—2—

Verifying a Prohibition on Nuclear Weapons

Steven Fetter and Ivan Oelrich[*]

Many defense and foreign policy analysts, military officials, and policymakers believe that the only legitimate reason for the possession of nuclear weapons is to deter the use of similar weapons by potential adversaries through the threat of retaliation in kind.[†] They believe that the global elimination of nuclear weapons would improve international security if it could be achieved and maintained over the long term, because any benefits that nuclear weapons might provide beyond deterrence of nuclear attack are outweighed by the risks associated with the possession or acquisition of such weapons, including the possibility of their accidental or unauthorized use or theft by terrorists.

Most nuclear-weapon states would be willing to eliminate their nuclear weapons only if they could be confident that other countries—especially potential adversaries—had also eliminated theirs. Because nuclear weapons are small and difficult to detect, no signatory to a disarmament treaty could have absolute confidence that all nuclear weapons had been eliminated at the outset of the regime. As discussed below, however, the use of various verification techniques should allow countries to develop, over time, an adequate degree of confidence that other countries had eliminated their nuclear arsenals and were not attempting to rebuild them. "Adequate" means that the residual uncertainties would be tolerable, taking into account the enforcement mechanisms put into place to protect against and remediate cheating and to punish those responsible.

It is sometimes asserted that nuclear weapons cannot be truly eliminated because they cannot be uninvented. It is true that the knowledge of how to build nuclear weapons would remain even if all existing weapons and production facilities had

---

[*] Steven Fetter was dean of the School of Public Policy at the University of Maryland when he contributed to this article. Ivan Oelrich is acting president of the Federation of American Scientists.

[†] An exception is the use of nuclear weapons to deter other significant threats, such as an invasion with conventional forces. This was a central feature of US and NATO policy during the Cold War, intended to deter an invasion of western Europe by the Warsaw Pact. Today Pakistan, and to a lesser extent Israel, believe that their nuclear arsenals deter non-nuclear threats to their security. As discussed elsewhere, a nuclear disarmament regime would have to adequately address non-nuclear threats to the security of certain nuclear-weapon states before they would seriously consider giving up their nuclear weapons. In this sense, confidence that other countries had eliminated their nuclear weapons is a necessary but not sufficient condition for a global prohibition.

been dismantled, all records and blueprints had been destroyed, and all then-living weapon scientists and engineers had died. But this does not mean that nuclear weapons could not be prohibited or that countries could not be successfully inhibited or prevented from building them. Formal global prohibitions exist on the possession of chemical and biological weapons, piracy, slavery, genocide, trade in endangered species, and the release of ozone-depleting chemicals. These global prohibitions have had powerful and beneficial effects on the behavior of states, despite imperfect compliance and enforcement and despite the fact that knowledge of these practices cannot be eliminated. Indeed, knowledge that other countries could build (or rebuild) nuclear arsenals would act as a powerful deterrent to cheating, because a country contemplating violating a ban on nuclear weapons would know that any advantage thereby obtained would be short-lived.

The fact that the continuing knowledge of how to build nuclear weapons means that many nations could undo a ban on nuclear weapons at some future point raises the question of what, exactly, would be banned. A prohibition on nuclear weapons would certainly ban assembled weapons and their components, but it might also ban stocks of fissile materials and infrastructures for manufacturing nuclear weapons, and could place varying levels of controls over civilian nuclear power programs. The purpose of a ban would be to delegitimize nuclear weapons as instruments of state power and to make a return to nuclear weapons as difficult and time-consuming as possible. In this chapter, therefore, we consider "zero" nuclear weapons to consist of a ban on weapons and their components and the monitoring of all stocks and all production and use of fissile materials, including the monitoring of nuclear fuel production for civilian purposes.[‡]

STANDARDS OF VERIFICATION

Verification is the process of gathering information and drawing conclusions about the compliance of parties to an agreement. Although a verification regime may involve highly technical elements, its results will rarely be clean yes-or-no answers. Given that irreducible ambiguities almost invariably cloud assessments of compliance, the standards set for verification, as well as conclusions about the compliance or noncompliance of particular parties, are inherently political judgments that cannot be separated from the strategic objectives of the participating parties.

The highest verification standard is the ability to detect, with high confidence, any violation of or noncompliance with a treaty, whether through inspections,

---

[‡] Controls on civilian nuclear reactors and their fuel cycles are discussed in greater detail in chapters by Hal Feiveson and Alexander Glaser elsewhere in this volume.

monitoring, data exchanges, intelligence collection, or other measures. For a treaty prohibiting nuclear weapons, the most important violations would be failure to eliminate existing nuclear weapons, production of new weapons, or possession or production of nuclear explosive materials outside of international safeguards. As we shall see in the discussion that follows, it would be difficult, at least initially, to have high confidence that all nuclear weapons had been eliminated, all nuclear material had been placed under safeguards, and no prohibited production activities were taking place.

A more realistic and useful standard for verification is the ability to detect, with high confidence, militarily significant violations in sufficient time to protect the security of other parties to the agreement. This was the standard set by US Ambassador Paul Nitze in his testimony to the US Senate on the Intermediate-Range Nuclear Forces (INF) Treaty: "We want to be sure that if the other side moves beyond the limits of the Treaty in any military significant way, we would be able to detect such violation in time to respond effectively and thereby deny the other side the benefit of the violation."[§] US Secretary of State James Baker confirmed this standard in Senate testimony on the Strategic Arms Reduction Treaty (START): "If the other side attempts to move beyond the limits of the Treaty in any militarily significant way, we would be able to detect such a violation well before it became a threat to national security so that we are able to respond."[**]

This standard does not settle the issue, however, as it immediately raises questions of what constitutes a "militarily significant" violation. Because nuclear weapons are the most destructive of all military instruments, there is a tendency to assume that possession of a single nuclear weapon by an adversary would constitute an unacceptable threat to the security of a state that had eliminated its nuclear arsenal. It is, however, difficult to construct a plausible scenario in which the use or threat of use of one or a few nuclear weapons could be used by a violator to achieve significant military or political goals, even if no other countries possessed nuclear weapons.

First, more than few nuclear weapons would be needed for anything other than empty threats. The cheater would need dozens of weapons to thwart reprisals (e.g., by attacking airbases or aircraft carriers from which international forces were preparing to launch a conventional attack) or to stop others from reconstituting their nuclear forces in retaliation. A violator would also want to

---

[§] U.S. Congress, Senate Committee on Foreign Relations, "The INF Treaty" (S. Hrg. 100-522, part 1, 100th Congress, Second Session, 1988), part 1, 289.

[**] U.S. Congress, Senate Committee on Foreign Relations, "Hearings on the START Treaty: Part I" (102nd Congress, Second Session, 1992), 467.

have dozens of additional warheads to guard against losses due to preemptive attack, malfunctions, successful defenses, and the ongoing possibility of further attacks or attempts at nuclear reconstitution. Thus, a militarily significant violation would involve at several dozen and as many as one hundred deliverable nuclear weapons.

Second, even a sizable nuclear force does not seem to be a usable military or political lever. One way to gain insight into the potential military significance of violations is to examine past crises and conflicts in which only one side of the dispute possessed nuclear weapons. According to one count, there were about 50 such crises from 1945 to 2005.[††] Although nuclear-weapon states prevailed in three-quarters of these cases, there is no case in which nuclear weapons clearly had a significant influence on the outcome of the crisis. In all but one case,[‡‡] the success of the nuclear-weapon state can be explained entirely by its overwhelming conventional military superiority over the non-nuclear adversary. Examples include Soviet suppression of uprisings in eastern Europe; US interventions in several Latin America countries; the British war with Argentina in the Falklands; Israeli intervention in Lebanon; joint US-UK action against Iraq and Afghanistan; and joint US-UK-French action against Iraq and Yugoslavia.

Far more impressive is the number of cases in which a militarily superior nuclear-weapon state failed to prevail against a non-nuclear adversary. Examples include US and French defeats in Vietnam, repeated border clashes between China and Vietnam, the Soviet defeat in Afghanistan, and the US failures to deter China's entry into the Korean War, prevent a humiliating defeat in the Bay of Pigs, and gain the prompt release of American hostages from Iran. The absence of examples in which unilateral possession of nuclear weapons played a role in success, combined with the abundance of examples in which nuclear weapons failed to prevent defeat, demonstrates that nuclear weapons have had little or no effect on the outcome of conflicts between nuclear-weapon and non-nuclear-weapon states. This suggests that violations of a prohibition on nuclear weapons, even if intolerable over the long term, would be unlikely to present an immediate

[††] The International Crisis Behavior Project reports that, of 350 crises after the end of World War II, there were 51 in which only one side possessed nuclear weapons and in which one or both sides were dissatisfied with the outcome; in 12 of those cases, the side possessing nuclear weapons was dissatisfied. These 51 cases exclude some crises in which it is difficult to say that all parties were truly satisfied (e.g., the Iran hostage crisis), and include some in which it is difficult to say that the nuclear-weapon state was satisfied, at least in the long term (e.g., the Gulf of Tonkin incident). International Crisis Behavior Project, www.cidcm.umd.edu/icb.

[‡‡] In only one case did a nuclear-weapon state without clear conventional superiority prevail over a non-nuclear adversary: the 1948 Berlin crisis. Perhaps the Soviet Union would have used force to assert control over West Berlin if the United States had not possessed nuclear weapons, although there are many other reasons that Soviet leaders would have wanted to avoid even a conventional war so soon after the enormous destruction that Russia suffered during World War II.

grave threat to the security of a country that had eliminated its nuclear arsenal. There would be time to respond.

This historical analysis is suggestive, but of course it is not proof. First, it considers only crises that actually happened. It is possible that the possession of nuclear weapons has prevented crises or conflicts from occurring in the first place, though we will never know for sure.[§§] Second, violation of a prohibition on nuclear weapons would be different in important ways from past confrontations involving nuclear-armed states. This is partly because any future international security environment would be different in many ways from the previous 60-plus years of the nuclear age and partly because additional changes would necessarily accompany a prohibition on nuclear weapons to guard against possible violations. Even so, we can examine possible advantages of cheating on a nuclear ban.

Consider, for example, a state that violated a nuclear-weapons prohibition by clandestinely retaining existing weapons or building new ones. The violator could not use hidden nuclear weapons in an attempt to coerce, compel, or counter actions by other states without revealing their existence. But revealing the existence of the nuclear arsenal would immediately trigger reactions by other states and international organizations, such as the enforcement mechanisms discussed by Rebecca Bornstein elsewhere in this volume. These mechanisms, which would be designed to deny any lasting advantage to the violator, could include sanctions, collective military action, and the reconstitution of national or multinational nuclear arsenals.

After revealing the existence of its nuclear arsenal, a violator would have a relatively narrow window—perhaps six months to two years—in which to attempt to use it to gain a significant and lasting military advantage. The violator, for example, might invade and occupy another country and use the threat of nuclear attack to deter resistance or intervention, or it might use or threaten to use nuclear weapons to deter or respond to collective military action, or to prevent other countries from reconstituting nuclear arsenals. A violator's threat to use nuclear weapons might be credible if there was no possibility of nuclear retaliation, but after other countries or groups of countries had reconstituted their

---

[§§] For example, it is possible that the possession of nuclear weapons by the United States, France, and the United Kingdom prevented the Soviet army from invading and occupying countries in western Europe during the Cold War, or that the possession of nuclear weapons by Israel deterred its neighbors from attacking after 1973, or that the acquisition of nuclear weapons by Pakistan in the late 1980s deterred subsequent Indian attacks. Of course, Egypt and Syria strongly suspected that Israel had nuclear weapons in 1973 and still initiated a war that almost brought Israel to its knees. Moreover, we do not know that nuclear deterrence was in fact the reason why the wars cited above did not occur—there is always the possibility that the apparently deterred aggressor had no intention of initiating a war. All we can say is that in each of the situations, the deterrence policy did not fail.

arsenals, threats to use nuclear weapons would become as empty and impotent as they would be in today's nuclear-armed world.[***]

A nation might keep a hidden cache of nuclear weapons with the intention of never using them, or even revealing their existence, unless attacked by an enemy's conventional forces. This would be the most benign motivation for cheating but assuring such a purely defensive motivation into the indefinite future would be impossible. A nuclear-weapon-free world would require other security guarantees that would make keeping nuclear weapons less attractive than giving them up. For example, mutual defense treaties could improve the sense of security of many nations, reducing the perceived need to maintain a clandestine stock of nuclear weapons, and such mutual defense treaties could be automatically annulled in the case of a defender using nuclear weapons.

In general, states must weigh the expected benefits of a disarmament treaty against the expected costs—including the potential risks of cheating. But such costs would be calculated for a world consistent with global denuclearization. Contingent mutual defense treaties are simply a specific example of how a nuclear-free world might be different. The current major nuclear powers would only give up nuclear weapons if they came to the conclusion that conflicts in which nuclear weapons might be useful were extremely unlikely. It would be a world in which the great powers and other states had accomplished a great deal in resolving long-term sources of conflict. Nevertheless, it can not be ruled out that a nation might be tempted to violate the treaty at some point if international circumstances changed so that the benefits it perceived from the treaty no longer outweighed the risks it perceived from cheating—especially if it believed cheating could go undetected. On the other hand, in the absence of a treaty prohibiting nuclear weapons, all nations continue to live with the risks of accidental, inadvertent, or unauthorized use of existing arsenals, to say nothing of their deliberate use in warfare, as well as the risks that additional states might acquire nuclear weapons and handle them recklessly and that nuclear weapons might fall into the hands of terrorists. A disarmament treaty need not have a perfect verification regime to ensure that the risks from cheaters are lower than the risks from continuing without a treaty.

[***] A country might also retain hidden nuclear weapons in order to deter threats to its vital interests. For example, a violator might reveal the existence of a small number of weapons if it was threatened with attack or invasion. Violations for purely defensive reasons would not directly threaten the security of other countries, and thus would not be as worrisome as violations in support of aggressive policies. As noted above, however, states that believe that they require nuclear weapons to protect their legitimate vital interests are unlikely to agree to a prohibition on nuclear weapons in the first place, unless it is accompanied by cooperative measures that effectively protect their security.

STRUCTURE OF A VERIFICATION REGIME

A treaty prohibiting nuclear weapons would establish an international organization with the authority to carry out the agreed inspection and verification procedures. Although the treaty might make use of the existing International Atomic Energy Agency (IAEA) for this purpose (with an amended charter), it probably would be preferable to establish a new entity with the sole mission of ensuring implementation of the treaty's provisions and resolving any questions or disputes that arise. Inspection and verification procedures, and the analysis of data collected by inspectors or provided by states that are party to the treaty, would be carried out by a technical staff. Because of the sensitive nature of nuclear weapons data and procedures, and to limit the further spread of knowledge about nuclear weapon technologies, the treaty might specify that this technical staff be drawn from a particular set of countries: the existing nuclear-weapon states, plus selected non-nuclear-weapon states with impeccable nonproliferation credentials and high levels of nuclear expertise. The list of possible inspectors, in any case, would be approved in advance by each country subject to inspection under the treaty, to prevent any delays in carrying out inspections.

A ban on nuclear weapons could be violated in two basic ways. First, instead of eliminating all of its weapons, a nuclear-weapon state could attempt to maintain a secret stockpile of weapons or of components from which weapons could be assembled rapidly. Second, a state could attempt to produce new nuclear weapons by secretly producing nuclear materials or diverting them from civilian facilities. Accordingly, the verification regime for such a ban would need two major parts. The first would be designed to confirm the elimination of all existing nuclear weapons and the monitored storage of all nuclear explosive materials. The second would be designed to confirm that nuclear materials were produced and used only for non-weapon purposes. In both parts of the verification regime, it also would be necessary to confirm the absence of clandestine stockpiles and prohibited activities.

ELIMINATING EXISTING NUCLEAR ARSENALS

In addition to the verified dismantling of all nuclear weapons, a treaty prohibiting nuclear weapons would also eliminate or restrict much of the infrastructure that is necessary to support and maintain a nuclear arsenal. This would include nuclear delivery vehicles, specialized nuclear explosive components and materials, and various types of nuclear facilities.

Delivery Vehicles

Over the last 40 years, nuclear arms control has focused on limiting the number of delivery vehicles—ballistic missiles, submarines, and aircraft—designed to carry nuclear weapons. The focus on delivery vehicles made sense, because early arms control agreements only limited what could be verified by "national technical means" (NTM), which includes all the methods that nations have for gathering information about other nations—except for human spies. The backbone of NTM is photo-reconnaissance satellites but also includes intercept of telemetry from missile test launches, radar tracking of test launches, and other means. Delivery vehicles could not be hidden easily from photo-reconnaissance satellites and other NTM—and those warheads mounted on long-range delivery vehicles had the greatest strategic significance in a world in which thousands of nuclear weapons were ready for immediate launch and thousands more might be held in reserve. Delivery vehicles also accounted for three-quarters of the cost of the strategic nuclear forces, making them the long poles in the nuclear tent. NTM has not been able to track individual nuclear warheads.

Control and accounting of nuclear delivery vehicles would become less significant and less of a constraint on nuclear weapons as the weapons were reduced in number and eventually eliminated, primarily because large numbers of functionally similar missiles, submarines, and aircraft would remain for other military purposes. The Strategic Arms Reduction Treaty (START), for example, specifies that all existing nuclear delivery vehicles must be declared and subsequently eliminated or converted to conventional roles or peaceful uses under agreed rules that would permit observation of the process. Ballistic missiles, for example, could be converted into space launch vehicles or to delivery vehicles for conventional munitions. Ballistic-missile submarines could be converted into carriers for cruise or ballistic missiles armed with conventional warheads, and bombers could be converted for non-nuclear missions. Inspections of converted missile launchers, submarines, and bombers would confirm that equipment designed for the command and control of nuclear weapons had been removed.

It is not plausible that significant numbers of long-range delivery vehicles could be hidden or secretly manufactured. A greater concern is that conventional missiles and aircraft could be readily restored to a nuclear delivery function. One might guard against this possibility by allowing occasional on-site inspections of long-range delivery vehicles, but a country intent on violating a prohibition could modify its stockpile of nuclear bombs and warheads to use the same attachments and interfaces as conventional bombs and warheads, so that bombers and missiles that had been converted to conventional roles could still carry nuclear weapons with little or no modification.

Nuclear Weapons

No nuclear arms control agreement has yet imposed verified limits on nuclear warheads themselves. The 2002 Moscow Treaty limits the number of deployed strategic offensive warheads but contains no provisions for verifying compliance and does not even place limits on warheads used on shorter-range weapons or on nondeployed warheads. Under the 1991 Presidential Nuclear Initiatives, the United States and Russia pledged to eliminate or reduce specific categories of nonstrategic nuclear weapons, but they are not formal treaties and have no verification provisions. START constrains the number of warheads on ballistic missiles, but the corresponding on-site inspections only confirm that the missile is not equipped with more than the agreed maximum for that type of missile. The total number of warheads is not verified directly but simply inferred by multiplying the number of each type of missile by the maximum number of warheads for that type.

To verify compliance with a prohibition on nuclear weapons, it would be essential to put in place a process for verifying the number of existing nuclear weapons and for verifying the dismantling of these weapons and the disposition of key weapon components. The structure of the verification regime would be roughly similar to that developed for the Chemical Weapons Convention, as described by John Freeman elsewhere in this volume.

Declarations

The warhead verification process could begin with a declaration by each nuclear-weapon state of the number and location of all nuclear weapons and other nuclear explosive devices. The declaration could take the form of a list of facilities, together with the number of each type of warhead present at the facility. The declaration might take place fairly early during the disarmament process, in which case some of the weapons might still be deployed (e.g., on ballistic missiles), or the declaration might take place later in the process when all the weapons have been moved to storage facilities.

Site diagrams could be provided for each facility, indicating the location of all storage bunkers or other locations at which nuclear weapons were (or might be) present. The number of warheads in each bunker would be specified. Ideally, each warhead listed in the declaration would be identified by a serial number or other unique identifier on the warhead or its container. The declaration could be updated at agreed intervals or whenever a warhead was moved.

The declaration would represent a snapshot in time of a country's nuclear stockpile. To build confidence in the accuracy and completeness of the declaration, it would be helpful to also provide historical records of warhead production, deployment, and dismantling, to show in detail how the current stockpile had been derived. For example, one might specify, for each year after a country's first nuclear test, the number of each type of warhead assembled and disassembled and the number stored or deployed at each facility.

A concern might be raised that a state's declaration would make it vulnerable because adversaries would have complete information on its nuclear arsenal and could use it to plan an attack on the arsenal. In the worst case, the information could tempt a nation into an attack that it might not otherwise consider, to achieve nuclear dominance over an old foe.

If declarations are made at an early stage, while weapons are still deployed, the danger of revealing information can be avoided through technical means. For example, it is possible for each party to make a declaration but encrypt the information in a way that is unreadable to the other parties. With the encrypted declaration on record, other parties could ask for some number of items to be decrypted and these items on the declaration could be confirmed as true through on-site inspection. If only 20 or 30 such items are checked and found correct, there will be high confidence that the entire declaration is accurate. Modern cryptographic techniques are available that make it impossible to submit a bogus declaration and attempt to provide accurate data for those items chosen for on-site confirmation. If there are concerns that advances in cryptography might make it possible for a party to decrypt an entire declaration, algorithms are available that can produce a distinct digital fingerprint or "digest" of each item in the declaration, without providing the data itself. Parties could request the data matching a selected digest and could confirm for themselves that these data produce the corresponding digest that had been provided in the declaration. One can, thereby, have high confidence that a declaration is irrevocable without having any information at all about what is in the declaration.

At later stages, warheads will be moved to storage depots and checking some of the declarations will give information about where those are, regardless of encryption techniques. Even so, as discussed above, a nuclear monopoly is less usable than it might seem at first glance, so the incentives for an attack against these locations would be limited. There would also be the risks posed by the defenses the attacked state might have deployed around its storage sites, to say nothing of the nuclear delivery systems, such as submarines, that it maintained deployed and on alert. The military value of the declarations would also be limited because the major nuclear powers, Russia and the United States, have invested enormous resources for uncovering information about each other's and other states' nuclear arsenals. Therefore, the Russians and Americans already know a great deal about the location of key nuclear storage areas. Finally, these comprehensive declarations would likely come at the end of an arms-limitation process that would have restrained the disarming attack capabilities of all sides.

Baseline Inspections

After declarations had been made, the verification agency's technical staff could perform a series of baseline inspections to confirm their accuracy and completeness. The staff would give a nuclear-weapon state short notice of its intention to carry out a baseline inspection of a particular facility. The facility would immediately stand down; any opening of bunkers, movement of warheads, or entry or exit of warhead transport vehicles prior to arrival of the inspection team would be prohibited. This could be confirmed by overhead satellites, or by sensors placed at the facilities when the declaration was made. Upon arrival, inspectors would ask to visit nuclear weapon sites to confirm that the number of nuclear weapons was the same as the number stated in the declaration.

Many of the techniques developed for existing arms control treaties could be used to verify stockpile declarations. The purpose of baseline inspections is to develop an accurate count of weapons so that number can later be compared to the number of weapons that are dismantled, confirming that no warheads were missed. It is important, therefore, that stored or deployed warheads are not undercounted. This suggests that the inspecting party will want to assume that anything that *could be* a nuclear weapon *is* a nuclear weapon and that the burden of proof would be on the inspected party to show otherwise. For example, some reentry vehicles atop missiles might not contain nuclear warheads but instead could be decoys or penetration aids. The inspected party would have to prove that those objects are not nuclear weapons, which should be easy because they will contain no nuclear material.

Anything of the size and shape that could be a nuclear weapon is counted as a potential nuclear weapon except when the inspected party will show that it is not. The inspected party always has the option of opening up or dismantling any object to allow direct visual inspection. Conceivably, some items, such as penetration aids, might need to be kept secret and would not be opened for inspection. Other procedures worked out for the START and INF could be used with some modification in such cases. For example, all fissionable material emits a small number of neutrons from spontaneous fissions and these neutrons can be detected. As part of the INF verification regime, the United States conducted passive radiation measurements near closed missile canisters without looking at the missiles themselves to distinguish between three-warhead SS-20 and single-warhead SS-25 missiles.

Warheads might be shrouded in neutron-absorbing material but such attempts to hide could be detected by active "interrogation" techniques, that is, transmitting a small burst of neutrons into the object to induce fissions that can then be detected. Portable neutron generators are available that are small and light enough to be carried by one person. Neutrons emitted from the generator would produce fissions that produce more neutrons, so detection of more neutrons coming out of an object than went in indicates the object contains fissionable material and can be assumed to be a nuclear warhead. Attempts to hide the fissionable material by wrapping it in neutron-absorbing shielding will be revealed because the shielding will also capture the neutrons from the neutron generator.[†††] In addition, fissions produce short-lived radioactive nuclei that emit gamma radiation and these can be detected with portable detectors. Fissionable material in suspect objects presented for examination would be revealed with high reliability. Not every potential weapon would have to be inspected; only objects that the inspectors believe *might* be nuclear warheads that the inspected party claims are not nuclear weapons would need to be inspected.

If serial numbers for individual warheads or warhead containers were available, these could also be checked against the declaration, dramatically increasing the statistical significance of the spot inspections. Inspectors also would check other possible storage locations, including bunkers that were declared to be empty or to have formerly held nuclear weapons, to ensure that there were no undeclared warheads there. Inspectors' discovery of weapons not listed in the declaration, or the inspected site's failure to produce nuclear weapons that were listed in the declaration, would be evidence of a violation.
Unique identifiers or *tags* could be applied to the warhead containers during the baseline inspections, along with tamper-revealing seals, to ensure that the container could not be opened without detection. In this way, inspectors could be sure that a warhead later delivered for dismantling was the same warhead listed in the declaration and counted in the baseline inspection.

Monitored Storage

The process of completely confirming declarations and resolving any questions that may arise could take several years. Subsequently, there might be an extended period during which states maintained small nuclear arsenals. Even when states undertake the final stage of elimination, the warhead dismantling process will take time. It may therefore be desirable, after the baseline inspections are completed, to implement continuous monitoring of stored nuclear warheads to

---

[†††] While almost impossible to execute in practice, in theory a warhead could be shrouded in just enough neutron shielding to counteract the neutron multiplication in fissionable material. But even this theoretical possibility can be defeated by using neutrons of various energies because the ratio of absorption to multiplication will depend on the neutron energy.

ensure that they cannot be removed without detection. This could take the form of a perimeter-portal monitoring system with a continuously staffed presence or a system of cameras and other detectors outside bunker doors, or even inside the bunker. For example, containers can be draped with blankets with magnets sewn into them so that sensitive magnetic detectors can sense any movement of the blanket. Any undeclared movements would be automatically reported to the technical staff via encrypted satellite or Internet link. The labor requirements for continuous or intermittent on-site staffed observation would be modest.

Dismantling

The final stage of verification of declared warheads is confirming their elimination.[‡‡‡] The assumptions and burden of proof at the dismantling facility would be reversed from those of the baseline inspections. The inspecting party will not want to allow the inspected party to be credited with dismantling a warhead unless it is proven to be a real warhead. Thus, objects will be assumed *not* to be warheads until they are proven to actually be warheads, a process called "authentication"—otherwise, a country could present dummy warheads for dismantling while hiding the real nuclear warheads at another location. Authenticating warheads is more challenging than the baseline inspections because the inspector needs to do much more than simply detect (or fail to detect) the presence of fissionable material. Moreover, authentication procedures must not reveal sensitive information about the nuclear weapon's design. Fortunately, possible techniques have already been demonstrated. While the dismantling verification task is more difficult than storage monitoring verification, the facility lends itself to installing larger, permanently emplaced measuring devices and computer systems.

Warheads intended to be dismantled would be transported to a designated facility, where inspectors stationed at the entrance could check the tags and seals on the warhead containers to ensure that they matched those noted in the baseline inspection and listed in the declaration. Alternately, or additionally, inspectors might travel with nuclear warheads to ensure that material was not diverted during transit. If inspectors did not travel with the warheads, monitoring equipment could be attached to each warhead or its sealed storage container and could record various times and locations along the route in encrypted form to ensure that no inappropriate stops were made between storage and dismantling facilities. Definitive authentication could be carried out at the dismantlement

---

[‡‡‡] Much of the following is taken from National Academy of Sciences, Committee on International Security and Arms Control, *Monitoring Nuclear Weapons and Nuclear Explosive Materials: An Assessment of Methods and Capabilities* (Washington, DC: National Academy Press, 2005). See also Department of Energy, Office of Arms Control and Nonproliferation, Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement, May 19, 1997 (available at http://www.fas.org/sgp/othergov/doe/dis/).

facility and could be accomplished using template or attribute matching. While each approach has certain strengths and disadvantages, both have been demonstrated to reliably identify nuclear weapons.

Template matching uses one or a few confirmed warheads to define the characteristics of other warheads of the same type. The template warheads might be chosen at random from the array of warheads contained in the initial declaration. The inspected side could not insert bogus warheads into its arsenal and insure that the inspecting parties would pick only those and thereby develop erroneous templates. In principle, templates could use various characteristics of the warhead, for example, weight or response to vibration, but in practice all techniques focus on the nuclear properties of the warhead. Templates can contain detailed information about the nuclear weapon, for example the amount of fissionable material, the ratios of plutonium to uranium, and the shape and size of the primary and secondary. This information must be measured using the originally selected warheads and stored such that the inspectors can be confident in the accuracy of the information but never actually get access to the information. While this may seem difficult, it can be done reliably with modern encryption techniques.

Attribute matching uses characteristics agreed by all parties that are consistent with a nuclear warhead or an amount of fissionable material sufficient to make a nuclear warhead. Attributes might include a minimum mass of plutonium or enriched uranium and a symmetric shape of the fissile material to confirm that it has the characteristics of a weapon and minimum limits on the ratio of plutonium or uranium isotopes and absence of plutonium oxide to confirm that reactor fuel was not being presented as weapon material.

All nuclear warheads contain fissionable material, either plutonium or highly enriched uranium (HEU),[§§§] and both template and attribute matching systems will use nuclear measurement for authentication. For example, an attribute system was developed to confirm the authenticity of plutonium pits delivered to a US-built storage facility in Russia. In the late 1990s, US weapon laboratories investigated whether template systems that had been developed for internal use could be adapted for possible use in a START-III treaty.

The fissionable materials in a nuclear weapon are all radioactive to some degree. The gamma emissions of some materials are weak, and the gamma signature can be dominated by impurities rather than by the isotope of interest. Pure uranium-

---

[§§§] It is theoretically possible to build nuclear weapons using other materials, such as americium and neptunium, but these materials are more difficult and expensive to produce and more difficult to use than plutonium or HEU. They could also be detected by the same techniques.

235, in particular, does not emit high-energy gamma rays that would necessarily penetrate to the outside of a nuclear weapon. The enriched uranium used in U.S. weapons is contaminated with uranium-232, which emits an easy-to-detect high-energy gamma ray, but such contamination is not inevitable. Fissionable nuclei also have a small probability of undergoing spontaneous fission and emitting neutrons in the process. Most neutrons emitted by the fissionable material will make it out of the weapons to be recorded but, again, the impurities often contribute more of the signal than the material of interest. For example, the spontaneous fission rate of plutonium-240 is thousands of times greater than that of the weapon material plutonium-239 so even with low levels of 240 impurity the neutrons come mostly from the 240. This raises the possibility that a neutron-detection system could be spoofed with small amounts of neutron-emitting material. Longer measurement times can, to a large extent, compensate for weak emission signals and would not slow the overall rate of warhead dismantlement.

Active "interrogation" is a far more powerful probe of the warhead. Fissionable material reacts when exposed to neutrons. Neutrons from small neutron generators would induce fissions in the nuclear explosive material, a miniscule number compared to the amount required to release dangerous amounts of radiation or explosive energy, but enough to be detected. The fission products produce additional neutrons, which are difficult to contain with shielding, and high-energy gamma radiation that is also difficult to block from detectors. The combination of the energy of the gamma rays and the rate at which the intensity of the gamma radiation drops off in the minute or so after exposure to a small neutron burst will unambiguously identify a mass of fissionable material and allow an estimate of the amount.

A complicating factor with any authentication method is the need to protect sensitive nuclear weapon design information. The passive and active radiation measurements needed for either template or attribute authentication will reveal potentially sensitive weapon design information. To prevent the release of this information, an information barrier system could be used to analyze the data automatically and provide a simple "yes" or "no" answer to the question: "Is this object a warhead of type X?" or "Is this object a nuclear warhead?" For example, an attribute authentication may want to determine simply whether there is, or is not, more than one kilogram of plutonium present but in the process of making the necessary measurement determines the exact amount of plutonium. Computer software, available to all parties, could analyze the data and make a determination and the computer would report a simple yes or no answer. The computer system can be designed to reveal any attempt at tampering. Inspection and calibration of the actual detectors providing input to the computer could be made before and after each measurement. Template authentication is more complex because the template itself can contain substantial design information so it must be protected from the inspectors while, at the same time, the inspectors must be confident the data are real. In addition to physical protection of data storage devices, the template data could be encrypted with a dual key encryption system with one key held by the inspected party and one key held by the inspectors. The inspectors could not read the data without the inspected party's key and the inspected party could not fabricate plausible bogus data without the inspectors' key. Only the secure computer would ever have both keys.

After the warhead is authenticated, it must be verifiably dismantled. Dismantling is carried out in specially equipped bays or cells that are designed to allow the safe handling of nuclear weapons and explosives. To facilitate verification, the bays or cells should have only one entrance, so nothing can be moved in or out without the inspectors seeing it. Before a warhead is dismantled, inspectors would confirm that the bay or cell contains no fissile materials. This could be done by human inspection or through permanently emplaced sensors. The authenticated warhead would then be moved into the bay or cell. The inspected party can then close the door and dismantle the warhead in privacy.
All nuclear weapons include an explosive device, which creates a chain reaction by rapidly forming a supercritical mass of nuclear explosive material. In modern weapons, rapid assembly of the critical mass is accomplished with implosion, in which high explosives are used to compress a sphere or shell of plutonium or HEU or combination of the two, known as the *pit*.[****] Most weapons deployed today are powerful "two-stage" thermonuclear weapons, in which the pit is the first stage or *primary*. It is detonated and its energy used to compress and detonate the *secondary*, which produces the main power of the explosion. Secondaries typically contain both fission and fusion materials and may contain HEU. In the United States, the secondary package is known as a *canned subassembly* (CSA). The pit and CSA are by far the most important components; the plutonium and HEU contained in them are the essential materials for producing a nuclear weapon. Accurate accounting and control of these components and materials is essential to verification.

The materials from the dismantled warhead will be divided into three or more parcels. The first parcel would be large enough to contain the pit but not an entire weapon. The second would be large enough to contain the CSA but not an entire weapon. Other parcels would contain all of the non-nuclear components,

[****] A supercritical mass also could be assembled by firing an HEU projectile into an HEU target. (This method will not work with plutonium, due to its high rate of spontaneous neutron emission.) Called a *gun assembly*, this method is less technically demanding but also far less efficient than implosion. Gun-type weapons or components probably no longer exist, but if they do, their verification and dismantling could be handled in a manner similar to that used for implosion weapons.

such as conventional explosives, arming, fusing, and firing systems, and structural elements. Once the dismantling process was complete, the door to the bay or cell would be opened and monitoring would resume. Measurements would confirm the nuclear contents of the parcels containing the pit and the CSA, and the absence of nuclear material from all other parcels. At that point, the warhead would be confirmed as dismantled and the parcels with the pit and CSA would be moved to monitored storage, described in the next section. Inspectors would again sweep the space to confirm than no nuclear material had been taken from the warhead and diverted and be prepared for the next warhead.

Nuclear Weapon Components

Weapons components will come from two sources: the monitored dismantling process described above and from weapons that were dismantled before monitoring was begun. For example, the United States now has thousands of pits and CSAs in storage from weapons that have already been dismantled. A system similar to that described above, using attribute or template matching, could be used to confirm that these existing components are authentic.

When a nuclear weapon is dismantled, the pit and CSA are isolated from other components and placed in their own containers. As with the complete nuclear weapons themselves, there could be a system of declarations, baseline inspections, and monitored storage while awaiting final elimination of the nuclear components. A declaration would include the current number of pits and CSAs at each location, as well as data on the historical production and destruction or recycling of components. Declarations would be confirmed periodically by a series of inspections, during which tags and seals would be applied to the component containers and monitoring equipment would be installed to detect any undeclared movement or removal of components. Inspectors could monitor the facility's perimeter and the entrance to ensure that no undeclared nuclear warheads, components, or materials entered or exited. Inspections of the interior of the facility would also be conducted at the beginning and end of the dismantling process, to ensure that no nuclear warheads or materials were hidden inside.

Eventually, the components should be eliminated to lengthen the time required to rebuild a warhead. As with dismantlement, the inspectors want to confirm that the components have been destroyed while the inspected party does not want to reveal too much information about the components, such as the exact quantities of plutonium and uranium and the shapes of pits and CSAs.

During the dismantling process, the warhead itself was authenticated, and so the inspectors would be confident that the corresponding components were also authentic. The main challenge, then, is to confirm that the items entering the final destruction facility are those that left the dismantlement facility. This can be accomplished though constant monitoring, probably not human, but by a system of recording cameras and other sensors that confirm that containers were never switched. Seals on the containers would confirm that they had not been opened and the component removed. Components that existed independently before monitoring was established would have to be authenticated by methods similar to those used for complete warheads.

HEU components are readily eliminated by machining them into shavings and chemically converting the HEU into a gas, and blending that with natural or depleted uranium to produce low-enriched uranium for use as nuclear reactor fuel. Such a program currently exists, converting old Soviet nuclear weapons into fuel for American nuclear reactors. Similarly, plutonium components can be converted into plutonium oxide and mixed with depleted or natural uranium to produce fuel for commercial reactors. Plutonium that has passed through a reactor would be no more useable for nuclear weapons than would the thousands of tons of plutonium in spent fuel that has already been discharged from nuclear reactors around the world. Therefore, the task of accounting for and controlling it would pass from the weapons monitoring system to the system that monitors civilian nuclear power, described by Hal Feiveson in a chapter in this volume, “Civilian Nuclear Power in a Nuclear-Weapon-Free World.”

Nuclear Explosive Materials

All other stocks of nuclear explosive materials would have to be monitored and verified as well. As with warheads and components, there could be declarations followed by inspections and the subsequent monitoring of stocks. Unlike with warheads and components, however, there would be no worry about the release of weapon-design information.

These materials might never be eliminated; indeed, they might be required for use in power reactors or other peaceful applications of nuclear energy. Verification that nuclear materials were not being diverted for military purposes would be complicated by the fact that bulk materials must be measured and assayed, while warheads and components can simply be counted. Nevertheless, the IAEA already applies safeguards to make sure such materials are not used for military purposes, and there is no reason why such safeguards could not be effectively applied, or even strengthened, and applied to all plutonium and HEU not contained in nuclear weapon components.

Nuclear Weapon Facilities

Nuclear-weapon states should also provide detailed information on all significant facilities in their nuclear weapon design and manufacturing complexes, both current and historical. This would include facilities for the design, testing, assembly and disassembly, storage, maintenance, and deployment of nuclear weapons, as well as facilities for the production and disposition of nuclear explosive materials and nuclear weapon components. If the facility continues to exist in some form, inspections could confirm the declared design and status of the facilities and also verify the absence of undeclared weapons, components, and materials. An important question that would have to be resolved in the negotiations for a disarmament treaty would be the types of nuclear-weapon facilities that signatories would be permitted to retain. The more a state is permitted to retain, the more quickly and easily it could break out of the disarmament regime and rebuild a stock of nuclear weapons. At the same time, because all signatories would be permitted to retain the same types of facilities, all would be able to respond to such a breakout with equal ease and rapidity. The agreement presumably would call for inspectors to verify the destruction of any type of nuclear weapon facility considered to be illegal under the treaty. It also would require that facilities that were retained were monitored to ensure that they were not reactivated to build new weapons.

Undeclared Stocks of Warheads, Components, or Materials

The verification procedures outlined above could provide very high confidence that declared stocks of nuclear weapons and components had been eliminated, and that any remaining declared stocks of plutonium and HEU were used only for peaceful purposes under international monitoring. But a state wishing to violate the treaty could simply move some existing nuclear weapons covertly to a clandestine facility and provide a false declaration indicating that these weapons had never been produced or that they had been destroyed in tests or dismantled. Alternatively, pits and CSAs or stocks of plutonium or HEU could be moved covertly to a clandestine storage facility and used at a later time to construct a hidden stockpile of nuclear weapons. Any verification system must have high confidence of detecting such hidden stockpiles. As with any verification scheme, the confidence level could never be 100 percent; the goal of verification must be to provide high confidence that any militarily significant hidden stockpile would be detected.

Technical Intelligence

The main problem with finding undeclared stocks is knowing where to look. For reasons of safety and security, nuclear weapons, components, and materials are typically surrounded by multiple fences and other barriers and protected by a large and visible guard force, making the facilities distinctive to satellite reconnaissance. Existing facilities, therefore, are relatively easy to identify, but a country wishing to hide weapons would take care to create a facility offering few if any such outward clues. Nuclear weapons are small; the warhead for the US air-launched cruise missile, for example, is said to weigh less than 300 pounds and to be less than three feet in length and one foot in diameter.[††††] If the cheating government was willing to set aside safety and security requirements, and to risk loss of control of the weapons to dissident factions within the government, dozens of weapons could be transported by a normal truck and stored in a building the size of a single-family home. The facility could be hidden in plain sight—for example, surrounded by commercial buildings in an industrial park with layers of security hidden inside—or it could be collocated with a military base or intelligence agency that required a high level of security for other reasons. In a large country, such as the United States or Russia, there would be hundreds or even thousands of candidate sites for clandestine storage within a few hours' drive of naval or air bases.

Nuclear weapons, components, and materials emit gamma rays and neutron radiation, but these are easily absorbed by shielding, and even without shielding they are detectable only at short ranges (about 100 meters). Radiation detection might prove valuable in finding hidden stockpiles if suspicions were raised about a particular facility or a particular sector of a city, but a wide-area search would not be practical.

Nuclear weapons require periodic inspections and maintenance to replace limited-life components such as batteries, and this activity might give clues about the existence and location of hidden weapons. Modern nuclear weapons are "boosted," that is, the yield of the primary explosion is substantially increased by adding small amounts of the heavy forms of hydrogen, deuterium and tritium, to the center of the pit. Tritium has a half-life of only 12 years, that is, every twelve years half of the original material decays away, and it thus needs to be replaced for the weapon to remain viable.[‡‡‡‡] To maintain boosted weapons over longer periods of time, the country would need to maintain a clandestine stockpile of tritium or an accelerator or reactor capable of producing tritium, so the agreement

---

[††††] Norman Polmar and Robert S. Norris, *The U.S. Nuclear Arsenal: A history of weapons and delivery systems since 1945*, (Annapolis: Naval Institute Press, 2009), p. 66.

[‡‡‡‡] It is believed that almost all of the existing nuclear weapons in the arsenals of China, France, Russia, the United Kingdom, and the United States use boosted primaries in thermonuclear weapons. Without sufficient tritium in the boost gas, the primary yield would be substantially reduced, resulting in little or no yield from the secondary. As a result, for example, a thermonuclear weapon with a normal yield of several hundred kilotons might, with insufficient tritium, have a yield of only one kiloton.

might call for both types of facilities to be monitored periodically.[§§§§] Alternatively, a country wishing to cheat could rely on the unboosted yield of existing weapons, or on simple, unboosted implosion or gun-type weapons, which could be designed to require little or no maintenance and which might be manufactured in advance of the treaty's entry into force.

Bulk nuclear materials require no maintenance and present fewer safety and security concerns during transport and storage. Because fewer people and fewer activities would be involved, it would probably be easier to keep secret the location of stockpiles of components and materials. On the other hand, fabricating bulk plutonium or HEU into weapon components and assembling nuclear weapons using these components would require a far larger and more skilled workforce than that required to maintain already-assembled warheads. Even so, a well-designed operation could be difficult to detect.

The existence of hidden stocks could be revealed by accidents, such as the detonation of high explosives or a fire that released radioactive material. Careful planning and maintenance of a small-scale operation could decrease the likelihood of an accident, but the need for secrecy and the need to minimize the number of people involved could substantially increase the risk compared to normal operations in existing facilities. Even so, accidents involving the production and storage of nuclear weapons have been relatively rare, and signatories could not count on accidents to reveal hidden stocks.

Human Intelligence

The surest way to locate undeclared weapons, components, or materials would be through human sources—an intentional or unintentional leak of information from someone with knowledge of the clandestine stockpile. There have been a series of serious breaches of secrecy in the nuclear weapon programs of the United States, Russia, and other countries. Even governments highly secretive about their programs, such as Iran, Iraq, Israel, and North Korea, have suffered defections ranging from low-level workers to mid-level scientists and engineers to high-level officials. A country contemplating violating a prohibition on nuclear weapons could never be sure that the existence of a clandestine stockpile would not be revealed by someone within the secret program.

[§§§§] For example, extending a boosted warhead's viability for an additional 50 years would require 16 times the amount of tritium needed to bring it into service in the first place. This could be accomplished by reserving the tritium from 16 dismantled warheads for every warhead in the hidden stockpile. Alternatively, a clandestine accelerator with a beam power of 200 kilowatts could be used to produce enough tritium to supply a dozen nuclear weapons indefinitely.

It might be possible to increase the likelihood that individuals who are aware of treaty violations will report them to the agency monitoring the treaty. For example, the treaty could make the production or possession of nuclear weapons a crime against humanity, punishable by life imprisonment. A large cash award might be offered to anyone who provided evidence of a violation, together with a guarantee of immunity from prosecution and personal protection for the individual and his or her family. Inspectors might be given the right to interview personnel in declared facilities privately, and to escort out of the country anyone who reported illegal activity. Declarations might provide the names and addresses of all personnel who worked in certain facilities, had particular skills, or performed key tasks such as warhead assembly and maintenance.

Audits of Records

An accurate historical record of warhead assembly and disassembly, component fabrication and conversion, and material production and consumption would, in theory, eliminate the possibility of hidden stockpiles, because declared current stocks would have to equal the total historical production minus the warheads, components, and materials that had been eliminated. Declarations of historical production and elimination can be verified indirectly through an examination of original facility records, to the extent that they exist. Such records could be examined for internal consistency (e.g., whether the declared production of pits of a certain type was consistent with the assembly of the corresponding warheads) or for consistency with archived intelligence information (e.g., the operating status of a facility indicated by photoreconnaissance satellite), and tested for authenticity using standard forensic techniques (e.g., whether the paper, ink, and printing instrument were consistent with the declared age of the records). The provision of original operating records, together with the availability of program personnel for interviews, played a major role in building confidence in South Africa's declaration of its nuclear stockpile. But records are likely to be missing in some cases, and the lack of records can not by itself be taken as evidence of a violation. Moreover, records—especially electronic records—can be falsified.

Nuclear Forensics

It is possible to gather more direct evidence of historical production of nuclear materials. In China, France, North Korea, Russia, the United Kingdom, and the United States, most or all of the plutonium produced for weapons was produced in graphite-moderated reactors. If the reactor core still exists, measurements of isotope ratios of impurities in the graphite can be used to estimate total plutonium production in the reactor with an error as small as 2 percent. It may be possible to develop similar techniques using the steel structures inside the water-moderated reactors that have been used by France, India, Israel, Pakistan, and the United States to produce plutonium for weapons. Declarations of HEU production might be confirmed by sampling the depleted uranium tails that were created at the same time, although the commercial enrichment of uranium means that the potential error in the measurement would be large compared to the requirements for many nuclear warheads. Finally, plutonium and HEU production also could be estimated from information about the size and design of plutonium production and uranium enrichment facilities. If these facilities still existed, the design information could be confirmed with inspections; if they had been dismantled, original design documents and photographs could be provided.

Size of Possible Hidden Stockpiles

As noted above, one might have high confidence that a nuclear-weapon state's declaration was accurate and complete, and that there were no hidden stockpiles of nuclear weapons or materials, if a complete set of original production records was available and could be authenticated. Otherwise, there is likely to be significant residual uncertainty, at least initially, because there would be no accurate and reliable method of detecting or inferring the existence of small hidden stockpiles.

One check on total production would be provided by estimates of plutonium and HEU production, which could be verified through the methods noted above. The table below gives estimates of current inventories in metric tons and in significant quantities. (A *significant quantity* is the amount needed to build one nuclear weapon—defined by the IAEA as 8 kilograms of plutonium or 25 kilograms of HEU.) Inspectors could realistically hope to confirm declarations of material inventories with an uncertainty of about 5 percent. The larger the violation, the greater the likelihood of being discovered. Assuming that records were destroyed or successfully falsified and that secrecy could be maintained, a country wishing to violate the treaty could probably be confident of concealing a stock of undeclared material, weapons, or weapon components amounting to one-fifth of the uncertainty margin, or 1 percent of its total production.

Table 1. Estimates of current nuclear inventories

	Known stockpiles			Possible hidden stockpiles (significant quantities)§†
	Plutonium (metric tons)	HEU (metric tons)	Plutonium or HEU (significant quantities)†	
Russia	145	1,100	60,000	600
United States	99	705	40,000	400
France	5	35	2,000	20
China	4	22	1,000	10
United Kingdom	3.20	23	1,000	10
India	0.43	0.5	70	1
Israel	0.56		70	1
Pakistan	0.04	1.1	50	1
North Korea	0.04		5	0

Source: Institute for Science and International Security, "Global Stocks of Nuclear Explosive Materials: Summary Tables and Charts," September 2005 (http://isis-online.org/global_stocks/end2003/tableofcontents.html).

† Rounded to one significant digit.

§ Assumes the uncertainty margin described in the paragraph above.

The nine existing nuclear-weapon states fit neatly into three categories. Four states—India, Israel, North Korea, and Pakistan—could not hide a significant stock of nuclear weapons or materials; their existing stockpiles are too small. Three states—China, France, and the United Kingdom—have sufficiently large existing stockpiles that it would be difficult to rule out with high confidence the existence of 10 to 20 undeclared nuclear weapons. As discussed above, stockpiles of this size are near the threshold of military significance; they might be sufficient to deter an aggressor from attacking a country's vital interests but would be insufficient to carry out aggression. Only two states—the United States and Russia—have such massive existing arsenals and have produced such large amounts of nuclear material that it would be difficult to rule out the existence of hundreds of hidden warheads (or enough hidden material to make them).

The United States and Russia thus present the main challenge to effective verification of a global ban on nuclear weapons. Of course, if the two nations verifiably reduce their arsenals prior to implementation of a multinational disarmament treaty, the stocks covered by the 5 percent margin of uncertainty will also be reduced, but the possibility that during this process one or both would covertly stockpile some weapons cannot be ignored. The international community could become more confident that the United States and Russia had completely eliminated their nuclear arsenals only with extensive transparency and thorough cooperation with inspectors. Confidence would build over time if evidence of a possible violation did not arise after the initial set of inspections, the verified dismantling of declared warheads, and the verified disposition of components and materials. Confidence might increase significantly after 10 to 20 years, once the maintenance cycle for existing warheads had passed. High confidence in the complete elimination of nuclear weapons might be achieved only after several decades, when current weapon scientists and engineers had passed from the scene.

Although it might be impossible through technical means of verification to quickly obtain high confidence that all nuclear weapons had been eliminated and all stocks of nuclear material had been declared, confidence might nevertheless be sufficient to support entry into force of a treaty prohibiting nuclear weapons. A key consideration will be various parties' perceptions of the benefits and drawbacks of violating such a treaty. If the risk of getting caught and the seriousness of the consequences are believed to greatly outweigh the potential benefits of cheating, then confidence in compliance will be substantially increased. Similarly, support for the treaty will be bolstered if the resulting decrease in risk—from existing arsenals and from the spread of weapons to additional states or even to terrorist groups—is believed to be greater than the risk of undetected violations of the treaty.

DETECTING THE MANUFACTURE OF NEW NUCLEAR WEAPONS

Only existing nuclear-weapon states can hide existing weapons, but any nation could attempt in the future to build new weapons. Such attempts would depend foremost on acquiring plutonium or HEU.[*****] A violator could try to exploit a civilian nuclear power program, diverting a portion of the fuel production for a clandestine bomb project. Alternatively, the violator could try to create a clandestine facility dedicated solely to producing material for bombs. The greatest concern is not the nuclear reactor itself but the plants that process fuel before and after it is used in the reactor.

Verifying that nuclear materials are not diverted from civilian production requires monitoring the enrichment of uranium and the reprocessing of nuclear fuel to recover plutonium. The IAEA long ago implemented procedures to do just this. Through a combination of periodic inspections, permanent unstaffed monitors, tamper-revealing seals, and laboratory analyses of collected samples, the IAEA can verify with high confidence that no HEU is being produced or has

[*****] If a thorium/uranium breeder cycle is developed (as hoped for by India), uranium-233 also could be used as material for a bomb. The thorium/uranium cycle is equivalent to the uranium/plutonium cycle. Whereas U-235 in natural uranium must be laboriously separated out from the chemically identical U-238, plutonium can be chemically separated out in bulk from uranium reactor fuel. Similarly, U-233 can be chemically separated from thorium reactor fuel and U-233 has been demonstrated to be useable as a nuclear explosive. Because India has large reserves of thorium and little uranium, it is particularly interested in thorium-powered reactors.

ever been produced in a declared uranium enrichment facility. Plutonium reprocessing facilities are a greater challenge, but monitoring could be much improved if the facilities were designed from the beginning to support it, as was the new plant in Rokkasho, Japan.

To protect against diversion for weapons use, monitoring of uranium production must account for two things: the material itself and its level of enrichment, which must be substantially higher for use in a nuclear weapon than for use in a power plant.

There are almost no civilian uses for uranium except in nuclear power plants, so monitoring could begin when the ore is mined. The challenge of monitoring such a large-scale industrial activity is balanced by the fact that the concentrations of uranium in ore are so small that very large quantities would have to be diverted to acquire enough uranium to construct a weapon. Natural uranium is made up of two isotopes, but only one, uranium-235, powers nuclear reactors and can be used in nuclear weapons. Natural uranium contains less than 1 percent uranium-235 and must be greatly enriched to produce it. All current uranium enrichment processes use uranium in a gaseous compound form, uranium hexafluoride. Enrichment of uranium begins with the conversion of uranium metal or oxide to uranium fluoride compounds; monitoring could begin at that stage to measure the total amount of uranium available to be enriched. Intake of uranium hexafluoride could be measured at enrichment plants and compared to the enriched and depleted uranium produced by the plant to assure that all material had been accounted for.

Commercial reactors use uranium enriched to 3 to 5 percent uranium-235. The International Atomic Energy Agency defines “highly enriched” as any material enriched to over 20 percent because building a bomb with lower enrichments is virtually impossible. If fact, the HEU needed in practice for nuclear explosives should be at least 80 percent and optimally 90 to 95 percent enriched. Many research reactors use HEU, but these can be, and are being, converted to use enrichments of less than 20 percent to meet the definition—and lower security requirements—of low enriched uranium. Stocks of HEU would require careful monitoring to ensure that they are not being diverted from their intended uses. Some naval reactors are thought to use uranium of such high enrichment that it also could be useable in a weapon and special provisions would be required to insure that any HEU produced for these reactors is indeed incorporated into a reactor. The level of enrichment can be measured at various stages throughout the process, although this is not currently done because of fears of revealing proprietary data. When natural uranium passes through any enrichment process, some material with higher U-235 concentration is produced but no uranium atoms are created or destroyed so a waste stream with lower concentration of U-235 is necessarily also created. This is usually called “depleted” uranium. The composition of the declared bulk quantities of enriched and depleted fractions could be measured to account for all of the U-235 that should have been present in the natural uranium at the beginning of the process and thereby reveal whether HEU could have been produced and hidden or removed.

Material monitoring would have to continue after the uranium hexafluoride was enriched. Low-enriched uranium cannot be used directly in a nuclear weapon. But a weapon program that begins with uranium already enriched to 5 percent U-235 can halve the time needed to further enrich it to weapon grade or can halve the amount needed to produce a weapon, compared to using natural uranium. Thus a declared commercial facility could be used in conjunction with a clandestine facility to facilitate breakout from a disarmament treaty. Monitoring must confirm that uranium hexafluoride is converted back into uranium oxide, the form that is used in reactors, which cannot be directly enriched further. With such monitoring in place, even with the head start provided by a commercial enrichment capability, a country would need months to break out, allowing other countries time for sanctions or even military reprisals.

Used fuel from a nuclear reactor contains plutonium, which would also need to be monitored. Although the technique is currently not economical, France, Japan, and Russia reprocess commercial fuel to recover plutonium. The plutonium recovered in this process is not ideal for use in nuclear weapons—specialized reactors produce almost pure plutonium-239 for that purpose. But it can be fashioned into bombs that have been proven to work or processed further to produce weapon-grade plutonium.

Monitoring of plutonium reprocessing could use the same logic as monitoring of uranium enrichment—inputs and outputs would be measured to detect diversions of material. But because plutonium is derived from reactor waste, which is intensely radioactive, measurements would be more difficult and costly. Also, even careful measurements have an irreducible margin of error that could be significant. For example, the new plutonium reprocessing plant in Rokkasho, Japan, was designed to enable IAEA safeguards and monitoring, and plutonium accounting there is thought to have an error of less than 1 percent. The plant, however, will process up to eight tons of plutonium a year, so a 1 percent error is 80 kilograms or enough to produce at least 10 nuclear weapons.

Both enrichment and reprocessing could be monitored more confidently if the facilities were operated under international control. The nuclear industry deals with materials and techniques that are essential to production of nuclear weapons.

Therefore, uranium enrichment and plutonium reprocessing face more difficult and dangerous issues than steel or petrochemical manufacturing and should be brought under tight international scrutiny. Alex Glaser discusses these prospects elsewhere in this volume.[†††††]

A would-be violator of a nuclear ban could also try to produce nuclear materials by secretly establishing a facility, to produce either HEU or plutonium, which would escape monitoring entirely. Clandestine uranium enrichment would probably be the greater worry. The current best enrichment method uses high-speed centrifuges. A centrifuge facility able to produce enough HEU for a few bombs per year would not have to be large or distinctive. It could be situated underground. Under normal operating conditions, such a facility would produce few tell-tale *signatures* or signs revealing its existence. Accidents, such as the inadvertent release of uranium hexafluoride gas, might be detected, but significant accidents are rare for experienced operators.

Nevertheless, it seems that no country has developed an enrichment capability without detection. The Iranians worked secretly for many years to develop a centrifuge enrichment capability, but their efforts were uncovered quickly once they actually began to construct a plant. The North Koreans have admitted to some sort of centrifuge enrichment program that is thought to be at an early stage. This effort was deduced by US intelligence agencies by tracking special materials needed for centrifuge manufacture. This sort of national and international monitoring of components and materials required for uranium enrichment would presumably continue, and probably intensify, under a disarmament regime. While any single import of materials might escape detection, developing a centrifuge program is a years-long program that would require the import of a variety of suspect items. Past experience suggests that it is unlikely that the entire program would escape detection.

Uranium enrichment using some new, as yet unproven, technology—for example, laser enrichment—could be much more difficult to detect, but if such approaches are developed further, it is likely that tell-tale signatures would be identified.

A country with declared enrichment facilities produced using indigenous technology might be more successful in hiding a clandestine enrichment program. To minimize the risk of detection, a completely parallel system of secret component manufacture and assembly would have to be built and operated. The staff of the clandestine facilities would have to be kept separate

---

[†††††] The chemical industry has already accepted international inspections under the Chemical Weapons Convention. See John Freeman's chapter in this volume for details.

from the staff of the declared facilities; otherwise, components and personnel in declared facilities could become contaminated with HEU, which could be detected during IAEA inspections. Substantial amounts of natural uranium would have to be produced and delivered to the clandestine facilities without detection. The practical barriers to executing such a plan over several years would be formidable.

Production of kilogram quantities of plutonium requires a nuclear reactor and a fuel reprocessing facility, and these do have distinctive signatures that would reveal their existence. Nuclear reactors produce heat that can be detected remotely, and both reactors and reprocessing plants almost inevitably release some radioactive materials that are easy to detect, even in very small amounts. In short, signatories to a disarmament treaty could have high confidence that a clandestine nuclear reactor program would be detected by remote sensors.

A clandestine nuclear weapon program also would require non-nuclear activities that might reveal its existence. For example, photoreconnaissance might detect tests of the high-explosive implosion assemblies that are used to compress the plutonium or uranium in the pit to create a critical mass that begins the nuclear explosion. All of these non-nuclear activities, however, would be less conspicuous than the production of nuclear materials.

Finally, an existing nuclear power is more likely to try to violate a ban on nuclear weapons by hiding existing nuclear devices rather than by producing a new nuclear weapon clandestinely. Clandestine production would most likely be attempted by a nation without prior nuclear experience—and, given the stakes involved, it might deem a test of the device to be essential. A nuclear test explosion would almost certainly be detected by its seismic and radiological signals and would certainly make clear that the country was planning to break out of the treaty—thus permitting other signatories to react, either by using collective military force to stop the breakout state, or by restarting their own nuclear weapon programs.

CONCLUSION

Verification of a global ban on nuclear weapons is feasible, and such an agreement could be in the security interests of each participating nation. Complete confidence in complete nuclear disarmament would not be possible. For some, that uncertainty means that nuclear disarmament is a dangerous fantasy. But the choice is not between risky disarmament and a risk-free status quo. The status quo has its own dangers—accidental or deliberate nuclear war, nuclear accidents, and nuclear terrorism.

Moreover, in the absence of disarmament, the future status quo may become even more dangerous as additional countries acquire nuclear weapons. We are forced to compare risks. Any verification regime would be less than perfect, but a combination of technical and human intelligence, declarations, inspections, and on-site monitoring could produce high confidence that militarily significant numbers of nuclear weapons would be detected in time for the world to respond in a way that would negate any potential advantage that might otherwise accrue to a would-be violator. This is true in part because the political or military utility of a small number of nuclear weapons is less than commonly supposed. Certainly, they could be used to kill many civilians. They would not be decisive militarily, however, and an alliance of nations with significant conventionally armed military forces would be able to defeat and punish the cheater.

Safeguards against the production of new nuclear material could effectively detect efforts to manufacture new nuclear weapons, although this would require international monitoring of the nuclear fuel cycle. The greater challenge is confirming the dismantling of existing weapons. There will always be some residual uncertainty in accounting for all the weapons in an arsenal, and that uncertainty will be roughly proportional to the original size of the arsenal. The two most worrying cases are Russia and the United States because their past production of nuclear weapons and current arsenals are so large. In the event of a disarmament treaty, the two nuclear superpowers may need to make a special effort at transparency to reassure the rest of the world that they have dismantled all of their nuclear weapons.