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Nuclear Export Controls and the CTBT: Where We've Been and Challenges Ahead

— Views of an Engineer

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Thank you for this opportunity to speak. I'm going to depart a bit from the normal format of an "information exchange talk" to give both a bit of history and a bit of philosophy formed by my working on nuclear export controls for 15 years. Then I will make some suggestions about how current developments may influence our future.

I believe we should all feel honored to be here. The work of the NSG is important for humanity and the world. Our countries have entrusted important work to us and we should feel both honored and humble because of that. This may seem a bit pious, especially from an engineer, but I believe it and I think all of us should believe it. And those feelings are good ones to have. We should savor them. Further, I note that this work has allowed us to travel to some of the most interesting meeting spots of the world. Most of us have enjoyed that! I'm especially happy to be here in Scotland – it's my first visit and I've brought my wife with me!

I don't think the purpose of the NSG is concisely and explicitly stated in our various documents, but I think there would be pretty universal agreement that the purpose is close to the statement in Part 2 of the NSG Guidelines: -- "With the objective of averting the proliferation of nuclear weapons ...." Avert is a somewhat nebulous word to me, so I had to check a dictionary to be certain of its meaning. I found "to ward off," "to prevent." **So the NSG exists to ward off or prevent the proliferation of nuclear weapons. That is our reason for being here.**

We meet that objective by developing transfer guidelines that our individual countries implement and follow. These guidelines control the transfer of nuclear commodities and technologies so that they will not be used in proliferant nuclear weapon programs.

I. The Importance of Export Controls

Every country that has built nuclear weapons has produced its own fissile material. However, <u>all</u> of those countries <u>have had to import</u> commodities and technology to speed that production. They have also imported commodities to speed the process of going from fissile material to deliverable nuclear weapons. These statements apply even to the multinational Manhattan Project centered in the United States during World War II. Much of the brainpower came from Eastern and Western Europe. Uranium ore was imported from Canada and Africa. Specialized materials were located and secured from several countries.

Today's proliferant countries vary in their need for imports to conduct a nuclear weapons program. Some of the programs that seem to have imported the least have also had very slow rates of progress. The suspected North Korean program has often been cited as an example of a highly indigenous program.

The history of the Pakistani nuclear program, started in the 1970s, is not official. However, much has been widely reported. The main source of fissile material for Pakistan is based on the theft of centrifuge technology from Western Europe. There is a long history – much of it in the records of export violations in our countries – of Pakistani "front companies" attempting to purchase commodities needed to implement every step of their program. The majority of these attempts were for "dual-use" commodities because access to "especially designed or prepared" trigger list items had effectively been denied by our adoption of the NSG Part I Guidelines. The record shows attempts, often successful, to purchase virtually every material, part, and machine tool needed to build uranium enrichment centrifuges. Other widely reported acquisition attempts include the casting molds for high explosives to drive an implosion weapon; -- components for weapon firing sets – capacitors and Krytron tubes; -- and high-speed cameras and flash x-ray systems needed to develop implosion systems. Although much was purchased before the NSG dual-use arrangement was in effect, clearly the rate of progress of the program seems to have been restricted by the rate at which commodities could be obtained.

The IAEA and UN Special Commission inspectors have extensively documented the Iraqi nuclear weapons program. This program clearly was made possible by dual-use imports. Virtually every item needed for the program was imported, and a large number of us, including my country, were unwitting suppliers to the program.

Control of nuclear and "dual-use" transfer is the first line of defense against nuclear proliferation.

II. Uniqueness of Nuclear Weapons and their Export Control Requirements

We hear much talk of the possible integration of export control regimes and of the harmonization of export controls between different regimes. I do not want to take any position regarding the worth of integration and harmonization. However, it is important to remember that nuclear weapons are unique, and nuclear controls need to be tailored to the nuclear problem.

First, let us consider the destructiveness of nuclear weapons. The detonation of a basic (a beginner's) nuclear weapon in a large city center is likely to cause 50,000 to 100,000 deaths in the first 24 hours, and the number of deaths may double over the next few months. This, of course, is coupled with extreme property destruction. No other weapon system could cause anywhere near so much devastation. Use of more advanced nuclear weapons could increase the destructive energy more than a thousand-fold. Sidney Drell, author of *Facing the Threat of Nuclear Weapons*, has pointed out that the sum total of all munitions expended in World War II from 1939 to 1945 added up to less than 6 megatons. Single nuclear weapons can be and have been built with greater power than that. And the delivery of nuclear weapons can vary from a few people carrying small suitcases of weapon parts into a city for in-basement assembly, to delivery in a small truck, to delivery in minutes from great distances on a modern ballistic missile. The risk of such extreme devastation, which can be delivered in the most mundane ways, creates a moral imperative to give special consideration to preventing nuclear proliferation. Remember. The first unique characteristic of nuclear weapons is their destructiveness.

Second, let us consider how the uniqueness of nuclear weapons relates to the probability of effective export control. The process of producing fissile material and developing nuclear weapons is time consuming, complex, and expensive and involves a large amount of technology. In a proliferant country, it may well take ten years or longer and it almost certainly will put a strain on the country's budget. The Manhattan District project, although lasting only about four years, required more than 200,000 people and 2,200 million dollars. The Soviet Union's program, although also done rapidly, is believed to have required more than a million people.

Export controls drive the cost of proliferation programs higher, lengthen the time needed to achieve proliferation goals, and may well force the country to simply decide that the weapon is not feasible. That is, the mere existence of export controls may have prevented some countries from even starting nuclear weapon programs. Because of the complexity of fissile material production and nuclear weapon development, export controls exert a relatively stronger and longer lasting deterrent over nuclear weapons than over any other weapon technology. It should also be noted that history shows that even after a country is able to build its first nuclear weapon, there is a continuing need for imports to sustain and maintain the program. That is, export controls continue to affect the rate at which a nuclear stockpile can be built.

III. Why Dual-Use Controls?

Historically, the scarcity of fissile material and the difficulty and expense of producing it have been considered the great barriers to nuclear proliferation. Much nonproliferation effort is dedicated to preventing the production or acquisition of fissile material. Article III of the NPT focuses on control of fissile material and is the basis for the Trigger List efforts. The early NSG extended the Zangger effort by covering certain technology transfers and heavy water plants. It also added criteria for the physical protection of fissile material. However, the underlying assumption was that nuclear technology was highly specialized and that it was sufficient to control only commodities "especially designed or prepared" for the production of fissile material.

The increasing (and desirable) spread of high technology throughout the world and especially the study of the Pakistani nuclear program in the 1980s made clear to nonproliferation scholars that controls on "dual-use" commodities were essential to stop the semi-indigenous building of fissile material production facilities.

In the 1980s some people also began to realize that although fissile material production would remain difficult, it would become more and more common, and the possibility of a country acquiring fissile material by transfer would grow. Therefore, we determined to look for possible commodity roadblocks on the route from having fissile material to having deliverable nuclear weapons. Studies of the weaponization process were done by some weapon states in the 1980s, resulting in some countries unilaterally controlling "dual-use" commodities for weaponization.

When this background knowledge was coupled with the findings of the early UN Special Commission and IAEA inspections in Iraq in 1991, the NSG "dual-use arrangement" moved rapidly toward its implementation in 1992. About half the items on the "dual-use" list are items controlled because of their use in weaponization. The NSG "dual-use" list represents the only international controls on the weaponization process.

One might ask if "dual-use" controls are sufficient for weaponization. Aren't there specialized non dual-use items for weapons that should be controlled? Yes, such items exist but they have always been kept classified by the nuclear weapon states. Therefor, there is no need for multilateral export controls on them, and the very act of describing such items would only spread useful information to proliferants.

IV. Recent Developments

Let's look at some recent nonproliferation developments beyond export control. The Comprehensive Test Ban Treaty (CTBT) is a historic milestone in efforts to reduce the nuclear threat and build a safer world. As of January 1998, it had been signed by 149 countries and ratified by eight. The cessation of all nuclear weapon test explosions and all other nuclear explosions, by constraining the development and qualitative improvement of nuclear weapons, constitutes an effective measure of nuclear disarmament and nonproliferation in all its aspects.

The CTBT makes it almost impossible for any weapon state to design a new nuclear weapon. However, in general, the willingness of the nuclear weapon states to sign the CTBT has been based on their belief that they can still maintain existing weapons and effective nuclear deterrents without testing. In the United States much of this process to maintain a nuclear deterrent is called "science-based stockpile stewardship." Basically the program involves gaining a much more detailed technical understanding of aging factors in weapons and their possible effects on weapon operation. To do this, specialized non-nuclear experimental facilities are being built, and computer simulation and visualization is being developed to a level of detail far beyond anything existing today. Other weapon states are pursuing similar programs. I will come back to these programs later in terms of some possible export control implications.

The IAEA's Safeguards Regime exists to provide timely warning of any diversion of fissile material from civil nuclear fuel cycles. Since 1993 implementation has gone forward on the Strengthened Safeguards System, and the IAEA is currently negotiating the Additional Protocol to the Safeguards Agreement with individual States to give the IAEA greatly increased access to information and locations. At the end of 1996 the IAEA had almost 100,000 Significant Quantities of fissile material under Safeguard agreement. That material was located in almost 1000 facilities distributed among about 65 countries. This represents more than a doubling of material under safeguards in a decade.[1] Note that a Significant Quantity is an amount of fissile material so large that the possibility of manufacturing a nuclear explosive device cannot be excluded. Therefore, the material under IAEA Safeguards represents, potentially, material enough for almost 100,000 nuclear weapons. Fissile material, although expensive, can no longer be said to be scarce.

The world inventory of fissile material continues to grow, especially because of plutonium creation during the operation of civil power reactors. However, that material is not very attractive to beginning bomb builders. Most weapon states have stopped or greatly reduced their production of fissile material for weapons. Under the START I arms control reduction agreements between the U.S. and the Soviet Union – and later, Russia - the number of deployed strategic nuclear weapons belonging to the two countries decreased by over 6000 warheads between 1990 and mid-1997.[2] The U.S. and Russia are also known to be dismantling or planning to dismantle many tactical nuclear weapons. Unquestionably, the risk of a major nuclear exchange between the superpowers has diminished greatly. The U.S. Department of Energy and nuclear authorities in Russia and several of the Newly Independent States are cooperating on a major program to upgrade nuclear material protection, control, and accounting (MPC&A) practices. Plans are being made under the Trilateral Initiative for the IAEA to verify fissile material that is transferred out of the defense sectors in the U.S. and Russia.

All of the above indicate that there continue to be ever-stronger efforts against nuclear proliferation in the world and that significant advances have been made. Nevertheless, many proliferation experts believe that the risk of a nuclear weapon being used in anger has actually increased! This is because the risk of diversion of weapons-usable material appears to be larger than ever because of the large quantities now available and the large amounts in the Former Soviet Union (FSU). In the FSU, relatively new governments are still developing their nuclear control and accounting systems while often being almost overwhelmed by economic problems.

The final recent development I want to mention is the growing amount of technical information about nuclear weapons, fissile material production, etc., that has become openly available in the past five years. With the end of the Cold War there has been considerable release of previously classified information that has to be helpful to proliferants. Unfortunately, the justification for its release, all too often, seems to be simply to satisfy curiosity, promote general openness, or boast to colleagues "look what we were able to do." I think too little attention is being paid to the resultant proliferation risks. Along with this release of information, there are a growing number of internet web sites that feature information on how to build nuclear weapons. That information is usually being imparted with the idea that it is good to have an informed public. Fortunately, much of the information is inaccurate, but it is certainly not in the interest of nonproliferation for such information to be distributed.

V. Some Non-obvious Challenges

A. Computer Modeling and Visualization

With the advent of the CTBT we are even more firmly into the era in which nuclear weapon testing will simply be too expensive for proliferants when measured in terms of its political cost. In the early days of proliferation, it was assumed that any country that designed a nuclear weapon would test it. The only way to be absolutely certain that the design was correct was to do a test. Furthermore, there was a sense of economic and technological prestige attached to such an accomplishment. Over time, the political cost of doing such a nuclear test has been raised step by step until now, with the advent of the CTBT, it is very unlikely that a proliferant would do a full-scale nuclear test. At the same time the ability to detect nuclear tests of low-yield continues to improve, and it is thought unlikely that a proliferant could conduct a clandestine test. Any test would probably be detected.

The first nuclear weapon used in war (the Hiroshima bomb) was not tested beforehand. Most nuclear experts have said that a capable proliferant probably could design, without full-scale nuclear testing, a first-generation weapon with good confidence of achieving significant yield. In this environment, one must ask whether "science-based stockpile stewardship" methods can benefit proliferants. Under "science-based stockpile stewardship" a variety of specialized facilities will be built and used to study and experimentally create some of the conditions that would exist in detonating nuclear weapons. Much of this experimentation will have a basic scientific flavor and will be published openly – having potential peaceful benefits for mankind. It should be noted that the design of nuclear weapons is complicated by the fact that the range of operating conditions within a nuclear weapon is greater than in anything else, manmade or natural, existing on earth. The processes are extremely complicated and are conducted in incredibly harsh environments. One deals with extreme temperatures (100 million degrees); high material velocities (over 1 million miles/hour); and small time scales (measured in thousandths of a microsecond). The forces are so large that the strongest metals compress and flow like fluids. The concept of designing a machine that by its very nature destroys itself and everything within a kilometer or so of itself in a fraction of a second when it operates obviously complicates the process of understanding its reliability and of refining the design. Consider further that some parts of the machine will have been vaporized in an explosion while other parts only a few centimeters away must be made to move smoothly and precisely, but very quickly, into new spatial configurations under the harsh environmental conditions described. Truly, nuclear weapon design is a unique challenge.

It is very difficult or impossible to simulate these conditions in a laboratory and almost as difficult to measure and observe them if they are simulated. Under the "science-based stockpile stewardship" program, large laser and large pulsed-power equipment will be built to simulate portions of the weapon operations environment. Specialized diagnostic equipment will record the experiments. However, the largest scientific stretch will be the computer modeling techniques that will be developed and applied on an unprecedented scale through use of computers at least 100 times more powerful than any that exist today.

I want to digress briefly and tell you about an exciting technological development in our time that we all benefit from – one that was driven by nuclear weapon designers. Traditionally science and engineering have proceeded based on an interrelationship between theory and experiment. That interrelationship is the root of the "scientific method" that has so strongly shaped modern society. At various times theory or experiment have led or lagged the other. But in most applications of technology the time and cost of doing experiments has been low enough to allow rapid progress, even if theory did not allow complete understanding in advance. The development of airplanes in the early part of this century is certainly one example of experiment leading theory, but the technology still developing rapidly. An earlier example, where this did not happen, was in Gothic cathedral building in medieval Europe. Citizens dedicated their entire lives to the construction of a single cathedral, often in competition with other city-states for the highest or widest building. Each new attempt (at a new height or expanded interior width) took about 40 years to test out. Buildings frequently fell, often with lethal consequences, during or after construction because the early designers had no theory with which to design and no capability to take factors such as wind loads into account. By trial and error they refined their craft in 40-year-long experiments, with the result that they could increase their *capability* to design only very slightly. They could increase their *capacity* to build by adding resources – mainly workers. The designers understood geometry and aesthetics but had insufficient understanding of structural forces.[3]

The design of nuclear weapons presented a similar challenge, not because the experiments (nuclear tests) took so long to do, but because they were so expensive, so obnoxious to society, and so difficult to measure and understand. In this environment some of the best mathematical minds in the world were working, and simultaneously the stored-program digital computer was being developed. Beginning in the early 1950s a third methodology beyond theory and experiment was developed, feeding both scientific and technological advances. Armed with the proper equations, which may come from either theory or experiment, we can model phenomena on high-speed computers. We can, in essence, do the 40-year cathedral design experiment in seconds on the computer and see which cathedral will collapse and which will withstand the 1000-year windstorm.

In recent years, we have added the power of computer graphics to provide visualization of processes. We can see a picture of the cathedral on a computer screen, we can see which stone first breaks or slips, we can watch the sequential failure of other parts of the cathedral. With such visualization, most of us, without any knowledge of structural design or material parameters, could figure out how to modify a cathedral design so the building would not collapse. That is, we can improve designs without fully understanding them.

On the computer we can change both time scales and spatial scales to fit our human perception scale. Processes that take millionths of a second can be lengthened to minutes; processes that take centuries can be compressed to minutes; and microscopic phenomena can be scaled to centimeters. If the describing equations are accurate and the computer is sufficiently large enough to model the problem in sufficient detail and fast enough to do it on a reasonable time scale, computer modeling and visualization is extremely powerful. Ideally one understands the physics of the process being modeled sufficiently to write equations from first physical principles that accurately describe it. To date this has been impossible in nuclear weapon design. Instead, weapon design codes are mixtures of equations based on known physics and empirical equations and correction factors based on actual nuclear weapon test data.

Most people are not aware of the extent to which computer modeling and computer visualization techniques owe both their invention and development to nuclear weapon design laboratories. Today computer modeling is taught in all engineering schools and we all benefit daily from these capabilities. Examples abound. Weather and climate prediction, computer designed automobile bodies that protect us in crashes, and city traffic flow designs that minimize congestion are some examples.

Under the "science-based stockpile stewardship" program, computer modeling and visualization will be taken to unprecedented levels of detail and speed. But also new understanding will be gained of basic physical processes under conditions of extreme temperatures and pressures allowing modeling of many phenomena from first physical principles for the first time. Both of these aspects can be expected to have civil benefits. However, there are accompanying proliferation implications in the ability to model certain physical phenomena from first principles, in the wide dispersal of computer modeling and visualization knowledge, and in the availability of computers with unprecedented speed and power at moderate cost. With this information, the modeling of implosion weapon designs from first physical principles may become feasible for some proliferants. Moderately large computers that can be bought for as little as $75,000 may become very useful to them.

B. Fissile Material Availability and Instant Nukes

Another concern, much simpler to explain, is the possibility of a country or even a terrorist group obtaining sufficient fissile material for a weapon, possibly by theft or clandestine means, and thereby being able to bypass the difficult and expensive problem of producing it. Sufficient material is about the size of a soda can and could be readily carried in a briefcase. Having fissile material, if they were to obtain a design that was both workable and possible to implement with the skills and equipment available to them, might allow them to go from the acquisition of the fissile material to a deliverable weapon in a few weeks. To do this would require much advance preparation, but the country could appear to become a nuclear power instantly. Here it should be emphasized that the nuclear weapons business has many paradoxes. If sufficient fissile material of the right type is available, quite simple designs and construction methods can produce weapons of 15 kilotons or so yield - truly devastating weapons. On the other hand, if conservation of fissile material is desired, and smaller weapons with higher yields and various specialized features are wanted, the design and engineering problems can challenge the world's best scientists and engineers for decades. The possibility of "instant nukes" would happen if the country or terrorist group had acquired needed expertise as well as needed weaponization equipment and materials in advance; and had practiced the necessary processes before acquiring the fissile material. Of course if a country hasn't done the pre-work but acquires fissile material, it may still build a weapon although the time span could easily be one or more years.

VI. Possible NSG Considerations

In view of the continuing concern about nuclear proliferation, the NSG should ask whether there are ways to make its controls more effective. Because of the possible direct acquisition of fissile material, the NSG dual-use list weaponization controls should be reviewed for completeness and effectiveness.

The U.S. is starting a review of the "science-based stockpile stewardship" program to determine whether any elements of it warrant export control protection. We would encourage other weapon states to do similar reviews of their programs. . Certainly we need to review the need for and possibility of controls on large computers and on certain types of computer modeling codes.

The dual-use arrangement is especially likely to require changes over time. Because of the character of dual-use commodities, controlled items can develop such widespread civil use and application that control is simply no longer feasible. Similarly, new technologies develop that simplify the nuclear proliferation process and utilize key commodities that it is feasible to control. Such commodities should be added to the list. However, I believe retaining commodities on the list after they are no longer feasible to control is as great a threat to the effectiveness of the NSG as failing to control things requiring control. The decision to remove or add items to the list is likely to remain difficult to reach agreement on.

Are our information-sharing practices as effective as they should be? We should review whether additional information should be stored on the NSG Information Sharing System and whether our data updates are adequately fast. Rapid reporting of denials is especially desirable both to thwart "license shopping" by proliferants and from a self-interest standpoint to prevent economic undercutting.

I think it would be helpful for technical working committees to pool information and develop some "best practice guides" on certain topics that member states all have to be involved in. Two obvious topics would be "license review practices and procedures" and the "design and implementation of computerized license review systems."

Finally, I believe we need clear guidelines for the review of "dual-use" commodities when economic factors are important in determining whether they should be controlled. A technical working group could develop a list of appropriate data and criteria for countries to present when they are arguing either for or against control changes. This might include lists of countries that manufacturer the item, documentation of civil applications, amount of civil sales versus controlled nuclear sales, etc.

In closing I want to stress that its important for the NSG and individual delegates to monitor the process of proliferation, to understand how it happened in the past, to understand how it may happen in the present and the future, and to understand how the NSG may exert control **to ward off or prevent nuclear proliferation**. I believe the importance of our work warrants a much higher level of study and dialogue than we've sometimes exhibited in the past.

I feel very fortunate to have been asked to work with the NSG during the past seven years. I'm especially proud to have been part of the original NSG Dual-Use Working Group, which met from May 1991 to January 1992 to develop and craft the "Dual-Use List".

I'm retiring from Los Alamos in June, but I hope to continue to be involved with you in some way as you continue your noble work toward nonproliferation goals.

Thank you – and farewell.

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[1] Safeguards information from IAEA 1996 Annual Report and IAEA Bulletin **39** No.4, December 1997.
[2] From *START I Memorandum of Understanding, July 1, 1997;* Arms Control Association.
[3] The discussion of medieval cathedral building is taken from "The Need for Supercomputers in Nuclear Weapon Design," U. S. Department of Energy report, January 1986.