or so unless we engage in a vigorous and enhanced science-based stewardship program. This decay in confidence will result from the cumulative effects of discovering problems in the stockpile, both latent problems that exist today but are as yet unknown and aging-related problems that will develop over time, and from the loss of expertise that will occur with the retirement of the current staff of nuclear-test-trained experts. Although there are those who believe (or hope?) that the weapons can be maintained by surveillance and or remanufacture alone, the conclusion of the current experts and responsible policy makers is that only the science-based stewardship approach will offer adequate confidence in the future.

The science-based approach to stockpile stewardship is to replace "brute force"—that is, an empirical methodology based strongly on nuclear testing—with more "brains"—namely, a vastly improved science base for predicting the behavior of nuclear explosives on a more first-principles basis. What makes this approach viable today are (1) the vast improvements in computer technology over the last decade and (2) experimental evidence that we can simulate some nuclear weapons phenomena in hydrodynamic and high-energy-density facilities adequately to maintain a level of confidence appropriate for a post-Cold War security environment. We believe that, with the computational and experimental facilities and capabilities planned for the SSMP, we can arrest the decline in confidence before it becomes a problem for deterrence and can eventually improve our confidence as new facilities prove the predictive capabilities. Although we do not expect to achieve the same level of confidence that would be provided with nuclear testing, we are optimistic that we can achieve sufficiently high levels of confidence to allow the national authorities to forego nuclear testing, barring a return to a more threatening nuclear environment or the failure of the SSMP to achieve its technical goals.

Ultimately the measure of an adequate nuclear capability is measured against our nuclear deterrent requirements. If the requirements are lowered the capability can be lessened; if raised then the capability must be improved. Much of the debate over what type of SSMP we need is really a debate over what kind of deterrent we need. For the nuclear enterprise, the marching orders are clear. From both the President and Congress, it is clear that high confidence in the safety and reliability of our nuclear stockpile is mandatory and that we must also maintain a nuclear expertise second to none. Our challenge is more than watching the stockpile and responding to problems. Rather, our challenge is to anticipate and avoid problems and to maintain a stimulating and challenging atmosphere that will continue to attract and train the best scientists and engineers to steward our stockpile.

The review conducted as part of the Hatfield-Exon-Mitchell process established the nation's present standard for safety and reliability. Subsequent reviews have reaffirmed that although we have encountered problems in the stockpile that would have resulted in nuclear tests in the past, there is no current need to test to achieve this standard.

A significant part of the confidence that we have today is a legacy of the expertise we gained during our period of nuclear testing. We have experts today whose judgment has been honed through the process of nuclear design and nuclear testing. These people will eventually retire, and without the capabilities designed into the SSMP our capability will decay as they leave. Even with the residual test-related expertise we have today, we have limited ability to rebuild or replace weapons in the stockpile if and when problems develop. Eventually, without SSMP, we will lose the ability to rebuild or replace the stockpile with any significant confidence. Our safety assessment capability will remain for some time, but even it will eventually become marginal without a successful SSMP. Ultimately, we will not be able to continue to certify confidence in the stockpile without the SSMP.

Detailed discussions covering specific examples of past problems and what we can or cannot do today and in the future were carried out within the administration as it reached its decisions on SSMP and the CTBT. Many of the details are classified and cannot be repeated in this paper or this forum. However, they must and will be repeated for Congress in order to reach a truly national consensus on a CTBT and the SSMP.

The discussions and debate that led to a consensus on what the SSMP could or could not do and on what level of program performance was required in order to forego nuclear testing began within and between the nuclear weapons labs, were challenged and improved via debate within the DOE, and were further challenged and refined in review and discussion with the DOD. Ultimately, the process included review at the level of the Chairman of the Joint Chiefs and the National Security Advisor. The decision to embrace the SSMP as the basis for supporting a "zero" yield CTBT has been endorsed by the leadership of all these institutions. Although there are individuals within each of these institutions who may disagree with the final decision or elements of the decision, or who may question the level of confidence that their leadership has expressed in the likely success of either the CTBT or the SSMP, the program proposed by the administration and supported by the nuclear weapons labs enjoys a unusually wide level of support for such a radical change in how we plan to maintain our nuclear deterrent. This confidence rests in large part on the extensive review and challenge that the SSMP encountered in its development. We anticipate that the upcoming Congressional review and debate will contribute to further improvements and support for the SSMP.

The Department of Energy published *The Stockpile Stewardship and Management Program* document in May 1995. This document outlines in some detail the DOE's plans to maintain both the nuclear weapons stockpile and the nuclear weapons expertise that is the basis for continuing stockpile confidence. The program is anticipated to cost approximately $4 billion per year over the next ten years, with roughly half of the funding going to stockpile stewardship and half to stockpile management. The program is judged by the nuclear weapons labs and the DOE to be the minimum integrated set of capabilities needed to perform the tasks set out by the President and Congress.

The key thrust of the stockpile stewardship part of the program is to replace the brute force and the empiricy of nuclear testing with a better scientific understanding of the fundamentals of nuclear weapon performance. The central technological feature of the stewardship program is advanced computations and modeling of the individual and integrated processes involved in a nuclear explosion so as to provide a reliable predictive capability of a nuclear weapon's performance. This requires modeling processes from the initial high-explosive detonation through the fission and fusion processes in the nuclear explosion in a manner that can address the issues of nuclear safety, weapon reliability, and overall performance.

Using advanced computers a thousand times faster than the computers currently in use, together with the expertise available in the weapons labs today, we plan to utilize past weapons test data, new experimental data from existing facilities, and new experimental data from soon-to-be-constructed facilities to demonstrate the enhanced predictive capability necessary to support a stockpile stewardship program without nuclear testing.

Key to this enhanced predictive capability are the new tools, specifically the new experimental facilities, that will enable us to obtain heretofore unavailable physics data on materials and processes that are critical to the operation of nuclear explosives and, in some cases, critical to validating the codes that will be used to predict the performance of a nuclear weapon without nuclear testing.

These new experimental facilities are also important in their role of attracting and challenging the next generation of scientists and engineers who will be relied upon to judge the safety and reliability of the stockpile in the future, when today's generation of weapons-test-trained scientists and engineers are gone. This aspect should not be undervalued, because without the ability to continue to attract first-class scientists and engineers to the weapons labs, we will not be able to maintain confidence in the stockpile in the long term. Second-rate science will not do in an area as critical as nuclear weapons expertise.

The central new experimental facilities identified in the plan laid out by the DOE and the labs are the Dual Axis Radiographic Hydrodynamic Test (DARHT) Facility, the Contained Firing Facility (CFF), the National Ignition Facility (NIF), and the Advanced Hydrotest Facility (AHF). DARHT, CFF and AHF will provide data critical to understanding the implosion and pre-nuclear performance of nuclear weapons, and NIF will simulate the high-energy-density conditions that occur in thermonuclear explosive conditions.

The other half of the SSMP is stockpile management. Stockpile management focuses on monitoring and assessing the stockpile and responding to the results of these assessments. New tools are being developed as part of the SSMP to improve our ability to provide detailed surveillance of the stockpile and to detect or predict potential stockpile problems at the earliest stages of their development. With the significant reduction in the manufacturing capacity of the post-Cold War nuclear weapons complex, we can no longer wait for problems to develop and then conduct major programs to fix the problems. We must now be able to anticipate problems and address them over a longer period of time in a smaller complex. This ability to address problems before they become serious is tightly coupled to the capabilities of the stockpile stewardship program. The same tools that are required under stockpile stewardship to model and predict the performance of nuclear weapons will be required to assess and predict the effects of emerging problems (and "fixes") in the aging stockpile. This is one of the key reasons why remanufacturing alone is not a credible answer to the long-term maintenance of the stockpile.

Stockpile management will also address the needs of a new and smaller weapons complex that will be able to refurbish or replace weapons components as they age or encounter performance or safety problems. The new complex will meet modern requirements for safety and environmental impact while having functionally equivalent processes to those originally used to build the nuclear weapons. Certification of this functional equivalency is another challenge for the stockpile stewardship program and further illustrates why stockpile stewardship and management must be viewed and executed as a single integrated program.

We are optimistic that the Stockpile Stewardship and Management Program will provide the nation with high confidence in the safety and reliability of its nuclear stockpile. The program is not without risk, but with the commitment of the administration and the Congress, the program has the strong promise of allowing us to maintain our stockpile into the foreseeable future without nuclear testing. This optimism is based upon the proven ability of the three weapons laboratories in the past and the commitment to provide the tools and financial support required to implement the program.

The risks in replacing nuclear testing with a science-based predictive capability lie not only in the risk that the science program will not be able to develop reliable predictive tools, but also in the risk that we may become overconfident about our predictive ability. High confidence can be misplaced, especially in complex systems. The Challenger accident is a vivid example of how the desire to achieve a national goal can blind people to the technological problems that stand in the way. The Report of the Presidential Commission on the Challenger accident concluded that "The contractor did not accept the implications of tests early in the program that the design had serious and unanticipated flaws . . . NASA did not accept the judgment of its engineers that the design was unacceptable and, . . . As the problems grew in number and severity, NASA minimized them in management briefings and reports." Parallels to the Stockpile Stewardship and Management Program are easily imagined.

The President has called for dual revalidation and certification to assure that the stockpile remains safe and reliable. The President has stated that he will seek Congressional support to withdraw from the CTBT under the "supreme national interest" clause to conduct nuclear tests if they are judged necessary to ensure high confidence in the safety and reliability of the enduring U.S. stockpile. This commitment was critical to developing the consensus to support a "zero" yield CTBT.

A decision on whether or not to test would be a difficult one to make, if the need ever arises. It would be all too easy to find justifications to avoid such a decision or to downplay the uncertainties or unknowns in the stockpile problems. Making the right decision depends not only on the skills of the scientists and engineers who must implement the technical details, but also on the judgments and response of the technical mangers as the technical issues arise and of the policy makers as they evaluate the technical issues and decide what course of action the nation should take. We must be careful to balance our enthusiasm and optimism for its success with a pragmatic and somewhat skeptical critique of its progress and vulnerabilities in order to be justified in the confidence we are placing in this important initiative.

Ultimately, a successful Stockpile Stewardship and Management Program represents both our best hope for being able to maintain our nuclear stockpile without nuclear testing and the best source of high-quality data to determine if the stockpile can or cannot be maintained without testing.

CHAPTER 5

THE COMPREHENSIVE TEST BAN TREATY IN THE CURRENT NUCLEAR CONTEXT

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INTRODUCTION

This paper provides a brief tour of the overall nuclear environment in which Comprehensive Test Ban Treaty (CTBT) ratification and entry-into-force will be considered in the years ahead. Despite, or perhaps because of the unconditional extension of the Nuclear Non-Proliferation Treaty in May 1995, the momentum toward disarmament that characterized the early 1990s has slowed. Russian ratification of the second Strategic Arms Reduction Treaty (START II) has been stalled, yet once START II does enter into force, a joint statement issued at the 21 March 1997 U.S.-Russian summit outlines the course of further strategic arms reductions. Both Russia and the United States are currently planning on retaining significant nonstrategic and reserve nuclear stockpiles that are about three times the size of their planned operational strategic stockpiles under START II. Paradoxically, even as a significant denuclearization of conventional combat forces has been implemented on both sides, both nations are veering in the direction of expanded first use doctrines for their nuclear deterrents, with Russia embracing NATO's doctrine of flexible response while the United States finds new roles for nuclear weapons in countering proliferation of "weapons of mass destruction."

Far from quietly accepting the limitations on the nuclear design establishment imposed by a "comprehensive" test ban, the U.S. government has embarked on a massive and costly effort to offset these limitations with an array of new experimental, computational, and weapons manufacturing capabilities dubbed "Science-Based Stockpile Stewardship and Management Program" (SSMP). The level of spending on this program is projected to exceed the Cold War average level for comparable activities for the next ten years. Aspects of this program will severely complicate CTBT verification and accentuate proliferation risks. Spying a big pot of money for "Big Science" (even though it is *nuclear weapons* science), leaders of the American physics community have lent their uncritical endorsement to the overblown program, even to the extent of urging the Department of Energy (DOE) and the Congress to construct a $1.2 billion laser fusion machine—the National Ignition Facility—in the face of major scientific uncertainty about the ability of the facility to achieve its stated goal of fusion ignition.

THE NUCLEAR DISARMAMENT OBLIGATIONS OF THE NUCLEAR WEAPON POWERS

Since March 1970, nuclear weapon parties to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) have been subject to the nuclear arms control and disarmament obligations contained in Article VI.[1] Compliance with this provision has long required that "effective measures related to cessation of the arms race"—such as the Comprehensive Test Ban Treaty and a "cutoff" of fissile material production for weapons—be pursued in good faith "at an early date." Other good faith negotiations, not necessarily at an early date, are also required on "effective measures related to nuclear disarmament." The NPT preamble further describes these as "effective measures *in the direction of* nuclear disarmament," leading to "the elimination from national arsenals of nuclear weapons and their means of delivery *pursuant* to a treaty on general and complete disarmament under strict and effective international control."

Despite the failure of the nuclear weapon powers to negotiate a cessation of the arms race at an early date, this race had indeed abated considerably by the time of the NPT's 25 year Review and Extension Conference in May 1995, with several arms reduction and arms race cessation measures already in place or pending. As a result the conference agreed to extend the NPT indefinitely, but also endorsed a "program of action" to achieve "the full realization and effective implementation of Article VI," including "the determined pursuit by the nuclear weapon-states of systematic and progressive efforts to reduce nuclear weapons globally, with the ultimate goals of eliminating those weapons, and by all States of general and complete disarmament under strict and effective international control."[2]

The World Court has ruled in a recent advisory opinion that "there exists an obligation to pursue in good faith and to bring to a conclusion negotiations leading to nuclear disarmament in all its aspects under strict and effective international control."[3] Some disarmament observers suggest that this statement will "put to rest any questions about linking the elimination of nuclear weapons to a treaty on general and complete disarmament; it is now settled that complete nuclear disarmament is a separate and distinct obligation under Article VI of the NPT."[4]

In reality, however, this aspect of the Court's pronouncement changes very little. By a 7-7 split decision, the Court ruled that current international law does not provide a sufficient basis to "conclude definitively whether the threat or use of nuclear weapons would be lawful or unlawful in an extreme circumstance of self-defense, in which the very survival of a State would be at stake." An interesting question, posed but not resolved by the Court's opinion, is whether a state caught in such an "extreme circumstance of self-defense" could, under duress, disregard the prin-

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[1] Article VI reads as follows:

> Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures related to the cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control.

[2] Final Document, Part I, Organization and work of the Conference, 1995 Review and Extension Conference of the parties to the treaty on the Non-proliferation of Nuclear Weapons, NPT/CONF. 95/32 (Part I), New York, 1995.

[3] International Court of Justice, The Hague, Communique No.96/23, 8 July 1996, p. 2.

[4] See for example, William Epstein, "Editorial Note on the Legality of the Threat or Use of Nuclear Weapons," *Disarmament Times* 19, no. 4 (September 1996), NGO Committee On Disarmament, New York, p. 1.

ciples and rules of international humanitarian law in carrying out its defense if such disregard were required to assure its "very survival." If so, then any nation subject to a short-warning threat of nuclear (or other catastrophic) attack would appear to be legally entitled to "defend" itself by means of a strategy of swift and assured nuclear retaliation, thereby unavoidably involving the risk of massive civilian casualties.

Thus despite the Court's view that "the threat or use of nuclear weapons would generally be contrary to the rules of international law," the "extreme circumstance" exception leaves room for rather robust nuclear deterrent strategies on the part of nations subjected to catastrophic threats to the survival of the state. In summary, the main message of the Court's opinion is that a global, legally binding instrument to eliminate nuclear weapons *per se*—without a host of crippling caveats and conditions—remains to be created by the international community.

SECURITY ASSURANCES AND NUCLEAR WEAPONS EMPLOYMENT POLICIES

The United States has long adhered to a nuclear doctrine that emphasized its willingness to employ nuclear weapons first in defense of its own and allied military forces. However, since 1978 this doctrine has been coupled with an explicit "negative security assurance" that the United States would not use nuclear weapons against a non-nuclear weapon state party to the NPT unless such a state was associated with a nuclear weapon state in an attack on the United States, its allies, or its armed forces.

The former Soviet Union long had a declaratory posture of endorsing and seeking international agreement on No First Use of nuclear weapons, but Soviet military doctrine emphasized early preemptive use of nuclear weapons, and the USSR accumulated a vast arsenal of battlefield nuclear weapons. In 1993, however, even the pretense of No First Use was dropped as Russia shifted to an explicit First Use policy in the face of the continuing degradation of its conventional forces.

Recent statements by senior Clinton administration officials, including former Defense Secretary Perry, have tended to confirm the expansion of nuclear weapon missions initiated during the Bush administration to include deterring and preemptively destroying forces equipped with "weapons of mass destruction (WMD)." On 4 April 1996, Robert Bell, the National Security Council Senior Director for Defense Policy and Arms Control, qualified United States adherence to the African Nuclear Weapons Free Zone (ANFZ, Pelindaba Treaty) as follows:

> Under Protocol I, which we signed, each party pledges not to use or threaten to use nuclear weapons against any ANFZ party. However, Protocol I will not limit options available to the United States in response to an attack by an ANFZ party using weapons of mass destruction.[5]

While Bell's statement appears to rule out the preemptive use of U.S. nuclear weapons to destroy chemical or biological warfare production facilities, it nevertheless contradicts the long-standing U.S. negative security assurance (reiterated by Vice-President Gore in his speech to the

[5] Press Briefing, transcript, Office of the Press Secretary, the White House, April 11, 1996, p. 3.

NPT Review and Extension Conference on 19 April 1995) by suggesting that such assurances would not apply to parties using chemical or biological weapons.

CURRENT STATUS AND FUTURE PLANS FOR NUCLEAR ARMS REDUCTIONS

The START I Treaty entered into force on 5 December 1994, and by the end of 2001, the treaty requires each side to have reduced its strategic nuclear forces to 1,600 deployed delivery vehicles having 6,000 "accountable warheads," of which 4,900 can be ballistic missile warheads. The START II Treaty, signed on 3 January 1993, requires that by 1 January 2003, each side shall have no more than 3,500 accountable warheads on its strategic nuclear delivery vehicles, of which 1,750 warheads may be deployed on multiple warhead submarine launched ballistic missiles (SLBMs), and the balance on single warhead ballistic missiles and/or bombers. "Heavy" intercontinental ballistic missiles (ICBMs) and ICBMs with Multiple Independently-Targetable Reentry Vehicles (MIRVs) are banned. "Reserve" stocks of strategic nuclear warheads, and nuclear weapons deliverable by shorter range systems, such as Sea-Launched Cruise Missiles (SLCMs) and tactical aircraft, are not covered by the agreement.

While the United States Senate consented to ratification of START II on 26 January 1996, the Russian Duma has not, and a substantial body of opinion in Russia views the treaty as giving the United States a nuclear advantage with respect to deployed strategic warheads. The treaty is also regarded as too costly to implement on the agreed timetable because it requires the early retirement of Russian ICBMs before the end of their useful service life, and the production and deployment of an additional 500 single warhead ICBMs just to reach the 3,500 warhead level by 2003. To maintain parity with the United States, additional resources will have to be dedicated for missile submarine and SLBM modernization, silo conversion, and improved command, control, communications, and intelligence (C^3I) systems. This situation should provide incentives for the Russian security establishment to seek a nuclear deterrent relationship with the United Sates at a much lower—and more economically sustainable—level of forces, and for the United States to relieve its own severe budgetary pressures by further reductions in the size and operating tempo of its nuclear forces.

At a summit held in Helsinki, Finland on 21 March 1997, Russian President Yeltsin and U.S. President Clinton signed joint statements regarding: further reductions in strategic nuclear weapons; the development of theater missile defense under the Treaty on the Limitation of Anti-Ballistic Missile Systems; and chemical weapons. The planned enlargement of the North Atlantic Treaty Organization (NATO) in 1999 to include former Warsaw Pact states dominated the summit, but the promise of new economic opportunities for Russia tempered a confrontation over security issues.

During the summit, Yeltsin gave a firm commitment to press the Russia Duma (the lower house of Parliament) to ratify START II. The joint statement on further reductions in strategic nuclear weapons describes the course of events subsequent to START II entry into force. Immediately thereafter, negotiations will begin on a START III treaty. The basic elements of START III will include the reduction of strategic nuclear warheads by Russia and the United States to a total of between 2000 and 2500 each by 31 December 2007. This is the level that President Yeltsin originally proposed, and the United States rejected, during START II negotiations in the spring of 1992. To promote the aim of making these reductions irreversible, START III will include measures relating to the transparency of existing nuclear warheads and warhead destruction.

Responding to the greater relative economic burden that START II places on Russia, the joint statement states the intention by both Presidents to extend the deadline for dismantlement of strategic systems under START II to 31 December 2007. Deactivation of these delivery systems will be completed by 31 December 2003, the original deadline for systems destruction.

In the context of START III negotiations, possible transparency and confidence-building measures relating to long-range, sea-based cruise missiles and tactical nuclear systems will be examined as separate issues. The joint statement concludes with the declared intention of Russia and the United States to study issues relating to transparency with regard to nuclear materials.

While the Helsinki summit produced agreements in principle on arms control matters between the leaders of Russia and the United States, ratification of START II by the Russian Duma and its approval of the green light given to U.S. theater missile defense may prove difficult. Immediately following the summit Sergei Yushenkov, one of the Duma's leading defense experts, stated that if NATO enlargement proceeded, ratification of START II would be out of the question. In the context of the summit NATO enlargement and the START process appeared compatible, yet they may not seem so to the members of the Russian Duma.

Nuclear Forces

The United States continues to modernize its strategic nuclear forces. By the end of 1996, Minuteman launch control centers will be upgraded with Rapid Execution and Combat Targeting (REACT) consoles, and missile guidance improvements will be implemented between 1998 and 2002. In fact, the number of operational U.S. strategic weapons has been increasing over the past two years with the addition of the sixteenth and seventeenth Trident ballistic missile submarines (SSBNs), and now stands at 8,100 warheads. This number could rise again in 1997 when the eighteenth and final SSBN joins the force, before dropping to fourteen if and when START II enters into force.

Retirement of four older SSBNs of the same class based on the Pacific coast has been delayed until close to the 2003 target date for full implementation of the START II reductions, costing taxpayers additional billions of dollars in operations and maintenance funding. The four SSBNs remaining in the Pacific fleet will be "backfit" with the Trident II missile between FY 2000 and 2005, and eventually two or three submarines will be shifted from the Atlantic fleet to balance the fourteen submarine fleet to be maintained under START II. All missiles will be downloaded from eight to five warheads each. Two-thirds of U.S. SSBNs are still at sea at any given time—a patrol rate comparable to those at the height of the Cold War—and each submarine continues to have two crews. If the planned SLBM Strategic Retargeting System (SRS) achieves an operational capability, U.S. SSBNs will have the ability for rapid targeting and retargeting of Trident IIs to any spot on the globe.

In Russia, the first of six Typhoon class SSBNs entered Severodinsk shipyard for overhaul and missile conversion in 1991, and it is still there. The five other Typhoons likewise await modernization with the SS-N-26 SLBM, but the missile has not gone into production. In fact, no SSBNs or SLBMs are in production, but a second new SLBM for the Delta V SSBN, and a new class of SSBN to replace the Typhoon and Delta IV, are under development. The SS-25 single warhead ICBM is the only strategic weapon system still under production, and flight tests of a new variant (called Topol-M) planned for silo basing continued in 1995 and 1996.

In a recent article, Russian Nuclear Energy Minister Victor Mikhailov and two senior colleagues from the Arzamas-16 weapons laboratory have raised the prospect of a radical reworking of Russia's nuclear arsenal to adapt to the changed circumstances of NATO's expansion eastward and the precipitous decline in Russia's capabilities to mount a credible conventional defense. According to Mikhailov:

> Militarily, Russia's security can only be guaranteed by nuclear deterrence policies . . . If Russia sees its interests ignored or NATO expansion proves spearheaded against Russia, it will have to take economic and military measures that should be prepared well in advance . . . In the military-technical field, Russia could strengthen its nuclear arms system: its strategic intercontinental missiles and those capable of reaching Europe. If the events take an unfavorable turn, Russia could restore its arsenal of missiles . . . which were scrapped under the 1987 medium and shorter-range missiles elimination treaty, develop new-generation battlefield nuclear arms with relatively low capacity and reduced side effects on the environment and population located outside the hostilities area.treaties. Nuclear arms modernization can be carried out within the framework of the Comprehensive Test Ban treaty, though this would require maximum mobilization of the Russian Atomic Energy Ministry capacities.[6]

U.S. and Russian Nuclear Weapon and Fissile Material Stockpiles

While the public and media perception is that U.S. and Russian nuclear weapon stockpiles under START II will be reduced to no more than 3,500 warheads each by 2003, the truth is that both nations are planning stockpiles that are three times this amount, each on the order of 10,000-11,000 warheads.

In addition to 3500 operational strategic weapons, Clinton administration plans call for the retention of an additional 950 warheads for nonstrategic nuclear forces (SLCMs and gravity bombs), another 2,500 warheads as a "hedge stockpile" for "uploading" on existing strategic delivery systems, 700 spares for the active inventory, and another 2,500 intact warheads in an "inactive reserve" status[7] (i.e., without tritium reservoirs and other limited life components), for a total stockpile of 10,150 intact weapons in 2003.

The balance of roughly 22,000 warheads from the 1990 stockpile will be dismantled, but some 5,000 of the 12,000 plutonium intact pits recovered in the warhead disassembly process will be retained as a "strategic reserve." We estimate that this pit reserve amounts to about 15 tonnes of plutonium, or roughly half the 32 tonnes that will remain in intact weapons, for a total of 47 tonnes to be retained for weapons use, out of a total stockpile of 85 tonnes of weapon-grade plutonium. The U.S. government has declared that the balance of 38 tonnes of Weapons-Grade Plutonium (WGPu)—almost half of it not in pit form—is surplus to military needs and may be permanently withdraw from the U.S. weapons stockpile.

As best we can discern, current Russian plans and programs call for the retention by 2004 of a force comparable to the planned U.S. force. Absent further agreements beyond START II, Russia has the nominal potential to retain as many as 10,000 intact strategic warheads (operational

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[6] Prof. Victor Mikhailov, Igor Andryushin, and Alexander Chernyshov, "NATO's Expansion and Russia's Security," *Vek*, 20 September 1996.

[7] "Inactive reserve" weapons could in theory be returned to service following a "surge" in the nuclear stockpile support base, but will more likely be used as test items and spares.

plus reserve) and another 10,500 former intermediate-range nuclear forces (INF) and nonstrategic warheads. In reality, the bulk of the 10,500 remaining nonstrategic warheads will become obsolescent over the next seven years, and Russian sources indicate that most or all are likely to be dismantled.

Even under an optimistic budget scenario, Russia is not likely to deploy more than about 2,800 operational strategic warheads under START II, leading to a larger inactive strategic reserve stockpile of some 5,000 weapons, and a smaller "hedge" stockpile of some 950 warheads for "uploading" on formerly MIRVed ICBMs. We assume that an active nonstrategic warhead inventory of 1,350 SLCM warheads and tactical bombs—comparable to the planned U.S. inventory—is retained, either partly or completely obtained from new production. Given Russia's defense budget crunch, even this estimate is probably on the high side. Likewise, some fraction or all of the 3,000 INF warheads could be retained in an inactive reserve status, but we will assume that Russia retains the same number of former INF warheads in an inactive reserve status as the United States, that is, one the order of 500 weapons. Assuming a spares allowance of 400 weapons (ten percent of the active inventory), then by our calculation Russia is likely to retain a total stockpile of around 11,000 weapons by the year 2004.

We estimate that Russian reactor production of WGPu since 1948 amounts to some 150-170 tonnes, of which 115-130 tonnes was actually fabricated into weapon components, with the balance in production scrap, solutions, residues, and losses to nuclear waste and the environment. An additional 30 tonnes of separated reactor grade plutonium is stored at Chelyabinsk-65. This estimate for Russian WGPu in pits is roughly double the 66 tonnes of WGPu contained in U.S. weapon pits, and Russia's total separated plutonium inventory of close to 200 tonnes is roughly double that of the United States Given the agreement in principle between the two sides that U.S. and Russian plutonium disposition programs should proceed in parallel, with the goal of reducing to equal levels of military plutonium, Russia will be required to dispose of its plutonium at a rate three times that of the United States to reach equal levels by a given date. For Russia to reduce its total separated plutonium inventory via the Mixed Oxide (MOX) option in pressurized water reactors to 50 tonnes in ten years would require full-core loading of 15 VVER-1000 reactors—all seven VVER-1000 reactors in Russia and most of the 10 operating VVER-1000s in Ukraine.

As for the disposition of highly-enriched uranium (HEU, >20% U-235) from weapons, the U.S. DOE has announced that it produced 994 tonnes for all purposes through 1992. In our estimates we assume that the United States had about 500 tonnes of "oralloy" ("Oak Ridge Alloy" ~93.5% U-235), and about 230 tonnes between 20% and 90%-enriched, in weapons or assigned for weapons use. Only about one-half of the 174 tonnes of HEU that the United States has declared excess to its military requirements was ever in weapons or produced for weapons use. The United States is currently continuing to reserve on the order of 680 tonnes of HEU for potential military use, including an estimated 340 tonnes in and for weapons and about 320 tonnes of oralloy for the Navy, sufficient for a 100+ year reserve.

While the total production of Soviet/Russian HEU has never been officially disclosed, it is believed to be on the order of 1,200 tonnes Under a 1994 contract for U.S. purchases of HEU derived from Russian weapons, Russia agreed to sell the United States up to 500 tonnes of HEU equivalent (in the form of low-enriched uranium) at a rate of 10 tonnes per year for the first five years, and 30 tonnes per year for the next 15 years. Thus far, however, the U.S. Enrichment Corporation, executive agent for the U.S. side of the deal, has taken delivery of 6 tonnes of HEU equivalent in 1995, and contracted for 12 tonnes in 1996, and 18 tonnes in 1997.

With the end of the Cold War and the retirement and dismantlement of tens of thousands of nuclear weapons each, the United States and Russia have acquired huge surplus stocks of weapon-usable fissile material. Consequently, both countries have announced that they no longer produce fissile material for weapons. Actually, the United States stopped producing HEU for weapons in 1964, and stopped (involuntarily) producing plutonium for weapons in 1988, when the aging production complex shut down for reasons related to environment, safety, and public health. The Bush administration announced in 1992 that the United States would no longer produce plutonium or uranium for weapons, making a formal policy of a suspension in production that was already in place.

The Soviet Union announced in October 1989 that "this year it is ceasing the production of highly-enriched uranium," and that it had adopted a program to close down the remaining plutonium-producing reactors by the year 2000. This policy was reaffirmed by President Boris Yeltsin on 29 January 1992. The last three Russian plutonium production reactors still in operation are dual purpose reactors—two at Seversk (Tomsk-7) and one at Zheleznogorsk (Krasnoyarsk-26)—producing heat and electricity. The year 2000 production cut-off was chosen as a date by which new power plants could be brought on line to replace these last three production reactors.

The United Kingdom and France have also announced that they have stopped producing fissile material for weapons, and China has indicated privately that it has stopped as well. This leaves the undeclared nuclear weapon states—India, Pakistan and Israel—as possibly the only states that continue to produce unsafeguarded fissile material for use in weapons.

Fissile Cut-Off Negotiations in the Conference on Disarmament

With the United States no longer needing new fissile material production for U.S. nuclear weapons, the "fissile material cut-off" emerged as one of President Clinton's principal arms control initiatives announced in August 1993. Recognizing that a cut-off would have no immediate impact on the United States and Russia, the administration's objective was to constrain nuclear weapon arsenals of the undeclared nuclear weapon states by capping the supply of fissile material produced outside of international safeguards. Urged by the United States, the Conference on Disarmament in Geneva set up a committee on 23 March 1995 to negotiate a convention to prohibit the production of fissile material (principally HEU and plutonium) for nuclear explosive purposes or outside of international safeguards. These negotiations are going nowhere, primarily owing to opposition by Pakistan and India (which want any ban tightly linked to disarmament negotiations and the reduction of existing stocks), by the non-participation of Israel, and by the obvious lack of enthusiasm by such important states as China and France.

The non-governmental arms control community continues to press for a formal ban on the production of fissile material for weapons, not only because of the constraint it would impose on the threshold states, but also because it is an important complement to other arms control initiatives. A number of organizations take the view, however, that a ban on the production of weapon-usable fissile materials per se (i.e., separated plutonium and HEU), or at least a ban on the production and use of such materials under purely national auspices, would be a far more effective limitation, particularly in view of the ultimate goal of transitioning to, and maintaining, a nuclear-weapons-free world.

DATA EXCHANGE, VERIFICATION, AND TRANSPARENCY

Russia and the United States have made almost no progress in completing and implementing formal agreements for nuclear stockpile data exchanges, reciprocal monitoring of warhead fissile material storage sites, and other cooperative measures to enhance confidence in reciprocal stockpile declarations. Russia has essentially cut off bilateral talks on these issues, and it is unclear when they will be restored. The 10 May 1995 "Joint Statement on Transparency and Irreversibility of the Process of Reducing Nuclear Weapons" remains essentially a dead letter.

In the FY 1997 National Defense Authorization Act (H.R. 3230, Section 3137), Congress prohibited DOE from working with China on "any activity associated with the conduct of cooperative programs relating to nuclear weapons or nuclear weapons technology, including stockpile stewardship, safety, and use control." The bill also requires DOE to report to Congress on past or planned "discussions or activities" with the Chinese regarding nuclear weapons activities. This effectively halted a budding U.S.-China lab-to-lab cooperative transparency program that was recently initiated by the three U.S. weapons laboratories and the Chinese Academy of Engineering Physics.

"SCIENCE-BASED STOCKPILE STEWARDSHIP AND MANAGEMENT" UNDER THE COMPREHENSIVE TEST BAN TREATY

Following two and a half years of negotiations, in August 1996 the United Nations (UN) Conference on Disarmament (CD) in Geneva completed the text of a CTBT. Final approval by the CD was blocked by India, whose veto prevented the consensus vote necessary for final adoption of the treaty by the CD. India cited its concerns that: (1) nothing in the treaty obligated the nuclear weapon powers to eliminate their arsenals; (2) the treaty did not prohibit further refinement of these arsenals by non-nuclear explosive simulations and experiments; and (3) the Entry Into Force provisions (Article XIV) infringed upon its sovereignty by leaving open the possibility that India could be subjected to unilateral or multilateral sanctions in the event that it does not join the treaty.

Led by Australia, 120 cosponsoring countries successfully sought approval of the treaty text by the UN General Assembly. On 10 September 1996, by a vote of 158 to three with five abstentions, the UN General Assembly approved the treaty without amendment. Voting against the treaty were India, Bhutan (whose foreign policy India controls), and Libya. The five abstentions were Cuba, Lebanon, Mauritius, Syria and Tanzania. The CTBT is now open for signature. President Clinton signed first on 24 September 1996.

The treaty will not enter into force unless signed and ratified by 44 specified countries—the five declared weapon states and 39 others members of the CD having power and research reactors—including Iran and North Korea and the three undeclared weapon states: India, Pakistan and Israel. Unless the entry into force provisions are modified within the next few years, this could be a very long while indeed. India has indicated it will not sign the treaty, which obviously creates uncertainties about Pakistan's long term adherence to the treaty even it elects to sign it in the short term (Pakistan voted for the General Assembly Resolution endorsing the CTBT).

Until the treaty formally enters into force, its parties cannot fully implement the treaty's International Monitoring System and on-site inspection provisions, increasing uncertainties about compliance that may erode confidence in the treaty.

Technically, a state that signs or votes for the adoption of a treaty is not bound by it until it ratifies the treaty. However the Vienna Convention provides that between the time of the signing and ratification, a state has a legal obligation not to act in a manner inconsistent with the treaty. For treaty ratification by the United States, much work will remain to be done in order to achieve the two-thirds approval of a conservative U.S. Senate. While the Clinton administration strongly supports the CTBT, under the National Defense Authorization Act for FY 1997 [H.R. 3230, Section 3163 (a)(6)], the United States is committed to maintaining the ability to resume underground nuclear testing at the Nevada Test site within one year of a national decision to do so.

On 11 August 1995, President Clinton announced:

> I am assured by the Secretary of Energy and the Directors of our nuclear weapons labs that we can meet the challenge of maintaining our nuclear deterrent under a Comprehensive Test Ban Treaty through a Science-Based Stockpile Stewardship program without nuclear testing.
>
> . . . In order for this program to succeed, both the Administration and the Congress must provide sustained bipartisan support for the stockpile stewardship program over the next decade and beyond. I am committed to working with the Congress to ensure this support.

What the President failed to mention was that in order to gain support for a CTBT from the Pentagon and the nuclear weapons laboratories, the administration had secretly committed to spend a minimum of $40 billion on the Science-Based Stockpile Stewardship and Management Program over the ensuing ten years. The administration's outyear budget projections were not revised to take account of this exorbitant pledge for another six months, however, and by then it was too late to indicate how it would be accommodated in the President's plan to balance the budget. So the administration resorted to an extraordinary device. For DOE "weapons activities," the budget presented a line for "gross" levels of expenditure, reflecting the promised level of nuclear weapons spending, followed by a line containing "offsets" (i.e., unallocated cuts in DOE or other agency programs) that reduced the net weapons spending to the budgeted levels. From 1998 through 2002, this additional "stockpile stewardship premium" varies between $600 million and $1.3 billion annually. To make this elevated level of spending palatable, prominent advocates of the proposed SSMP, such as Prof. Henry Kendall of MIT, compare it to the spending levels that prevailed between 1984 and 1992, when spending on nuclear weapons research, development, testing and production was, according to Kendall, "between $5.5 and $6.2 billion annually." This view, as shown in a 1996 government briefing chart, appears to show a steep decline from "cold war" levels, and ignores the fact that these years coincide with the nuclear weapons buildup of the Reagan-Bush era. In reality, the new planned spending level averages $4 billion or more annually through the year 2001, and then drops to $3.6 billion in fiscal year 2002. As shown in Figure 5.1, this is well above the $3.7 billion (in 1997 dollars) average annual expenditure for nuclear weapon design, testing, and production (exclusive of nuclear material production) for the entire cold war period, 1948-1990. This level is particularly excessive when you consider that the period 1997-2002 contains no nuclear explosive testing, no "new" warhead engineering development, and only pilot production activities, in stark contrast to the norm during the Cold War years.

Whether this level of spending can be politically sustained for the entire decade promised by the President once the CTBT has entered into force is open to question. But so likewise is the ultimate entry-into-force of the treaty, which is impaled on a formula requiring ratification by

India and other countries that may well withhold ratification for an extended period, if not indefinitely.

Figure 1.
U.S. DOE Nuclear Weapons Activities - Annual Budget Authority.
(Constant FY1997 Dollars -- millions)
1948-1995: Weapons Research, Development, Testing and Production
1996-2002: "Science Based Stockpile Stewardship" and "Stockpile Management"

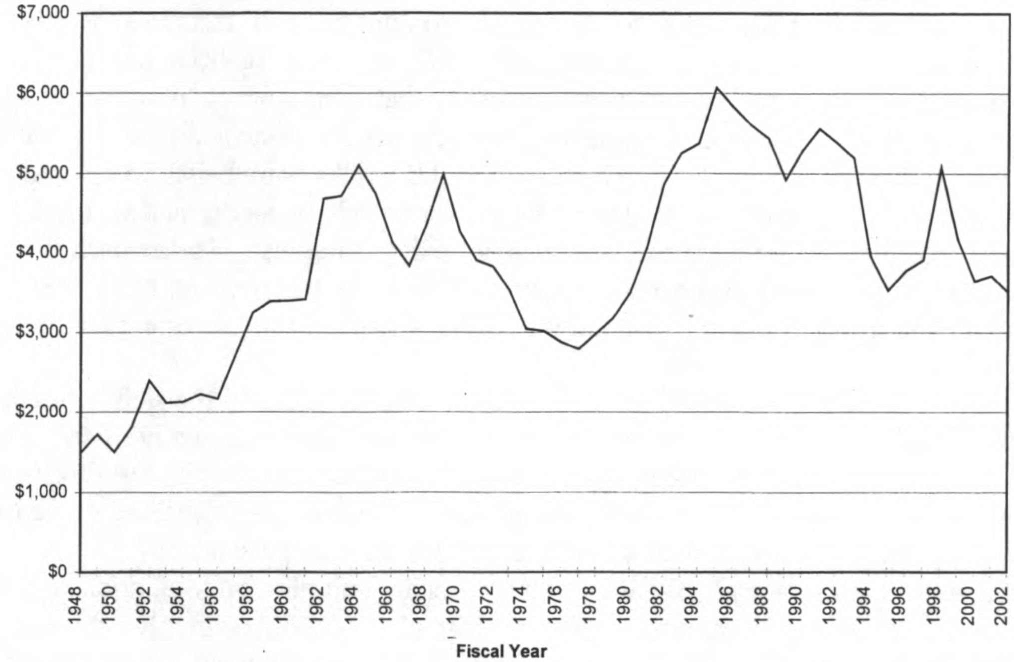

Figure 5.1: U.S. Department of Energy nuclear weapons activities—annual budget authority (constant fiscal year 1997 dollars in millions). 1948-1995: weapons research, development, testing and production. 1996-2002: Stockpile Stewardship and Management Program.

The planned Stockpile Stewardship and Management is clearly overkill if the goal is solely merely to maintain, as so often stated, "the safety and reliability" of an "enduring stockpile" of nuclear weapons under a permanent CTBT. In reality the goals are much broader than that, and include the acquisition of a wide range of improved calculational and experimental capabilities to partially offset, and—to the extent possible—overcome the limitations on the nuclear weapons design and engineering process imposed by a ban on nuclear explosive testing. Initially, at least, this process under a CTBT will be confined to qualifying existing nuclear weapon designs in new delivery configurations, such as the ongoing conversion of the B61 Mod 7 strategic bomb to a B61 Mod 11 earth-penetrating configuration, thereby finally "allowing" the retirement of the 9MT B53 strategic bomb. But the longer-term goal is the integration of three-dimensional nuclear design codes with computer-aided manufacturing techniques to create an "advanced product realization capability" that will create a highly flexible capability for designing, engineering, manufacturing and improved components for existing designs and ultimately entirely new weapons.

Subcritical Underground Tests

One particularly ill-advised aspect of the SSMP is the proposed program of subcritical experiments to be conducted 1000 feet below ground in the Low Yield Nuclear Explosives Research (LYNER) facility at the Nevada Test Site. The first scheduled test (Rebound 1) involves three Los

Alamos high-explosive driven, flying plate experiments to provide equation-of-state information on a plutonium alloy subjected to pressures above 2 megabars, and the second, HOLOG, is a Livermore-sponsored spall experiment employing a hemisphere of plutonium. While the technical stewardship justification and relative urgency of these tests are certainly open to question, of greater concern are the verification difficulties they pose, and their proliferation implications if the U.S. example is widely imitated.

Despite rashly and publicly deciding to conduct such tests in June 1996, just as the CTBT talks were scheduled for conclusion, the DOE and other agencies had conducted no analyses of how other parties to the treaty would verify that a hydronuclear or larger nuclear test had not occurred deep underground coincident with planned high-explosive equivalent energy releases as large as 500 pounds of TNT. Even as the CTBT talks were being completed in August, the U.S. government still had not developed an answer to this question, and to my knowledge an agreed protocol for monitoring such tests does not exist. Likewise, if other parties to the treaty conduct similar underground experiments, how will the United States and other treaty parties verify that such experiments have not violated the CTBT's implied (but never explicitly defined) "zero yield" threshold.

Given the nondiscriminatory nature of the CTBT and the U.S. assertion that "subcritical experiments" are not "nuclear weapons tests" and need not involve fissile material in weapons configurations, on what basis will other parties to the treaty, including threshold state parties and other non-weapon NPT parties with advanced nuclear programs, be denied the prerogative of conducting such "experiments"—for example, for the purposes of alleged "basic research" or "breeder reactor safety." What is the permissible limitation on total nuclear energy release if such high-explosive driven subcritical experiments also—or only—involve releases of nuclear energy from Deuterium-Tritium fusion, as currently planned by both weapon design laboratories? Among nuclear weapon states, both Russia and the United States are known to have conducted extensive tests of high-explosive driven "impact" fusion systems, and similar experiments have been conducted by Poland, a nonweapons state.

There appears to be no technical or political consensus on the answers to the above questions, either within the U.S. government or among the U.S. government and other important treaty parties. While subcritical tests were delayed for a year until the CTBT negotiations were completed, the December 1996 Final Environmental Impact Statement for the Nevada Test Side includes them as part of the government's "preferred alternative" for continued operations at the site.

Proliferation and the U.S. SSMP

Another explicit function of the program is to maintain a CTBT breakout capability for the United States—that is, to maintain a cadre of nuclear weapon scientists that will be in a position, from a nuclear weapons design and test diagnostics perspective, to capitalize promptly on any resumption of underground nuclear explosive testing.

To accomplish these traditional nuclear arms race objectives in a radically altered political environment has required the adoption of a whole host of new "warm and fuzzy" euphemisms for nuclear weapons research activities, and a commitment to "transparency and openness" in sensitive technical areas that may well undermine the achievement of global nonproliferation objectives. To deflect both foreign and domestic criticism of the massive U.S. "stewardship" effort, the U.S. government has made pledges of transparency and civilian user access to facilities and data that it may be unwise to keep.

The move to greater openness also stems from the reality that, in the post-cold war world, classified nuclear weapons research now longer commands the prestige and vital sense of national purpose that it once did—qualities that, along with generous salaries, compensated for the inability to publish in the open literature and gain the kudos of scientists "on the outside." To retain accomplished personnel in the new political climate, and attract competent younger scientists to nuclear weapons work, the laboratories are seeking to construct a more open work environment, partly by declassifying a great deal of technical data and by creating new experimental programs in "high energy density physics," "neutron science," and "advanced strategic computing" that are designed to bridge—and perhaps blur—the dividing line between weapons and non-weapons work, and thereby provide more opportunities for peer review and publication in the open literature.

For example, the Department of Energy steadfastly maintains that it can manage the proliferation risks of the National Ignition Facility (NIF) through a combination of "transparency measures,"—to soften foreign intelligence estimates that the facility is being used to design new weapons under a CTBT—and "screening procedures"—to deny access to researchers from nations bent on acquiring nuclear weapons. From a technical perspective, this is an exceedingly naive view of how nuclear weapons design capabilities proliferate. Other nuclear weapons states will look at the extensive weapons research program planned for NIF (freely available over the Internet) conclude that NIF is part and parcel of the U.S. nuclear weapons program, and seek maximum collaboration in order not to be left behind. Likewise, undeclared and threshold nuclear weapons states will likewise seek access—some, such as Israel, already enjoy such access—and if denied will seek to build their own programs, while scavenging what they can from the recent and likely future Inertial Confinement Fusion (ICF) declassification actions, undertaken to give this field a veneer of civil respectability it does not deserve. As for technically advanced non-weapon states, how will DOE "manage" the latent proliferation risk through "transparency and screening" if the non-weapon state harbors a long-term, undeclared objective of maintaining a thermonuclear weapons option through an ICF program, in other words, an objective virtually identical to DOE's own stewardship objective?

It is noteworthy that the European Science and Technology Agency (ESTA) Working Party, in its report "Inertial Confinement Options to Control Nuclear Fusion" (27 March 1996), recommended that the European Union beef up its ICF research to take advantage of DOE's rapidly evolving process of declassification of weapon-related ICF research. The ESTA recommended: "Advantage should be taken where possible of active collaboration with the extensive declassified US programmes . . ." and "Special action should be taken to ensure crucial access for European researchers to a small-scale program on the French and U.S. laser-driven ignition facilities."

Conclusions

The same potentially corrosive dynamic between technical "openness" and non-proliferation objectives exists in virtually every aspect of the "science-based stockpile stewardship" program. Despite its warmer, fuzzier name, this program remains nuclear weapons research, and all science, even nuclear weapons science, abhors secrecy. Over a decade or more, the SSMP has the potential of evolving into a proliferation debacle on the same scale as Eisenhower's Atoms for Peace program. And just as that program was a self-serving conceit (to mask U.S. abandonment of nuclear disarmament and its permanent embrace of nuclear deterrence), so to is the SSMP a kind of oxymoronic delusion, all the more so when one envisions not one but at least eight, and possibly more, such programs, all generating, using, and publishing data and computer codes across the full spectrum of weapons physics.

To those who argue that the United States will show discretion and restraint—even though the historical record of U.S. disclosures does not justify such a conclusion—who can guarantee that the Russian and Chinese and French and Indian programs will do likewise? And given the evolution and integration of computer networks and operating systems, the potential for near instantaneous global communication of complex software and data sets, and the possibilities for technical collaboration no matter where located (e.g., the missile designers in bankrupt Russia now working for Chinese weapon laboratories), the only secure defense against further proliferation of nuclear weapons related information is not to generate it in the first place. This is particularly true when the financial "barriers to entry" are quite steep, as they are in the case of NIF and several other proposed Stewardship facilities. Rather than encourage and stimulate such investments, the United States should discourage and stigmatize further explorations in "nuclear weapons science," and shrink U.S. nuclear weapon research capabilities to the bare essentials required to maintain an inventory of a few proven, reproducible designs pending international arrangements to eliminate nuclear weapons altogether.

CHAPTER 6

CAN A PROLIFERANT STATE ACQUIRE A NUCLEAR WEAPONS STOCKPILE WITHOUT TESTING?

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ABSTRACT

This paper provides technical background, insofar as it can be done in an authoritative, unclassified manner, leading to conclusions regarding the ability of proliferant nations to develop and stockpile with confidence nuclear weapons under the Comprehensive Test Ban Treaty (CTBT). Non-nuclear weapon states are likely to have to remain at the technical level of unboosted fission weapons without the ability to do nuclear tests, and even these will be much larger and use more scarce fissile material than would be the case if the nation could perform nuclear explosion tests. Two-stage fission-fusion weapons are essentially out of the question. Even the simplest nuclear weapon will leave substantial doubt in the minds of the potential military users unless it has been tested. Advanced nuclear weapon states such as Russia and France will be unable to design third-generation nuclear weapons such as x-ray lasers, which need no longer be feared as a threat to the United States. In addition to the major direct non-proliferation benefits of a CTBT, the political benefits are enormous; a CTBT aligns the United States and the other nuclear weapon states with the vast majority of non-nuclear weapon states in the world and allows them to assume a leadership position in measures against any state that conducts a nuclear weapon test or even acquires nuclear weapons in violation of the Non-Proliferation Treaty.

INTRODUCTION

President Clinton signed the Comprehensive Test Ban Treaty in New York on September 24, 1996, as did representatives of all five nuclear weapon states (NWSs), together with many others. Senate approval of ratification need not be long delayed. For instance, the Limited Test Ban Treaty of 1963 was signed by the United States, Great Britain, and the Soviet Union on August 5, 1963; formally transmitted to the Senate by President Kennedy on August 8; and the Senate approved ratification September 24 by a vote of 80 to 19.

BACKGROUND

A lot has been written on the CTBT, much of it by myself.[1]

In the present paper I do not discuss verification, or stockpile maintenance in the nuclear weapon states, or peaceful nuclear explosions, etc., but limit myself to the question of the title, "Can a proliferant state acquire a nuclear weapons stockpile without testing?" By definition, we are considering a state outside the Nuclear Non-Proliferation Treaty (NPT) either because it is not a signatory (as in the cases of India, Israel, and Pakistan), or if a signatory, is acting in secret violation of its obligations under the NPT (as was the case with Iraq).

It is evident that a proliferant state can indeed acquire a stockpile of nuclear weapons without nuclear explosive testing, but the question is what confidence it would have that one of the stockpile weapons would work, and what penalty is imposed by the inability to test. The inability to test poses a very significant obstacle to the confident acquisition of a nuclear weapon capability, as we will see, restricting a proliferant state to heavier weapons using more fissile material and to lower yields than would be the case if they could test.

A CAUTION

From the point of view of the great majority of non-nuclear weapon states (NNWSs) that have signed the CTBT or will do so, the purpose of the CTBT is to place further impediments to the spread of nuclear weapons to additional states, supplementing the barriers created by the NPT. Most states support also the barriers inherent in the CTBT to the advancement of nuclear weapons technology in the NWSs, where the NPT provides no impediment at all. We should be careful that actions under a CTBT not undermine the barriers to the spread of nuclear weapons so painfully erected by the NPT and the CTBT.

It is natural for those involved in nuclear weapons development in the NWSs to consider the designs of 30 to 50 years ago as obsolete, as indeed they are for their own purposes; but "obsolete" does not mean that these designs should be freely discussed or allowed to leak to NNWSs.

Even if the CTBT persists forever, we shall see that it does not constitute such an effective barrier to proliferation that weapon designs can be freely communicated; no test is needed for a weapon built according to a certified blueprint. Worse, there is some possibility that the CTBT era will come to an end, and it would be most unfortunate if negligence during its duration would facilitate the later spread of nuclear weapons.

Thus the text of this paper is less specific than the knowledge of its author.

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[1] "Monitoring and Verification of a CTBT," by R.L. Garwin, 3rd Pugwash Workshop on the Future of the Nuclear-Weapon Complexes of Russia and the USA, Moscow, Russia, March 24-26, 1996. "The Comprehensive Test Ban Treaty in September 1996" by R.L. Garwin, presented at the 46th Pugwash Conference on Science and World Affairs, Security, Cooperation, Disarmament: The Unifinished Agenda for the 1990s, September 2-7, 1996, Lahti, FINLAND. In addition, portions of this paper are based on one in preparation with V.A. Simonenko for a Pugwash Workshop in London, October 25-27, 1996.

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 status of a state toward the acquisition of advanced telecommunications capability, it would be ludicrous to expend much effort in monitoring its production of "vacuum tubes"—i.e., hot-cathode radioelectronic valves. For ordinary communications it is now both more effective and simpler technology 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 and widespread use of vacuum tubes.

In the 51 years since the detonation of the first nuclear weapons there have been successive revolutions in the ability to model physical systems on computers and an enormous expansion in the population with access to such tools. Many other aspects of technology have evolved over the half century, among them the widespread deployment of nuclear reactors for the production of electrical power, that each produce some hundreds of kg of plutonium per year (for a reactor powering the nominal million kilowatt generating plant). Furthermore, hundreds of tons of "weapon-grade" Plutonium (Pu) have been incorporated into nuclear weapons in the Russian and U.S. inventories, and tens of tons of weapon-Pu have been declared excess by the United States. On each side, at least 50 tons of Pu from weapons is expected to be declared excess by the year 2003, as a result of the Strategic Arms Reduction Treaty I (START-I) and START-II reductions, but there is already more than 100 tons of separated "civil Pu" from commercial reprocessing of spent fuel from power reactors.

Some 2 million kg of highly enriched uranium (HEU)—much of it 85-95% U-235—has been built into the Russian and U.S. weapon stockpiles or produced for use in reactors for propulsion of ships or submarines, and this HEU is very 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 kg of Pu or 60 kg of HEU used in the first two nuclear explosives in 1945), constraints on the spread of nuclear weapons are more legal and political than technical—with the exception of the extremely important NPT barriers to transfer of weapons-usable material, especially plutonium and high-enriched uranium. The political and legal barriers are thus all the more important, including the CTBT.

The world's first two nuclear weapons typify two approaches:

- "Gun assembly," in which two sub-critical masses are brought together in some milliseconds (10^{-3} seconds) by ordinary propellant such as is used to propel artillery shells.
- Implosion assembly, in which high explosive with similar energy content to propellant but much higher speed of reaction (detonation) is used to propel or to compress fissile materials to exceed a critical mass in a time measured in microseconds (10^{-6} seconds) rather than milliseconds.

The world-class team assembled at Los Alamos in 1943 to actually design and build the nuclear weapons from the high enriched uranium and the plutonium that were to become available from the production facilities perfected the technology for the gun-type explosive, and then faced the unexpected need for a faster assembly system because of the large spontaneous neutron production from plutonium. In addition to solving design problems and working with materials that are highly radioactive and chemically reactive, the Los Alamos group (with Peierls, Frisch, and

Serber as forerunners) avoided such pitfalls as apparently trapped Heisenberg[2] into an estimate that the critical mass would be tons of U-235.

Just about one bare-sphere critical mass of HEU was used in the gun-type weapon, and only about 0.6 critical masses in the implosion weapon. In both cases neutron sources were devised that would begin emitting neutrons at the appropriate time, and rapidly enough so that the chain reaction would with high probability be initiated before the material disassembled mechanically at speeds similar to that with which it was assembled.

While it is possible to produce weapons of this type without a nuclear explosion test, it is not the height of prudence to stockpile them without non-nuclear tests. The tests to validate an exact copy are different from those that might be required in a native development. But anyone seeing the unclassified pictures of mangled steel tubes that were supposed to be uniformly imploded by early attempts at implosion driven by high explosive begins to get a feeling for the problems inherent in an indigenous nuclear weapon 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 last few years has it been generally accepted, as was briefed by U.S. weapons scientists 20 years ago in support of the NPT[3] that nuclear weapons can quite readily be made from civil plutonium. This was first published at length by Carson Mark,[4] and the CISAC study[5] notes the problems added by civil plutonium for weapon production—high neutron background, more highly penetrating gamma rays, and increased heat evolution—and concludes "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." This is not to say that making an implosion weapon of civil plutonium is easy, but that it is not much more difficult than making an implosion weapon from "weapon-grade" Pu-239, and the difficulties involved are not of a different type.

The fact that there are no national nuclear weapons stockpiles built of civil plutonium does not in any way reduce the possibility that separated civil plutonium could be used to make one, a few, or even hundreds of nuclear weapons. It is all the more important that we have a CTBT to prevent the experimental verification of designs using civil plutonium.

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[2] J.L. Logan, "The Critical Mass," in American Scientist, May-June 1996, pp. 263-77.

[3] R. Selden, "Reactor Plutonium and Nuclear Explosives," December 1976.

[4] J.C. Mark, "Explosive Properties of Reactor-Grade Plutonium," Science and Global Security, vol. 4, no. 1, 1993, pp. 11-128.

[5] J.P. Holdren (Chair), C.M. Kelleher, W.K.H. Panofsky, J.D. Baldeschwieler, P.M. Doty, A.H. Flax, R.L. Garwin, D.C. Jones, S.M. Keeny, J. Lederberg, M.M. May, C.K.N. Patel, J.D. Pollack, J.D. Steinbruner, R.H. Wertheim, and J.B. Wiesner, "Management and Disposition of Excess Weapons Plutonium," Report of the National Academy of Sciences, Committee on International Security and Arms Control, January 1994, pp. 32-33.

INSIDE A NUCLEAR WEAPON

The first design of a nuclear weapon in the United States was the "gun assembled" system, by which some 60 kg of high-enriched uranium[6] was moved by normal artillery propellant in a short gun barrel from a "subcritical" configuration into a more compact configuration so that only a relatively small fraction of the neutrons from each fission escaped. A nuclear explosion can take place only when an unbounded fission chain reaction can occur, in which a neutron causes fission, liberating two or three neutrons, more than one of which goes on to cause another fission, and so on. In the fissionable materials used in nuclear weapons—U-235, plutonium, and U-233—the fission is caused by fast neutrons, which go only a distance of 7×10^{-10} cm before colliding with a nucleus, so that each doubling of the neutron population occurs in about 0.01 microseconds. The power of compound interest is such that if one begins with a single fission, the time required for 80 such doubling intervals to cause fission of 1 kg of fissionable material (approximately 2.5×10^{24} nuclei) is less than one microsecond. The result of such rapid energy release [17 kilotons high-explosive equivalent (HEE) per kilogram of material fissioned] is not only the blast effect that is similar to the actual detonation of that amount of high explosive, but also the radiation of a substantial fraction of that total as thermal radiation, giving rise to combustion of wood, etc., out to a radius ranging from kilometers to tens of kilometers, depending on the yield. In addition, the neutrons left over that escape from the nuclear explosive, together with the gamma radiation from the fission process itself, and the fission products contribute an enormous source of "prompt" radiation.

THE ACQUISITION OF A NUCLEAR WEAPON

The separation of U-235 from the 140-times as abundant ^{238}U is a costly and difficult process, which was not sure to provide fissile material as rapidly as was thought to be needed in the second World War. Accordingly, with the discovery of the artificial element plutonium, manufacturable in natural-uranium nuclear reactors by the parasitic capture of neutrons on ^{238}U, production reactors were built at Hanford, Washington to produce such plutonium. The first Hanford reactor with a thermal power of 250 megawatts (MW) produced about 250 g of Pu per day, of which about 6 kg was used in the bomb first tested at Trinity (New Mexico) July 16, 1945. An identical weapon was detonated over Nagasaki, four days after the gun-type bomb was used at Hiroshima. However, Pu cannot be used in a gun-assembled weapon, since the metallic charges are moved too slowly by the propellant used in artillery or naval guns.[7]

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[6] More than 90% U-235, although HEU is a term used to refer to anything more than 20% U-235.

[7] U-235 is hardly radioactive at all, half of it surviving 700 million years. On the other hand, the most common plutonium isotope in nuclear weapons (Pu-239) has a half-life of 24,000 years—almost 30,000 times shorter than that of U-235. Furthermore, Pu-239 is accompanied to some extent by Pu-240, which has a "spontaneous fission" decay that injects neutrons continuously into any mass of Pu. Thus, the relatively slow (milliseconds) assembly of metallic blocks in a gun would allow time for such neutrons to start the chain reaction when the assembly is barely supercritical, leading to the generation of enough energy to fairly gently blow the material apart

Thus the implosion method of assembly was mandatory for the plutonium weapon, in which the assembly occurs on a time scale of microseconds or tens of microseconds—so to speak, between the individual stray neutrons. Nevertheless, there was a significant probability for the Nagasaki bomb that a spontaneous neutron would occur at the worst possible time, and even that would have led to a yield no less than 1 kt.[8]

In the years following 1945, innovations were made to reduce the amount of costly fissionable material needed for nuclear weapons and to improve the safety. The initial configuration was thus much farther from "criticality" or unbridled neutron multiplication, and was hence safer against undesired nuclear explosion. Nevertheless, one could conceive of accidents in which the high explosive would detonate at one point, for instance by the impact of a rifle bullet on the explosive, or accidental dropping of the nuclear bomb, as happened several times. Thus almost from the beginning it was required that nuclear weapons be safe against such undesired nuclear explosions. For some years this was accomplished by systems in which the fissile core of the weapon would be kept separate from the explosive and inserted only during the flight of the aircraft. This impeded military readiness and flexibility, so later weapons were designed with internal safing systems or which were "inherently" one-point safe.

THE BOOSTED FISSION WEAPON

In 1951, the United States first tested the "boosting concept" under which a small amount of thermonuclear fuel was added to the ordinary fission bomb. This is currently accomplished by the use of a gas mixture of deuterium (D) and tritium (T) within the hollow "pit" of an implosion weapon. At the temperatures reached in the incipient fission explosion, a fraction of the D nuclei react with the T nuclei to form ordinary helium nuclei, plus neutrons of 14 million volt energy, which are extremely effective at causing fission in the fissionable material in the neighborhood. Thus the relatively small amount of energy from the thermonuclear reaction produces a substantial number of neutrons and steps up or "boosts" the fission reaction to a higher level. The boosting concept increases the safety of such an explosive, since otherwise to reach the yield that can readily be achieved by boosting, a larger amount of fissionable material would need to be used.

However, boosting adds its own problems to nuclear weapon design and also to maintenance, because hydrogen reacts chemically with plutonium or uranium. Furthermore, the artificial isotope of hydrogen, tritium, has a 12.3 year half-life, so that tritium produced in nuclear reactors and deployed with the nuclear weapons must be renewed on a scale of some years. Even for

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without a yield in the kiloton range.

[8] Mark, J.C., "Explosive Properties of Reactor-Grade Plutonium," by J.C. Mark in Science & Global Security, 1993, Vol. 4, pp. 111-128. Garwin, R.L., "Technical Interpretation" and "Explosive Properties of Various Types of Plutonium," in *Managing the Plutonium Surplus: Applications and Technical Options*, R.L. Garwin, M. Grubb, and E. Matanle, eds., pp. 1-22, NATO ASI Series, 1. Disarmament Technologies, Vol. 1, November 1994.

Russia and the United States, tritium decay imposes the requirement for continued production of tritium if nuclear weapon numbers do not fall with time faster than the decay rate of tritium.[9]

TWO-STAGE THERMONUCLEAR WEAPONS

In 1952, the U.S. MIKE test demonstrated with its ten megaton yield the concept introduced in early 1951 by Edward Teller and Stanislaw Ulam, by which the energy from a "primary" nuclear explosion is used to assemble a "secondary" charge of thermonuclear fuel. Initially that charge was liquid deuterium, and the U.S. built as well several Emergency Capability Weapons (named "Jughead") deliverable by the B-36 aircraft. These were soon replaced by "solid-fuel" thermonuclear weapons, using deuterium that was solidified by chemical binding to lithium, in particular to the naturally occurring lighter isotope of lithium—^{6}Li that had to be separated from the more abundant ^{7}Li. ^{6}Li has an avidity for neutrons such that the D-D reaction that leads 50% to ^{3}He plus neutron and 50% to ^{3} H plus proton, is an important contributor to the thermonuclear energy and neutron generation. In particular, the neutrons captured on ^{6}Li produce ^{3}H (tritium) plus ^{4}He, and the tritium goes on to react with the deuterium fuel.

It has long been a rule of thumb that many thermonuclear weapons typically produce about half of their total energy from the thermonuclear fuel and half from the fission of uranium (natural or depleted or enriched) in the proximity of that thermonuclear fuel.

The nuclear weapon stockpiles of the NWSs are typically either boosted single-stage weapons or two-stage weapons as described here.

THE TRADITIONAL ROLE OF NUCLEAR-EXPLOSION TESTING

In an unconstrained environment, nuclear testing has served the following functions:

- Development of new models of nuclear weapons.
- Production verification of a developed design.
- Proof of concept of some new weapon idea.
- Study of weapon *effects*.
- Obtaining physics results related to weapon design.
- Non-weapon physics.
- Demonstration of peaceful nuclear explosion (PNE) effects.
- Development of PNE explosives.
- Conduct of PNEs for non-military benefit.

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[9] Indeed, the United States is committed a rate of reduction faster than that, even if by the year 2003 one only has the START-I level of some 8000 nuclear warheads. And if one is optimistic about reducing nuclear weapon holdings, it may be that U.S. and Russian warheads could be reduced to 2000 or fewer total warheads on each side by that time. This has significant consequences for the required tritium production or acquisition capability.

The United States typically has used some six nuclear explosion tests in the development of each new model of nuclear weapon, while France is said to have used some 22 per model. The study of a new concept might include the first tests on the transfer of energy by radiation for use in multi-stage weapons, or tests that might lead eventually to a nuclear-weapon pumped x-ray laser.

As for weapon physics, such nuclear explosion tests might be used to measure the properties of materials ("equation of state" or opacity) in the relevant range of pressure and temperature that can not be reached by high explosives. Non-weapon physics tests might include such interesting questions as the existence of metallic hydrogen, the properties of metals like iron when squeezed to ten times their normal density, and the like.

To the extent that all knowledge is valuable and has beneficial applications, such experiments have been pursued in the past. However, they have not in any formal way been put into competition with other uses for the same dollars, and many of the experiments would have failed that test.

An additional set of experiments and applications of nuclear explosions is to be found in the "Peaceful Nuclear Explosions," toward which the United States dedicated more than 20 nuclear explosions, and the former Soviet Union more than 100. We shall return to these later, stating now that the United States found no application that was economically competitive with accomplishing these missions by conventional means. And in 1995, the current Minister of Atomic Energy in Russia (Viktor Mikhailov) in an published interview commented on the U.S. and Soviet PNE programs, "So far, they have not proven to be economical." Still, Mikhailov is reluctant to ban any tool of scientific progress.

MORE ABOUT NON-NUCLEAR-EXPLOSION TESTING

Of course, much of the maintenance of stockpile weapons is done without nuclear explosion testing, and indeed very few tests thus far have been for the purpose of verifying that weapons are still all right. In the non-explosion testing realm, a whole panoply of techniques has been used both for development and for monitoring. In the present context of proliferation, it is the development that is of interest.

First, there are the various quality control methods used largely in production to verify that the materials of fabrication (or refabrication) are up to standard. To the extent that the individual component can then be fully tested (as is the case of the detonators for the high explosive), additional confidence is available.

The high explosive itself is tested 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 for the fabrication of metal parts, pressure vessels, and the like.

Even the flight of a nuclear weapon can be mimicked by dropping a bomb with an inert weapon or launching a missile, so that the "weapon" itself goes through the entire stockpile-to-target sequence (STS) as would a real weapon, right up to the point of firing the high explosive. High-fidelity telemetry can be used, or some of the warheads or bombs could be recovered by parachute rather than 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" or other means of determining the performance of the pit or partial pit—that is, the fissile material surrounded by a metal shell to constitute the "sealed pit" and driven by high explosive. The designer wants to prescribe the position vs. time of the inner surface of the plutonium shell, and this is measured in multiple experiments on partial pits by the use of numerous fine "pins" or metal contacts. Laser imaging of the imploding pit is also used, and all of these techniques can be useful to ensure that high explosive in the actual weapons in storage as well as HE for remanufacture is within original production specification.

If actual plutonium needs to be used in experiments, the experiments can be done at reduced scale, so that of the approximately three neutrons from fission, less than one remains within the assembly to cause further fission, and the system will be subcritical with no energy release. Because of the toxicity of Pu arising from its natural radioactivity, such experiments must either be done underground[10] or, alternatively, experiments involving tens or even hundreds of pounds of high explosive could well be done in rugged steel containment above ground, as at Los Alamos for instance.

Many modern nuclear weapons have a boosted primary; for it to work properly, the design conditions must be achieved for the boost gas and the fissile material. Uncontrolled mixing between them must be avoided, and that mixing may depend upon the surface condition of the plutonium.

A lot of information can be obtained in an actual nuclear test, and some of that information is not available without nuclear explosion testing. Nevertheless, so called "hydrotesting," in which inert material is used, or material at "subscale" so that one does not reach criticality, can allow the gas and the metal to be brought to the stage that in a larger assembly or with the correct material would result in a nuclear chain reaction and boosting. Much use is made of flash radiography by pulsed x-ray systems in order to observe the interior of such hydrotests.

DOES A CTBT IMPEDE NUCLEAR PROLIFERATION?

A CTBT greatly impedes vertical proliferation—that is, the development of thermonuclear weapons or weapons using substantially modified design. The United States need no longer fear the development of surprisingly new weapon concepts by Russia, such as the x-ray laser or other third-generation nuclear weapons.

It also has 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 weapon that was used at Hiroshima and that was built in six copies by South Africa before that nation destroyed them and became a non-nuclear weapon state; or a U-235 implosion device, for economy of material.

For the use of plutonium, even the choice of some supposedly sure-fire configuration would not provide a lot 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 them would work. The largest non-proliferation influence of a CTBT, however, is political, but very important. As the nuclear

[10] DOE had scheduled two subcritical experiments for June 18, 1996 and September 12, 1996, and more during the next fiscal year. In a DOE fact sheet of 10/30/95 available on the Internet at DOE.gov it is announced that the 1996 experiments will be conducted in the "Lyner facility," 980 feet below ground at the National Test Site.

weapon states see it in their national security interest to reduce the number of nuclear weapons held by others in the world (and perforce their own), 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.

Even without testing, they could squander the good will and political support that might otherwise be theirs (for instance, by not reducing severely the number of nuclear weapons), but 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.

A universal CTBT 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, having a nuclear test explosion.

DISCUSSION

Several of the potential proliferant nations—Iran, Iraq, India, Pakistan, and Israel—have scientific and engineering resources at a very high level. If a sufficient team can be put together to support what is represented as the national security against an external threat, and if adequate experimental and computational resources are provided, there is little doubt that such a state could acquire as many gun-type weapons as it has material to supply them. Nor do these gun-type weapons need to be very heavy, as indicated by the fact that such systems have been used in artillery-fired projectiles.

As for implosion weapons, one should distinguish between problems of design and problems of implementation. Although Soviet scientists had a design of their own in 1949, with all the peril failure would have entailed for them, they chose for their first test to fire a copy of the U.S. Nagasaki bomb, which worked at the Soviet test site as it did at Nagasaki and New Mexico. A proliferant nation, however, would presumably prefer to have a weapon of smaller size and mass, for which there are many examples, although with less detailed information published than for the original Fat Man. They might try to use plutonium in the form of a hollow shell, since it is unclassified information that such hollow "pits" are common in U.S. weapons.

It is clear that the implosion system has to be of much higher quality to assemble metal originally in the form of a hollow shell into a compact ball, and the diagnostics for such assembly are not trivial. If one assumes the use of flash radiography with multi-MeV electrons to produce the x-rays, it is possible that the military customers might have enough confidence in repeated experiments and designs to accept the creation of an untested arsenal of some dozens of weapons. But very likely they would not.

To go beyond pure fission weapons to boosted weapons brings one to a region in which the perils may well outweigh the gains. Material for boosting occupies regions of prime value for the fission chain reaction itself, and with boosting uncertain, a state is unlikely to take the risk. It would probably stay with pure fission weapons.

Computer codes, of course, can help, but only if they are benchmarked against reality. In this respect, a general purpose code that covers an enormous range and has been benchmarked by advanced nuclear weapon states against past nuclear explosion data as well as inertial confinement fusion, for instance, would be valuable to the proliferant state.

CONCLUSION

To have very high confidence of the workability and yield of its untested nuclear stockpile, a proliferant state may well choose to remain with the U-235 gun-type weapon, using some 60 kg of U-235 per weapon. A state that is less risk averse might opt for a plutonium weapon containing some 6 kg of weapon Pu or somewhat more of civil Pu. With weapon-grade plutonium it would probably achieve a maximum yield considerably less than 20 kt, especially in smaller high explosive systems, and with civil Pu, while the maximum yield might be similar, the actual yield might often be in the one kiloton range. With greater computational and theoretical ability, and greater use of diagnostic tools, a weapon made with civil plutonium could achieve much higher yields than 1 kt.

Boosted fission weapons are less likely to figure in an untested stockpile, and two-stage weapons are essentially out of the question for a stockpile in which one could have some confidence without nuclear explosion tests.

It is not possible to rely on a CTBT to totally prevent the acquisition of an indigenous stockpile of nuclear weapons by a proliferant state, nor can the CTBT prevent their theft of an intact nuclear weapon. Nevertheless, a CTBT is exceedingly important to prevent and to counter proliferation of nuclear weapons because it aligns the nuclear weapon states with the vast majority of non-NWSs and provides legitimacy for their leadership of measures to counter the acquisition not only of nuclear weapons by additional states but especially biological and chemical weapons.

These indirect non-proliferation benefits of the CTBT are enormous, and should be locked in by an early ratification of the Treaty. In addition, the direct non-proliferation aspects of a CTBT are significant, as is the massive impediment it poses to the ability of our nuclear-weapon competitors to develop new nuclear weapons of advanced type.

CHAPTER 7

SEISMOLOGICAL METHODS OF VERIFICATION AND THE INTERNATIONAL MONITORING SYSTEM

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INTRODUCTION

This paper gives general background on seismology and on test ban monitoring, and reviews the main steps that must be taken by the International Monitoring System (IMS) to carry out seismological monitoring for the Comprehensive Test Ban Treaty (CTBT). General comments are included on the primary and auxiliary networks of the IMS, and on supplementary data that may be used by the IMS.

The most important technical issues in monitoring a CTBT all became apparent between 1958, when the so-called "Conference of Experts" was convened in Geneva, and 1963, when the Limited Test Ban Treaty (LTBT) was quickly negotiated, signed, and entered into force. In 1963 there was a general perception that seismological methods for monitoring underground nuclear explosions were inadequate—a view that helped to prevent the conclusion of a CTBT in this early period. The text of the CTBT opened by the United Nations for signature on September 24, 1996 is about fifty times longer than the text of the LTBT of 1963, in large part because of the extensive provisions (in the CTBT) for verification. And the formal treatment of verification issues in the CTBT will continue to be developed and documented in extensive detail over the next few years, because this new treaty and its Protocol mention six different Operational Manuals, not yet written, that will spell out the technical and operational requirements for:

- Seismological Monitoring and the International Exchange of Seismological Data;
- Radionuclide Monitoring and the International Exchange of Radionuclide Data;
- Hydroacoustic Monitoring and the International Exchange of Hydroacoustic Data;
- Infrasound Monitoring and the International Exchange of Infrasound Data;
- the International Data Centre; and
- On-Site Inspections.

The IMS seismographic stations and the associated International Data Centre (IDC) can be expected to provide data adequate to monitor for underground explosions down to about magnitude 4, which, for an explosion executed in the usual way without making special efforts at concealment, corresponds to a yield of around half a kiloton. However, it is clear from the negotiating

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record that the United States desired a significantly better monitoring capability,[1] often summarized as "a few kilotons, evasively tested," which would correspond to seismic signals of about magnitude 3. Assessments as to whether a given monitoring system is adequate for treaty verification, or not, will therefore be driven by perceptions as to the plausibility of efforts at treaty evasion. U.S. monitoring goals will apparently not be met by the stations of the IMS alone, but can be met by the use of additional stations.

GENERAL BACKGROUND ON SEISMOLOGY

Up to 1963 when the LTBT was negotiated, very few underground nuclear tests had been carried out. Seismographic data then consisted of paper analog recordings from a few hundred stations around the world—data derived almost entirely from earthquakes and chemical explosions. But today, more than thirty years later, we have had the practical experience of monitoring over 1500 underground nuclear test explosions.[2] And today, seismology is based upon several thousands of stations acquiring data that is recorded digitally so that the signals can easily be processed on computers. Such data in many countries are gathered electronically into nationally- and internationally-organized data centers, for purposes of scientific research and for the study of earthquake hazard and hazard mitigation, as well as for nuclear explosion monitoring. A growing trend since the mid-1980s has been to use stations equipped with sensors that respond to a broad band of frequencies, using recording systems of high dynamic range so that both weak and strong signals are faithfully documented. Hundreds of such stations now exist, sending their data to centers from which data segments may be freely accessed, and hundreds more such stations are being planned for earthquake studies.

The thousands of seismologists who use such data have learned to identify and use several different seismic waves. Each wave generates—indeed is—a physical motion of the ground at the site where it is recorded, and each wave propagates with distinctive characteristics from the seismic source to the seismometer, which may be less than 10 km away, or on the other side of the Earth, more than 10,000 km away.

The fact that there are so many different types of seismic waves, each with its distinctive characteristics that vary strongly over the distance ranges for which that particular wave is observable, is, on the one hand, an enormous burden in the effort to explain seismology to newcomers; and on the other hand, the essential key to the effectiveness of seismology as a monitoring tool, because so much information about the seismic source is potentially available.

The seismic waves of principal interest in CTBT monitoring are labeled as *P, pP, pS, Pg, Pn, S, sS, sP, Sn, Lg, Rg, Love*, and *Rayleigh*. Use is sometimes made of *PL, PP, SS* and *PKP*. Numerous additional waves are used to probe details of the Earth's internal structure—knowledge of which is required in order to interpret the waves used in monitoring explosions and earthquakes.

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[1] For example, the Geneva working paper CD/NTB/WP.53 of 18 May 1994 stated the U.S. position that: "The international monitoring system should be able to . . . facilitate detection and identification of nuclear explosions down to a few kilotons yield or less, even when evasively conducted, and attribution of these explosions on a timely basis."

[2] A few nuclear explosions have been conducted that assist in evaluating evasion scenarios—for example, by carrying out the explosion in an underground cavity.

The basic reason for the effectiveness of seismology as a monitoring technology is simply that the different types of seismic sources—earthquakes, explosions (both chemical and nuclear), volcanic eruptions, mine collapses—have been found to differ in their ability to generate the various types of seismic waves. It has therefore been possible to develop procedures for making measurements from seismograms, and then to analyze the measurements objectively, in order to identify the nature of the seismic source.

The different types of seismic motions are traditionally grouped into teleseismic waves and regional waves. An understanding of these terms is essential for an understanding of the practical problems of CTBT monitoring—and of solutions to these problems. The underlying reason for the grouping into teleseismic and regional is a property of the Earth associated with a zone of lower velocities and/or lower velocity gradient in the upper mantle, beneath which is a region of higher velocity and/or higher gradients at greater depths. The net effect is that the most important seismic wave—which is essentially a type of sound wave, labeled as "*P*" because it is the first ("primus") to arrive—is defocussed and thus has low amplitudes at distances within the range about 1000 to 2000 km from a seismic source. Figure 7.1 shows schematically the way in which the amplitude of seismic waves at first decreases and then increases as the waves propagate to greater distances. Waves beyond 2000 km are teleseismic, and *P*-waves throughout most of this range are simple, having very little change in amplitude with distance out to more than 9000 km.

The sound waves of seismic motion known as *Pg* and *Pn* are regional in the sense that they do not propagate to teleseismic distances. But the word "regional" here carries the additional implication that such waves are dependent on local properties of the Earth's crust and uppermost mantle—which can vary quite strongly from one region to another. Regional waves can have large amplitudes (and can thus be easily detected if a seismometer is operated at a regional distance from a source of interest), but they are complex and thus harder to interpret than teleseismic waves. An extensive dataset of seismic signals from a given region must first be acquired and understood before regional waves recorded in it can be interpreted. (Sometimes, however, the data from a second, more easily accessed region, can be used to aid in the interpretation, if the two regions are geologically similar.)

Seismic motions can also be grouped into body waves and surface waves. *P*-waves are a type of body wave, and they are the strongest signals generated at the site of an underground nuclear explosion. The body-wave group includes the type of shearing motion known as *S*, which propagates about 40% more slowly than *P*. The body waves used for monitoring typically have wavelengths in the range from a few tenths of a km, up to about 10 km. The difference between *P*-waves and *S*-waves, apart from their speed, is that when *P*-waves arrive, the ground moves in a direction aligned with that in which the wave is traveling; but when *S*-waves arrive the ground moves sideways, i.e., perpendicular to the direction of travel. Thus, for a *P*-wave arriving from the North, the ground can move either North or South. But for an *S*-wave arriving from the North, the ground moves East or West, and/or up or down. *S*-waves are typically the strongest signals generated in the vicinity of an earthquake source. The work of identifying the various seismic waves in a seismogram is greatly assisted if the ground motions are recorded for three different directions, typically up/down, North/South, and East/West.

The key methods of event identification, all discovered too late to have any impact in the early period of CTBT negotiations (1958–1963), entail comparison of the amplitude of different seismic waves. Thus, slow-traveling surface waves (known, after their discoverers, as Rayleigh waves and Love waves), with wavelength several tens of km long, are generated much more efficiently by shallow earthquakes than by explosions. This result was obtained in academic research

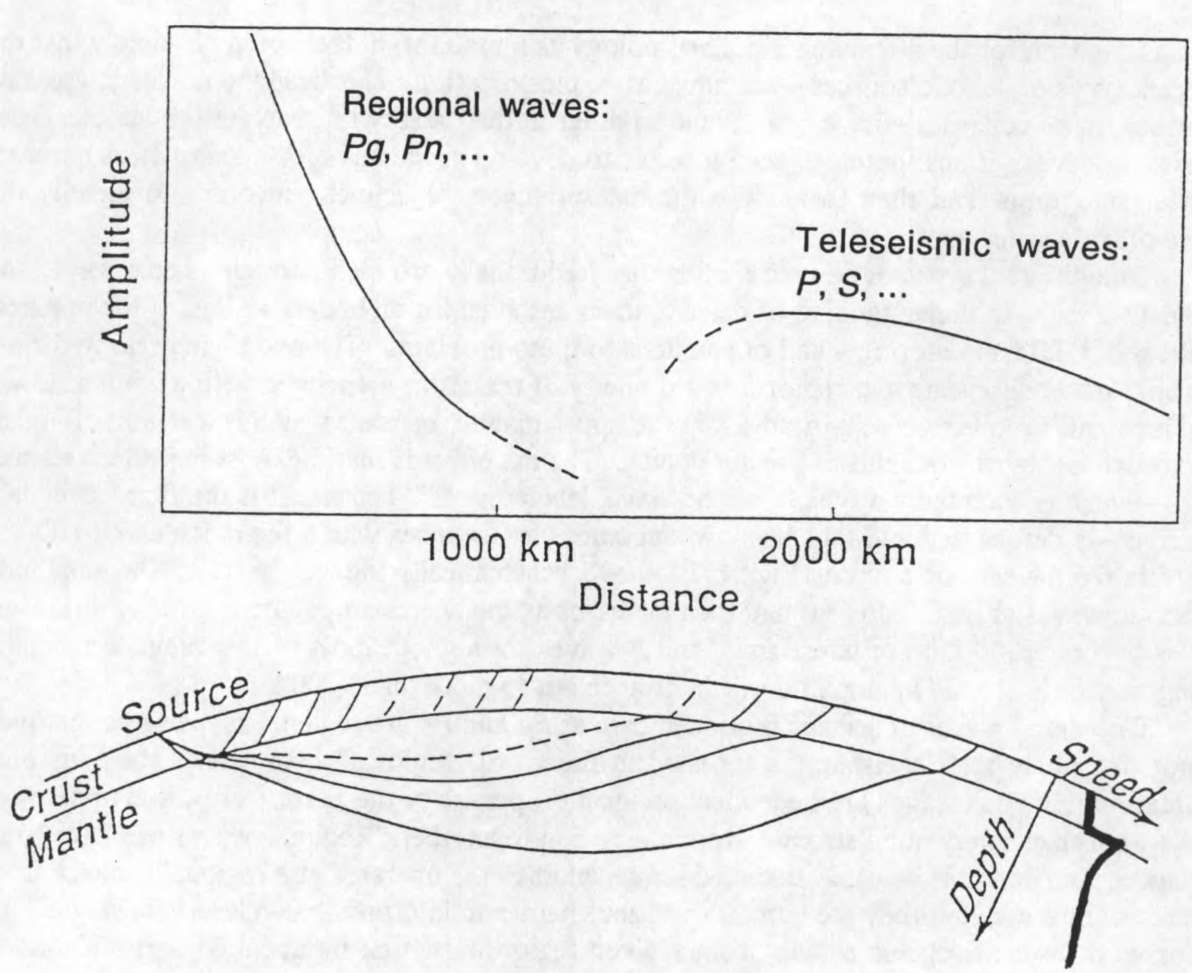

Figure 7.1: Seismic wave amplitudes at regional distances are strong near the source but decrease and can disappear at about 1000 km, then resume at around 1500–1800 km and vary little to greater (teleseismic) distances. The reason for this behavior is the variation in seismic wave speed with depth in the Earth (heavy line, bottom right), which affects the path of propagation of the fastest seismic waves (lower section, showing ray paths of propagation in the crust and upper mantle). For decades following the LTBT of 1963, when nuclear testing was carried out underground and in-country monitoring was not permitted, monitoring was conducted by National Technical Means (NTM) using teleseismic signals. With the CTBT and the permitted use of in-country stations, attention returns to the study of regional waves since they provide the strongest signals. Regional waves may be the only detectable seismic signals, from small magnitude sources. Adapted from Romney (1960).

in the mid-1960s, became thoroughly documented over the subsequent ten years, and proved (during the era of underground nuclear testing) to be a reliable method for discrimination using teleseismic signals for sources down to magnitudes in the range 4 to 4.5. Over the last 15 years there has been growing recognition that regional *P*-waves (such as *Pg* and *Pn*) are often generated much more efficiently by explosions than by earthquakes, in comparison to the excitation of another type of regional wave, namely *Lg* (which is a group of shear waves, often having the strongest amplitude on a seismogram, that are trapped in the Earth's upper layers). If signals can be recorded with high enough quality, then the comparison between regional *P* and *Lg* often enables discrimination between earthquakes and explosions to be carried out down to low magnitudes—even lower than magnitude 3.

GENERAL ASPECTS OF COMPREHENSIVE TEST BAN TREATY MONITORING

The main part of the CTBT dealing with verification is Article IV, of which ¶1, in its entirety, reads as follows:

> In order to verify compliance with this Treaty, a verification regime shall be established consisting of the following elements:
> (a) An International Monitoring System;
> (b) Consultation and clarification;
> (c) On-site inspections; and
> (d) Confidence-building measures.
> At entry in force of this Treaty, the verification regime shall be capable of meeting the verification requirements of this Treaty.

Discussion of methods of seismic monitoring must eventually undergo a transition from those that are *possible* to those that must be *implemented*. The underlying difficulty is making the trade off between simple methods of analysis that are robust, objective, unchanging, and easily explained to people who lack technical training, and those more sophisticated methods which, to a highly-trained audience, are demonstrably more effective but that require a greater degree of subjective expert judgement and which will surely change from year to year as methodologies improve. The very existence of so much practical and specialized experience, and of so many seismological resources generating potentially useful data, can complicate the choice of methods of analysis and the selection of stations from which data are used.

The CTBT will in practice be the subject of three types of monitoring, namely:

- that carried out directly by the IMS;
- that carried out by National Technical Means by various countries, all having rights (per CTBT Article IV, ¶34 & 37) to use National Technical Means (NTM) as a basis for requesting an on-site inspection; and
- that carried out by numerous private or national organizations, each acquiring and analyzing data of some relevance to CTBT monitoring.

The third of these types of monitoring, associated with what the CTBT (Article IV, ¶27 & 28) calls supplementary data, is more nebulous than the other two types, but is nevertheless very important, for example as a confidence-building measure and as a source of much basic information and many skills the IMS will need. Vast regions of North America, Europe, the Western Pacific, and parts of Central Asia, North Africa and the Middle East are now being monitored closely for earthquake activity down to magnitude 3 or lower, by organizations whose data and methods of analysis are freely available. It is from this type of earthquake monitoring, and from field programs to study the structure of the crust and uppermost mantle, that the broad seismological community has acquired its knowledge of regional wave propagation; and familiarity too with the differences between seismic signals from earthquakes and from blasting associated with the mining, quarrying, and construction industries. Seismology is still a growing science, likely to be driven indefinitely by the need to understand and mitigate earthquake hazards. Individual earthquakes can still kill many thousands of people, and are one of the few catastrophic phenomena capable of matching the trillion-dollar levels of damage a single nuclear weapon can inflict. It can hardly be emphasized too much that explosion monitoring for the CTBT will be greatly improved in the long term by linking the CTBT IMS to organizations responsible for earthquake monitoring. Supplementary data may also be used to meet U.S. monitoring goals.

The work of monitoring for underground nuclear explosions using seismological methods can usefully be broken down into the separate steps of:

- detecting seismic signal;
- associating into a single group the various seismic signals that are generated from a common seismic source;
- estimating the location of that source, and the uncertainty in the location; and
- identifying the seismic source (whether earthquake or explosion), together with estimating the source size. The role of the IMS, vis-à-vis identification, is that of "Assisting individual States Parties . . . with expert technical advice . . . in order to help the State Party concerned to identify the source of specific events." (CTBT Protocol, Part I, ¶20(c).) The responsibility of identification is left to each State Party, as discussed further, below.
- Seismology also plays a role in on-site inspections and in confidence-building measures.

It follows that much of the IMS work will focus on the development of routine procedures for data acquisition and data analysis of all detected events. But historically it is known that monitoring for nuclear explosions results in the need, in practice, to pay special attention to what are called "problem events," which by definition are events that are detected but that cannot be unambiguously identified routinely as not being nuclear explosions. Such problem events become targeted for special efforts in the acquisition of additional data, and for the execution of additional data analysis. In writing the Operational Manuals for the IMS, care will be needed in spelling out appropriate procedures for addressing problem events, since, by their very nature, singling out a detected event as a problem (requiring more than merely routine analysis) entails a preliminary effort to identify the event—which is not an IMS function.

We are here at the heart of a structural difficulty in spelling out the work of the IMS, since the selection of problem events for further analysis entails in part a political judgment as well as a technical judgement about the possibilities for the nature of the event. Different countries will likely reach different conclusions on how to treat a problem event, given the territory on which the event appears to be located, and given the possible predisposition of one or more State Parties to believe that serious efforts might somewhere, someday, be taken to conceal a small nuclear explosion. For example, much has been written on the possibility (or impossibility) of masking a nuclear explosion with a large chemical explosion, and/or reducing its seismic signals by carrying out the nuclear explosion secretly in a large underground cavity that has been sealed to prevent the escape of radionuclides. We may note Article II ¶51 of the CTBT, which states (with reference to the Technical Secretariat) that "The Director-General may, as appropriate, after consultation with the Executive Council, establish temporary working groups of scientific experts to provide recommendations on specific issues." However, if problem events arise with great frequency, an advisory group convened to deal with them could be overwhelmed. Only time will tell how much of the work of attempting to identify problem events will be done by the IMS, and how much will be done by States Parties. The question for the near future is: What levels of analysis associated with efforts at identification will be spelled out in the IMS Operations Manuals?

With the above as background, I turn to brief reviews of the specific steps in CTBT monitoring by seismological methods.

DETECTION OF SEISMIC SIGNALS

The CTBT Protocol lists 50 sites around the world at which either a three-component seismographic station or an array of seismometers is to be operated, sending uninterrupted data on-line to an International Data Center. It is generally understood (though not stated) that this is a digital datastream, available at the IDC in near real time. These stations constitute the primary network, deployed at sites illustrated in Chapter 8, Figure 8.1. Much experience is now available from a network of similar size, operated since 1 January 1995 as part of the Group of Scientific Experts Technical Test #3 (GSETT-3, carried out under the auspices of the Conference on Disarmament).

An array consists typically of a number of separate sensors, between about 10 and 30, spaced over tens of square km and operated locally with a central recording system. From the detection of slight differences in the arrival time of a particular seismic wave at the different sensors, it is possible to infer the direction from which the wave must have come, much in the way our ears and brain can tell us the direction from which we hear specific sounds. For seismic waves coming from a pre-specified direction, array data can also be processed by a system of signal delays at each sensor and then signal summation, to improve the strength of coherent signals and to reduce the incoherent noise. The resulting improvement in signal-to-noise ratio enables a single array to detect teleseismic signals approximately down to magnitudes 4 to 4.5 (Jost et al., 1996), and significantly lower in some cases if the array is well sited. The magnitude here refers to an amplitude measurement made on the teleseismic *P*-wave. It is symbolized as m_b. Seismic magnitudes are assigned on a logarithmic scale because measurable amplitudes can vary across a vast range, which for *P*-waves runs from about 1 cm down to a few tenths of a nanometer (Aki and Richards, 1980, p. 495).

It has been the practice in GSETT-3 that array sites also include at least one three-component seismograph. Three components are needed in order to sense ground motion separately in the up-down direction (i.e., the vertical), the North-South direction, and the East-West direction. As noted above, the measurement of ground motion in three dimensions assists in identification of the various *P*-waves, *S*-waves, and surface waves.

The use of arrays for nuclear explosion monitoring began in the early 1960s. Arrays are particularly suited to the detection of weak teleseismic signals from small events ($m_b \sim 4$ or less in some cases) and they can also improve the signal-to-noise ratio of regional waves. It is, however, notable that national seismographic networks used to study earthquakes almost never use arrays. For a fixed budget, it appears that earthquakes can better be characterized down to small magnitude (i.e., magnitude about 3 or much less in some regions) by using a network of numerous separate stations to record the regional signals, rather than by clumping sensors together into arrays. Modern national and regional networks routinely use three–component stations.

For seismic sources whose signals are detected by the primary network, and for which the location estimate and other attributes of the source are likely to be better quantified if additional signals are acquired, the CTBT Protocol lists an additional 120 sites around the world at which either a three-component seismographic station or an array is to be operated. These stations, constituting the auxiliary network (also illustrated elsewhere in this collection of papers), are to operate continuously; but their data are to be sent to the IDC only for time segments that are demanded by a message from the IDC. Much experience with such an auxiliary network, of somewhat smaller size, has also been acquired during GSETT-3.

What then is the expected detection threshold of the CTBT primary seismographic network? (Note, the auxiliary network does not contribute to the IMS detection capability.)

For detection of enough signals to provide some type of location estimate, GSETT-3 was planned (CD/1254) to have a threshold detection capability in the magnitude range below 3 for large parts of Eurasia and North America, above magnitude 3.4 in some continental areas of the southern hemisphere, and above magnitude 3.8 in parts of the southern oceans.

The design capability of the CTBT primary network has not been specified. In practice, however, the CTBT 50-station primary network may not reach the intended GSETT-3 planned capability, for three main reasons:

- The GSETT-3 primary network detection capability in practice does not appear to have attained its design capability,[3] even in areas such as North America where the primary network is complete. For example, GSETT-3 has missed several events of magnitude 4 and above in California.
- The CTBT primary network is to have a slightly smaller number of stations than that planned for GSETT-3.
- Some of the CTBT primary stations are at noisy sites and will therefore contribute little.

To appreciate the importance of this last point, Figure 7.2 shows the signals recorded at several stations in Europe in 1995 from a French nuclear explosion in the South Pacific ($m_b = 4.8$ as measured from 85 stations by the U.S. Geological Survey a few days after the event). These particular signals were retrieved by a research institution in Germany. It is very clear that the ratio between signal and background noise varies substantially across these stations. For the stations with high signal-to-noise, detection would clearly be possible even if the signal were more than ten times smaller (i.e., more than one full magnitude unit less).

ASSOCIATION OF SIGNALS

Each year, somewhat more than 7000 earthquakes occur with magnitude $m_b \geq 4$; and about 60,000 earthquakes occur with $m_b \geq 3$. While chemical explosions with $m_b \geq 4$ are rare (a few per year, if any), there are probably on the order of a few hundred at the $m_b \geq 3$ level, and many thousands at smaller magnitudes that are detectable at stations close enough.

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[3] A Department of Defense Report to Congress, June 1, 1994, on plans to develop advanced technologies for monitoring a Comprehensive Test Ban Treaty, with reference to GSETT-3, states (p. 13) that "Capability estimates indicate that the three-station (including at least one array) detection threshold for the Primary network will be magnitude m_b 3.5 or better for Southern Hemisphere continents, m_b 3.8 in the oceans, and m_b 3.0 or less for most of North America and the Former Soviet Union. Lowering this threshold in regions of particular concern to the US would require increasing the number of sensitive stations and/or arrays in those regions, for example through bilateral agreements."

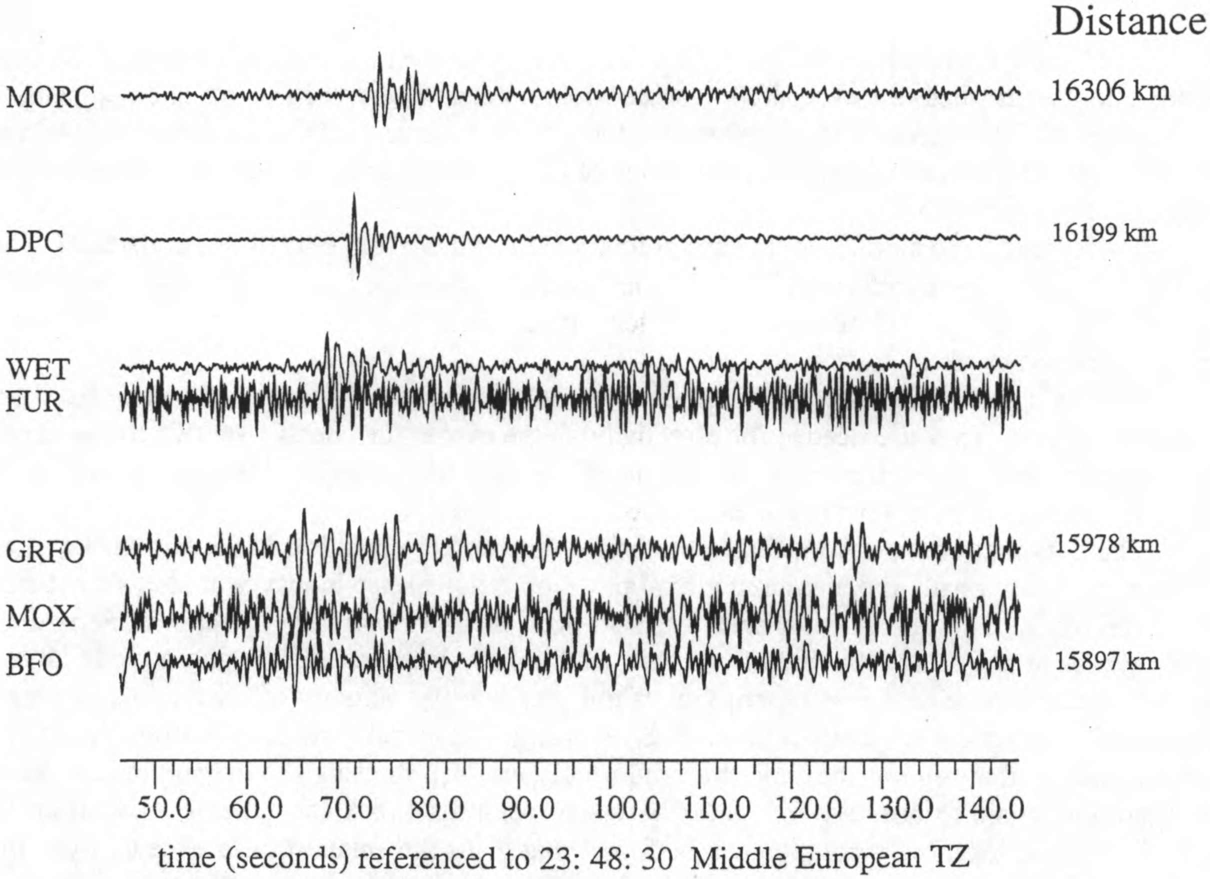

Figure 7.2: Examples of the seismic signals from a French nuclear explosion, recorded at a few stations in Europe at distances of around 10,000 miles. These seismograms, i.e., records of ground motion (note the horizontal time scale, in seconds), are spaced vertically at distances corresponding to their distance from the source at Mururoa. These seismic waves are known to be naturally amplified (focussed) for distances around 16000–16300 km, by virtue of features within the Earth's fluid core. For purposes of monitoring Mururoa from distant parts of the globe, clearly one would choose stations DPC, MORC and WET over the remaining four. (However, none of these stations are in the IMS list.)

The problem then arises, of sorting through the numerous (~ tens of thousands) of signals that will be detected each day at a large data center, and collecting together all the signals that are associated with the same seismic source. Sufficient here to say, that this has been the major computational problem of the GSETT-3 IDC. Effective methods of solution have been found, but in practice 40% or more of the detections recorded on a given day remain unassociated (see *Evaluation of the First Full Year of GSETT-3*, GSE/CRP.262, 29 March 1996). Novel methods are being tried to achieve improvements that, for example, can cope with larger numbers of contributing stations. This experience will no doubt be available to the CTBT IDC. Array data have the advantage over single station data, when faced with associating a set of detections, since array data can be used to point to the source location—and even to point to two or more different sources whose signals are arriving at the array from different directions at about the same time.

The CTBT Protocol, Part II, ¶3, states that "The area of an on-site inspection shall be continuous and its size shall not exceed 1000 square kilometers. There shall be no linear dimension greater than 50 kilometers in any direction." Also, ¶41(b) states (with reference to an On-Site Inspection request) that the proposed boundaries of the area to be inspected are to be specified on a map in accordance with ¶3.

These conditions amount to an extraordinary technical challenge for those at the IDC, who may have to estimate the location of an event that could become the basis of an on-site inspection request. The challenge will be especially difficult if the event is small and the estimate is based upon primary and auxiliary station data alone.

Accurate location estimates are needed not only for events destined to be considered for on-site inspection. They are needed for essentially all the events for which a set of detections can be associated, since in practice an interpretation of the location (including the event depth) is the most commonly used basis for rapid identification.

The data that are used to estimate the origin time and the location of an earthquake or an explosion are traditionally the measured arrival times of various seismic waves at stations situated around the world. If arrays are available, it is also possible to measure the directions of arrival of seismic waves at the array. Such data are then traditionally interpreted by using a model of the Earth's velocity structure, i.e., a description of the way that the velocity of seismic waves varies with position throughout the Earth's interior. By starting with a trial location (for example, underneath the station that reports the earliest arrival time), and then revising the origin time and location again and again to improve the match between measured times and times computed in the model for a given location, a solution can be found that gives the smallest difference between the observed arrival times and the times predicted for that Earth model. By examination of the way that computed arrival times change for changes in location in the vicinity of the "best-fitting" location, one can also hope to find a relationship between the *uncertainty in measured arrival times*, and the *size of the region* in which the source is expected to lie. Such uncertainty is conventionally reported in terms of an "error ellipse," a type of two-dimensional confidence interval that is designed to contain the actual solution 90 times out of 100.

Since the error in measuring the arrival time of seismic waves is usually less than one second (and is usually less than 0.1 second when signal-to-noise ratios are good), and since the velocity of seismic waves is typically less than 6 km/s in the Earth's outer layers where the events of interest occur and where the measurements are made, it might appear that seismic sources can routinely be located to within a few km, and an areal uncertainty much less than 100 km^2. However, this conclusion is incorrect at present, because we do not yet have or do not use a sufficiently good model of the Earth's velocity structure. This is the principal problem in determining locations and location uncertainty, discussed further below. A secondary problem arises if seismic waves are detected only within a narrow range of azimuths from the source, for then the arrival-time data can often be fit equally well by locations that, in comparison with the true source, are nearer or further away from the detecting stations; and then using a time of occurrence for the seismic event (the "origin time") that is later or earlier, in order to compensate for the location error. In such cases, we find the error ellipse has a large radius along the azimuths toward the detecting stations. The ellipse also has a large radius in the directions perpendicular to these azimuths, if the station data do not permit accurate estimation of the so-called backazimuth (the direction from the stations, back to the event of interest). In practice, therefore, it is desirable to have detections from stations within at least two quadrants from the event (and preferably from three or from all four), to reduce the triangulation errors in working back from the detecting stations to the source location.

There are three principal ways to work around the problem of ignorance of Earth structure:

- by using numerous stations at different azimuths and different distances around the source and thus averaging out the effects of the difference between the Earth's actual velocity structure and that of the model;
- by building up information about the Earth's velocity structure and thus finding a more sophisticated and presumably more accurate model, which has lateral variability rather than a spherically symmetric structure; and
- by "calibrating" the station (or array), so that in effect the source of interest is located with reference to another event, whose location is known accurately, and which preferably is not far from the event of interest. In this approach, the data for the unlocated event are the *difference in arrival times* for the two events, as recorded at each station. From such data, we can often estimate accurately the *difference in location* between the reference event and the event of interest, and hence estimate the unknown location of the latter event.

There is a long history of surprises in estimates of explosion locations based upon seismic data. As a recent example, Thurber et al. (1993) showed for the last 20 explosions at the Balapan region of the Semipalatinsk test site that locations determined to within about ±100 m from SPOT photographs were outside the seismically determined 95% confidence ellipses in most cases. In this region, the ellipses were only about 5 to 10 km^2 in area, and had been determined by using the known location of a reference event. The ellipses would have included the actual locations 95% of the time if they had been enlarged to about 20 km^2, so in this case the seismologically determined locations were quite good. But the fundamental problem remains, that until ground truth becomes available, it is usually not possible to estimate correctly the size of the confidence ellipses. Thus, we still do not know how to translate our uncertainty in knowledge of Earth structure, into knowledge of the uncertainty in an event location.

North (September 1996) summarized the GSETT-3 IDC's difficult experience with event location:

> The full-scale phase of GSETT-3 has now been running for over 20 months, and much valuable experience has been obtained. [The Reviewed Event Bulletins produced] two days after real time . . . are in many parts of the world superior in terms of detection thresholds to those produced by other agencies after much longer delays. The event definition criteria used in GSETT-3 are however more liberal than those of these other agencies, so that many of the events listed in the GSETT-3 Reviewed Event Bulletins (REB) are poorly located. The 90% confidence ellipses exceed 1000 sq. km for 70%, and 10000 sq. km for 30%, of all REB events. Furthermore, comparison by various countries of the locations produced by their own denser national networks with those in the REBs show that the REB 90% confidence ellipses contain the national network location less than half of the time . . . One feature of the GSETT-3 network and its successor in the proposed International Monitoring System (IMS) that is particularly troublesome is that many events will be recorded only at teleseismic distances, and that few will be recorded

> only to region (< 2000 km) distances. Thus an appropriate means of implementing path-dependent teleseismic travel times, and of transitioning from these to regional travel time curves, will need to be developed.

IDENTIFICATION OF SEISMIC SOURCES

As noted above, the IDC's role in event identification is that of providing assistance to State Parties. Further detail is given in Annex 2 to the Protocol, which indicates that the IDC may carry out standard screening of the available data. Such screening shall be based on the standard event characterization parameters and, with reference to seismology, the following may be used:

- location of the event;
- depth of the event;
- ratio of the magnitude of surface waves to body waves;
- signal frequency content;
- spectral ratios of phases;
- spectral scalloping;
- first motion of the *P*-wave;
- focal mechanism;
- relative excitation of seismic phases;
- comparative measures to other events and groups of events; and
- regional discriminants where applicable.

The Operational Manuals will no doubt cover these methods in detail, and for the present paper a few examples must suffice.

Thus, Figure 7.3 shows a map of Europe and North Africa, together with the location of a few nuclear explosions, and numerous earthquakes. The magnitude of *P*-waves, m_b, is plotted against the magnitude M_s, which is a logarithmic measure of the amplitude of long-wavelength surface waves. The lower part of the figure illustrates the classic m_b: M_s discriminant, discovered over 30 years ago at what then was called the Lamont Geological Observatory, exploiting the fact that explosions are far more efficient than earthquakes in exciting *P*-waves, for events with comparable surface waves.

But how shall a line be drawn on a figure such as this, separating the dots from the crosses, for use in the interpretation of future events in an area whose m_b and M_s magnitudes can be measured with adequate confidence? The IDC functions will certainly include measurement of m_b and M_s, for events that are large enough in a particular region, and may, perhaps, extend to drawing some type of line that separates the two populations. (The nuclear explosion values will have to come from past experience, if any.) But it is not for the IDC to decide the significance of any event that falls close to the line, or on the "explosion" side. Rather, as stated in the Protocol, Part I, ¶21:

> The International Data Center shall, if requested by a State Party, apply to any of its standard products, on a regular and automatic basis, national event screening criteria established by that State Party, and provide the results of such analysis to that State Party. This service shall be undertaken at no cost to the requesting State Party.

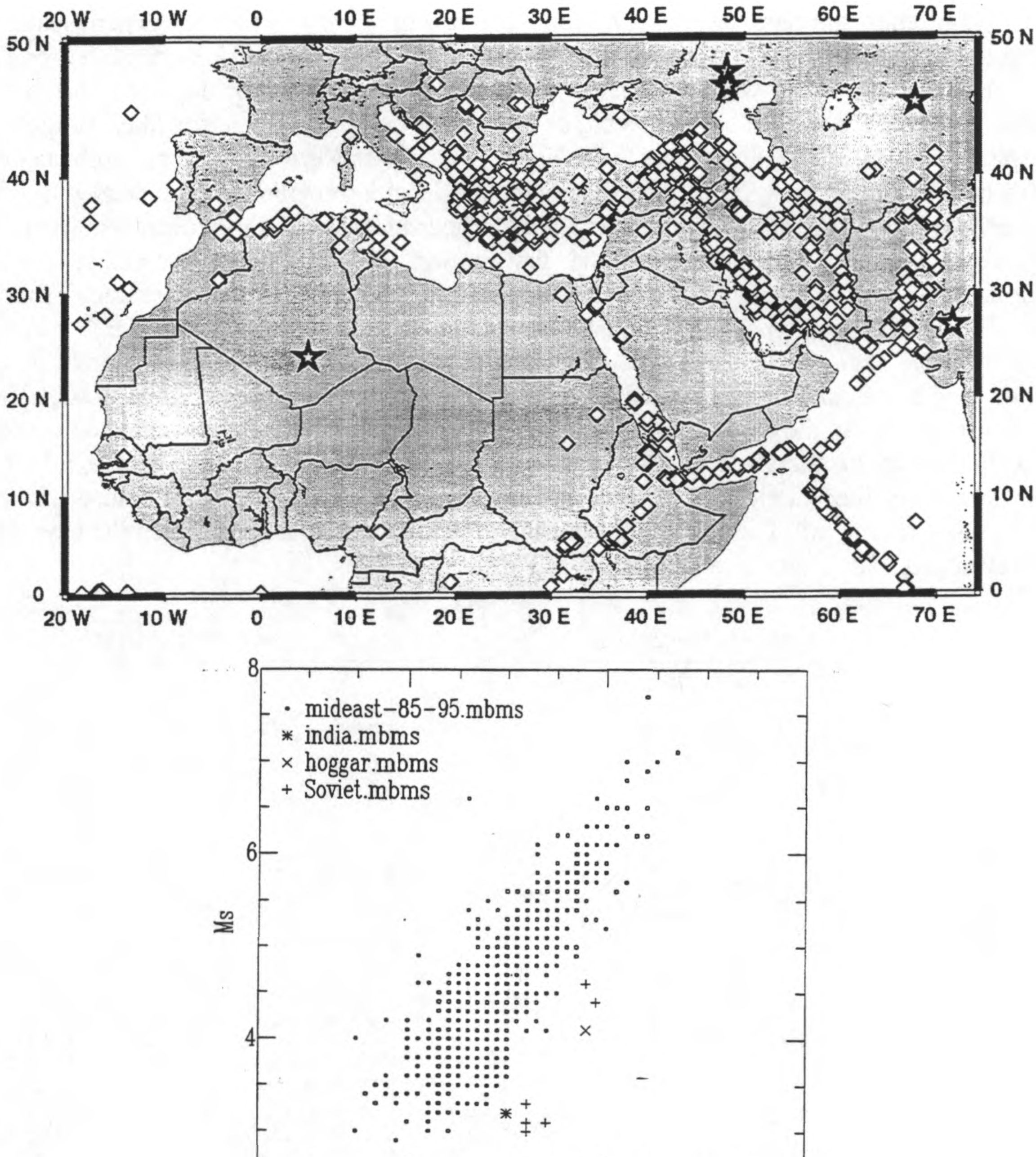

Figure 7.3: (Upper) Map showing main locations of underground nuclear tests (stars), and 1985–1995 earthquakes (diamonds) with USGS m_b and M_s values, in the Middle East and North African region. The explosion location in Algeria is the former French test site, in Hoggar granite. (Lower) Corresponding plot of m_b: M_s. The separation of events is quite good, with all explosions lying below and to the right of all earthquakes. However, there are very few measurements for events with $m_b < 4$, and $M_s < 3$. Out of 49,000 events in the 1985-1995 USGS catalog, 4126 with $m_b > 4$, only 932 have both M_s and m_b. Beginning in 1996, operators of over 500 stations in this region have begun to cooperate in producing a superior regional bulletin (figure is from Walter et al., 1996).

Concerning the classical m_b: M_s discriminant, it is of interest to note the experience of monitoring two seismic events that occurred in 1995, one on January 5 in the Urals, the other on February 3 in Wyoming. They were both mining accidents, in which deep underground chambers collapsed, generating signals of about magnitude 5, and showing up as "explosionlike," or quite close to explosionlike, on m_b: M_s diagrams such as Figure 7.3. These were regarded as "problem events" at the time by researchers, in the sense that although local information soon indicated the events were mine collapses, the m_b: M_s method appeared to be inadequate to distinguish them clearly from large explosions. For close-in stations, the "first-motion of the *P*-wave" could be used, and such motions at least in Wyoming were dilatations (motion toward the source), characteristic of an implosion or of certain types of earthquake rather than an explosion (for which the first motion is away from the source). But it is well-known that the "first-motion" method is unreliable (since background noise can prevent an analyst from making the correct choice of time window for the true first motion). In the case of these two problem events, a method of discrimination was developed (in a sense, hand-crafted) by Pechmann et al. (1995). It is illustrated in Figure 7.4, and the issue here is whether an analysis of this type, which is highly sophisticated in comparison to the m_b: M_s discriminant, will find acceptance outside the expert community in which the new method was developed. Such questions are for States Parties to decide.

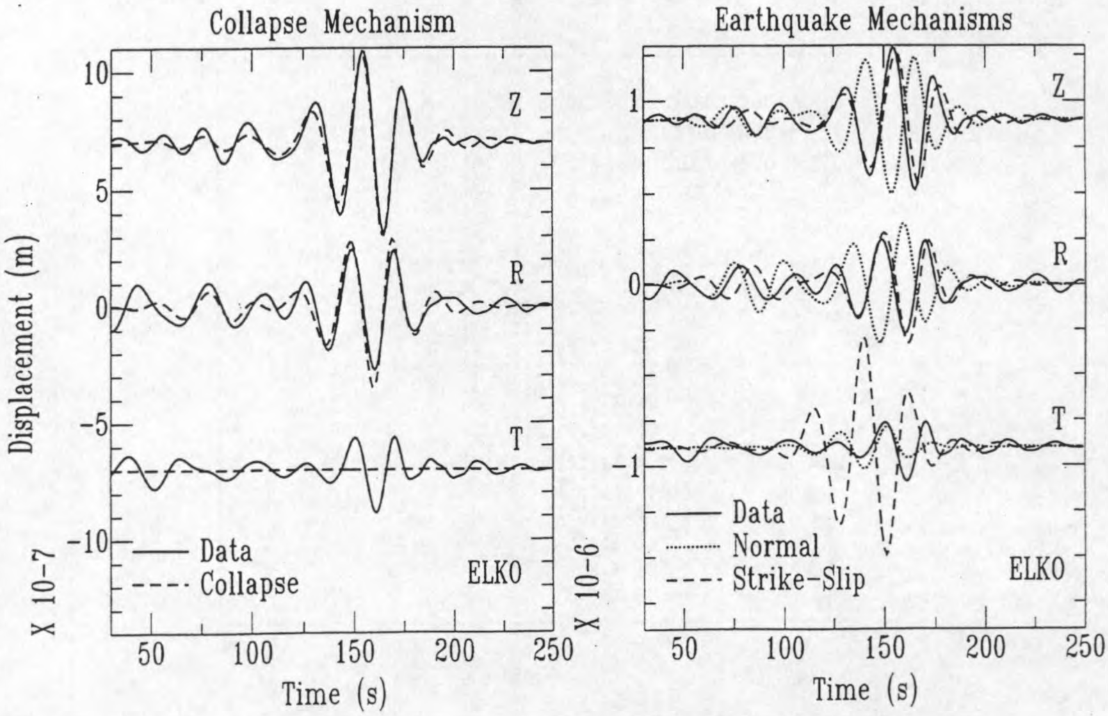

Figure 7.4: The three-component seismic surface wave data for the Wyoming mine collapse of February 3, 1995, as recorded at Elko, Nevada (a distance of about 300 km), are shown as solid lines. On the left, the data are well modeled by a collapse mechanism, for which the expected seismic motions are shown as dashed lines. An explosion would generate signals of opposite polarity (i.e., reversal of sign). On the right, the data are poorly modeled by the (dashed line) seismograms expected for the types of earthquake appropriate for this area. The expert conclusion offered here, is that the event was most likely a collapse and not an earthquake or an explosion. From Pechmann et al. (1995).

If a nuclear explosion is conducted deep underground at the center of a large spherical cavity in hard rock, with radius greater than or equal to about 25 meters times the cube root of the yield in kilometers, then the seismic signals are reduced by a so-called decoupling factor of about 70, i.e., by almost two magnitude units. It is easier to build cavities of the same volume that are elongated rather than spherical, and apparently such aspherical cavities can also achieve high decoupling factors, but they also increase the concentration of stress on the cavity and make it much more likely that radionuclides will be released into the atmosphere. An overall evaluation of the cavity decoupling scenario therefore raises several different technical issues:

- Does a country considering an evasive test have access to a suitably remote and controllable region with appropriate geology for cavity construction?
- Can the site be chosen to avoid seismic detection and identification (recognizing that seismic events are routinely reported down to magnitude 2.5 by earthquake monitoring agencies for many areas in industrialized countries)?
- Can cavities of suitable size and shape and depth be constructed clandestinely in the chosen region?
- Can nuclear explosions of suitable yield be carried out secretly in sufficient number to support the development of a deployable weapon? (This question covers numerous technical issues, including the ability not to underpredict the yield prior to the first test, and to keep all yields of a test series small enough to escape identification.)
- Can radionuclides be contained?

Each of these questions has been the subject of extensive technical analyses.

My own opinion is that it is technically possible to address a few of these issues in a clandestine program in isolation from the others, but mastery of all these issues combined could not be achieved except possibly by a full-blown multi-billion dollar effort by a nation that already had practical experience with nuclear testing. Such a nation would have little to learn technically, much to lose politically, and the treaty evasion program would still be at great risk of discovery since multi-billion dollar efforts intrinsically attract attention in the modern world.

Another evasion scenario is the use of mining operations and large chemical explosions to mask or disguise an underground nuclear explosion. There is a limit on the yield of any nuclear explosion that could be hidden in this way. Chemical explosions are almost always ripple-fired at shallow depths, so they are inefficient in generating seismic signals, relative to nuclear explosions that are tamped. It therefore appears that only mines with the largest blasting operations are plausible candidates for hiding militarily significant efforts at CTBT evasion.[4]

Although the above arguments speak to the difficulty of carrying out and successfully hiding a militarily significant nuclear test, they do not address the reality of how the IMS and State Parties will handle large blasting operations—or the occasional single-fired chemical explosion

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[4] Largest, that is, in the sense of generating large signals. Technical evaluations of this scenario conclude that a chemical explosion as carried out in a typical mining operation would have to be about ten or more times greater than the yield of a concurrent tamped nuclear explosion, in order to mask the latter.

(whose seismic signals may indeed look just the same as those of a small nuclear explosion). The CTBT Article IV, ¶68, states that

> In order to . . . [c]ontribute to the timely resolution of any compliance concerns arising from possible misinterpretation of verification data relating to chemical explosions . . . each State Party undertakes to cooperate with the Organization and with other State Parties in implementing relevant measures . . .

These measures are spelled out in the Protocol, Part III. They provide, on a voluntary basis, information on single-fired chemical explosions using 300 tons or more of TNT-equivalent blasting material; and information on mine blasting (such as mine locations) for all other chemical explosions greater than 300 tons TNT-equivalent.

There are two types of technical effort that can be carried out to help monitor mining regions for compliance with a CTBT. The first of these is installation of nearby seismographic stations that record digitally at high sample rates. The purpose here is to provide high quality data that can distinguish between single-fired explosions and the multiple-fired explosions typical of mining operations. The second is provision of technical advice to mine operators so that they execute their blasting activities using modern methods of ripple-firing—which have economic advantages, as well as enabling the blasting of rock in ways that do not make the large seismic signals typical of old-fashioned methods of blasting. To the extent that mine blasting remains a serious concern, problems can be addressed with nearby installation of infrasound and radionuclide monitoring equipment, and with site visits. These activities would be voluntary under the CTBT. But as with deployment of special seismographic stations and arrays (see footnote 3), these mine-monitoring activities could be carried out under bilateral agreements.

CONCLUDING REMARKS

The work of monitoring the CTBT by seismological methods will be demanding, because of the technical difficulty and the scale of organizational effort that will be required, and because of the need to interact with political and bureaucratic decision-making. Evaluations of CTBT monitoring capability may be carried out as part of the domestic ratification process in each of the different signatory States. Evaluations will certainly be carried out, together with budgetary review, by numerous government agencies, not all of which are eager to put resources into a major initiative in nuclear arms control. Once the Treaty has entered into force, political and technical decision-making will have to be combined in consideration of problem events, particularly for any that rise to the levels of visibility associated with potential or actual requests for on-site inspection.

The organization of the technical work is complicated by the existence of major seismological resources other than the IMS primary and auxiliary networks and the IDC. Nevertheless, such complications, if managed with care, can over a period of time be turned to advantage, into a system that will greatly enhance the monitoring capability of the IMS networks alone. As pointed out in footnote 3, bilateral agreements can be reached to improve monitoring capability in regions of concern to the United States.[5]

The CTBT and Protocol make several references to the need to take national monitoring networks into account. In this regard, it is relevant to note that national seismographic networks are not operated by military organizations, but rather by civilian agencies such as, in China, the State Seismological Bureau, and, in the United States, the US Geological Survey.[6] National networks are increasing in number and quality. They are associated with the production of detailed bulletins of regional seismicity that typically are intended to meet objectives in the study of earthquake hazard. Such bulletins can be very helpful in CTBT monitoring, for the study of problem events and for improving the IDC's routine seismicity bulletins.

The Operational Manuals, once written, will presumably settle many of the technical and organizational issues raised in this paper. Many decisions will be needed in writing these Manuals, such as how much effort to place on routine processing, and how much on the treatment of problem events. As always, the devil will be in the details, which will determine whether the Operational Manuals will be used to bring supplementary data into the IDC, or to keep such data out. On the time scale of a few years, it may not make much difference whether supplementary data are used or not. But over a period of a decade and longer, it is likely that the background of earthquakes will provide a means of calibration and new methods of data acquisition and data analysis, so that large numbers of supplementary stations will be able to provide timely and useful

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[5] Since it is not necessary for the United States to achieve monitoring capability down to magnitude 3 on a global basis, it is more efficient for it to focus on areas of interest rather than taking the IMS approach of fairly homogeneous global coverage.

[6] The USGS/National Earthquake Information Center (NEIC) in Golden, Colorado, operates the US National Seismographic Network—a set of broadband stations designed to characterize seismicity on U.S. territory down to about magnitude 3—and also the National Earthquake Information Service (NEIS). The NEIS has the responsibility to publish global earthquake bulletin data that are used throughout the world for basic seismological research, including hazard assessments, earthquake prediction, the study of tectonics, source mechanisms, and Earth structure. To prepare these publications, data are received from numerous seismographic stations around the world in addition to data from the NEIC Network. (In 1995 about 2600 different seismographic stations reported to the NEIS.) Thus the USGS/NEIS publishes the weekly Preliminary Determination of Epicenters (PDE), which lists the location, magnitude and felt effects of about 50 earthquakes a day. (The weekly PDE prior to 1995 averaged about 20 events/day, but in recent years the USGS has been able to incorporate data from the GSETT-3 IDC, and thus issues prompt and quite accurate locations for many more events.) The weekly PDE is followed about four months later by the Monthly Listing (of earthquakes and explosions) and a corresponding Earthquake Data Report (EDR), in which all events published in the weekly PDE are recomputed using additional data. For the Monthly Listing, additional events, which had insufficient data at the time of the PDE, are added, and this final USGS bulletin now has about 60 events/day. The EDR contains a listing of all the arrival times of various seismic waves at the reporting stations for each event. These products are important for evaluation of the accuracy of IDC event locations, since the Monthly Listing and the EDR emphasize accuracy of location rather than speed of production. The USGS only includes events in its bulletins when the data are adequate to provide a good location.

information that will improve the work of the IMS, and assist in the attainment of U.S. monitoring goals for a CTBT.

I conclude that if a coordinated effort can be made, to combine the skills of seismologists who have long studied earthquakes with the skills of those who have long studied nuclear explosions—recognizing that these skills are found internationally and that there are decades of prior experience with international teamwork in geophysics—then the IMS will indeed be able to meet its responsibilities under the CTBT, and U.S. monitoring goals can be met.

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The GSETT-3 IDC maintains an informative worldwide web site, http://www.cdidc.org/ in which can be found the CTBT text, numerous Conference on Disarmament working papers, technical reports on the operation of various networks and of the IDC itself, and up-to-date listings of various seismic events. Typically these are earthquakes and large chemical explosions (though they are not identified as such), which have been detected and located by the IDC, based upon primary and auxiliary GSETT networks. This IDC has occasionally used additional data, from open (i.e., freely accessible) stations that are not part of the GSETT-3 networks (for example, to locate recent

French and Chinese nuclear explosions)—a fact to bear in mind when using GSETT-3 experience to attempt to characterize future capabilities of the CTBT Organization's IMS.

CHAPTER 8

A SYSTEMS PERSPECTIVE OF COMPREHENSIVE TEST BAN TREATY MONITORING AND VERIFICATION

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ABSTRACT

On September 24, 1996, after decades of discussion and more than two years of intensive international negotiations, President Clinton, followed by representatives of (to date) more than 125 other countries, including the other four declared nuclear weapons states, signed the Comprehensive Test Ban Treaty (CTBT). Each signatory now faces a complex set of technical and political considerations regarding the advisability of joining the treaty. Those considerations vary from country to country, but for many countries one of the key issues is the extent to which the treaty can be verified. In the case of the United States, it is anticipated that treaty verifiability will be an important issue in the U.S. Senate Advice and Consent Hearings. This paper will address treaty verifiability, with an emphasis on the interplay between the various elements of the international monitoring regime as prescribed in the CTBT Treaty Text and its associated Protocol. These elements, coupled with the national regimes, will serve as an integrated set of overlapping, interlocking measures to support treaty verification. Taken as a whole, they present a formidable challenge to potential testers who wish not to be caught.

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INTRODUCTION

For the purposes of this paper, a distinction will be made between the terms monitoring and verification. Monitoring will be taken to mean the act of collecting, processing, and reviewing the information used to assess treaty compliance. Verification will be the act of interpreting that data, in conjunction with other considerations and possibly additional data, to make a judgment regarding treaty compliance. The significance of this distinction is that monitoring is primarily an objective activity involving, for the most part, technical data, and is a major function of the international regime. Verification, on the other hand, is a more subjective process whose responsibility resides primarily with the National Authorities of the States Parties to the Treaty.

When assessing the verifiability of the treaty, it is necessary to consider the full range of monitoring assets and means available to the National Authorities. This includes those prescribed by the Treaty and its associated Protocol as constituting the international regime, and also other means that individual States Parties choose to implement as part of their national regimes. It is also important to understand that verifiability is in the eye of the beholder. Each State Party has a unique set of national security and internal and external political considerations which will determine its standard for adequate verifiability.

INTERNATIONAL REGIME

The major elements of the international regime are: (1) the International Monitoring System (IMS), consisting of networks of seismic, hydroacoustic, infrasound, and radionuclide sensors and an International Data Center (IDC), (2) Confidence Building Measures (CBM), (3) consultation and clarification, and (4) On-site Inspections (OSI). The following sections provide a general description of each of these elements, in order to better appreciate their capability to support verification when utilized as an integrated set.

International Monitoring System

The IMS is the backbone of the international monitoring regime. It consists of four different types of monitoring networks, a data communications network, and an International Data Center. The four monitoring networks were defined by multinational experts groups with the goal of providing global coverage across a range of potential test environments: seismic for underground, hydroacoustic for underwater, infrasound for atmospheric, and radionuclide for any event which might release radionuclide products into the atmosphere. Data from these networks are transmitted across a communications system to the IDC, which serves as the hub of the network by collecting, processing, distributing, and archiving the data.

Seismic Moitoring Network. The primary purpose of the seismic network is to monitor underground tests, but in some circumstances it may also be able to detect tests conducted on or above the earth surface or underwater. As shown in Figure 8.1, it includes a primary network of 50 seismic stations, which provide data to the IDC continuously and in near real time. Many of these primary stations are actually arrays of 9-20 seismometers spaced 0.5 kilometers (km) to 2 km apart in order to enhance the signal relative to the background seismic noise. The primary network is the mechanism by which seismic events will be detected.

If events detected by the primary network have characteristics suggesting a need for closer scrutiny, additional seismic data can be requested from an auxiliary network of 120 stations (Fig-

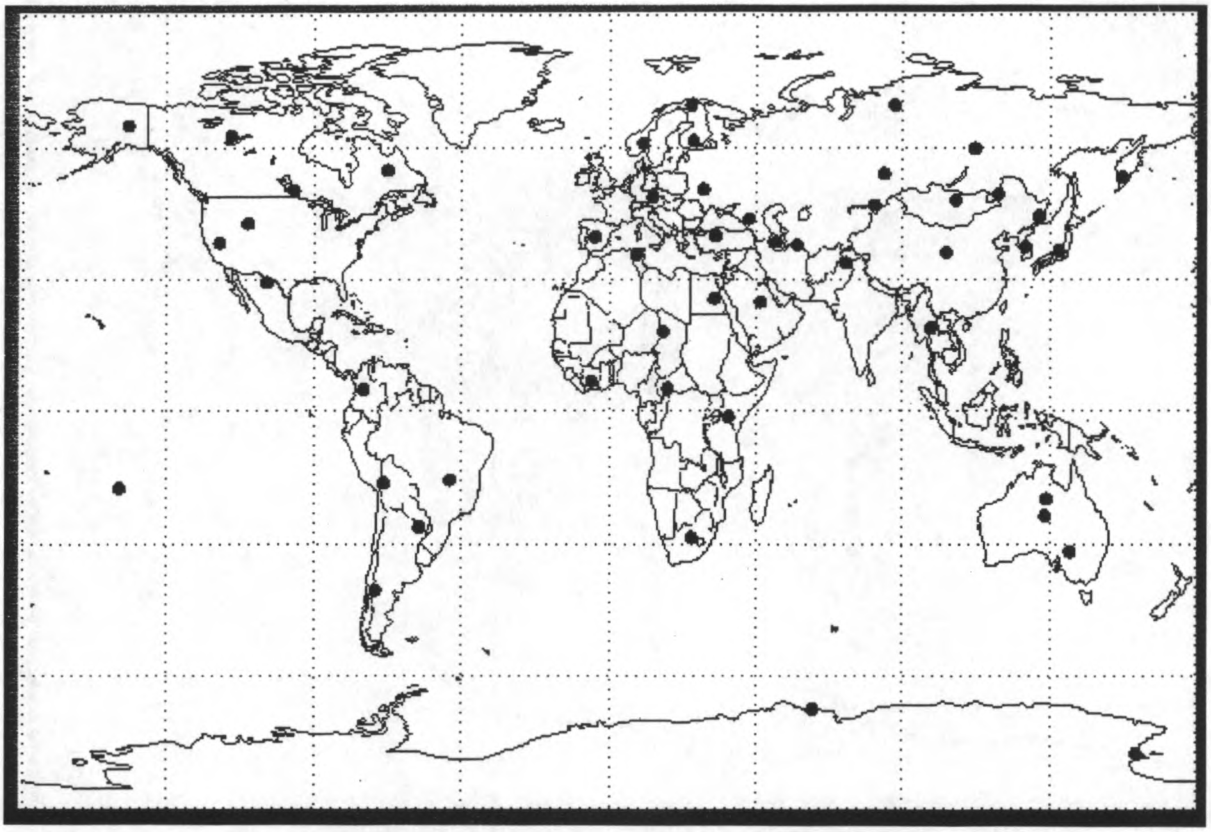

Figure 8.1: IMS Primary Seismic Network

ure 8.2), which provide data only upon request. It is anticipated that data from nearby stations in the auxiliary network, most of which are 3-component stations (as opposed to array stations), will improve location estimation accuracy and also help distinguish explosions from earthquakes.

Models of these seismic networks estimate that the primary network will have a reasonably uniform detection threshold that corresponds to roughly a 1 kiloton (kt) fully coupled underground nuclear explosion.[1] The models also predict that by using the combined primary and auxiliary networks, location estimates for underground events will have accuracies on the order of a few hundred to a thousand square kilometers, assuming that the source-to-receiver paths through which the seismic signals travel are sufficiently well characterized (note that the Treaty text allows requested On-site Inspection areas to be as large as 1000 km^2). Characterization of the travel paths will have a significant effect on location accuracies and also on the system's ability to discriminate between explosions and earthquakes.

Average global seismicity rates suggest that there will be on the order of 50 to a few hundred earthquakes per day whose magnitudes are as large as a 1 kt explosion (fully coupled and decoupled, respectively). In addition, chemical explosions from mining and excavation work will

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[1] Claassen, J.P. "Performance Estimates of the CD Proposed International Seismic Monitoring System," 18th Annual Seismic Research Symposium on Monitoring a Comprehensive Test Ban Treaty, 4-6 September 1996, PL-TR-96-2153, *Environmental Research Papers*, No. 1195, 676-684.

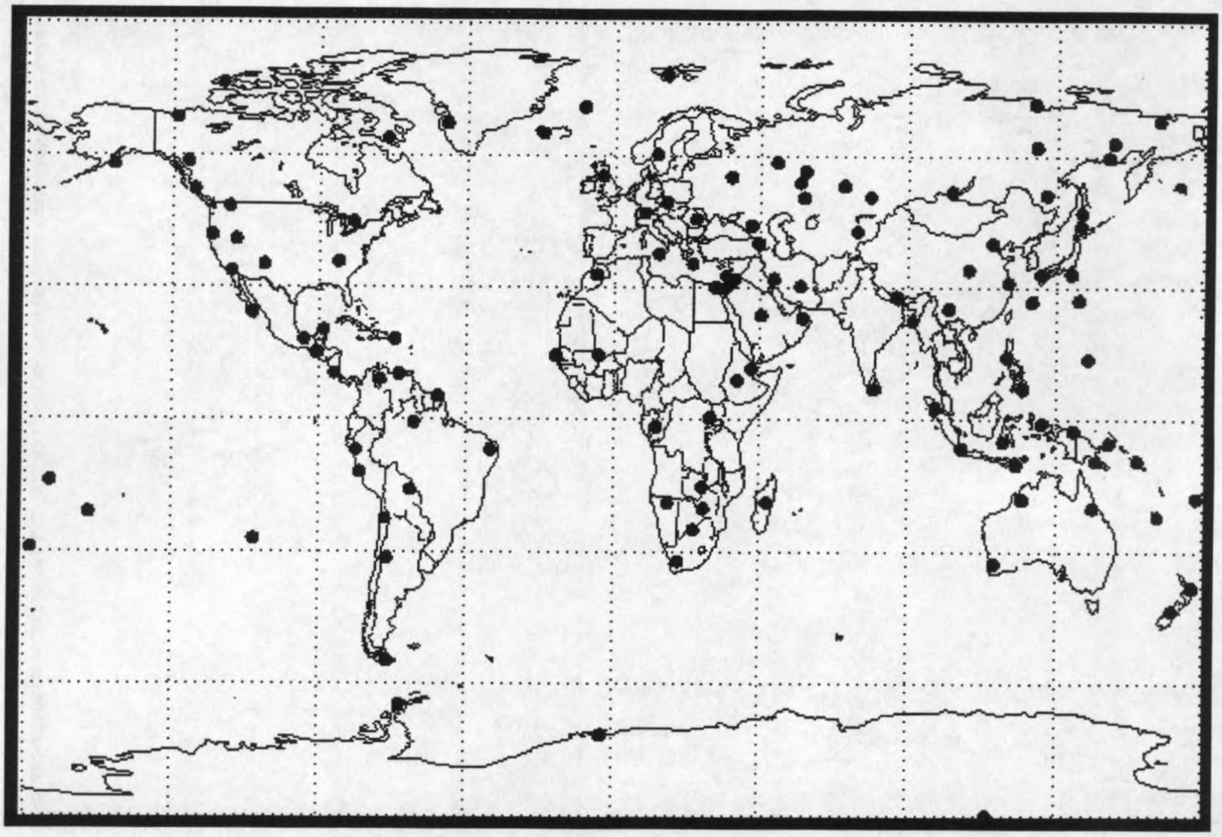

Figure 8.2: IMS Auxiliary Seismic Network

also produce signals that can be detected by the network. Some of these events can be quickly eliminated from further scrutiny by virtue of their location (e.g., too deep to be a nuclear test or not in an area of interest for a given verifying State Party) or other obvious technical characteristics, but the remainder will require careful application of technical screening criteria and expert judgment. In general, techniques have been developed that are fairly successful at distinguishing between earthquakes and explosions, but they tend to vary from one region to the next and don't work as well at low signal-to-noise ratios. Large, singly-detonated chemical explosions present a special challenge because they appear to produce seismic signals that are indistinguishable from those emanating from nuclear explosions.[2] Other elements of the international or national monitoring regimes will be needed to differentiate the two.

Hydroacoustic Monitoring Network. Figure 8.3 depicts the IMS hydroacoustic network, consisting of six underwater hydrophone stations and five island-based T-phase stations. Explosions in or above the surface of the ocean create hydroacoustic signals which are propagated very efficiently in an oceanic acoustic waveguide called the SOund Fixing and Ranging (SOFAR) chan-

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[2] Denny, M., P. Goldstein, K. Mayeda, and W. Walter (1996) "Seismic Results from DOE's Nonproliferation Experiment: A Comparison of Chemical and Nuclear Explosions," Kluwer Academic Publishers, Dordrecht, The Netherlands, and presented to NATO Conference on Monitoring a CTBT, Algarve, Portual.

nel.[3] The hydrophone stations are designed to detect these signals directly, while the T-phase stations detect the seismic signal created when the hydroacoustic wave impinges on the island. As such, the hydrophones are much more sensitive (on the order of a factor of 100), but they are also considerably more expensive to deploy (a factor of 10).[4] In the IMS, the more sensitive hydrophone stations will be located mostly in the southern oceans where distances between stations are larger and there is less shipping traffic (hence perhaps better venues for attempted clandestine testing), while the T-phase stations will be located mostly in the northern oceans. Because hydroacoustic signals propagate so well, it is expected that underwater events significantly smaller that 1 kt will be detectable by the IMS hydroacoustic stations. Preliminary research results suggest that for events detectable by three or more stations, and assuming well characterized propagation paths, location accuracies in the broad ocean area should be less than 1000 km^2.

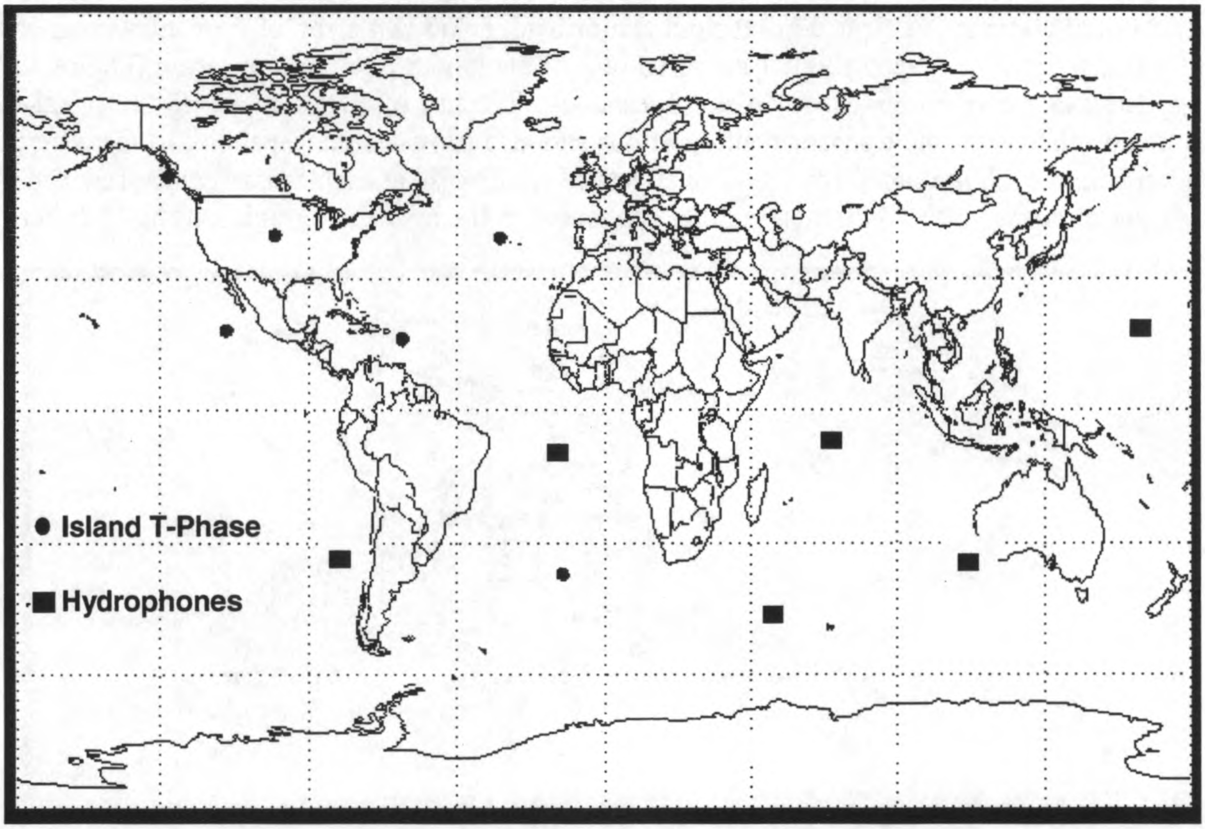


Figure 8.3: IMS Hydroacoustic Network

[3] "Comprehensive Test Ban Treaty Research and Development Program," *1995 DOE Progress Report*, DOE/NN-96005281.

[4] Clarke, D., D. Harris, T. Hauk, E. McDonald, G. Orris, J. White, and R. Wong, "IMS Hydroacoustic Network Site Selection and Performance," 18th Annual Seismic Research Symposium on Monitoring a Comprehensive Test Ban Treaty, 4-6 September 1996, PL-TR-96-2153, *Environmental Research Papers*, No. 1195, 843-852.

As with the other sensor networks, one of the key challenges facing the hydroacoustic network is identifying nuclear test events in the presence of competing background events, including undersea earthquakes and ocean-based chemical explosions (military, oil exploration). Certain classes of underwater explosions produce signatures that are readily distinguishable from earthquakes. It does not appear likely, however, that nuclear explosions will be distinguishable from chemical explosions on the basis of hydroacoustic signatures alone. Other elements of the International Monitoring System may be needed to identify an event remotely.

Infrasound Monitoring Network. The infrasound network is intended to detect the low frequency sound waves generated by an above-ground or, in some cases, below-the-surface nuclear test explosion. These infrasound signals propagate long distances through the atmosphere via a reflection and refraction "waveguide" effect that is somewhat analogous to the SOFAR channel discussed in the hydroacoustic section. Typically, kiloton-size explosions in the atmosphere can be detected at a few thousand kilometers.[5] As depicted in Figure 8.4, this network will consist of 60 infrasound stations. A typical infrasound station will include an array of four infrasound sensors (microbarographs) spaced about 1 km apart in a "triangle-and-one" configuration (Figure 8.5), though the exact configuration will be site dependent. The use of arrays improves the signal-to-noise ratio relative to single sensor configurations and also provides the capability to measure the direction from which the signal comes. The effects of wind noise at each sensor can be reduced by using a set of hoses, each 10-20 meters long, connected to the microbarograph sensing chambers.

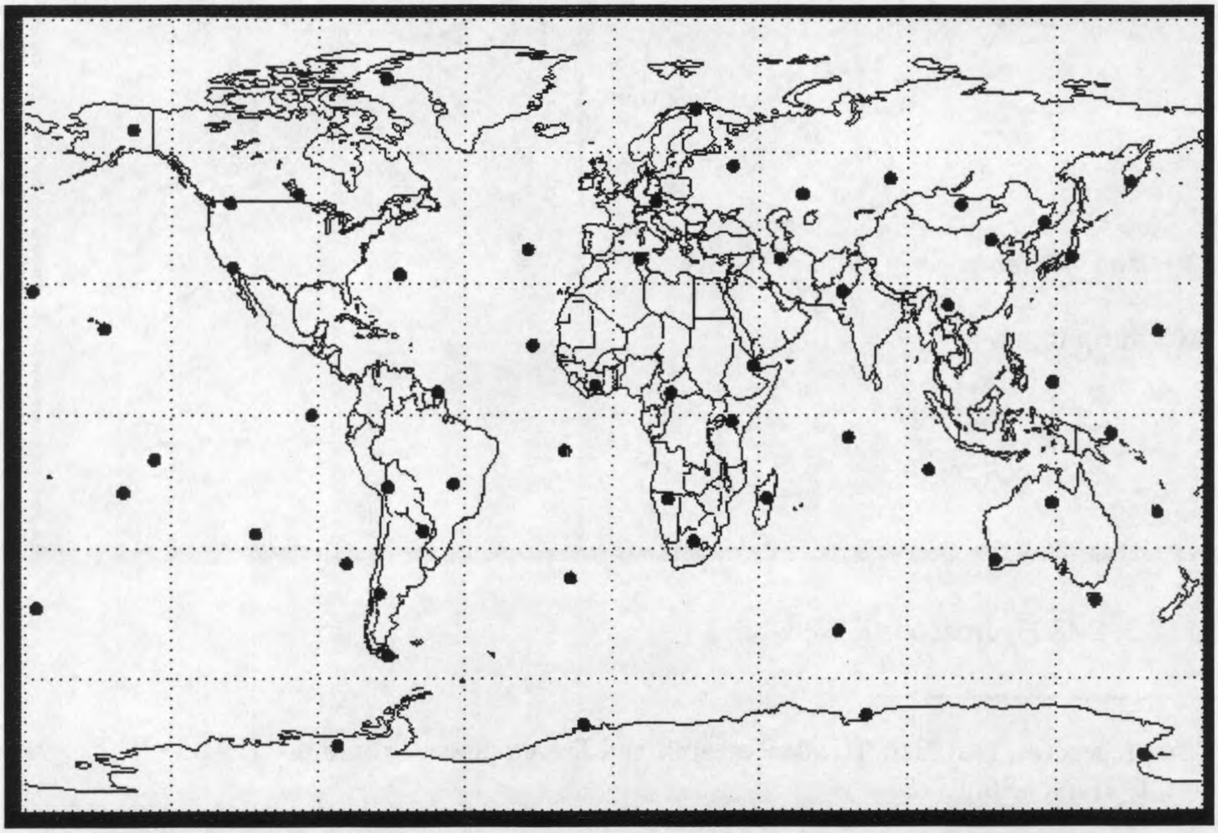
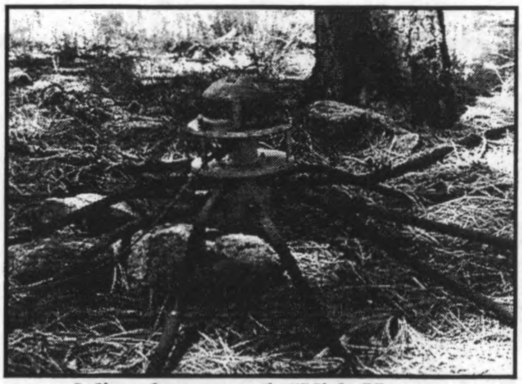


Figure 8.4: IMS Infrasound Network

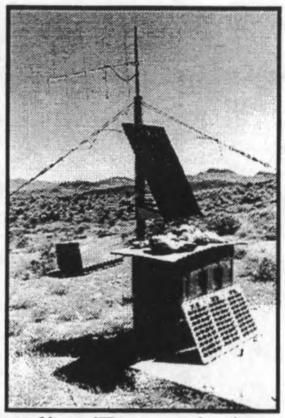
[5] "Comprehensive Test Ban Treaty Research and Development Program."

Discussions in the experts meetings in Geneva, as well as related modeling efforts, suggest that the infrasound network will be able to detect explosions in the 1 kt range globally, but the exact thresholds are dependent on atmospheric conditions, and thus will vary regionally and seasonally.[6] Preliminary estimates of the location capability of the infrasound network operating alone range from about 1000 km^2 to over 10,000 km^2, but improved processing algorithms (to get better bearing estimates) and the combined use of infrasound, hydroacoustic, and seismic data should offer improvements.

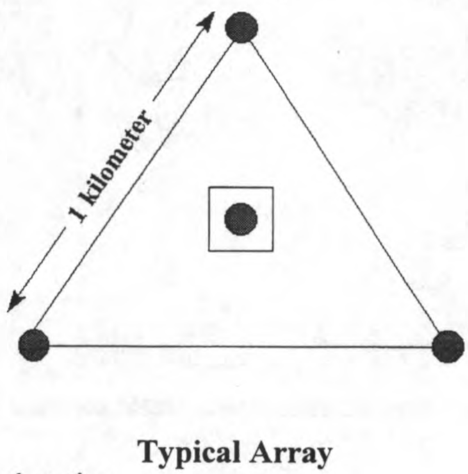
As is the case with the seismic and hydroacoustic networks, discriminating nuclear explosions from other events will be a key issue. Preliminary research suggests that explosions can generally be differentiated from other classes of events such as thunderstorms, bolides, volcanic eruptions, and sonic booms, but that nuclear explosions and chemical explosions are probably not distinguishable based on infrasound data alone. Other elements of the international or national monitoring regimes will be needed to differentiate the two.



Microbarograph With Hoses



Recording/Transmission Site



Typical Array

Figure 8.5: Typical IMS infrasound station

[6] Edenburn, M.W., M.L. Bunting, A.C. Payne, R.R. Preston, and L.C. Trost, "Synergy Among International Monitoring System Technologies," 18th Annual Seismic Research Symposium on Monitoring a Comprehensive Test Ban Treaty, 4-6 September 1996, PL-TR-96-2153, 714-725, *Environmental Research Papers*, No. 1195, 714-725.

Radionuclide Monitoring Network. The purpose of the 80 station IMS radionuclide network depicted in Figure 8.6 is to detect the presence of airborne radionuclide products created by a nuclear test explosion. The detection threshold of these systems will be less than 1 kt for above ground explosions. For subsurface detection the threshold will depend on the extent to which venting occurs. While the other detection systems respond on the scale of minutes to tens of minutes, the radionuclide network depends on atmospheric winds to move the debris from the event site to a monitoring station, a process which may require several days. In addition to a delayed response time, this can result in limited location accuracy due to uncertainties regarding wind patterns. An important feature of the radionuclide system is its ability to discriminate between nuclear explosions and other events. It too must deal with competing noise signals (in this case naturally occurring radionuclides and those produced by nuclear reactors, nuclear fuel reprocessing, or medical isotope production and usage), but given adequate signal-to-noise ratios the radionuclide signature can provide strong evidence of a nuclear explosion.[7]

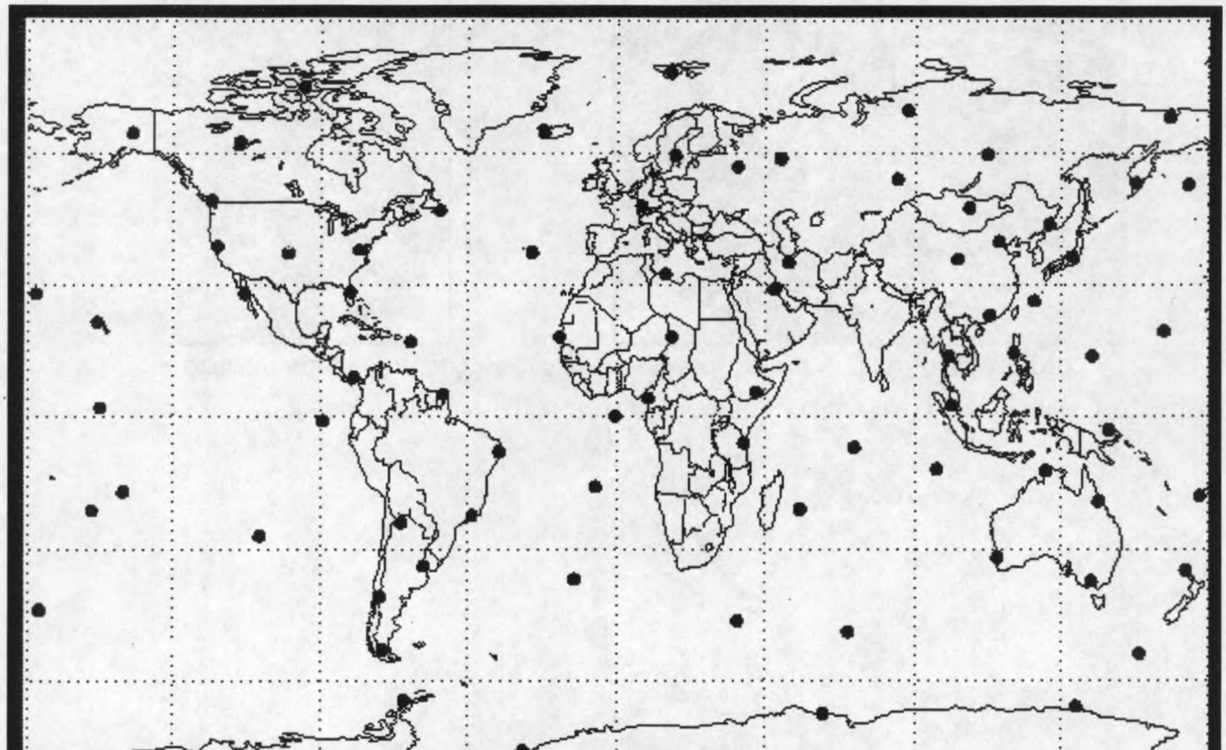


Figure 8.6: IMS Radionuclide Network

The IMS will include two types of radionuclide sensor systems. All 80 sites will utilize particulate samplers, which measure radionuclides transported on airborne particles. At entry into

[7] "Comprehensive Test Ban Treaty Research and Development Program."

force of the Treaty, 40 of the sites will also include noble gas sensors, which measure xenon radionuclides, with the possibility that this number will be expanded to include all 80 sites at a later date. For above ground tests, the particulate radionuclide stations will provide the greatest sensitivity, but for subsurface tests it is possible that only xenon radionuclides will escape into the atmosphere.

Because of the radionuclide network's unique attributes (good detection threshold and identification capability, but relatively slower response time and higher location uncertainties), it is most effective working in conjunction with one or more of the other networks. The challenge will be correlating (in space and time) signals detected by the radionuclide network with events detected and located, but not identified, by the other networks.

Prototype radionuclide stations have been developed that can automatically analyze samples at the stations and forward the results to the IDC. In addition, the Treaty calls for the establishment of certified labs to which samples can be sent for more detailed analysis.

INTERNATIONAL DATA DENTER (IDC)

The IDC is the focal point for collecting, processing, distributing and archiving IMS data. As shown in Figure 8.7, data from the IMS sensor networks will be forwarded to the IDC either directly or through the National Data Centers (NDCs). Upon receipt, raw data will be verified for authenticity, archived, and made available for distribution to NDCs. In addition, the IDC will routinely process incoming data to produce a set of standard products on behalf of all States Parties. These standard products include integrated lists of all signals detected by the IMS, values and uncertainties of parameters calculated for each event, event bulletins that have been screened according to an agreed-upon set of screening criteria, executive summaries, and customized extracts or subsets of the above as requested by States Parties. In addition, the IDC will provide technical assistance to requesting States Parties in the form of expert technical analysis of data and

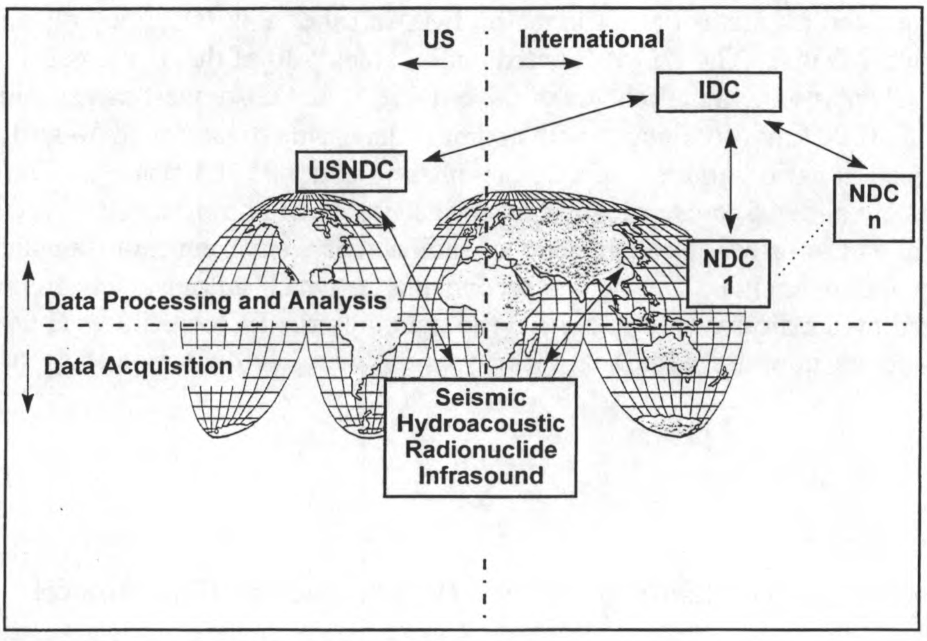


Figure 8.7: CTBT International Monitoring System

formulation of requirements for customized selection and screening of data products, and by installing at the IDC algorithms and software provided by States Parties.

Confidence Building Measures

In recognition of the special verification challenges posed by large chemical explosions, the Treaty includes voluntary confidence building provisions aimed at decreasing compliance concerns about such explosions. On a voluntary basis, States Parties are encouraged (preferably in advance) to provide notification of and information about any singly detonated chemical explosion in excess of 300 tons.[8] Also on a voluntary basis, States Parties are encouraged to annually provide information on the location, nature, and frequency of all other chemical explosions in excess of 300 tons. The latter provision would include multiply detonated explosions, which are expected to be somewhat less problematic than singly detonated explosions since they tend to produce smaller seismic signatures per weight of explosive and since those signatures sometimes include features not present in nuclear explosions. Also on a voluntary basis, States Parties may invite representatives of the CTBT Organization or other States Parties to visit sites related to the above activities. States Parties are also encouraged to conduct these or other explosions in a manner that will support efforts to better calibrate the propagation of seismic signals in that region.

Consultation and Clarification

States Parties may avail themselves of the consultation and clarification provisions of the Treaty in order to attempt to resolve possible non-compliance issues without having to invoke an On-Site Inspection (though it is done without prejudice to the right of a State Party to request an OSI). Under these provisions, any State Party may request of another State Party, either directly or through the Organization, clarification regarding a matter of possible non-compliance.[9] The clarifying party is obligated to respond within 48 hours and provisions are included in the Treaty regarding approaches for dealing with lack of response or unsatisfactory response.

On-Site Inspections. The Treaty also provides for the possibility of an On-Site Inspection to help resolve whether or not a nuclear explosion has taken place in contravention of the treaty. OSIs can be requested by States Parties based on IMS or other data (including open sources and National Technical Means). The OSI is initiated only if at least 30 of the 51 members of the Executive Council (EC) approve within 96 hours of the request. The OSI request can specify an inspection area of up to 1000 km^2 (contiguous with no linear dimension greater than 50 km). The nominal 60-day inspection period consists of a 25-day phase 1 and a 35-day phase 2. During the first phase, inspectors are allowed to use such techniques as visual and photographic inspection (including multispectral and infrared), measurements of radioactivity, environmental sampling, and passive seismology (aftershocks). During the second phase, which automatically follows the first unless terminated by a majority vote of the EC (no action by the EC constitutes approval to continue), the inspectors may use additional techniques including active seismology, magnetic and

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[8] Comprehensive Nuclear Test Ban Treaty, Article IV, ¶ 67, and Part III of Protocol.

[9] Comprehensive Nuclear Test Ban Treaty, Article IV, ¶ 29-33.

gravitational field mapping, ground penetrating radar, electrical conductivity, and drilling. The inspection team may request a 70-day extension, subject to majority vote approval by the EC.[10]

NATIONAL REGIMES

National Authorities

Each State Party is obligated to designate or set up a National Authority which will serve as the national focal point for liaison with the Organization and with other States Parties.[11]

National Data Centers

Annex 1 to the Treaty Protocol lists the IMS stations and identifies the State Party responsible for each station. Many States Parties, including the United States, are establishing National Data Centers in order to fulfill their responsibilities for implementation, maintenance, and operation of these stations, and to support national processing of data from IMS and national sensors. The U.S. National Data Center is currently being prototyped at the Air Force Technical Application Center (AFTAC).

National Technical Means (NTM)

The Treaty allows State Parties to utilize "relevant technical information" obtained from NTM data to support requests for OSI.[12] In addition, State Parties will use NTM to support their own verification judgments. In the case of the United States, NTM will be used to fill the gap between IMS capabilities and the U.S. monitoring requirements.

Open Data Sources

The Treaty provides a mechanism by which a State Party may designate as Cooperative National Facilities stations that are not formally included in the list of IMS stations. Once approved and certified by the Organization, these stations can be called upon by the IDC, if requested by a State Party, for the purposes of facilitating consultation and clarification and the consideration of On-Site Inspection requests.[13] In addition, States Parties can utilize other open data sources, including non-IMS type sensors such as commercial imaging.

SYNERGY BETWEEN ELEMENTS OF THE MONITORING REGIME

By design, the various elements of the international and national monitoring regimes interact synergistically at a number of levels. At the most basic level, the four IMS monitoring net-

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[10] Comprehensive Nuclear Test Ban Treaty, Article IV, Section D ("On-Site Inspections"), ¶ 34-67, and Part II of Protocol ("On-Site Inspections").

[11] Comprehensive Nuclear Test Ban Treaty, Article III, ¶ 4.

[12] Comprehensive Nuclear Test Ban Treaty, Article IV, ¶ 37.

[13] Comprehensive Nuclear Test Ban Treaty, Article IV, ¶ 27-28.

works augment each other by focusing on different potential test environments: underground, underwater, and in the atmosphere. In some cases they also provide overlapping coverage that can improve detection, location, and identification capabilities. One such example is in the oceans where underwater events may produce signals detectable by both the hydroacoustic and seismic networks. Similarly, events at the medium interfaces (air-water, air-land) may produce signals detectable by a combination of all four sensor types. Modelling efforts comparing the detection effectiveness and location accuracy of the integrated system versus each technology subsystem individually for a small, shallow-buried or submerged nuclear explosion show that the integrated system covers significantly more geographic areas and provides significantly better location accuracy (by as much as a factor of 10 in some areas) than can any individual subsystem.[14] Figures 8.8a and 8.8b portray this effect qualitatively for a notional small, shallow-buried or submerged event by plotting estimated detection effectiveness (white is better, black is worse) as a function of event location for individual networks and the combined network, respectively.

Considering Figures 8.8a and 8.8b from a potential evader's perspective reinforces the value of the combined use of the IMS technologies. For the test scenario modelled, geographic areas not well covered by one technology are generally covered by another. Attempts to change the test scenario in order to avoid detection by one technology tend to increase the probability of detection by another. For example, testing deeper in order to avoid detection by infrasound or radionuclide tends to improve the performance of the seismic and hydroacoustic networks and vice versa. Compounding this with IMS performance variability (due, for example, to changing winds and background noise levels) further increases the challenge to a potential evader.

At a higher level, Treaty provisions for Confidence Building Measures, consultation and clarification, and On-Site Inspection offer escalating steps that can be taken to resolve compliance issues. The interaction between OSI and the other elements of the regime is particularly important,

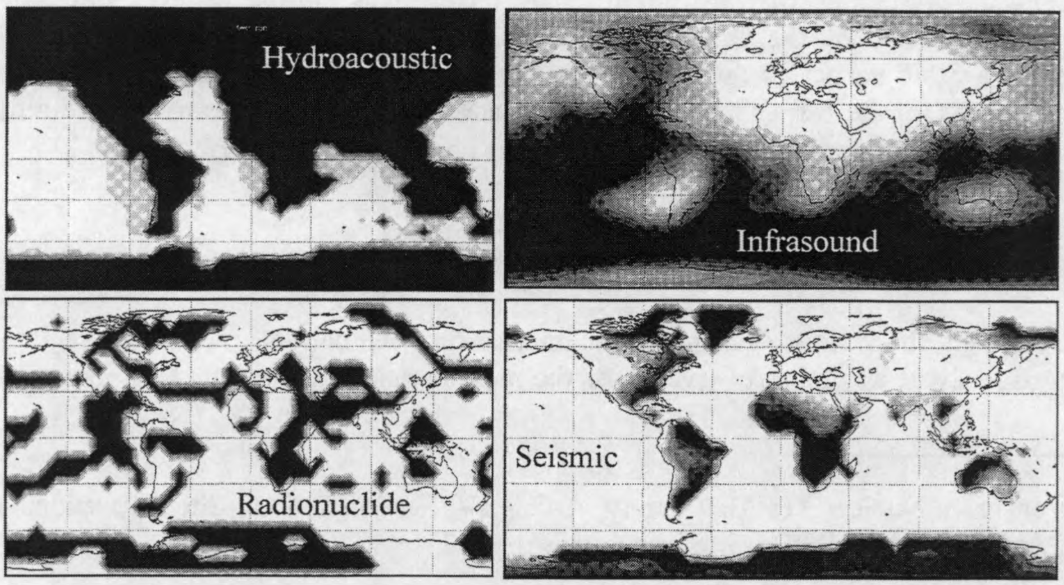

Figure 8.8a: Detection Effectiveness for a Small, Shallow-Buried or Submerged Event

[14] Edenburn, M.W. et al., "Synergy Among International Monitoring System Technologies."

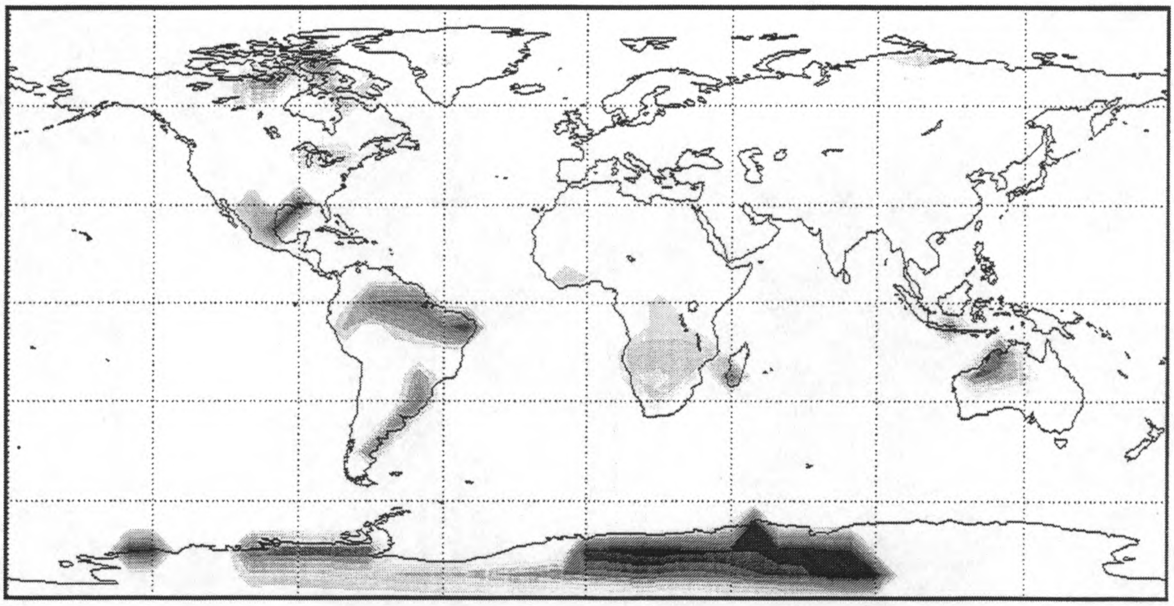

Figure 8.8b: Detection Effectiveness of Combined IMS Network for a Small, Shallow-Buried or Submerged Event

since those other elements will be used to make the case for OSI and since they will determine the area to be inspected. It is obvious that the success of an OSI, as well as the need for an OSI, will depend strongly on the accuracy with which ambiguous events can be located.

Finally, the interplay between a State's NTM and the international regime can significantly improve the verifiability of the Treaty. In addition to improving the technical performance of the monitoring system relative to the IMS system alone, NTM has an additional deterrent benefit. This benefit stems from the fact that a potential evader can estimate with some confidence the capabilities and vulnerabilities of the IMS, but is much less able to do so for another State's NTM.

SUMMARY

The issue of CTBT verifiability is a complex one driven by a number of technical and political considerations. Taken as a whole the combined set of verification means and measures proposed for the international and national regimes will present a formidable challenge to evaders, but important work remains to be done to ensure that the full potential of this regime is realized. From the U.S. perspective, key elements of the prescribed IMS networks as well as planned upgrades to U.S. NTM must be implemented and research to improve detection, location, and identification capabilities should continue.

CHAPTER 9

DEVELOPING DATABASES FOR MONITORING AND VERIFYING THE COMPREHENSIVE TEST BAN TREATY

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ABSTRACT

With the signing of the Comprehensive Test Ban Treaty (CTBT) by most states, we now need to focus our attention on the operational aspects of global monitoring. The CTBT includes provisions to develop a new approach to test monitoring in order to detect small yield nuclear explosions: regional monitoring. But regional monitoring on this scale has never been applied in an operational mode and this raises considerable challenges to the treaty implementation. Previous monitoring experiments, such as the Threshold Test Ban Treaty (TTBT), have been quite successful because of the large yield threshold. Teleseismic monitoring was quite adequate for the TTBT implementation and enforcement. With the CTBT much smaller nuclear explosions need to be monitored. In order to detect seismic signals from a potential, small-sized nuclear explosion, recordings need to be done near the source region, owing to weaker energy released. This regional monitoring is further complicated by the complexities in geologic structures. Since the upper part of the earth's interior (~ first 200 miles) is much more heterogeneous than its deeper sections and regional scale seismic energy travels within this complex part, successful monitoring requires that we document and understand this part of the earth. In this paper we give examples of such prototype studies focussed on understanding regional scale earth structures and developing a digital information system that will aid both the scientists working on monitoring issues and the decision makers who need to access extremely large data sets and information in a very short time.

Our study includes developing and organizing multidisciplinary geological and geophysical databases and access tools under Geographic Information Systems (GIS). Our initial efforts concentrated on the Middle East and North Africa region owing to our expertise achieved through work done in the past in this region. However, we are expanding our research to include global databases appropriate for use by the International Monitoring System (IMS). Preliminary models of our databases are already functional at the U.S. National Data Center and being tested for the U.S. monitoring systems. Samples of our databases can be accessed over the Internet using Worldwide Web (WWW) browsers at http://atlas.geo.cornell.edu.

INTRODUCTION

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* Research in this paper is supported by Department of Energy contract F19628-95-C-0092 and Department of Defense Nuclear Treaty Programs Office Grant No. DASG609610002.

Concentrated efforts toward a global Comprehensive Test Ban Treaty that will ban all nuclear explosions on earth are currently underway. Effective monitoring for such a treaty is essential if all nations are to adhere to its stated articles, conditions, and guidelines. For the past few decades, emphasis has been placed on using seismological observations and techniques to monitor a limited test ban, especially to assist in the precise calibration of explosive yields at a few specific sites. The Comprehensive Test Ban scope of zero yield requires credible strategies for effective monitoring: the ability to detect, characterize, calibrate, discriminate, and verify any suspect event for any region on earth. Recently, other technologies, such as radionuclide, infrasound, and hydroacoustic monitoring systems, are increasingly being used and integrated with seismic monitoring systems to more accurately and comprehensively monitor the CTBT. As these varied technologies progress and the sizes of the discrimination thresholds get smaller (< 1 kiloton), it becomes apparent that other geophysical, geological, and satellite imagery data sets, in automated digital form, could significantly contribute to the overall monitoring objectives. Specifically, this "auxiliary" information can make it possible to better characterize and calibrate recorded events in a given region by providing accurate observations that are pertinent to the region under investigation. Examples of such critical observations are crustal velocities and densities, locations and depths of sedimentary basins, locations of active faults and well-determined earthquake locations.

New data, both seismological/geophysical and geological, are required to constrain advanced theoretical modeling efforts in order to better understand the propagation of high-frequency seismic waves produced by very low yield events at regional distances. For these monitoring efforts to be successful, researchers must be able to detect, characterize, calibrate, discriminate, and verify any suspect event for most regions on earth. Important to a successful monitoring strategy, such data must be swiftly accessible to researchers via computer networks in order to integrate with real-time recorded events to provide ground-truth for timely verification, especially during On-Site Inspection efforts.

Our objective is to collect and organize all available seismological, geophysical, topographical, and geological data sets for any region on earth to form a digital information system that is accessible via the Internet from Cornell. In cases where there are recent, unstudied data that can be used to constrain some of the existing information and/or provide new information, we use these data to obtain more accurate results and include them in our databases as new information. Hence, we view our ongoing and planned GIS efforts to continue to progress and evolve in the future as new and more detailed data become available. It is important that our digital, network-accessible information system is complete, comprehensive, multidisciplinary, unified, easy to update, and of direct relevance to monitor the CTBT or any other agreements.

DATABASES AND COMPUTERIZED DATA ACCESS TOOLS

We continuously add more information into our database in order to construct a complete crustal structure database as well as other types of geophysical and geological databases. The database system is divided into four different categories: geographic, geologic, geophysical, and imagery. In this report, we present some of the available data and access tools that we have recently developed. The entire database system is developed on an Arc/Info Geographic Information System. All data are kept in Arc/Info format and can be accessed through custom designed, menu-driven access tools. The entire system is self sufficient and requires no prior knowledge of Arc/Info software commands. A user can search, study, manipulate, download and make prints or slides of any part of this database using this menu-driven system. One of the biggest advantages of this newly developed system is that all the data are available on one computer and the user can select and display any parts of the various databases within a few seconds. Multiple layers of data can be displayed in the same graphic window allowing the user to comprehend the study area in its entirety.

SAMPLES OF DEVELOPED DATABASES

Global and local earthquake locations

Figure 9.1 shows a global seismic event locations map for one year (1986). In a year there are tens of thousands of earthquakes located throughout the globe. The number of recorded earthquakes would be increased if we were able to detect all events down to about magnitude 3.5 globally. The accuracy of these locations and their depths are also critical. As can be seen from Figure 9.1 most of the events are located along major plate boundaries. However, there are numerous earthquakes located in the interior of plates such as central Asia and the Middle East. In order to obtain accurate locations we are also including in our databases seismic bulletins from local government networks. These kinds of data can be used for studying previous seismic events. This becomes particularly important in a situation where a "suspicious" event is located in a region. These data sets provide means of quickly obtaining information concerning the extent, depth, and exact mechanism of past seismicity for any given region. Researchers will also be able to use these data in their studies, for example by looking at velocity distribution and depth estimation of these events and their accuracies. This type of information will be critically important for decision makers who may have to issue alerts or request on-site inspections under the auspices of the CTBT.

Tectonic map of the Middle East

Figure 9.2 shows fault distribution extracted from a recently developed tectonic map of the Middle East region. Using this tectonic map, faults (or any other features in the map) can be used in conjunction with earthquake locations to study the location of a suspicious event and its correlation with the surrounding tectonic units. The advantage of this system is that it allows a user to interactively select any item from the map and study its attributes. For example, a user can click on a fault and obtain information about style of deformation along the fault or whether or not the fault is active. Similarly, it is possible to click on the computer screen and obtain information about a seismic event that is near a fault. These interactive tools make the system efficient to use for multiple purposes and allows decision makers and researchers to access the data and information rapidly.

Mine locations

With the collaboration of the Lawrence Livermore National Laboratory we developed a database of mine location sites for some countries (see Figure 9.3). This information is critical for CTBT monitoring, as many of these mines use large chemical explosions on a regular basis. In a hypothetical situation in which a country might detonate a small nuclear explosion, these mine

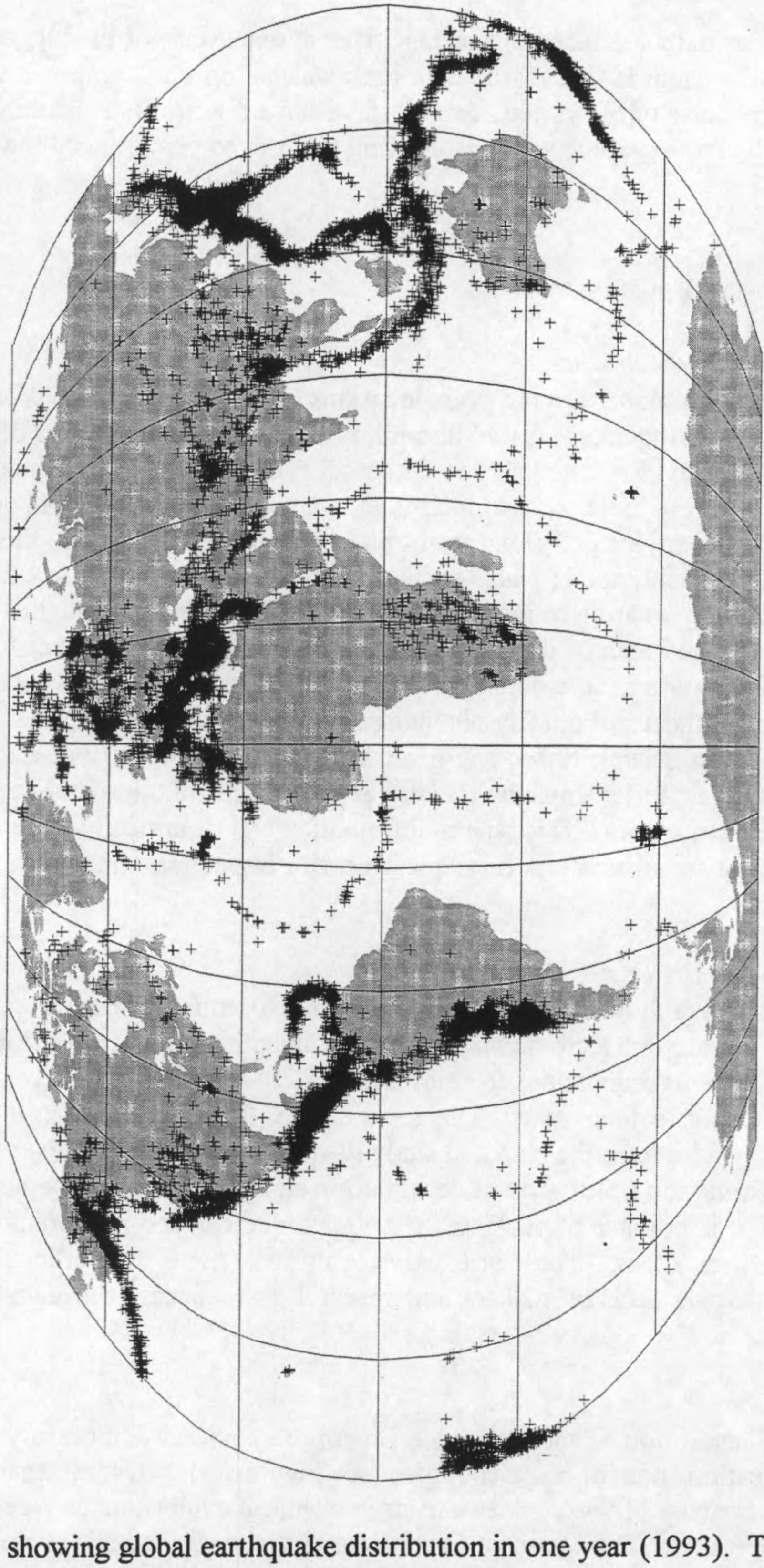

Figure 9.1: Map showing global earthquake distribution in one year (1993). Tens of thousands of earthquakes with varying magnitudes are located every year.

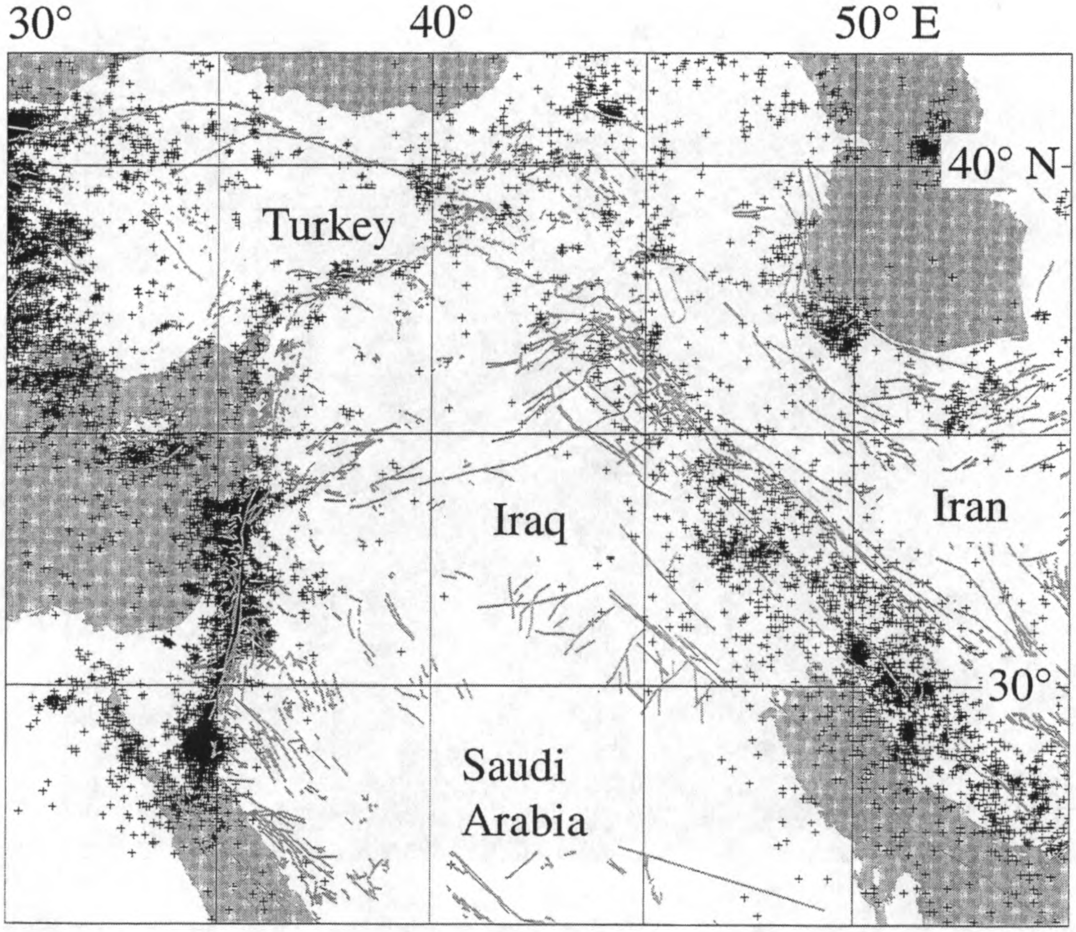

Figure 9.2: Map showing earthquake locations and fault distribution in the Middle East region. Developed database system allows selection of a number of information layers from the database. In this map only faults are selected from the digital tectonic map and earthquake locations are overlain for analysis of spatial correlation between earthquakes and faults.

locations are potential sites and could be chosen to mask the seismic signal, as there are always large explosions conducted near them. Some of these mine sites also include large cavities that could be used as a potential nuclear test sites. In our databases we have not only recorded locations of these mines, but also their style of operation, the commodity that is mined, and whether or not these mines are active in the present time.

Additionally there are many other data sets that are already developed and ready to be used in our database systems, including satellite imagery, subsurface structure and velocities beneath most of the Middle East, North Africa and Eurasia regions, seismic waveform propagation quality factors, gravity data, focal mechanisms of seismic events, and geographic information such as country borders, coast lines, rivers, lakes, roads, and railroads. These data sets are an essential part of CTBT monitoring efforts and allow decision makers to be alert in case there are any suspect events near mine sites.

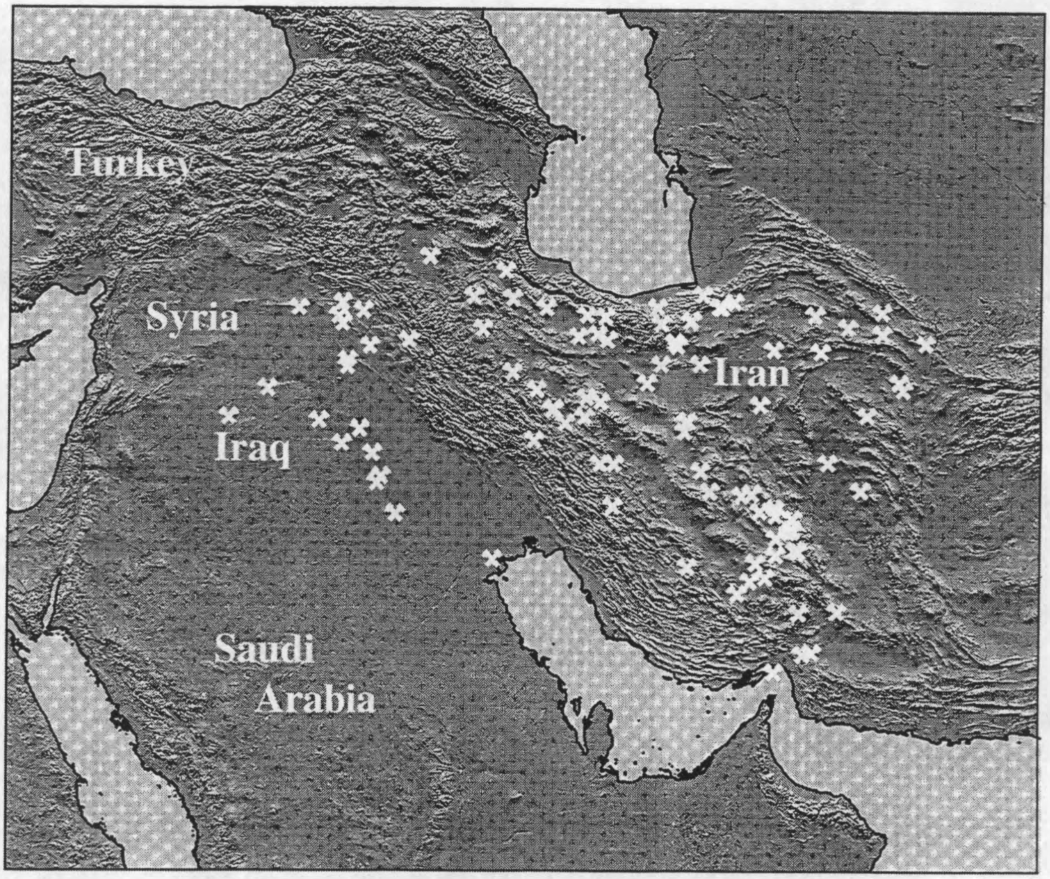

Figure 9.3: Hill shaded topography map of the Middle East region. Overlain are producing mine locations shown only in Iraq and Iran. This type of information is critical to CTBT monitoring.

ACCESS TO CORNELL DATABASES

Because the commercial software we are using is not freely available to research groups and decision makers, we are also developing an Arc/Info–WWW interface to permit ready access to our developed databases. Our newly established system is now available and functioning at our WWW address, http://atlas.geo.cornell.edu. Access to Arc/Info databases is provided through specially designed programs. We are striving to keep the architecture in the Web pages as close to those in Arc/Info system as possible. Although it is not possible to give as much flexibility in data manipulation, 80-90% of the menu driven system's functionality will be accomplished under this WWW system (see Figure 9.4). This system is most convenient for IMS users, as they may not be able to construct advanced data processing and analyses labs. They will be able to use the Web sites like ours or the International Data Center's to monitor other regions. This will allow equality for all the state parties involved. Our sophisticated Arc/Info GIS databases will be available to the U.S. organizations and data centers.

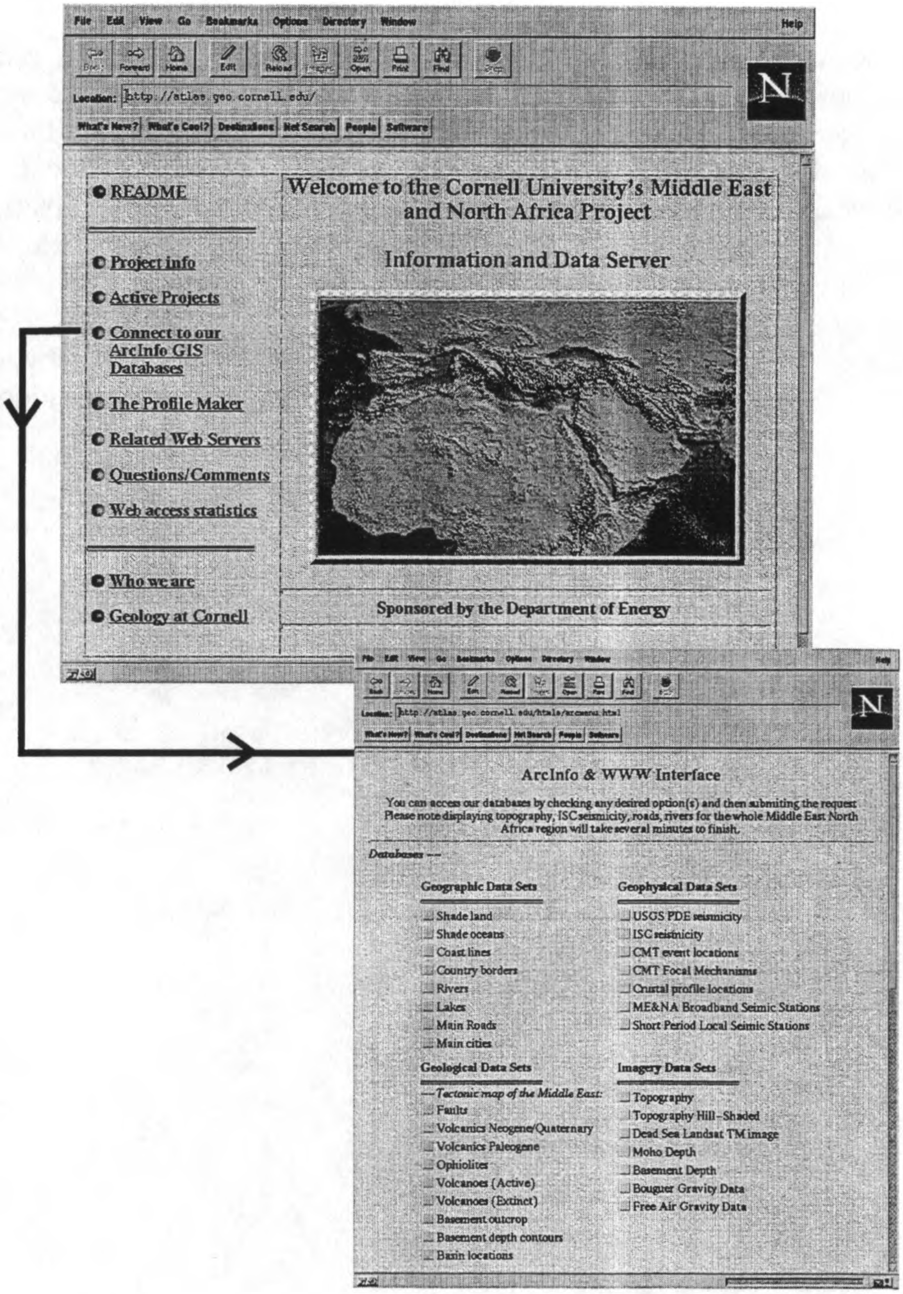

Figure 9.4. Cornell databases are available through the World Wide Web. Under this Web server it is possible to design and plot maps and copy the resultant images.

CONCLUSIONS AND RECOMMENDATIONS

Our expanding digital geological and geophysical information system will be an essential tool in the implementation of the CTBT and in nuclear nonproliferation monitoring. These databases provide important ancillary information on the structure of the crust and upper mantle that may affect the propagation of seismic phases at regional distances. In turn, this bears on the detection, discrimination, calibration, on-site inspection, and yield estimation of nuclear explosions and other suspect events.

We recommend that to monitor the multilateral comprehensive nuclear test ban and non-proliferation treaties, comprehensive digital databases be made available and accessible to decision makers in local computers and similar information be made available over the Internet for use by researchers. New data, both seismological/geophysical and geological, are required to constrain advanced theoretical and modeling efforts in order to better understand the propagation of seismic waves produced by very low magnitude events at regional distances. For these monitoring efforts to be successful, researchers must be able to detect, characterize, calibrate, discriminate, and verify any suspect event for most regions on earth. As important to the success of any monitoring strategy, such data must be swiftly accessible in digital form to researchers via networks in order to integrate with real-time recorded events to provide ground-truth for fast verification purposes.

CHAPTER 10

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

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

I. NUCLEAR PROLIFERATION

Conclusions:

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

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

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

Answer I.1:

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

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> NPT (1968) and TTBT (1974) Preambles: "Recalling the determination expressed by the Parties to the 1963 Treaty . . . to seek to achieve the discontinuance of all test explosions of nuclear weapons for all time and to continue negotiations to this end,"

> TTBT Resolution of Ratification (September 1990): ". . . the United States shares a special responsibility with the Soviet Union to continue the bilateral Nuclear Testing Talks to achieve further limitations on nuclear testing, including the achievement of a verifiable comprehensive test ban."

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

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

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

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

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

Answer I.2:

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

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

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

Answer I.3:

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

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

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

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

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

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

Answer I.4:

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

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

II. NUCLEAR ARMS CONTROL

Conclusions:

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

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

Question II.1: Constraints on the Nuclear Weapon States

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

Answer II.1:

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

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

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

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

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

Answer II.2:

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

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

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

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

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

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

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

Answer II.3:

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

Question II.4: Nuclear Weapon State Nuclear Forces

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

Answer II.4:

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

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

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

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

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

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

III. WARHEAD RELIABILITY

Conclusions:

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

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

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

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

Answer III.1:

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

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

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

Answer III.2:

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

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

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

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

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

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

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

Answer III.3:

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

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

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

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

Answer III.4:

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

Question III.5: Reliability Tests

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

Answer III.5:

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

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

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

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

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

Question III.6: Actionable Defect Types

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

Answer III.6:

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

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

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

Question III.7: Missile Reliability

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

Answer III.7:

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

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

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

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

Question III.8: Competence of Weapon Designers

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

Answer III.8:

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

Question III.9: Performance Enhancements

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

Answer III.9:

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

Question III.10: Purpose of Reliability

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

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

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

Answer III.10:

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

IV. WARHEAD SAFETY

Conclusions:

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

Question IV.1: Accidents with Nuclear Weapons

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

Answer IV.1:

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

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

Question IV.2: How Safe is Safe?

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

Answer IV.2:

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

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

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

Answer IV.3:

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

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

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

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

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

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

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

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

Question IV.4: Military Views on Testing for Safety

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

Answer IV.4:

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

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

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

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

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

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

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

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

V. VERIFICATION

Conclusions:

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

Question V.1: Seismic Capabilities

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

Answer V.1:

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

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

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

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

Question V.2: High Confidence and Deterrence

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

Answer V.2:

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

Question V.3: Cavities

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

Answer V.3:

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

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

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

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

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

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

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

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

Answer V.4:

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

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

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

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

VI. VERIFICATION-COMPLIANCE PROCESS

Conclusions

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

Question VI.1: Effective Verification

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

Answer VI.1:

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

> What do we mean by "effective" verification? We mean that we want to be sure that if the other side moves beyond the limits of the Treaty in any militarily significant way, we would be able to detect such violation in time to respond effectively and thereby deny the other side the benefit of the violation.[21]

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

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

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

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[21] START Treaty, Senate Executive Report.

[22] START Treaty, Senate Executive Report.

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

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

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

Answer VI.2:

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

Question VI.3: Threshold Test Ban Treaty Compliance

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

Answer VI.3:

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

Question VI.4: Comprehensive Test Ban Treaty Violation

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

Answer VI.4:

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

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

FURTHER READING

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

APPENDIX I

ACRONYMS AND ABBREVIATIONS

ADT	Actionable defect type
ALCM	Air-launched cruise missile
CBM	Confidence building measures
CD	Committee on Disarmament
CEP	Circular error probable
C^3I	Command, control, communications and intelligence
CTBT	Comprehensive Test Ban Treaty
CTBTO	Comprehensive Test Ban Treaty Organization
D	Deuterium
DOD	Department of Defense
DOE	Department of Energy
EC	Executive Council (of the CTBTO)
EDR	Earthquake data report
EIF	Entry into force
EMP	Electro-magnetic pulse
ESTA	European Science and Technology Agency
HEU	Highly enriched uranium
H^3	Helium three
GLCM	Ground-launched cruise missile
GSETT	Group of scientific experts technical test
IAEA	International Atomic Energy Agency
ICF	Inertial confinement fusion
IDC	International Data Center
IMS	International monitoring system
INF	Intermediate-range nuclear forces
LANL	Los Alamos Nuclear Laboratory
LLNL	Lawrence Livermore Nuclear Laboratory
LTBT	Limited Test Ban Treaty
LYNER	Low yield nuclear explosive research
MIRV	Multiple independently retargetable reentry vehicle
MMIII	Minuteman III
NATO	North Atlantic Treaty Organization
NEIC	National Earthquake Information Center
NEIS	National Earthquake Information Service
NIF	National Ignition Facility
NNWS	Non-nuclear weapons states
NPT	Nonproliferation Treaty
NTM	National technical means
NWS	Nuclear weapons states
OSI	On-site inspections
PDE	Preliminary determination of earthquakes

PNE	Peaceful nuclear explosions
Pu	Plutonium
SLBM	Submarine-launched ballistic missile
SLCM	Submarine-launched cruise missile
SOFAR	Sound fixing and ranging
STS	Strategic retargeting system
SSBN	Ballistic missile submarine
SSMP	Stockpile Stewardship and Management Program
START	Strategic Arms Reduction Talks
T	Tritium
TTBT	Threshold Test Ban Treaty
UN	United Nations
USSR	Union of Soviet Socialist Republics
WG Pu	Weapons grade plutonium
WMD	Weapons of mass destruction
WWW	Worldwide Web

APPENDIX II

Author Biographies

Mauwia Barazangi is a senior scientist and faculty member in the Department of Geological Sciences and the Institute for the Study of the Continents (INSTOC), Cornell University. He is the associate director of INSTOC, and leader and coordinator of the Middle East and North Africa Project at Cornell University. His academic background includes a B.S. degree in physics and geology from Damascus University (Syria), an M.S. degree in geophysics from the University of Minnesota, and a Ph.D. in seismology from Columbia University, Lamont-Doherty Earth Observatory (New York). Professional experience includes global tectonics, tectonics of the Middle East and North Africa, structure of the continental lithosphere, and structure of intracontinental mountain belts. Recently, Barazangi and his research group have focused on developing an extensive Geographic Information System (GIS) of geologic/geophysical/seismological/geographic data for the Middle East and North Africa region to support CTBT objectives.

Pierce S. Corden is Chief of the Arms Control and Disarmament Agency's International Security and Nuclear Policy Division, where he directs the formulation and implementation of arms control policy on nuclear testing, particularly the Comprehensive Test Ban Treaty. He is chairman of the interagency backstopping group that supported the U.S. delegation to the Geneva Conference on Disarmament (CD) for the test ban negotiations, and is now responsible for the U.S. participation in the CTBT's Preparatory Commission, which he also serves as the U.S. Representative. His responsibilities include chairing the backstopping group for the CD's involvement in anti-personnel landmine negotiations, and handling the broad range of other issues addressed in the CD and in the United Nations First Committee and Disarmament Commission. Dr. Corden has published contributions on the ethics of nuclear deterrence, on confidence- and security-building measures, and on the United Nations' role in post-Gulf War disarmament in Iraq. He was Deputy Executive Chairman of the UN Special Commission for Iraq in 1992-93.

Lawrence J. Ferderber is the Deputy Associate Director for National Security at the Lawrence Livermore National Laboratory. He has been at Livermore for 29 years, the vast majority of that time associated with the nuclear testing program. During the late 1980s he participated in Threshold Test Ban Treaty negotiations in Geneva and in bilateral treaty monitoring activities in the United States and the Soviet Union. In 1993 he was temporarily assigned by the Department of Energy to the Office of Senator Reid (D-Nev) to work on issues related to the future of the Nevada Test Site. He returned to Livermore in 1995.

Richard L. Garwin is IBM Fellow Emeritus at the Watson Research Center, Yorktown Heights, NY and also Adjunct Professor of Physics at Columbia University. From 1950-93 he was a consultant to the Los Alamos Scientific Laboratory, especially in the design of nuclear weapons and their testing, to which he made significant contributions. He is now a consultant to the Sandia National Laboratory. He is Chairman of the Director's Advisory Committee of the Arms Control and Disarmament Agency, and in 1996 received the R.V. Jones Intelligence Award of the U.S. government foreign intelligence community. He is a member of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine.

David Hafemeister is a Professor of Physics at California Polytechnic State University. He is presently a Foster Fellow at the Arms Control and Disarmament Agency working on START I, II and III. He was the lead on technical matters for the ratification of the START, CFE and TTBT arms control treaties while serving as a professional staff member of the Senate Committees on Foreign Relations and Governmental Affairs (1990-1993). Other arms control tasks were as the Science Advisor to Senator John Glenn (1975-1977), Special Assistant to Deputy Under Secretary of State Joseph Nye (1977-78), and at the State Department Offices of Nuclear Proliferation Policy (1979) and Strategic Nuclear Policy (1987).

Matthew G. McKinzie is a Project Scientist in the Nuclear Program at the Natural Resources Defense Council in Washington, DC. During 1995-97 he was a Postdoctoral Associate with the Peace Studies Program at Cornell University. He received his Ph.D. in experimental nuclear physics from the University of Pennsylvania in September 1995.

Christopher E. Paine is a Senior Research Associate in the Nuclear Program of the Natural Resources Defense Council, Washington, DC and co-director of its nuclear warhead elimination and nonproliferation project. He has long been associated with congressional and public efforts to end U.S. nuclear testing and production of weapon-usable nuclear materials. From February 1987 to May 1991 Mr. Paine was a staff consultant and legislative assistant for nuclear energy and weapons production issues to Senator Edward M. Kennedy (D-Mass). He has also served as a consultant to the Project on Nuclear Policy Alternatives, Center for Energy and Environmental Studies (CEES), Princeton University (1985-87), a MacArthur Fellow-in-residence at the Federation of American Scientists, Washington, DC (1985-87), and staff consultant for nuclear nonproliferation policy with the Subcommittee on Energy Conservation and Power, U.S. House of Representatives (1985-86). Paine was a member of the first western delegations to visit the secret Soviet atomic city, Chelyabinsk-65, in 1989 and the controversial Soviet early warning radar at Krasnoyarsk in 1987, and he was a part of the U.S. nongovernmental technical team that in May 1986 negotiated installation of the first joint U.S.-Soviet seismic monitoring network in the vicinity of the nuclear test site in Kazakhstan. From 1974 to 1979 he worked as a journalist and researcher covering Middle East political and arms sales issues. He is a 1974 graduate of Harvard University and the author or co-author of numerous NRDC Nuclear Weapons Databook reports and articles on arms control and defense policy.

Paul G. Richards holds a bachelor's degree in Mathematics (1965) from the University of Cambridge and an M.S in Geology (1966) and a Ph.D. in Geophysics (1970) from the California Institute of Technology. Since 1971 he has taught at Columbia University where he is currently the Mellon Professor of Natural Sciences in the Department of Earth and Environmental Sciences. He is a member of the American Geophysical Union (president of the seismology section, 1992-1994), of the Seismic Review Panel of the Air Force Technical Applications Center (1985 to present) and of the Council on Foreign Relations. He has given invited Congressional testimony on several occasions concerning the ability of seismological methods to verify nuclear test ban treaties. He is co-author of *Methods of Quantitative Seismology* (1980), author of about 100 technical papers on seismology (about 30 of them concerned with monitoring nuclear explosions); and co-discoverer (with Xiaodong Song) of the differential rotation of the Earth's inner core, which was listed by *Science* magazine as one of the top ten scientific discoveries of 1996.

Annette Schaper has a Ph.D. in experimental physics and is senior research associate in the Non-proliferation Program at the Peace Research Institute Frankfurt. Her main interest is nuclear arms control and its technical aspects, including test ban, cut-off, nuclear disarmament, fissile materials disposition, and nonproliferation problems arising from the civilian-military ambivalence of science and technology. She was a consultant of the German CD delegation in Geneva in the test ban negotiations and member of the German delegation at the NPT review and extension conference.

Lawrence Scheinman is Assistant Director of the United States Arms Control and Disarmament Agency for Nonproliferation and Regional Arms Control and Professor Emeritus, Cornell University. Dr. Scheinman has also served in the Department of State, the Department of Energy, the Energy Research and Development Administration and the International Atomic Energy Agency. He was a member of the tenured faculties of the University of California at Los Angeles and the University of Michigan before coming to Cornell in 1973. He is an internationally recognized authority on nonproliferation and international security affairs and the author of numerous books, monographs and articles.

Dogan Seber is a Postdoctoral Associate in the Institute for the Study of the Continents (INSTOC), Cornell University. His academic background includes a B.S. degree in geophysics from Istanbul Technical University (Turkey), an M.S. degree in seismology from Saint Louis University (Missouri), and a Ph.D. in seismology and remote sensing from Cornell University. His professional experience includes seismotectonics of the Middle East and North Africa, tomography of body waves, surface waves, seismic refraction, and gravity studies. Recently he has worked on the development of an extensive Geographic Information System (GIS) of diversified databases for the Middle East and North Africa region that are accessible via the Web.

Larry S. Walker is the Manager of Sandia's CTBT Verification R&D program. He has been involved in the design, development, and management of sensor and data processing systems for treaty verification, arms control, and nonproliferation since joining Sandia in 1977. He also served as scientific advisor to the US delegation negotiating START and as a technical expert to the CTBT negotiations and the CTBT Preparatory Commission.

APPENDIX III

ISSUES SURROUNDING U.S. CONGRESSIONAL RATIFICATION OF THE COMPREHENSIVE TEST BAN TREATY

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