Working Paper

How Verification Can Be Used to Ensure Irreversible Deep Reductions of Nuclear Weapons

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Abstract

Verifying nuclear disarmament is a complex technical process. This paper examines the techniques that could be used to verify future nuclear weapon reductions and analyzes the motivation for the nuclear states to accept deep weapon cuts and the prospect for future nuclear reductions. To allow large nuclear reductions and ensure credible verification, several steps are suggested in this paper: All nuclear warheads should be registered and tagged; the total inventories of plutonium and high-enriched uranium as well as the fissile cores dismantled from the warheads should be verified; the nuclear delivery vehicles and launcher numbers and types should be monitored as outlined in the START and INF treaties; and nuclear-capable delivery vehicle production should also be monitored.

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Introduction

Since the building of nuclear weapons in the United States and the Soviet Union, and since the destructive effects of nuclear weapons shown in Hiroshima and Nagasaki, nuclear disarmament has become a most important international security issue. The distrust of the parties makes verification a key factor in any disarmament or arms control agreement.

Verifying nuclear disarmament is a complex technical process. It will never be totally effective, but verification can play an essential role in providing the trust necessary to support the ongoing process of reducing nuclear arsenals. This paper examines the techniques that could be used to verify future nuclear weapon reductions.

There are several methods of verification. National technical means (NTM) have been used in most arms control agreements, and they will play an important role in any future treaty. On-site and near-site inspection or monitoring have been used in the Intermediate-Range Nuclear Forces (INF) treaty, the Strategic Arms Reduction Treaty (START), and the Comprehensive Test Ban Treaty (CTBT). More intrusive on-site means will probably be used in future nuclear reduction agreements.

Verification is a highly subjective process. It is a product of negotiation and compromise among the parties. The provisions for and intrusions of verification measures are mainly decided by political agreement instead of technical analysis. The very motivation of the parties to approach the treaty makes such an agreement on verification possible. The quantity and type of deployment of nuclear weapons determine the kind of intrusive measures used in any verification provisions. This paper analyzes the motivation for the nuclear states to accept deep weapon cuts and the prospect for future nuclear reductions. Accordingly, verification is part of the broader commitment to make nuclear disarmament accords irreversible.

To allow large nuclear reductions and ensure credible verification, this paper advocates:

1. Registering and tagging all nuclear warheads. The locations and types of nuclear warheads covered by the agreement should be verified; warheads in excess of the agreement should be dismantled under strict verification.

2. Verifying the total inventories of plutonium and high-enriched uranium as well as the fissile cores dismantled from the warheads. Any fissile material that exceeds agreed amounts must be disposed of under monitored procedures.
3. Monitoring the nuclear delivery vehicles and launcher numbers and types as outlined in the START and INF treaties.
4. Monitoring agreed nuclear-capable delivery vehicle production.

This paper analyzes the verification provisions for a future nuclear weapons reduction agreement from a technical point of view, and some methods for verification are outlined. It is impossible to prevent some cheating under any kind of verification regime. The verification regime described here tries to minimize cheating and to ensure that any undetected violations will not alter the military balance or undermine the basic agreement.

Prospect for Deep Reductions in Nuclear Weapons

During the Cold War, both the United States and the Soviet Union pursued a nuclear arms race and built huge nuclear arsenals. After the Cold War, the collapse of the Soviet Union changed the world security regime. The world has been in a transition from the confrontational bipolar system of international relations to a unipolar world dominated by the United States.[1] Nevertheless, common interests between Russia and the United States continue, though they still need to change the relationships formed in the Cold War. Both states need to cooperate to face the common threat of nuclear proliferation and other international security issues. Both have expressed the desire to initiate deep cuts in their nuclear forces and to reduce the high alert status of their strategic forces in order to lessen the risk of a nuclear exchange.

On the U.S. side, nuclear weapons have continued to play a unique and indispensable role in U.S. security policy. The United States insists on maintaining nuclear weapons to face the challenges of an uncertain future, ensure stability in the international environment, and promote U.S. nonproliferation goals.[2] The United States still assumes that nuclear deterrence between it and potential nuclear adversaries will be stable, and that stable nuclear deterrence means that nuclear weapons on both sides will help defuse a crisis rather than escalate to all-out war.[3] At the same time, the United States tries to build cooperation to enhance mutual confidence with Russia. Washington wants to open discussions with Russia about future nuclear cuts in strategic and tactical nuclear weapons[4] and to support the nuclear fissile material cutoff treaty.

During the 1980s, the Soviet Union proclaimed a no-first-use policy. The collapse of the Soviet regime has caused severe social and economic problems, and the poor conventional force performance in the first Chechen war made Russia more reliant on the nuclear weapon. Moscow has announced that it is abandoning the Soviet Union's no-first-use pledge. But maintaining its large nuclear and conventional arsenals became an increasing economic burden and accelerated Russia's decline from a superpower to a second-rank economic nation. The lack of resources prevents Russia from maintaining, let alone expanding, its existing nuclear arsenal. Even if Russia were to keep its deployed nuclear forces at the level of START III, which is around 2,000 weapons, it would have to spend $14 billion in the next 10 years—which would be about 27 percent of its present defense budget.[5] It still exceeds Moscow's economic capability.

The Russian strategic nuclear forces are a triad consisting of land-based (in silos as well as mobile rail- and truck-based), sea-based, and air-based strategic components. Many of them (both strategic and tactical) are approaching the end of their projected lifetimes, and Moscow does not have the resources to refurbish them or to produce a new generation of weapons. Right now, and in the foreseeable future, Russia will not have the economic means to maintain a large number of deployed intercontinental ballistic missiles (ICBMs). Its delivery systems are rapidly aging and will probably have to be scrapped.[6] Russia does not even have enough money to develop or test a new generation of tactical nuclear warheads under the restrictions imposed by the CTBT.

In these new circumstances, the Russian government has moved away from the policy of confrontation that it pursued in earlier decades. It wants to concentrate on more immediate and pressing threats, such as the conflicts in the Caucasus and Central Asia. Its leaders appear to believe that in the short term (the next 5–10 years) Russia will not face any major external military threats. There is a common understanding that it would be beneficial for Russia to accept a START III agreement with even lower levels than were agreed to at the Helsinki summit. President Vladimir Putin has called for further cuts and stepped-up efforts to streamline Russia's nuclear capabilities and has said, "Our aim is to make our nuclear weapons complex more safe and effective."[7]

The British government also plans to reduce its nuclear forces. London has made it clear that it would not use the full capacity of the Trident submarines, and each of its four submarines would deploy fewer than the maximum load of 96 warheads.[8] In July 1998, Britain's Labor government announced that only one British submarine would patrol at any given time. Each boat would carry a reduced load of 48 warheads, and Britain will maintain fewer than 200 operationally available warheads. This is a one-third reduction from the previous Conservative government's plan. Britain will purchase a total of 58 rather than 65 Trident D-5 missiles.[9]

In the French case, dramatic decisions on nuclear arms control were made in the 1990s. In February 1996, President Jacques Chirac announced that the S3D intermediate-range missile would be retired without replacement. On September 16, 1996, all 18 missiles on the Plateau d'Albion were deactivated. Two years later, the silos and complex were fully dismantled.[10] Recently, France reduced the total warheads in its stockpile to 470.[11]

China has the smallest nuclear arsenal of all of the five nuclear states. In 1996 the People's Republic of China (PRC) signed the CTBT agreement, which limited its capability to develop a new generation of nuclear weapons. China has supported the fissile material cutoff negotiation, and a cutoff agreement would dramatically limit China's nuclear arsenal. Beijing's no-first-use policy and minimum deterrence posture ensure that China will not build or develop a large number of nuclear weapons. China is the only nuclear weapon state that voted for the Malaysian resolution on negotiations toward a nuclear weapons convention.[12] The PRC plans to be very active in promoting the world nuclear disarmament process.

As important as other countries are, the United States and Russia hold the key to fundamental nuclear disarmament in this regard. The former presidents Bill Clinton and Boris Yeltsin agreed that the next step after START II enters into force should be the negotiation of a START III agreement. According to the joint statement, START III will establish by December 31, 2007, a ceiling of 2,000–2,500 strategic nuclear weapons for each of the parties, and it would include measures relating to the transparency of strategic nuclear warhead inventories, the destruction of strategic nuclear warheads, and the transparency of fissile material production and inventories.[13] This would be the first treaty to deal with warhead limits and fissile material disposal, and the verification regime under it would set the direction for future nuclear reductions.

Even with this treaty, the nuclear warheads of Russia and the United Stated still far exceed what they need. A committee on international security and arms control has analyzed the post–Cold War security environment and how it relates to the future of the U.S. nuclear policy. It recommends a reduction of the U.S. and Russian nuclear weapons to a total inventory of about 1,000 warheads each after START III comes into force. This could lead to still deeper cuts; that is, to totals of a few hundred each in the U.S. and Russian arsenals.[14] At a level of about 1,000 warheads, survivability can be ensured if the United States were to deploy Trident submarines carrying a reduced number of missiles. This level also offers the Russian government the option to place a greater proportion of its nuclear forces in a survivable posture at sea or in a land-mobile status.

A force of a few hundred nuclear warheads would be able to carry out the essential missions against even the most challenging potential U.S. adversaries under any credible circumstances, assuming that strategic defenses remain limited and transparent enough to avoid surprises. The other nuclear powers probably would deploy fewer than 100 nuclear warheads to maintain their minimum deterrence. From a purely technical point of view, a few hundred nuclear weapons—of which at least 100 warheads were secure, survivable, and deliverable—should be adequate to conduct a nation's basic military missions.[15]

Declarations of Warheads and Fissile Materials

START II limits the number of warheads mounted on strategic delivery vehicles. It does not limit the number or types of warheads that each side may possess. Therefore it would be legal under START II to store and maintain for redeployment the warheads that must be removed from delivery vehicles to meet the treaty's limits. This failure to limit warheads, combined with the inherent capability of some delivery vehicles to carry many more warheads than START II permits, provides the possibility of rapid breakout.[16] Large numbers of nondeployed warheads present a serious potential for reconstitution of larger nuclear forces, especially if the delivery means are readily available. A deep reduction program, therefore, requires Russia and the United States to agree on a method for reducing warheads under verifiable conditions, to make the reductions irreversible, and to find a way to confirm how many nondeployed warheads exist.[17]

Both the U.S. and Russian presidents agreed that START III will include measures relating to the transparency of strategic nuclear warhead inventories and the destruction of strategic nuclear warheads. The nuclear warheads should be declared and registered. This is especially important because estimates by national intelligence agencies are highly inaccurate. For example, a Central Intelligence Agency official testified in 1992 that Russia had 30,000 nuclear warheads, "plus or minus 5,000."[18] Subsequent statements by Russian Minister of Atomic Energy Victor Mikhailov that the Russian stockpile peaked at 45,000 warheads in 1986 cast doubt on the CIA's estimation abilities and illustrated the difficulty of estimating warhead stockpiles by national intelligence means alone.[19] Declarations of total stocks of weapons and fissile materials—with their locations disclosed and with exchanges of operating records and inspections of material production sites—would reduce the large uncertainty in present estimates of these stocks.[20]

The quantity of weapons-grade fissile material determines how large the nuclear arsenal could be. Only if the fissile material could be controlled would the reversal of arms reductions become more difficult. Large stockpiles of nondeployed warheads or fissile materials create the potential for rapid and large-scale breakout from treaty obligations. A well-designed plan to hide warheads or materials would give few clues about where to look for them. To exchange detailed historical information on the nuclear stockpiles as part of the initial declaration would be very important. These records could be examined for internal consistency and consistency with the current stockpile declaration, and they could be compared to archived intelligence information. Declaring the number of nuclear warheads and the size of fissile material inventories would be a most important first step in the START III treaty.

In May 1995, the United States and Russia agreed on the description of what the U.S. and Russian governments would do in the area of nuclear material inventory data exchange.[21] They agreed to a regular exchange of detailed information on aggregate warhead stockpiles and on stocks of fissile materials. A cooperative arrangement for reciprocal monitoring at storage facilities of fissile materials was adopted to enhance the confidence in the validity of the declarations on fissile material stockpiles.

In June 1995, the United States proposed a modest stockpile data exchange agreement of total current inventories of nuclear weapons and all fissile materials, as well as the total number of nuclear weapons dismantled each year since 1980 and the type and amount of fissile material produced each year since 1970. Russia rejected the proposal because it was deemed "too comprehensive."[22] In fall 1995, Russia broke off the transparency negotiations, and they have not been resumed. The technical groundwork for implementing transparency measures, however, has now been laid, so it would be possible to enact the measures relatively quickly once Moscow decides to move forward.[23]

The United States has published a report that provides a comprehensive accounting of its plutonium inventories, the quantities of plutonium in its weapons stockpile and in pits, and the records of its plutonium production.[24] Russia is not willing to release information on its plutonium stockpile based on security considerations and economic reasons.

To make any further nuclear reductions irreversible, all information that limits the relevant nuclear forces and makes their verification reliable should be exchanged and registered. Such information would include the type and serial number of every nuclear device; the location and serial number of each fissile component recovered from a dismantled warhead; the total inventories of plutonium and highly enriched uranium (HEU); and a detailed inventory for each facility for bulk fissile materials. To enhance confidence that these declarations would be as accurate and complete as possible, information on the history of the warhead, fissile material stockpiles, and the facilities should be exchanged to support future verification.[25] For stored warheads or warhead components, the location would be a particular storage facility; for deployed warheads, it would be the corresponding launcher. The serial number could serve as a unique identifier for each item, or special “tags” could be used for exchanging data and for registration purposes.

Unique identifiers or tags would have three key advantages. First, tags make it easier to certify the completeness of a declaration, because the discovery of an untagged warhead or canister would constitute an unambiguous violation. Second, it would not be necessary to inspect or count each and every controlled item to gain confidence in the accuracy of the declaration. Inspectors could authenticate the tags on randomly selected items, thereby reducing the inspection effort and its degree of intrusiveness. Third, tags would show a chain of custody in which individual warheads could be tracked from deployment sites to storage bunkers to dismantlement facilities. Similarly, canisters containing warhead components could be tracked from dismantlement facilities to storage sites to facilities for civil use or to disposal facilities.

Verification would be improved if all declared nuclear warheads and canisters containing pits or fissile materials were equipped with a unique identification number or tag that was specified in the declaration. Several different kinds of applied tags have been tested, such as bar-coded labels, plastic holographic images overlaid by a tamper-proof tape, microscopic photography of parts of the outside surfaces, and spray paint to produce photographed “signatures” that are almost impossible to change or reproduce without detection.[26] Tags have been used by the United Nations Special Commission (UNSCOM) in Iraq to log and track items that could be used for both civilian and military purposes. They have also been used by the International Atomic Energy Agency (IAEA) to safeguard civilian nuclear materials, and by the U.S. military to track weapons.[27] This technique has proven to be efficient and effective in ensuring compliance to a treaty. Although certain technical issues would have to be worked out, there should be no problem in instituting an effective tagging system for canisters containing warheads, warhead components, or fissile materials. START also has used tags for verification.[28]

Verifying the Declarations of Warheads and Fissile Material

All declaration information should be verified to ensure that all warheads and fissile material are declared. All legal items should be tagged and sealed. The inspectors could compare the tags with the record to identify possible violations. Now, we discuss how to verify such declarations.

The warheads deployed on strategic missiles are covered by the START agreements. Nearly all other warheads are in storage. The inspector would visit a particular storage facility and check that the declared number of warheads is present. These could be regular or short-notice inspections, combined with challenge or suspect-site inspections. The inspectors would select a random sample of warheads and verify that each had a valid tag corresponding to a warhead listed in the declaration. A sample of 20 or 30 warheads in a site containing hundreds would be enough to inspire confidence that the declaration was accurate.[29]

For verifying the undeclared nuclear warheads, the warhead production record should be checked carefully. The production record and declared nuclear warheads should be consistent.

Weapons-useable fissile material control accounting is the key factor to minimize the uncertainty of undeclared nuclear warheads. We discuss that later. Challenge inspection should be permitted to any suspect site.

Tags and seals alone, it should be noted, are not so secure and possibly can be defeated.[30] It would be necessary for inspectors to make certain that tagged objects contain authentic nuclear warheads or fissile components. This could be dealt with by developing "fingerprints" or templates of warhead types and by using random sampling to confirm that a particular warhead is the declared type. A set of agreed characteristics could be measured: length and diameter; mass and center of gravity; the relative strength of neutron emissions or gamma-ray emissions at certain points; and heat output. Fingerprints of this type would be extremely difficult to counterfeit.[31] Any reliable inspection would, of course, have its limits to avoid compromising sensitive information. Only some information on the warhead would have to be detected, and only the necessary information for reliable verification would have to be revealed.

Arms-control experts have proposed a so-called "passive detection" method that detects the radioactive rays (include neutron and gamma rays) caused by the fissile material decaying in the warhead. This method has already been used to detect the existence of concealed warheads in canisters.[32] The results show that neutrons can be detected at a distance and that little sensitive information is thereby revealed. The difficulty is how to distinguish a weapon from a nonweapon neutron source. The gamma-ray-spectrum detection method could confirm the presence of plutonium or highly enriched uranium but could not confirm so easily that the object inside the canister was an authentic nuclear warhead or pit without revealing sensitive information like the configuration of the weapon.[33] To protect sensitive weapon-design information, some suggest that an automated system could be devised to give a simple "yes" or "no" answer to the question of whether a nuclear weapon is present. Devices that give a yes or no answer have been demonstrated. The detector receives the signature gamma rays at a specified threshold. This would differentiate a real warhead from a fake. The device accomplishes this task with a high-resolution gamma-ray detector and a special-purpose computer with only a temporary memory (to protect important secrets). Another active detection technique is one that can detect the secondary radiation, including radiation from delayed fission caused by external radioactive rays. For example, under the INF treaty, a low-resolution X-ray can confirm a weapon's configuration without revealing detailed design information.[34]

Untagged objects should not contain warheads or pits. For small objects, gamma-ray-spectrum and neutron detection could confirm the absence of the plutonium. The radioactive emissions from highly enriched uranium produce fewer gamma rays, and thus active neutron detection could be used. An external neutron or high-energy gamma-ray source introduced into a targeted object could confirm the presence of HEU. However, large objects could contain enough shielding to prevent such detection, and it is very difficult to detect the HEU with a normal nuclear detector. In these cases, experienced inspectors could open the object's cover and conduct a visual inspection, and this method plus the historical record would help them verify an object with reasonable confidence.

Verification of the declared fissile material would comprise two aspects. One verifies the covert fissile material production, while the other focuses on the material inventory.

With respect to covert production, the uranium enrichment technologies are now spreading.[35] There are several methods of uranium enrichment. The electromagnetic isotope separation method that was used by Iraq is less efficient. The nuclear weapon states, including the those not party to the Non-Proliferation Treaty (India, Pakistan, and Israel), have seldom used this technique in HEU production. The two main forms of enrichment technology today are gaseous diffusion and the gas centrifuge. Normally these enrichment facilities occupy a big area and consume large amounts of energy. They are easy to identify with national technical means (NTM) and on-site monitoring if the separation plant is in operation. The newer methods of laser enrichment are used only in the laboratory. For technical reasons they have not been used in industrial production. The equipment for laser enrichment is small, and the separation can go on in a normal laboratory. The discovery for this method would need on-site inspection. IAEA routine inspection techniques can effectively verify the facility design, operations, and inventory changes for such enrichment technologies as gaseous diffusion, gas centrifuge, and aerodynamic enrichment. The verifying techniques for the laser isotope and other advanced enrichment methods are still under research and development.[36]

Plutonium is produced in nuclear reactors when U-238 absorbs a neutron and decays two times in very short time. There are some different types of nuclear reactors suitable for the production of plutonium that can be used in nuclear weapons. Normally the weapons-grade plutonium reactor keeps the burnup of the fuel at a low level (less than 1000MWd/t).[37] Separation of plutonium is a chemical process. The processes include decladding, spent fuel dissolution, plutonium and uranium separation, and plutonium separation.

The separation of plutonium can go on in a normal laboratory. It is very difficult to verify a concealed facility for spent fuel reprocessing without very intrusive inspection. To verify an undeclared plutonium-reprocessing plant would be difficult using optical or infrared surveillance technical means, because a small plant would not be physically distinctive. Fortunately, when spent fuel is being decladded, the isotopes of Kr-85 and I-129, which are produced in the reactor as fragments of the fission, would escape from the fuel rod. The radioactive signatures of Kr-85 and I-129 emissions from the facility, detectable by environmental sampling or monitoring, offer relatively conclusive evidence of plutonium separation.[38] Verifying plutonium production would begin by examining records of the fabrication of uranium fuel and target rods for a plutonium-production reactor. Inspectors should constantly monitor the spent fuel of these reactors. They can check that operating records are consistent with the declaration and that the records are internally consistent. It may be possible for the inspectors to find physical evidence to corroborate these records. For example, measurements of isotope ratios in the permanent structural components of plutonium-production reactors can be used to verify, at least approximately, declarations of the total production of plutonium at that reactor.[39]

Verifying declarations of highly enriched uranium inventory would begin with a material balance for each enrichment facility. The record of HEU production normally is complete. The efficiency of the separation does not change very much for the same technological process, so the quantity of the HEU production would be known. The production also is easy to control. Using standard assay and sampling techniques, inspectors could verify that selected canisters contain material of the amount and isotopic composition specified in the declaration.

Irreversible disarmament would require ending the production of fissile material for weapons. The fissile material cutoff treaty proposal is now before the UN Conference on Disarmament (CD).[40] Verification of the cutoff would involve monitoring all declared facilities that are shut down as well as all the fissile material production facilities that are used only for nonweapon purposes. These facilities should be under international safeguards. In addition, inspections to discover clandestine production facilities should be required.[41] The necessary verification techniques are being developed and would be negotiated in CD.

Verifying the Dismantling of Warheads and the Disposition of Fissile Material

There are only three fundamental types of nuclear warheads: pure fission, boosted fission, and thermonuclear. Pure fission warheads derive their explosive energy entirely from rapid fission chain reactions. Boosted fission warheads incorporate small quantities of deuterium and tritium that release large numbers of neutrons when they react at the temperatures produced by a fission explosion. These neutrons then speed up the rate at which the fission chain reaction proceeds and increase the overall yield of explosion. Thermonuclear warheads require pure fission or boosted fission explosions to produce the conditions needed to ignite sufficient quantities of thermonuclear fuels.[42] There are several types of physical coupling between nuclear warheads and their delivery systems, such as the missile, bomber, and artillery. Basically, a nuclear weapon consists of a case or reentry vehicle, nonnuclear components, and the nuclear weapon physics package. The nonnuclear components include items such as contact fuses, radar components, aerodynamic structures, arming and firing systems, gas transfer systems, neutron generators, explosive actuators, safety components, batteries, parachutes, nuts, bolts, brackets, and other items. These are destroyed when a weapon is disassembled.[43] The most sensitive fissile core or pit is usually stored in a special container and disposed of in a specified facility.

Verification of warhead dismantlement requires a much greater effort than the destruction of the delivery vehicle. The warhead dismantlement process consists of several stages: disassembly of nonnuclear components, removal of tritium containers, removal of the nuclear explosive physics package, and removal and disassembly of the secondary. Disassembling the nuclear explosive physics package begins with removal of the climate control system, then separation of the high explosive from the nuclear components, and then disassembly of the pit. Parts of the pits made of fissile material are placed in special canisters. Next, the secondary is disassembled, and all of its nuclear parts are also placed in canisters.

Most countries classify the information about reentry vehicles, penetration aids, and all the details about the design of specific nuclear warhead. The data about weapon yields and weight; quantities of contained materials; and dimensions, configurations, and weights of fabricated components are also treated as sensitive. Governments must be sure that sensitive information would not be disclosed during the mandated inspections.

Directly verifying warhead dismantlement will disclose some nuclear weapon design information. There is always a conflict between effective verification and sensitive information protection. Some information that is believed to be sensitive needs to be transparent. Weapon designers always worry that, from the information detected from the warhead dismantlement, one can derive important weapon design information. It should be asked whether this information could increase the adversary's weapon design capability. If not, the information should not be considered sensitive. With the comprehensive nuclear test ban in place, new designs would be impossible to develop with only the information derived from verification. For example, the quantity and isotopic composition of the pit are not sensitive, although many nuclear weapon designers can derive some important information from these data, including the size of the explosive element and the main configuration of the weapon. Some U.S. and Russian experts consider it impossible to get enough help from this information to develop a nuclear weapon design.[44] If the quantities and the isotopic composition of the fissile core are known, the effective verification of disarmament can proceed.

To ensure that the nuclear weapon disarmament is irreversible, some experts suggest that the following steps be taken in the verification process:[45]

1. All materials in the warheads should be contained within well-defined boundaries from the time they are placed in shipping containers at the deployment sites until they have been dismantled.
2. Any attempts to divert any of the warhead components to unauthorized purposes must be detected.
3. All major components of the warheads or other payload items should be destroyed, in the sense that they would require refabrication to be used again in warheads.
4. All the uranium 235 and plutonium in the warheads should be accounted for to measure the output of these materials from the dismantlement facilities.
5. Substitution of fake warheads should be detected before dismantlement operations begin.

If the warheads and attached payload components (such as reentry vehicles and guidance packages) are destined for dismantlement at the deployment sites, they should be placed inside shipping containers by the owner country. Inspectors should observe the transfer of warheads from delivery vehicles or storage to the shipping containers. Then the containers should be tagged, sealed, and authenticated by the inspectors. The tagged and sealed warhead containers should be temporarily stored at a specified site because it is impossible to dismantle all the warheads in a very short time. The warhead containers would then be shipped to a warhead dismantling and destruction facility in the owner country. Inspectors would examine all the tagged and sealed containers to ensure that they have not been tampered with before they are dismantled. The tags and seals are highly vulnerable and may be of limited value in maintaining the security of the item if they are not under some monitoring (within less than two hours if the seal was not under some form of monitoring).[46] The radiation detection should prevent the fake nuclear warheads from being dismantled before the warheads are dismantled. The radiation "fingerprinting" procedures could show that the object to be dismantled was an authentic warhead of a given type. For the protection of sensitive information, the computers that give only a "yes" or "no" answer (as mentioned before) could be used. This would make it possible to conduct inspections at a mostly unclassified level. Neutron detection can also be used in warhead verification. All the nuclear weapons of the nuclear weapon states contain plutonium. The emission of spontaneous neutrons is strong enough to be detected, and from the numerical analysis the neutron detection would not reveal much sensitive information. Neutron detection can distinguish a fake from a real warhead.

The perimeter-portal monitoring could be used at the dismantling facility and the deployment sites. For all nuclear weapon states, there is already some kind of perimeter. Inspectors can install several surveillance or monitoring systems. They can patrol the outside of the boundary. The main function of portal-monitoring equipment is to detect unauthorized removals of fissile materials from the facility or the introduction of unauthorized items into the facility. The portal to be used for incoming shipping containers with warheads inside is the only one authorized for incoming fissile materials. The portal authorized for outgoing fissile materials is the only one used for the removal of fissile materials after extraction from warheads. These portals would be equipped with systems to verify the authenticity of warheads entering the facility and to detect any fissile materials exiting the facility. The monitoring party could track the warhead up to the disassembly cell. The warhead would then be dismantled. The fissile components (pits) would be put in containers by the owner side. The inspectors would tag and could confirm them with nuclear detection at the portal and track them from the disassembly cell to the storage area. At certain times (for example, holidays), the facility could temporarily halt the dismantlement procedure and let the inspectors go into the disassembly cell to verify there are no warheads or warhead components left in the cell before or after the disassembly procedure.

The principal inputs to the facility would be the tagged and sealed containers with warheads and other payload hardware. These should be tested with radiation-detection to ensure that each container has the same type of warhead. All other inputs, such as processing materials or new equipment needed for the dismantlement operation, should be kept to a minimum.

The principal outputs are fissile material pits that include plutonium and highly enriched uranium, and other residues of compaction or incineration of the other components of the warheads and payload items. For the plutonium pits, the density is very high. At only a few millimeters depth near the pit surface do gamma rays exist in sufficiently high ratio to be directly emitted to the detector. Gamma-ray detection might verify the plutonium pit from a dismantled warhead of a certain type. This method would not reveal much sensitive information if the gamma-ray spectrum is kept to a lower energy range. Neutron detection can be used at the same time to provide additional evidence.

Uranium pits have lower levels of radiation. The character gamma ray 185 KeV of uranium 235 is easily shielded by a normal container, and very few spontaneous neutrons come from uranium 238. To detect the uranium pit, the inspectors should use active detection. The delayed neutron detection would be a useful way to detect the uranium pit. By irradiating the pit with a burst of neutrons, the delayed neutrons and the fission-product gamma-ray signature of the pit can be measured a few seconds later. My analysis shows that this method can give good evidence of the pit existence without exposing very sensitive information about the pit. With comparable quantities of weapons-grade uranium and depleted uranium, the delayed neutron emission of a weapons-grade uranium pit is 10 times higher than that of depleted uranium. If the nuclear countries think that the quantity of the fissile material is not sensitive, the pit could be weighed in its container to ensure that no fissile material taken from the pit would be transferred to military purposes.

The high explosives in the warheads could be burned at the dismantlement site. The deuterium and tritium could be extracted to a common unit. The other nonnuclear components would be destroyed or be formed into insensitive shapes. They would be subjected to detailed visual and instrumental inspection at the portal. The liquid waste output from the site could be subjected to detailed visual and radiation detection to prevent the escape of the extra plutonium or weapons-grade uranium extracted from weapon.

Warhead containers could be re-used. After the warheads have been removed, the containers could be weighed and inspected to ensure that no treaty-limited items (TLIs) are shipped out. The containers could be tagged and sealed by the inspectors and scanned by an external radiation source to ensure that there is no uranium or plutonium inside.[47] At the deployment boundary, the containers would be externally inspected and scanned by a radiation source again to ensure there is no warhead is inside. The containers then could be used to contain other warheads outside the boundary.

If dismantling and stockpile maintenance activities are done at the same facility, the different perimeters and portals could distinguish the maintenance from the dismantlement activities. The maintenance facilities would be segregated from the dismantlement ones. Inspectors could check the tags and registers of the warheads and verify the warhead by the radiation detection at the portal of the maintenance facility. When it has left the facility, the weapons should be put under new tags and registered again. This could be confirmed by radiation detection. It would be necessary, however, to verify that maintenance facilities were being used solely to repair or replace existing warheads, not to build additional warheads.

To prevent the nuclear weapon from being rebuilt after dismantlement, verifying that the dismantling is irreversible is an important step. Fortunately, the nuclear weapon system is different from systems for conventional weapons. Any damage to the pit would cause the weapon to become inoperative, and none of the nuclear weapon states could use it, although it could still be explosive according to a physicist's understanding. Such damage could be caused by drilling a hole in the pit or directly hammering the pit to change the shape. This damage could be detected with α detection. The escort inspector would put a detector at the broken area and could thereby detect the damage at a long distance to ensure that the pit is not seen.

After leaving the dismantling facility, the tagged and sealed containers of pits and other fissile material components would be stored at monitored sites. All the pits and fissile materials not for military use should be subjected to IAEA safeguards. To prevent the release of sensitive information on the weapon's design, the pit could be changed to an insensitive shape. A comprehensive nuclear weapon disarmament regime would have to provide confidence that the components from dismantled warheads and other excess fissile materials would not be available to rebuild nuclear arsenals. The goal should be to render these materials at least as unattractive for use in nuclear weapons as is fresh or spent civilian reactor fuel.[48]

In the case of HEU weapons components, transparency measures have already been negotiated to provide confidence that the low-enriched uranium that the United States is purchasing from Russia for civilian reactor fuel is derived from dismantled warheads.[49] The HEU transparency regime focuses on verifying the origin of the blended-down HEU being purchased by the United States. The regime began with limited transparency but has developed over time. The United States is now able to verify that the material originated as HEU metal, but does not have complete confidence that the metal was derived from dismantled warheads as required by the agreement.

Disposing of plutonium pits will be more difficult. Almost all the plutonium, which is not under the IAEA safeguards, is used for weapon purposes. Transparency and subjecting nuclear material to IAEA safeguards will not cause much difficulty for a large nuclear weapon state. The difficulty is how to dispose of that material. Plutonium is different from weapons-grade uranium. It cannot blend with natural materials, and all isotopes of plutonium can make nuclear weapons. How to dispose of plutonium is still open to question. The plutonium could be used to fabricate mixed-oxide (MOX) fuel elements for civilian reactors, but to reconstruct a reactor to fit MOX would cost huge amounts of money. Using plutonium fuel is much more expensive than using uranium fuel, but this method can dispose of the plutonium more thoroughly. The plutonium could be mixed with vitrified high-level radioactive wastes. But this method would permit easier retrieval of the plutonium, and it could be used for very high quality weapon-useable plutonium. The third option is to dispose of the plutonium in a deep hole. There are good reasons to believe that if the Pu materials are emplaced at great depths, they could be isolated from the environment for periods comparable to or possibly longer than those expected for other geologic repository methods. But significant uncertainties must be solved.[50] In any case, IAEA-type safeguards could provide assurance that no plutonium had been diverted.

Control of Delivery Vehicles and Launcher Numbers

Nuclear delivery vehicles and associated launchers have always been the main focus of disarmament negotiations. The cost of the delivery system is much higher than the cost of the warhead itself. In past and possibly in future disarmament agreements, limitations restrict the numbers and characteristics of the delivery systems. The INF treaty and START provide valuable precedents and experience on how to verify these systems. The INF treaty eliminated all the U.S. and Soviet nuclear-armed ground-launched ballistic and cruise missiles with ranges between 500 and 5,500 kilometers, as well as their infrastructure. The INF treaty contains the most comprehensive verification regime ever achieved. In addition to measures to enhance national technical means of verification, the treaty contained pioneering on-site inspection (OSI) provisions, including baseline data inspections, inspections of closed-out facilities, short-notice inspections of declared sites, and inspections to observe the elimination of the missile systems. It also established the first continuous monitoring operations at the portal and perimeters of former missile production facilities in each country to confirm that the production of prohibited missiles had ceased.

The START agreements limit all categories of strategic delivery vehicles: ICBMs, SLBMs (submarine-launched ballistic missiles), and bombers. The treaties limit the number of nuclear weapons each delivery vehicle may carry. They include an intrusive verification regime consisting of a detailed exchange of data and extensive notifications, 12 types of OSI, and continuous monitoring activities designed to help verify that the signatories are complying with their treaty obligations. Baseline inspections have been established to confirm the accuracy of the numbers and types of weapons. START also contains provisions that permit inspectors to conduct continuous portal monitoring at one U.S. and two former Soviet sites.

To monitor the number and type of warheads deployed, OSI could be used. The tag techniques could be used in future deep-cut agreements. For silo-based missiles, constant perimeter monitoring can ensure there are no additional missile deployments in the sites. Routine OSI ensures that there are no additional entries of missiles in the site and no illicit missiles are deployed.

For the mobile ICBMs, a combination of NTM and OSI might monitor the number of reentry vehicles (RVs) on multiple independently targetable reentry vehicle (MIRV) missiles. The number of RVs can be detected by NTM. On-site inspection of deployed missiles by tag checks, visual inspections, and NTM could possibly deter any party from violating the agreement. The tags of major parts should be checked before they are used for the missile flight tests, and such tags could be put on first-stage rocket motors when they are removed from a declared facility. Challenge inspections could detect a clandestine facility. Notifications should be given for missile transfers and monitored by NTM. In this way, missile parts from an illicit, clandestine factory could not be flight-tested.

Submarines and their launch tubes can be readily verified. They are large and require a highly visible production and support infrastructure. Under START, the United States and Russia restrict SLBMs to carrying no more than the maximum number of RVs with which they have been tested. OSIs have been used to meet the verification requirement. In any future nuclear deep-cut agreement, more intrusive measures could possibly be used. For example, to verify SLBM RVs, a short-notice inspection of a submarine base could be requested, and activities at the base would be curtailed until the inspectors arrived. The inspectors would select a limited sample of missiles to be checked, the nose cones would be removed, and the number of the RVs would be counted. Sensitive information could be protected by a shroud over the nonrelevant parts of the missile in the same way that it is protected under START.[51]

Monitoring heavy bombers also is not difficult. They are large, distinctive, and observable objects. They require an extensive production, test, and support infrastructure. START II provides for on-site inspection of heavy bombers to confirm that they are equipped to carry no more than the declared number of nuclear bombs or nuclear-armed air-launched cruise missiles.

The elimination of flight tests and the exchange of telemetry data would help to build confidence in RV loading. START prohibits flight tests of MIRV ICBMs after 2003, and tapes containing all telemetric information broadcast during a flight test must be provided to the other party. These methods can help build confidence and could possibly be used in a future agreement.

Verifying the Elimination and Conversion of Missiles

Future nuclear deep-cut agreements would require on-site inspections of elimination and conversion activities to confirm that the treaty-limited weapon systems to be destroyed are actually destroyed or rendered incapable of performing their nuclear functions. Elimination inspections would be held to confirm that treaty-limited items and equipment have been destroyed in accordance with treaty provisions. These provisions would ensure that destruction is carried out in such a manner that the item or equipment either could not be restored at all or could only be restored at a prohibitively high cost; that is, at a cost well above normal manufacturing cost.[52] The elimination procedures are verified in many treaties.

The INF treaty required the elimination of all types of ground-launched ballistic and cruise missiles with ranges between 500 and 5,500 kilometers (Pershing II, BGM-109G, Pershing IA, Pershing IB: SS-20, SS-4, SS-5, SSC-X-4, SS-12, and SS-23), including the launchers, launch pad shelters, nuclear missiles, and missile transporter vehicles. For both parties, all training missiles, training missile stages, training launch canisters, and training launchers are subjected to elimination. The conduct of the elimination procedures is subject to on-site inspection. The inspecting party could conduct a visual inspection of the contents of launch canisters if it deems it necessary. The "close-out" inspection is to verify the elimination of specified facilities. The "elimination" inspections are to observe actual elimination of missiles, launchers, and support equipment at these facilities, and to confirm the completion of the process of elimination with respect to items lost or accidentally destroyed or placed on static display and with respect to training equipment.[53] Because all the types of short- and intermediate-range missiles are to be prohibited, if it were found by NTM that any party was keeping or training with these missiles, the violation of the treaty would be obvious.

START I specifies procedures for eliminating ICBM silos, mobile ICBMs and their launchers, SLBM launchers, and heavy bombers.[54] START II eliminates heavy ICBMs and all other multiple-warhead (MIRV) ICBMs, and only ICBMs carrying a single warhead will be allowed.[55] Specified mobile ICBMs, their launchers, and their launch canisters must be eliminated at specified facilities that are subject to on-site inspection. Under START I, if the number of permitted missile warheads is reduced by more than two below the warhead loading specified in the initial declaration, the old delivery system must be destroyed and a new one deployed. START II relaxes the last condition on economic grounds.[56] The missiles and the nuclear bombers converting to conventional roles are subjected to specified requirements designed to allow verification. The converted bombers used in nonnuclear missions cannot be used in exercises for nuclear missions. These bombers should have observable differences from nuclear versions, and nuclear weapons must be located at least 100 kilometers from the converted bomber.

All these verification measures may be used in future nuclear deep-cut agreements for missile elimination. Furthermore, the excess warheads and missiles should be in monitored storage and verifiably dismantled in future nuclear deep cuts. The nuclear sea-launched cruise missiles or air-launched cruise missiles also should be included in any future agreement. Verification would be more difficult than in recent treaties because some types of missiles have both nuclear and nonnuclear versions.[57] A nuclear missile is not radioactive if the warhead has been removed, and it is open to question how an elimination inspection can be conducted without exposing sensitive information and how to ensure that the eliminated missile is nuclear instead of conventional.

Data exchanges concerning all the nuclear missile deployments and practices would clearly be helpful in treaty verification. For more effective verification, the nuclear missiles should be tagged and registered by their own country, and the data should be exchanged according to the agreement. The treaty-limited nuclear missiles to be eliminated should be subjected to on-site inspection similar to INF and START. When the missiles arrive at the destruction site, the inspectors would check the tags and seals and compare them with the exchanged data to confirm that the missiles to be destroyed are the nuclear ones. In fact, the ignition systems and some other parts are different between the nuclear and nonnuclear missiles. Experienced inspectors can determine if the missile can be opened and allowed to be inspected.

Monitoring Missile Production Facilities

Military usable missiles are built and deployed within an industrial, operational, and support infrastructure that is difficult to conceal indefinitely. NTM, OSI, tags, and other cooperative measures can discern traces of clandestine missiles at various stages of their lifecycle: design and development, test and evaluation, production, deployment, storage, maintenance and repair, exercise, reliability testing, and elimination.[58] Concealing strategic weapons systems is more difficult because they are quite costly and produced in smaller numbers. These very large weapons systems contain single parts that can only be fabricated on a limited number of machines. Large presses, forges, casting plants, and milling machines, in turn, can be produced only at selected plants, and all of these machines could be traced. NTM now has high capability and reliability. The facilities in nuclear weapon states used in the nuclear delivery vehicles are likely to be identified. Satellites can possibly detect and monitor missile transportation.

The INF treaty provisions include “short-notice” inspections of certain declared and formerly declared facilities to verify that all treaty-prohibited activity has ceased, as well as “continuous portal monitoring” at the designated portal and perimeter of the facility. The United States has installed a perimeter fence at Votkinsk, at which SS-25 and SS-20 missiles have been assembled, to ensure that stages of the SS-20 are not covertly manufactured as stages of the SS-25 ICBM. Russia installed continuous portal monitoring at the designated portal and perimeter of the Hercules Plant #1 in Magna, Utah, at which stages of Pershing II missiles formerly were produced. The United States could reestablish continuous portal monitoring anywhere else. At midnight May 31, 2001, continuous monitoring at missile assembly plants was concluded. The newly signed amendment provides principles and procedures for the completion of INF inspections by means of continuous monitoring.[59]

START provides continuous monitoring activities at production facilities of mobile ICBMs to help confirm the number of ICBMs produced. The inspected party should design, construct, and maintain a fence around the perimeter of each facility subject to continuous monitoring. Monitors confirm the numbers and variants of types of items for continuous monitoring that are declared to exit from the monitored facility, and also confirm that no other items for continuous monitoring exit from the monitored facility. In addition, START provides that each party can conduct suspect-site inspections. The purpose of such inspections is to help confirm that the covert assembly of ICBMs for mobile launchers of ICBMs or the covert assembly of first stages of such ICBMs is not occurring. The suspect-site inspection can go on in any facility that is suspected of producing ICBMs.[60]

Production monitoring attempts to count key components or entire weapon systems or their launchers by going to the source, the factory. By counting these items as they are produced—and perhaps again when they are destroyed—each side can maintain an accounting of the other's inventories of weapons.[61] Production monitoring includes the continuous monitoring of that facility's perimeter. Challenge inspections prevent the covered facilities from engaging in forbidden activities.

In future nuclear deep cuts, the few remaining production facilities for replacement missiles could be monitored using portal-perimeter systems, as is done under the START and INF treaties, and by short-notice inspection. The portal and perimeter monitoring systems in the INF and START treaties are good methods for monitoring production at a vital missile production facility without intrusive interior inspections of the plant, and they keep secret the sensitive information on missile production techniques and equipment. Suspect-site inspections could help build confidence between the parties.

Some other nuclear-capable delivery vehicles should come under monitoring, because these should be restricted to prevent breakout and to help build confidence in the stability of the deep-cut regime.[62] The air-launched cruise missiles (ALCMs) and sea-launched cruise missiles (SLCMs) that are not included in START should also be monitored. The SLCM (or ALCM) lifecycle would be difficult to monitor with NTM. They are small, and production or assembly facilities are in the light industry sector. Their transportation and tests are hard to detect with satellite systems. Static engine tests could occur indoors and thus also escape detection by overhead systems. Special inspection facilities are suggested. At the facilities, all cruise missiles would be checked, tagged, and sealed. The tags could be read at loading and unloading facilities.[63] Radiation detection could distinguish conventional missiles from nuclear ones. Suspect on-site inspection could prevent cheating. The total number of long-range bombers, both conventional and nuclear, should also be limited. Monitoring compliance would be easier with the measures used in START.

Conclusion

The United States and Russia each have a colossal nuclear arsenal caused by the Cold War nuclear race. After the collapse of the Soviet Union, Russia sank into a deep economic and social crisis. The likelihood of a direct nuclear exchange between the West and East disappeared, and cooperation replaced conflict. The United States and Russia should lead by initiating deep reductions in nuclear weapons, followed by similar reductions in the other nuclear weapon states.

The elimination of nuclear weapons is a noble objective. The total elimination of nuclear weapons is impossible in the foreseeable future, but there is a real possibility of major nuclear weapon reductions because of the huge nuclear arsenals of the United States and Russia.

START III is surely the next step in nuclear disarmament. It will demonstrate a new mode in disarmament methods and verification. The United States and Russia will then deploy only a few hundred nuclear warheads, and other nuclear states will then be able to have fewer than one hundred nuclear warheads. A new and vital component of the verification system is the comprehensive and verified declaration of all nuclear weapons and stocks of fissile material in the nuclear weapon states. The intrusive verification regime taking shape under START I and II would continue future verification provisions. Furthermore, future nuclear reduction agreements must include deployed and nondeployed nuclear warheads. To make the nuclear cuts irreversible, weapon-useable fissile material also should be counted and controlled in the future agreements.

All nuclear warheads should be registered and tagged by the owner countries. The inspectors should have the right to verify the location and type of nuclear warheads and the dismantlement procedures of the excess warheads. The weapon-useable fissile materials are the key to building the weapons. They should be strictly controlled. The weapon-useable fissile material cutoff is an important step to future nuclear reduction. NTM and near-site inspection will play an important role in verification. The total inventories of plutonium and high-enriched uranium as well as the fissile core dismantled from the warheads should be declared, and the extra fissile material should be subjected to IAEA safeguards and disposed of under the monitored procedures.

The nuclear delivery vehicles and launcher number and types should be monitored as outlined in the START and INF treaties. Some nuclear-capable delivery vehicle production should be placed under monitoring. Data exchange would be the basis for the future verification regime. Tags and seals are important technologies for the verification regime, but even these can be defeated. They also can be used in weapon production and elimination verification processes. Continued perimeter monitoring begun with the INF treaty should be extended to weapon production facilities, to the deployment sites, and to the elimination facilities to ensure that no treaty-limited items leave the facilities and no unaccounted for weapons are deployed.

No verification regime could provide absolute assurance that the parties had not concealed a few nuclear warheads. The important point is that the uncertainties should not affect the future security environment of nuclear weapon reductions given a residual nuclear force together with other political and security arrangements. With the comprehensive verification regime, breakout would be difficult, and the chances for global security would be increased.

Notes

[1] A. S. Diakov, *Nuclear Arms Reduction: The Process and Problems* (Dolgoprudny, Russia: Center for Arms Control, Energy, and Environmental Studies at the Moscow Institute of Physics and Technology, October 1997).

[2] Center for Counter Proliferation and Research, *U.S. Nuclear Policy in the 21st Century—A Fresh Look at National Strategy and Requirements: Executive Report* (Washington, D.C.: Institute for National Strategic Studies, July 1998. Available at <http://www.ndu.edu/inss/ccp/nucpolicy/nucpolicy.html>.

[3] Michael M. May, "U.S. Enlargement Strategy and Nuclear Weapons," working paper, Center for International Security and Cooperation, Stanford, CA, March 2000.

[4] Center for Counter Proliferation and Research, *supra*, note 2.

[5] Alexei G. Arbatov, "The Next Steps in Arms Control: A Russian Perspective" (statement at the Carnegie Endowment for International Peace, Washington, D.C., May 9, 2000). Available at <http://www.ceip.org/files/events/arbatovroundtable050900.asp>.

[6] Harold A. Feiveson, ed., *The Nuclear Turning Point: A Blueprint for Deep Cut and De-Alerting of Nuclear Weapons* (Washington, D.C.: The Brookings Institute, 1999), p. 4.

[7] "Chance for a Safer World: We Must Embrace Russia's New Willingness to Fight Nuclear Terrorism," *The Washington Post*, April 24, 2000, sec. A, p. 25.

[8] Therese Delpech, "The Future of Nuclear Weapons: A European Perspective," in *Arms Control Issues for the Twenty-First Century*, ed. James Brown (Albuquerque, NM: Sandia National Laboratories, 1997), pp. 139–140.

[9] "NRDC Nuclear Notebook—French and British Nuclear Forces," *The Bulletin of the Atomic Scientists* 56, no. 5 (September/October 2000): pp. 69–71.

[10] Delpech, *supra*, note 8, p. 140.

[11] "NRDC Nuclear Notebook," *supra*, note 9.

[12] United Nations General Assembly, Resolution 51/45 M, *International Court of Justice Advisory Opinion on the Legality of the Threat or Use of Nuclear Weapons*, submitted on October 29, 1996. Adopted by a vote of 115-22, with 32 abstentions.

[13] U.S. and Russian Federation, "Joint Statement on Parameters on Future Reductions in Nuclear Forces," March 21, 1997, Helsinki, Finland. Available at <http://www.ceip.org/files/projects/npp/resources/summits6.htm>.

[14] Committee on International Security and Arms Control, National Academy of Sciences, *The Future of U.S. Nuclear Weapons Policy* (Washington, D.C.: National Academy Press, 1997), p. 76.

[15] Ibid., p. 80.

[16] Ibid., p. 37.

[17] Feiveson, *supra*, note 6, p. 174.

[18] House Defense Appropriations Subcommittee, *Nuclear Weapons Control and Dept. of Defense Space Programs*, testimony of Lawrence K. Gershwin, May 6, 1992.

[19] William J. Broad, "Russian Says Soviet Atom Arsenal Was Larger Than West Estimated," *New York Times*, September 26, 1993, sec. A, p. 1.

[20] Committee on International Security and Arms Control, National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium* (Washington, D.C.: National Academy Press, 1994), p 7.

[21] U.S. and Russian Federation, "Joint Statement on the Transparency and Irreversibility of the Process of Reducing Nuclear Weapons" Moscow, May 10, 1995. Available at <http://www.ceip.org/files/projects/npp/resources/summits4.htm#nuclear>.

[22] Steve Fetter , "A Comprehensive Transparency Regime for Warheads and Fissile Materials," *Arms Control Today* 29, no. 1 (January/February 1999): pp. 3–7.

[23] Feiveson, *supra*, note 6, p. 217.

[24]U.S. Department of Energy, *Plutonium: The First 50 Years* (Washington, D.C.: U.S. Dept. of Energy, 1996).

[25] Fetter, *supra*, note 22.

[26] Theodore B. Taylor and Lev. P. Feoktistov, "Verified Elimination of Nuclear Warheads" in *Verification: Monitoring Disarmament*, Francesco Calogero et al., eds. (Boulder, CO: Westview Press, 1991), p. 54.

[27] Fetter, *supra*, note 22. "A specific tamper-tape system used in Iraq and in the United States is the so-called "CONFIRM" seal. This is a tape placed over a unique identifier. The tape is an adhesive, imbedded with microscopic beads of colored glass in several strata forming a specific design (such as the UN logo). The tape is see-through and is read through reflected light."

[28] Annex 6 to the Inspection Protocol of START I allows for "a non-repeating alpha-numeric production number, or a copy thereof, that has been applied by the inspected Party, using its own technology." Available at <http://www.state.gov/www/global/arms/starthtm/start/inannex.html#INANNEX.6>.

[29] Fetter, *supra*, note 22.

[30] According to R. G. Johnston (leader of Vulnerability Assessment Term, Chemical Science and Technology Division, Los Alamos National Lab), "all the tags and seals can be defeated quickly, easily and inexpensively using low-tech methods. Most of these security devices can be significantly improved with minor changes in their design and/or in how they are used." See R. G. Johnston and A. R. E. Garcia, "Simple, Low-Cost ways to Dramatically Improve the Security of Tags and Seals," IAEA Symposium on International Safeguards, Vienna, Austria, October 13–17, 1997.

[31] Fetter, *supra*, note 22.

[32] In 1989 the Russian government allowed a U.S. group of nongovernmental scientists to conduct measurements of neutron and gamma radiation of a nuclear warhead aboard the Russian ship *Slava*.

[33] The gamma ray spectrum could expose the weapon design information. Because different energy of the gamma ray has the different penetrated ratio for materials. Theoretically, four-character gamma rays could analyze the four-layer construction of the warhead. The composition of the material of warheads and other sensitive information also could be obtained by analyzing the gamma ray spectrum.

[34] The U.S. is already using special X-ray machines under the INF treaty to determine the general nature of the contents of containers leaving the Votkinsk final assembly plant for ballistic missile. See Spurgeon M. Keeny Jr. and K. H. Panofsky, "Controlling Nuclear Warheads and Materials: Steps toward a Comprehensive Regime," *Arms Control Today* (January/February 1992): p. 5.

[35] There are many books explaining the uranium separation technology. See Richard Kokoski, *Technology and the Proliferation of Nuclear Weapons* (New York: Oxford University Press, 1995). pp. 9–68.

[36] Canada. Dept. of Foreign Affairs and International Trade, *Verifying a Fissile Materials Cut-Off: An Exploratory Analysis of Potential Diversion Scenarios* (Ottawa, ON: Dept. of Foreign Affairs and International Trade, 1994), p. 14.

[37] The U.S. Department of Energy defines weapons-grade plutonium as that containing less than 7 percent Pu-240. See Kokoski, *supra,* note 35, p. 79.

[38] Canada. Dept. of Foreign Affairs and International Trade, *supra,* note 36, p. 18.

[39] Steve Fetter, "Nuclear Archaeology: Verifying Declarations of Fissile-Material Reduction," *Science and Global Security* 3, nos. 3–4 (1993), pp. 237–259.

[40] The cutoff treaty bans future production of fissile materials for nuclear weapons. It has not begun to be negotiated yet, since there are some debates on what should be included in the treaty. See George Bunn, "Fissile Material Cut-off Treaty: What Added Inspections Would It Require of Civilian Nuclear Power Facilities?" (paper presented at the Global '99 Conference, August/September 1999, sponsored by the American Nuclear Society).

[41]Feiveson, *supra,* note 6, p. 228.

[42] Theodore B. Taylor, "Verified Elimination of Nuclear Warheads," *Science and Global Security* 1 (1989): pp. 1–26.

[43] Taylor and Feoktistov, *supra,* note 26, pp. 57–58.

[44] Steve Fetter and A. S. Diakov expressed this view in the seminar The Future of Russian–US Strategic Arms Reductions: START III and Beyond, February 2–6, 1998. Summary available at <http://www.armscontrol.ru/transforming/summary.htm>.

[45] Taylor, *supra,* note 42.

[46] Eric. R. Gerdes, Roger G. Johnston, and James E. Doyle, "A Proposed Approach for Monitoring Nuclear Warhead Dismantlement," to be published in *Science and Global Security*.

[47] Taylor, *supra,* note 42.

[48]Fetter, *supra,* note 22.

[49] In February 1993, the United States and Russia signed "The Agreement between the Government of the United States and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted from Nuclear Weapons" (the Russian HEU Agreement), which provided for the United States to purchase 500 metric tons of Russian HEU over a 20-year period.

[50] In some countries, plutonium is thought to be the most important energy resource after uranium has been exhausted. Because of economic and safety reasons and because there are enough uranium mines, plutonium energy seems to have no future use, although some countries still research it. For disposition of plutonium, see Committee on International Security and Arms Control, *supra,* note 20.

[51] Feiveson, *supra,* note 6, p. 237.

[52] George L. Rueckert, *On-Site Inspection in Theory and Practice—A Primer on Modern Arms Control Regimes* (Westport, CT: Praeger, 1998), p. 101.

[53] See "Protocol on Procedures Governing the Elimination of the Missile Systems Subject to the Treaty between the United States of America and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-Range and Shorter-Range Missiles," available at <http://www.fas.org/nuke/control/inf/text/inf4.htm>.

[54] Feiveson, *supra*, note 6, p. 234.

[55] See "Treaty between the United States of America and the Russian Federation on the Further Reduction and Limitation of Strategic Offensive Arms," January 3, 1993. Available at <http://www.dpi.anl.gov/dpi2/hist_docs/treaties/start2.htm>.

[56] Feiveson, *supra*, note 6, p. 237.

[57] Valerie Thomas, "Verification of Limits on Long-Range Nuclear SLCMs," *Science and Global Security* 1 (1989), pp. 27–57.

[58] Congress of the U.S., Office of Technology Assessment, *Verification Technologies: Measures for Monitoring Compliance with the START Treaty* (Washington, D.C.: Congress of the U.S., Office of Technology Assessment, 1990).

[59] At the signing ceremony on December 14, 2000, in Geneva, at the Twenty-sixth Session of the Special Verification Commission (SVC), representatives of the United States of America, the Republic of Belarus, the Republic of Kazakhstan, the Russian Federation and Ukraine signed an amendment to the INF treaty's Memorandum of Agreement (MOA). They agreed to end the INF inspection.

[60] See "Protocol on Inspections and Continuous Monitoring Activities of the START I Treaty," and "Annex 5: Procedures for Continuous Monitoring of Inspection Protocol," July 31, 1991. Available at <http://www.fas.org/nuke/control/start1/text/inannex.htm#inannex/5>.

[61] Ivan C. Oelrich, "Production Monitoring for Arms Control," in *Verification and Compliance—A Problem-Solving Approach*, eds. Michael Krepon and Mary Umberger (Cambridge, MA: Ballinger Publishing Co. in association with the Carnegie Endowment for International Peace, 1988), pp.109–110.

[62] Feiveson, *supra*, note 6, p. 237.

[63] Congress of the U.S., Office of Technology Assessment,*Monitoring Limits on Sea-Launched Cruise Missiles* (Washington, D.C.: Congress of the United States, Office of Technology Assessment, 1992), pp. 14–15.