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Chapter 11

Verifying Deep Reductions In Nuclear Forces

Countries will not agree to deep reductions in their nuclear forces if they believe that their security could be undermined by undetected violations. Such concerns should be dealt with by designing the residual forces so the stability of deterrence would not be sensitive to undetected cheating, and by establishing a verification system that would detect cheating or preparations for a break-out on a scale that would be judged significant. As we shall see, achieving the second goal will require an unprecedented degree of transparency and cooperation among the nuclear-weapon states.

A comprehensive verification system would have three key components:

1. measures to monitor restrictions on allowed numbers of nuclear warheads and fissile-material production and stockpiles, and to improve safeguards on peaceful nuclear activities;

2. measures, patterned after those established by the START treaties, to monitor allowed numbers and types of nuclear delivery vehicles; and

3. measures to monitor restrictions on the deployment and alert status of nuclear forces.

Some of these measures, particularly those which involve the monitoring of nuclear materials and related facilities, could be carried out by the International Atomic Energy Agency (IAEA). Other verification tasks, especially those which involve the monitoring of nuclear warheads and missiles, could be performed by a new verification authority established by the parties to the deep-cuts agreements. Such an authority might evolve from the bilateral arrangements already created by the START agreements and other arrangements that are being discussed by the United States and Russia for monitoring the storage and dismantling of excess nuclear warheads.[1]

Nuclear Weapons and Fissile Materials

Nuclear arms control agreements in the past have not sought to control nuclear warheads directly, concentrating instead on large nuclear-weapon delivery systems which can be monitored through national intelligence capabilities far more readily than can warheads. For the deep reductions in nuclear forces advocated in this paper, however, it

[1] Frank von Hippel, "Fissile Material Security in the Post-Cold-War World," *Physics Today*, June 1995.

is absolutely essential that nuclear warheads and the fissile materials necessary for their construction come under direct control. Although national intelligence will remain important in an expanded verification system, monitoring limits on nuclear warhead and fissile-material stockpiles will require a series of cooperative verification measures, including:

- declarations of the location and status of all nuclear warheads and fissile material stockpiles;
- verification of these declarations through on-site inspections and exchanges of data on the design and operating history of the facilities used to produce warheads and fissile materials;
- verification of the dismantling of nuclear warheads and of the storage and disposition of the fissile materials contained therein;
- verification of a ban on the production of additional fissile materials for weapons; and
- improved IAEA safeguards on peaceful nuclear activities.

Declarations of Warheads and Fissile Materials

Comprehensive declarations. At the outset of the disarmament process, the United States and Russia, followed later by the other nuclear-weapon states, would produce a comprehensive declaration of the location, type, status, and unique identifier for all nuclear explosive devices and all canisters containing pits or other forms of fissile material. The declarations, which would be updated at agreed intervals, would include information on all deployed and stored nuclear warheads in the active stocks and warheads awaiting dismantlement, and fissile components and materials. For stored warheads and warheads being assembled or dismantled, the location would be a certain declared facility and a position within that facility. For sea-based or mobile land-based systems, the warhead location might be given as the corresponding ship hull number or mobile-missile base.

The idea of a declaration of nuclear weapons, although unprecedented in scope and ambition, has been advanced in various forums. For example, the establishment of a comprehensive register for nuclear weapons was a principal recommendation in the report of the National Academy of Sciences on the *Management and Disposition of Excess Weapons Plutonium.*[2] Such a register was also suggested by Germany in 1993, although

[2] 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), pp. 7-8 and *passim*.

subsequently dropped at the request of the United States and other nuclear-weapon states.[3]

Until recently, the United States and Russia had resisted declarations and associated transparency measures on the grounds that they might reveal sensitive information about the status or design of nuclear weapons. This attitude has begun to change, however. The two countries agreed at the January 1994 and succeeding summits to exchange data on warhead and fissile-material stockpiles and to arrange reciprocal inspections to confirm declarations of excess warheads and fissile materials.

The most complete description of what the U.S. and Russian governments agreed to do in this area is found in the joint statement issued by Presidents Clinton and Yeltsin after their meeting in Moscow on May 10, 1995.[4] As a first step in putting the transparency procedures in place, the joint statement called for a U.S.–Russian agreement allowing the two governments to exchange sensitive information needed to confirm that declared objects were real warheads or warhead components and providing that this information would be fully protected. The U.S. Congress has twice waived certain provisions of law so that such an agreement could enter into force soon after the President had certified that it met U.S. national security needs. Unfortunately, as described in more detail in chapter 8, Russia broke off the transparency negotiations in the fall of 1995 and they have not yet been resumed. However, much of the technical groundwork for implementing transparency measures has now been laid, and it should be possible to put the measures in place relatively quickly once Russia decides to move forward.[5]

In addition, the U.S. Department of Energy (DOE) has taken a valuable step toward increased transparency by publishing a report that summarizes U.S. plutonium production and use from 1944 through 1994.[6] The report, *Plutonium: The First 50 Years*, provides a comprehensive accounting of plutonium inventories at each DOE facility, including the sum of the quantities of plutonium in the U.S. nuclear weapons stockpile and in pits at the Pantex warhead assembly/disassembly facility. It also provides a summary of the production of plutonium at DOE sites, small acquisitions of foreign plutonium, and removals of plutonium from the stockpile. A similar report on the production and use of highly enriched uranium is in preparation. As discussed later, however, these reports point to several difficulties which will bedevil verification of declarations of fissile-material stockpiles.

<u>Tags</u>. Verification would be enhanced if all declared nuclear warheads and canisters containing pits or fissile materials were equipped with a unique identification number or

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[3] Harald Mueller, “Transparency in Nuclear Arms: Toward a Nuclear Weapons Register,” ***Arms Control Today***, October 1994, pp. 3-7.
[4] Joint Statement on the Transparency and Irreversibility of the Process of Reducing Nuclear Weapons, Moscow, May 10, 1995.
[5] Frank von Hippel and Oleg Bukharin, “U.S.-Russian Cooperation on Fissile Material Security and Disposition,” prepared for the Summer Course of the International School on Disarmament and Research on Conflicts, Sienna, Italy, July 29-August 8, 1996.
[6] U.S. Department of Energy, *Plutonium: The First 50 Years*, DOE/DP-0137, February 1996.

“tag” that was specified in the declaration. These tags, sealed so that they could not be altered, removed, or replaced without alerting inspectors, would have two key advantages. First, they would allow a “chain of custody” in which particular warheads could be tracked from deployment sites to storage bunkers to dismantlement facilities. Similarly, canisters containing pits or other fissile warhead components could be tracked from dismantlement facilities to storage sites to facilities for the civil use or disposal of the material. Second, tags would simplify verification, because the discovery of an untagged warhead or canister would constitute a violation. Thus, 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 in a randomly selected sample of items, thereby reducing the inspection effort and its degree of intrusiveness.[7]

A tagging scheme could rely on existing serial numbers or surface features, or it could use several different kinds of applied tags, such as bar-coded labels or plastic holographic images, overlaid by a tamper-proof tape.[8] Tags are used by the United Nations in Iraq to log and track items which could be used both for civilian and military purposes, by the IAEA to safeguard civilian nuclear materials, and by the U.S. military to track weapons (including nuclear warheads).[9] These tags require that inspectors have physical access to the tag, but it is possible to imagine a tag that could be authenticated outside of a container or at a distance. For example, electronic tags could be developed that would emit a coded signal containing the unique identifier of the weapon component when interrogated by a radio transmission.[10] The use of tags for verification, while not yet

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[7] Without sampling, inspectors would have to count every warhead or container of fissile material at every site in a reasonably short amount of time for comparison with the declaration, and possibly verify the authenticity of each warhead and the contents of each canister of material. Sampling could greatly reduce the number of warheads and canisters that would be examined. For example, a detailed inspection of only 28 randomly selected warheads would provide at least 95 percent confidence that no more than 10 percent of the warheads are bogus, and that the number of warheads at declared sites does not exceed the declared number by more than 10 percent. In addition, there would be at most a 25 percent chance that a 5 percent violation would escape detection (i.e., 50 of 1000 warheads were phony or undeclared), and a 1 percent chance that a 15 percent violation would go undetected. Even a 1 percent violation would have a 25 percent chance of detection. These calculations are valid for a large, but unspecified, number of declared warheads; the confidence level would be higher (but the inspection savings due to sampling proportionately lower) if the number were low (e.g., less than 100).

[8] Annex 6 of the Inspection Protocol of the START I treaty defines a unique identifier as “a non-repeating alpha-numeric production number, or a copy thereof, that has been applied by the inspected Party, using its own technology.”

[9] 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. [Lt. Col. Guy Martelle, On-site Inspection Agency, private communication, July 25-26 1996.]

[10] Steve Fetter and Thomas Garwin, “Using Tags to Monitor Numerical Limits in Arms Control Agreements,” in Barry M. Blechman, ed., ***Technology and the Limitation of International Conflict*** (Washington, DC: The Johns Hopkins Foreign Policy Institute, 1989), pp. 33–54; Timothy Wade, “An Asset Tag for Treaty Verification”, Mitre Corporation, manuscript, undated.

applied to warheads, is provided for in the START Treaty.[11] Although certain technical issues would have to be worked out, there should be no problem in instituting an effective tagging system for warheads and sealed canisters containing warheads, components, or fissile materials.

Verifying the Declaration

Nuclear Warheads. Data on warheads (or canisters containing pits) would be verified primarily by regular and short-notice inspections at declared facilities, combined with challenge or suspect-site inspections to verify the absence of warheads at other locations. Inspectors could, for example, count the number of warheads in a particular declared storage bunker and compare this to the number listed in the data exchange. As noted above, the use of tags would allow inspectors to select a random sample of warheads, and to verify that each had a valid tag corresponding to a warhead listed in the declaration.

It would be necessary for inspectors to assure that tagged objects contain authentic nuclear warheads or fissile components. Gamma-ray detectors 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 design information. One possibility is to use a combination of radiation and other distinctive signatures to “fingerprint” types of nuclear warheads or pits, which could then be used as a template to assure that warheads or pits in tagged canisters are authentic. A detailed signature would be extremely difficult to spoof, but would have to be formed in a way that did not reveal important design information. The United States and Russia are currently developing such a system to verify the authenticity of plutonium pits held in storage facilities.[12]

It also would be necessary to assure that other, untagged objects do not contain warheads or pits. If the object is not too large, gamma-ray and neutron detectors could confirm the absence of plutonium or highly enriched uranium. Large objects could contain enough shielding to prevent such detection in a reasonable amount of time, however, in which case the inspected party should be required to use other methods to demonstrate that no warheads or pits are contained within.

Confidence in verification at declared facilities could be enhanced substantially by installing portal-perimeter systems. Objects entering and exiting the facility would be monitored as they passed through the portal; declared warheads or pits would have their tags authenticated, while other objects would be inspected to assure that they do not contain warheads or pits. (Once again, sampling could be used to minimize disruption of the normal operation of the facility.) In this way, portal-perimeter systems would foreclose the possibility that undeclared warheads or pits could make use of declared

[11] Annex 6 to the Inspection Protocol of START I, which describes procedures for associating unique identifiers with mobile missiles or their launch canisters.
[12] The measurements would determine roughly the isotopic composition of the pits, the approximate amount of plutonium that they contain and their approximate size.

facilities, forcing a cheater to develop a parallel, clandestine systems to store, maintain, repair or deploy illegal warheads. Because portal perimeter monitoring is expensive, its use would likely be limited to a small number of sites.

To further increase confidence in the accuracy and completeness of the declaration, detailed information could be exchanged on the history of each nuclear device (e.g., date and place of assembly, deployment, disassembly, test explosion, etc.) and the operation of facilities at which nuclear explosives had been designed, tested, assembled, stored, deployed, maintained, modified, repaired, and dismantled, as well as facilities that produced key weapon components and materials. These records could be checked for internal consistency and for consistency with the declaration and with archived intelligence data. Allowing extensive interviews with former and current officials responsible for nuclear weapons would also improve confidence in the declarations.

Fissile Material. In general, verification of fissile-material declarations would be more difficult than of warheads. This is principally because warheads are subject to simple item accounting, while fissile materials are not. In general, also, record keeping is likely better and more accurate for warheads than for fissile materials. While it is likely that the nuclear-weapon states know, with very little uncertainty, how much plutonium and highly enriched uranium (HEU) they have in nuclear weapons and in discrete storage forms, such as pits, metal “buttons,” and canisters filled with plutonium oxide, they will know less precisely how much plutonium and HEU is in spent fuel, in metal scraps, in powders lining pipes and glove boxes, and in various liquid solutions and wastes. Indeed, the best estimates of national inventories *even by the owners of the fissile materials* will contain uncertainties of at least a few percent. A “few percent” corresponds to a lot of weapons, as shown in table 7.1, which gives estimates of military fissile material accumulations by the nuclear-weapon and threshold states.

[Insert table 7.1 near here.]

It would be fairly straightforward, if time-consuming, to verify the accuracy of some categories of information provided in a fissile-material data exchange. For example, inspectors could verify, using standard assay and sampling techniques, that selected canisters contained material of the amount and isotopic composition specified in the declaration. However, other information, such as the amount and composition of fissile materials in a particular type of warhead, would likely remain unverified, at least until that warhead type was slated for dismantling. Indeed, some such data might not even be exchanged, much less verified. The amount of sensitive information would grow smaller as the number of allowed warheads decreases, however, and the prospect that such data eventually would be subject to verification would be a powerful incentive to give accurate declarations at earlier stages.

More problematic than verifying the *accuracy* of a fissile-material declaration, however, would be verifying its *completeness*. Even if we could verify the amount of plutonium in every declared warhead or canister, how could we be sure that every container or kilogram of plutonium was declared? The obvious approach is to verify the total size of the stockpile by verifying estimates of the total amount of material produced. Although production estimates inevitably contain uncertainties, they provide a useful cross-check of stockpile declarations and limit the size of possible undeclared stocks.

Verifying plutonium production would involve examining records of the fabrication of uranium fuel and target rods for plutonium-production reactors; the design of the fuel and the reactors and typical fuel loadings in the core; dates of fuel loading and discharge and monthly production of thermal energy; the design and operating records of the reprocessing plants; and volume, isotopic concentrations, and disposition of the various waste streams. Verifying HEU production would involve reconstructing, from records of facility design and operation, the daily flow rates and uranium-235 concentrations of natural uranium feed, enriched uranium product, and depleted uranium tails flowing through the enrichment cascades, as well as the amount of uranium of various enrichments in wastes or released into the environment.

The value of this method of verifying production declarations would depend almost entirely upon the accuracy, completeness, and authenticity of the records that are provided. One can check that operating records are consistent with the declaration and that the records are internally consistent, but this should not be confused with confirming their accuracy. It may, however, be possible for inspectors to find physical evidence to corroborate the records. For example, the ratio of neutron transmutation products in permanent components of plutonium-production reactors would provide an estimate of the total amount of heat and plutonium produced during the life of the reactor.[13] Estimates derived in this way would be uncertain by perhaps ten percent, but would be largely independent of record-keeping by the host country. In the case of uranium enrichment, ages determined by accumulated products of uranium radioactive decay and isotope ratios in depleted uranium tails stored at the facilities could confirm records of product and tails assays over a particular time period.

Because of the inevitable uncertainties in verifying past production, it might be possible for the United States and Russia to conceal the existence of a large number of undeclared warheads (or enough material to build them), although to do so might require the withholding or doctoring of records. It is difficult to say, without detailed study, how much these uncertainties could be narrowed. One benchmark is provided by *Plutonium: The First 50 Years*. According to this report, out of slightly more than 100 tons of plutonium produced in the United States for weapons, 2.8 tons are designated as "inventory difference," which is defined as the difference between the quantity of nuclear material held according to records of production and disposition and the quantity measured by a physical inventory.[14] This does not mean that uncertainties in the U.S.

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[13] Steve Fetter, "Nuclear Archaeology: Verifying Declarations of Fissile Material Production," *Science and Global Security*, Vol. 3, Nos. 3-4 (1992).

[14] This does not mean that 2.8 tons of plutonium is missing or was stolen or diverted. It is believed that much, if not all, of the inventory difference can be attributed to systematic overestimates of plutonium production in reactors, together with systematic underestimates of plutonium retained in equipment and discharged in wastes. In other words, less plutonium probably was produced, and more plutonium probably exists in the stockpile in difficult-to-measure forms, than appears in the accounting records. The

stockpile of plutonium cannot be reduced to below 2.8 tons, but it does suggest how difficult it may be to do so. To put this uncertainty in perspective, 2.8 tons of plutonium is enough to build at least several hundred nuclear weapons, and it is larger than the entire estimated stockpile of weapons plutonium of the U.K. Uncertainties in HEU production are likely to be even larger, because the United States did not measure how much HEU went into waste streams and did not keep precise records of the enrichment even of various product streams.[15] Soviet record-keeping was probably still more imprecise.

As noted above, challenge inspections could be used to search for hidden stockpiles of warheads or fissile materials at undeclared facilities. Although concealed warheads and fissile materials would be almost impossible to detect in the absence of information indicating where to look, a country would always face the risk that the such locations would be revealed as a result of leaks or whistle-blowing. Indeed, citizen reporting of treaty violations by governments should be encouraged and protected under national and international law.[16]

Nevertheless, in assessing the stability of a regime of deep reductions, it would be prudent to assume that the United States or Russia could, if they chose, conceal several hundred warheads—or enough fissile material to build several hundred warheads. Given equal degrees of transparency and assuming proportional uncertainties, China, France, Britain, and the threshold states could conceal a few tens of warheads (or an equivalent amount of fissile material).

The recent experiences of verifying the nuclear disarmament of South Africa and Iraq also suggest caution in this regard. These countries had produced far less fissile material than any of the nuclear-weapon states. In both cases, inspectors had an unusually wide access to facilities, records, and people, and yet it was difficult for inspectors to verify with high confidence that they had identified all significant inventories of fissile material.

South Africa announced in March 1993 that it had secretly built, and later dismantled, six nuclear bombs. The decision to disarm was made in July 1990, and within one year the nuclear bombs were dismantled, documents were destroyed, production and assembly facilities were decommissioned, and HEU weapon components were cast into standard shapes for storage and international inspection.[17] The South African government subsequently decided that a full disclosure of its nuclear program would be required to secure international confidence in its non-nuclear status and gave the IAEA a complete history of the program and permission to conduct inspections at any relevant locations and to interview former managers and workers.

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inventory difference might be reduced substantially as facilities are decontaminated and the resulting plutonium wastes are analyzed.

[15] Len Myers, U.S. Department of Energy, private communication [DATE?]

[16] Joseph Rotblat, "A Nuclear Weapon-Free World Leading to a War-Free World," Presentation at Pugwash Conference on Science and World Affairs, United Nations, April 1996.

[17] David Albright, "South Africa's Secret Nuclear Weapons," *ISIS Report*, May 1994.

IAEA inspectors easily verified that declared weapons and facilities had been respectively dismantled and decommissioned and that the declared amount of HEU had been placed in monitored storage. But providing assurance that South Africa did not have any undeclared weapons or HEU was more difficult -- a matter of concern because South Africa claimed that the Valindaba enrichment plant had produced considerably less HEU than its design capacity would have allowed. A materials balance of the plant revealed very large uncertainties, owing to the fact that plant operators kept poor records of the enrichment of the depleted uranium tails.[18] In the end, however, the IAEA concluded that "the amounts of HEU which could have been produced by the pilot enrichment plant are consistent with the amounts declared."[19] This conclusion was based largely on an analysis of the original operating records of the plant, which the IAEA judged to be authentic.

The Iraqi case, of course, featured a much more adversarial relationship between the inspectors and the host country. In the aftermath of the Gulf War, the Security Council established the United Nations Special Commission on Iraq (UNSCOM) to uncover and destroy Iraq's chemical, biological, and long-range missile capabilities and to assist the IAEA in eliminating Iraq's nuclear weapons program. An "anytime, anywhere" inspection system was imposed on Iraq, in which UNSCOM and IAEA inspectors "had the right to conduct no-notice inspections of declared and undeclared facilities throughout Iraq with full access and no right of refusal."[20] Despite this, Iraq was able to conceal for some time several significant undertakings to produce fissile material. Iraq made incomplete and misleading declarations, impeded inspections, destroyed documents, and disguised certain activities. Eventually, UNSCOM and the IAEA gained confidence that they had located all significant nuclear weapons activities, but the process to gain this confidence took time and, in some instances, threats of force.[21]

The South African and Iraqi experiences show that verifying warhead and fissile-material declarations will not be quick or easy. However, these cases also show that it is possible to gain adequate and widespread confidence if the process includes a comprehensive set of measures, including routine and challenge on-site inspections, examination and analysis of facility records, interviews with key personnel, remote sensing, and environmental monitoring.

Verifying warhead and fissile-material declarations will be an enormous undertaking. Because it will take many years for states to gain confidence in the accuracy and completeness of the declarations, verification should begin as far in advance of deep reductions as possible. In the first stage of reductions, uncertainties in the nuclear weapon stockpiles would not be of much concern; but as the United States and Russia move to lower levels of nuclear weapons, it will become important that they gain confidence in the

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[18] Thomas Cochran, "Highly Enriched Uranium Production for South African Nuclear Weapons," *Science and Global Security*, Vol. 4, No. 2 (1994).
[19] Ibid.
[20] Jonathan B. Tucker, "Monitoring and Verification in a Non-Cooperative Environment: Lessons from *The Nonproliferation Review*, Spring-Summer 1996, p. 2.
[21] Ibid., pp. 3-14.

initial stockpile declarations. As the number of allowed nuclear weapons falls into the hundreds, states are far more likely to have confidence in a declaration whose accuracy had been verified for several years and for tens of thousands of nuclear warheads, than one whose verification had begun recently and only after thousands of warheads had already been dismantled.

Dismantling Warheads and Disposition of Fissile Material

Once warheads destined for dismantling are declared, tagged, and authenticated, their destruction could be monitored with a high degree of confidence by tracking them from deployment or storage sites to dismantlement facilities and finally to the storage and ultimate disposition of the recovered fissile materials.

In the first step, the tagged warheads would be checked periodically from the initial declared deployment or storage site to the dismantlement facility. The actual dismantling of the warheads probably could not be monitored directly without revealing sensitive information, so an indirect approach will be necessary. One such method would be to install a portal-perimeter system around the dismantlement facility, and to monitor the inflow of nuclear weapons and the outflow of canisters containing plutonium pits and HEU components, with periodic checks that no warheads or fissile components remained inside. A particular nuclear warhead would be counted as dismantled when the corresponding component is placed in monitored storage. If desired, the components could be fingerprinted according to their emissions of neutrons and gamma rays in response to a neurtron source, and associated with particular warhead types.

A possible complication is added if dismantling and stockpile maintenance activities are done at the same facility. In such circumstances, it would simplify monitoring if dismantling and maintenance activities could be segregated by using different perimeters and portals within the same facility. 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.

After emerging from the dismantling facility, the tagged and sealed containers of pits and other fissile-material components would be stored at monitored sites. This could be done under the authority of the IAEA, perhaps using inspectors drawn from the nuclear-weapon states to guard against the dissemination of nuclear-weapon design information. Later, the components could be converted to unclassified forms using the same portal-perimeter procedures.

A Ban on the Production of Fissile Material for Weapons

An essential element of a deep-cuts regime would be an agreement by all nuclear-weapon and threshold states not to produce any additional fissile material for weapons. Four of the nuclear-weapon states have announced that they have permanently ended their production of fissile material for weapons and the fifth, China, has indicated privately that it is not producing material for this purpose. India, Pakistan, and Israel may be producing fissile material for weapons, but, if so, at a relatively low rate.[22] A universal and verified ban on the production of fissile material for weapons or outside of international safeguards is under consideration by the Conference on Disarmament in Geneva, but is currently being blocked by the insistence of India, Pakistan, and a number of non-weapons states that any ban be linked to negotiations on global nuclear disarmament.

The starting point for verifying a production ban would be declarations by the nuclear-weapon and threshold states of the status and location of all facilities at which plutonium had been produced and separated and where uranium had been enriched. Verification of the cutoff would then involve:

monitoring all declared facilities that are shut down;

monitoring all declared facilities that are operating, to confirm that any HEU or separated plutonium produced in the future is used only for nonweapons purposes under international safeguards; and

verifying the absence of clandestine, undeclared production facilities.

Each of these tasks has been investigated by the IAEA.[23] The most comprehensive verification system examined with respect to declared facilities would apply full-scope "safeguards-type measures to all nuclear material in a State or under its control, except those military stocks of fissile material which would exist at the date of entry into force of a cutoff treaty."[24] In such a system, safeguards would be applied to all uranium enrichment plants, nuclear reactors, stores of spent fuel, reprocessing plants, and facilities for the storage, conversion, or fabrication of nuclear materials (except for existing military stocks). A less-comprehensive system would exempt power and research reactors fueled with natural or low-enriched uranium, facilities for fabricating fresh fuel for these reactors, and their spent fuel stores.

Monitoring Shut-down Facilities. Table 6.2 shows known facilities in the nuclear-weapon and threshold countries that have produced weapons-usable materials. Included in table 7.2 are many plutonium-production reactors, reprocessing lines, and enrichment facilities that are no longer operating. Verifying that these facilities remain shut down should be straightforward. Remote visual observation from satellites would be able to detect renewed activity at a shutdown facility, and infrared observations would be able to detect heat from reactors or gaseous-diffusion enrichment facilities which began to operate. In addition, inspectors could apply seals on critical plant equipment and install cameras and other devices that could detect any restricted activities. Periodic on-site

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[22] Pakistan claims that it has not produced HEU since 1990. However, Pakistan presumably is producing LEU, and this LEU could be enriched to HEU very quickly.
[23] Thomas Shea, "Safeguarding Reprocessing and Enrichment Plants: Current and Future Practices," Seminar on Safeguards and Non-Proliferation, IAEA Headquarters, November 16-17, 1995.
[24] IAEA Secretariat, "A Cutoff Treaty and Associated Costs," Working paper, presented by Vilmos Cserveny at the Workshop on a Cut-off Treaty, Toronto, Canada, 17-18 January 1995.

inspections would check the seals and surveillance equipment and also be used to verify that there was no unexplained activity at the site.

[Insert table 7.2 near here.]

Monitoring Operating Facilities. Some nuclear-weapon and threshold states will continue to operate civilian reprocessing and uranium-enrichment facilities after a ban on the production of fissile materials for weapons purposes takes effect. In addition, some military reactors and reprocessing lines might be operated for non-military purposes. For example, Russia continues to operate three plutonium-production reactors to produce heat and electricity for neighboring communities, and it continues to separate plutonium from the spent fuel discharged by these reactors because the spent fuel is not suitable for long-term storage. Russia also operates two tritium-production reactors. Similarly, the United States is operating a military reprocessing line at Savannah River to stabilize certain radioactive wastes and plans to resume tritium production in the future.

Such activities could be safeguarded using measures now employed by the IAEA to safeguard similar activities in non-nuclear-weapon states. These include establishing and reviewing material accountancy and control systems, independent measurements of inventories and inventory changes, and application of containment and surveillance measures. Facilities that handle large quantities of fissile material in bulk form—reprocessing plants, enrichment facilities, and certain chemical conversion and fuel-fabrication facilities—would demand the most attention and resources. In these cases, the IAEA has been developing various special procedures. For example, at enrichment plants designed for LEU production, the enrichment of uranium-fluoride in cascade header pipes could be measured either continuously or intermittently to verify the absence of HEU production.[25]

A special problem arises in monitoring facilities that are collocated with allowed nuclear-weapon-related activities. For example, sites with operating or shut-down reprocessing and enrichment plants may also contain facilities for the storage or processing of allowed military stocks of plutonium and HEU, tritium production, or nuclear-weapons research and development. In such cases, verification would be complicated by the desire of the inspected country to protect classified information.

A 1993 study prepared for the U.S. Department of Energy analyzed this problem for many U.S. facilities.[26] The study examined a variety of verification measures of varying degrees of intrusiveness, including remote sensing, environmental monitoring, IAEA-type safeguards, and challenge inspections. The study noted that sensitive weapon-related operations generally could be cordoned off from operations central to verifying a production cutoff. In instances where it would be essential for inspectors to have access

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[25] Shea, op cit.
[26] "Transparency Measures for DOE SNM Production Facilities," prepared for the US Department of Energy by Brookhaven National Laboratory, Oak Ridge National Laboratory, Oak Ridge Y-12 Plant, Pacific Northwest Laboratory, and Savannah River Technology Center, Washington, DC, revised December 1993.

to areas with classified activities, shrouding and masking measures could be employed to protect sensitive information. We expect that the problem of protecting sensitive information would lose importance over time as the number and intensity of weapon-related activities shrinks and the degree of transparency of nuclear operations increases.

Detecting undeclared facilities. As important as verifying that material for weapons is no longer produced at declared facilities is providing assurance that no undeclared facilities for this purpose exist. The IAEA study lists the measures that would be required to provide such an assurance: systematic analysis of open literature and expanded state declarations, expanded access for routine inspections, provisions for challenge inspections to investigate suspect sites, and wide-area environmental measurements of radionuclides that might be emitted in conjunction with undeclared reprocessing and enrichment operations. The last set of measures could include airborne radiation mapping and sampling of soil, water, and sediments. The 80 to 100 radionuclide monitoring stations currently envisioned as a monitoring network under the Comprehensive Test Ban Treaty might be used to complement other environmental sampling measures. Analysis of these various measures is now underway in the IAEA, partly in regard to a cutoff, but more directly, under its “93+2 Programme,” to enhance the present safeguards regime.

HEU for non-weapons purposes. The verification of a cutoff is complicated by the use of HEU for non-weapons purposes. At present, all U.S. and U.K. nuclear-powered ships and submarines are fueled with weapon-grade HEU, and many Russian submarines also use HEU. HEU-fueled naval reactors typically require an initial charge of 200-400 kilograms of uranium-235, with refueling every 5 to 20 years or more. The total HEU requirements for the United States and Russia are one to two tonnes per year for each country, and for Britain, 0.1 to 0.2 tonnes per year. These requirements are small compared to the quantities of HEU that are being extracted from excess weapons and available in buffer stocks. Such sources, therefore, would be more than sufficient to supply all existing naval reactors over their remaining lifetime, obviating any need for new production. Nevertheless, this material will somehow have to be accounted for, and some assurance given that it is not being diverted to weapons.

One approach could be that taken under Paragraph 14 of the INFCIRC/153 model safeguards agreement, which provides that nuclear material, including HEU, may be released from IAEA safeguards for “non-proscribed military activity” (e.g. for naval reactors). The Agency must be kept informed of the total quantity and composition of the unsafeguarded nuclear material, and safeguards must be applied when the material is discharged from the reactor and returned to the civil inventory. Under this procedure, which has never been invoked, a country would declare that a certain quantity of HEU would be used in naval reactors, allow the IAEA to verify that this amount of HEU had been fabricated into naval reactor fuel, and then, after a period of several years, invite the IAEA to assay and safeguard the spent HEU fuel after it had been removed from the reactor. This approach,while straightforward in theory, might have to be modified in practice to accomodate sensitivities of the U.S. Navy, and perhaps the navies of other countries, regarding the detailed design of their nuclear fuels.

However, the time during which the HEU in naval-reactor fuel would be outside of safeguards could be very long—from 5 to more than 20 years. This is not significant for the nuclear-weapon states today given their large stockpiles of unsafeguarded HEU, but it could raise serious questions in the later stages of the disarmament process, or if the non-nuclear-weapon and threshold countries developed nuclear-powered submarines. For this reason, we advocate that all future naval reactors be fueled with LEU. Although current LEU-fueled naval reactors are refueled more frequently than the most modern U.S. naval reactors, a 20-year refueling period could be achieved by reactors using uranium enriched to only 20 percent or lower. The LEU cores would be larger, however, than those employing HEU for the same core life.[27]

Costs of Verification. The IAEA Secretariat recently estimated that a comprehensive verification effort that applied "safeguards-type measures to all nuclear material in a State or under its control, except those military stocks of fissile material which would exist a the date of entry into force of a cutoff treaty," would require approximately 25,000 person-days of inspection effort (PDI) per year, at a cost of $140 million per year, to monitor 995 facilities in the eight nuclear-weapon and threshold countries. This can be compared to the 8,200 PDI and $67.5 million expended by the IAEA Department of Safeguards in 1993.[28] The costs of such a comprehensive verification system would represent a substantial increase in the IAEA safeguards budget, but in comparison to the costs of maintaining nuclear forces in their current scale, or even to the costs of verifying other arms control agreements (e.g., INF, START, CWC), they are very modest.

Improving Safeguards on Peaceful Nuclear Activities

Certain types of facilities and activities in the civilian fuel cycle are very difficult to safeguard using current technology, and the possibility that significant diversions of fissile materials might not be detected in a timely manner could undermine confidence in a deep-cuts regime. Particularly worrisome are facilities which handle or produce (or are capable of producing) weapon-usable materials in bulk form: uranium enrichment, reprocessing, and mixed-oxide fuel-fabrication facilities. Such concerns could be ameliorated by improving safeguards to provide better assurance of nondiversion, or by modifying, restricting, or prohibiting these activities.

First is the danger that uranium enrichment facilities that produce low-enriched uranium for reactor fuel could be reconfigured to produce weapons-grade uranium. To give a sense of the magnitude of this problem, consider that an enrichment plant producing

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[27] Director, Office of Naval Propulsion, *Report [to the Congress] on Use of Low Enriched uranium in Naval Nuclear Propulsion*, June 1995.

[28] The IAEA also estimated the costs of less-comprehensive monitoring systems. For example, a system that covered all stores of separated fissile materials (except exempted stocks), mixed-oxide, HEU and U-233 conversion and fuel-fabrication plants, uranium enrichment plants capable of producing HEU, plutonium-fueled power reactors, and fast power and test reactors, but did not cover thermal power reactors, R&D facilities for uranium enrichment, or spent fuel stores, would require approximately 5000 PDI per year and should cost in the range of $40 million. "A Cutoff Treaty and Associated Costs," pp. 7–18.

LEU for ten large power reactors would have a total separative capacity of about one million separative work units (SWU) per year. If this one plant, which represents only 2–3 percent of current world separative capacity, were reconfigured to produce weapons-grade uranium, it could produce 5 tons of HEU per year—enough to build at least 250 warheads per year.[29] This can be compared to a total allowed warhead stockpile for the United States and Russia in our third stage of 200 warheads.

The safeguards problem is particularly acute for civilian reprocessing and plutonium recycling programs. A typical, large power reactor discharges approximately 200 kilograms of plutonium annually in its spent fuel—enough for more than 20 nuclear weapons. The plutonium discharged from power reactors contains a higher fraction of certain undesirable isotopes (plutonium-240 and plutonium-241) than the "weapon-grade" plutonium produced in dedicated military production reactors. The radioactive decay of these undesirable isotopes produces neutrons and heat, complicating bomb design and leading some observers to argue that "reactor-grade" plutonium is unsuited for weapons. Unfortunately, it has now been established that a state or group that could make a nuclear explosive with weapon-grade plutonium could make an almost equally effective device with reactor-grade plutonium.[30]

The plutonium produced by power reactors is unusable for use in weapons as long as it remains locked in the highly radioactive spent fuel, but increasingly it is being separated in civilian reprocessing facilities. Indeed, the large civilian reprocessing plants now operating in France, the United Kingdom, and Russia together produce over 20 tonnes of plutonium each year—enough plutonium to make several thousand nuclear weapons per year. Undetected diversions of, say, 1 percent per year from such plants could, over a period of several years, equal the allowed military stockpiles of plutonium in the third stage of our deep-cuts program. Opportunities for diversion also exist in mixed-oxide fuel-fabrication plants, where a mixture of separated plutonium and natural uranium is used as a substitute for low-enriched uranium in the manufacture of fresh reactor fuel.

More worrisome than large, clandestine diversions by nuclear-weapon states would be small diversions by non-nuclear-weapon states and the possibility of large-scale break-out by any state with enrichment or reprocessing facilities. The nuclear-weapon states are likely to require that barriers to the acquisition of nuclear weapons by current non-weapon states be increased as one condition for agreeing to deep cuts in their own arsenals. In addition, the weapon states will be concerned about the possibility that another weapon state might use large stocks of separated civilian plutonium to rapidly expand its nuclear arsenal. For this reason, restrictions on civilian uranium enrichment and plutonium separation and use should be considered under a deep-cuts regime.

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[29] At a tails assay of 0.3 percent U-235 in the depleted uranium, it requires about 200 SWU to produce one kilogram of HEU from natural uranium. A one-million SWU plant then could produce 5000 kilograms of HEU or enough for 250 to 400 warheads, assuming that 12 to 20 kilograms of HEU would be needed to build an implosion-type weapon.

[30] National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, Chapter 1; J. Carson Mark, "Explosive Properties of Reactor-grade Plutonium," *Science & Global Security*, Vol. 4, No. 1 (1993), pp. 111-128.

Several types of restrictions could be considered. First, only economically-justified production and use of separated fissile material shouldgo forward. By this standard, all current separation of plutonium should end, at least until plutonium fuels become economically competitive with LEU fuels. And even if plutonium fuels become economical several decades hence, the separation of plutonium should not exceed the demand for plutonium fuels. Second, we should explore new institutional arrangements that would provide better assurance against diversion and break-out. For example, enrichment, reprocessing, and mixed-oxide fuel-fabrication plants could be owned and operated by international consortia, with the IAEA acting as custodian for all separated plutonium. In addition, such facilities could be located only on the territory of countries judged "proliferation safe" by the international community. Third, we should investigate technical innovations that could make diversion and break-out significantly more difficult. For example, fuel cycles could be developed that do not produce or use plutonium in forms that are usable in nuclear weapons without extensive additional processing.[31]

While none of these restrictions will eliminate the risk that civilian nuclear facilities could be used for weapons purposes, they could decrease substantially the magnitude of the problem. We should bear in mind, however, that even the complete elimination of the civilian nuclear power industry would not eliminate the possibility of proliferation or break-out. As long as the scientific and engineering knowledge of how to build nuclear weapons and related facilities exists, so too will exist the possibility that clandestine facilities might be built, or that countries might withdraw from the deep-cuts agreement and embark on a massive bomb-building program, perhaps using the huge stocks of plutonium in buried spent fuel or vitrified waste.

Delivery Vehicles and Launchers

At each stage of the disarmament process, various limitations would be placed on the numbers and characteristics of nuclear delivery vehicles and associated launchers. Verification of these limitations would include monitoring:

- the elimination or conversion of all delivery vehicles of a specified type and associated launchers beyond those allowed;
- limitations on the production of nuclear-capable delivery vehicles and associated launchers;
- limitations on the maximum number of warheads allowed on delivery vehicles of a specified type; and
- limitations on the number of delivery vehicles of a specified type and associated launchers.

[31] See, for example, Alex Galperin, Paul Reichert, and Alvin Radkowsky, "Thorium Fuel for Light Water Reactors -- Reducing Proliferation Potential of Nuclear Power Fuel Cycle", *Science & Global Security*, Vol. 6, No. 3, 1997.

The INF and START treaties provide valuable precedents and experience on how each of these verification tasks could be accomplished. The INF Treaty eliminated all U.S. and Soviet ground-launched missiles with ranges between 500 and 5,500 kilometers. The START treaties limit the number of various categories of strategic delivery vehicles—ICBMs, SLBMs, and bombers—and the number of nuclear weapons that each type may carry.[32] Many of the verification arrangements established by these treaties could simply be extended, with minor modifications, to a multilateral deep-cuts agreement among all the nuclear-weapon states.

In each of these treaties, the initial step is a comprehensive exchange of data, followed by "baseline" inspections to verify the accuracy of the data. For ICBM silos, ballistic-missile submarines, and strategic bombers, these declarations can be verified with high confidence. Verification of treaty provisions is achieved through a combination of national technical means (NTM—satellite observations, monitoring of telemetry, and other intelligence information), "cooperative measures" to enhance NTM, and on-site inspections. A multilateral deep-cuts agreement might rely less on NTM if the second-tier nuclear-weapon states (particularly China) believe that it puts them at a disadvantage vis-à-vis the United States and Russia.

Elimination and Conversion. START specifies procedures for eliminating ICBM silos, mobile ICBMs and their launchers, SLBM launchers, and heavy bombers.[33] For example, mobile ICBMs and their launchers and launch canisters must be eliminated according to certain procedures at specified facilities that are subject to on-site inspection. The elimination of heavy bombers is handled in a similar manner. ICBM silos are to be destroyed in situ, and SLBM launchers must be eliminated in designated facilities by removing the missile section or the launch tubes from the submarine. The elimination of silos and SLBM launchers is verified by NTM, aided by prior notification and other measures to facilitate monitoring.

Except for mobile ICBMs and heavy ICBMs, START does not include provisions for eliminating missiles, nor does it limit the number of missiles that may remain outside of launchers. A deep-cuts agreement should, however, require the elimination of all missiles above the permitted level, except for a specified number for replacement, testing, and space launch. This could be accomplished according to the procedures specified for mobile and heavy ICBMs in START or for missiles destroyed under the INF Treaty.

START allows the conversion of nuclear bombers to conventional roles, subject to a specified set of requirements designed to allow verification. These include requirements that the converted bombers be based separately from nuclear bombers; that the bombers be used only for non-nuclear missions and that neither they nor their crews be used in

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[32] The verification procedures and protocols under these treaties are explained in detail in the treaties themselves and in documents prepared by the U.S. Department of Defense's On-Site Inspection Agency: "START," October 1994; "Article by Article Analysis of START," undated; and Joseph Harahan, "On-Site Inspections Under the INF Treaty," Washington, D.C., March 1993.

[33] See Protocol on Procedures Governing Conversion or Elimination of START I.

exercises for nuclear missions; and that the bombers have observable differences from bombers with nuclear roles. In addition, storage areas for heavy-bomber nuclear weapons must be located at least 100 kilometers from air bases where converted bombers are based. These provisions are subject to on-site verification.

Monitoring Production Facilities. A small number of facilities in the nuclear-weapon states have been used to produce nuclear delivery vehicles. It is highly likely that these have already been identified by intelligence agencies, if not already made public by the producing countries. Most of these facilities would be shut down under a deep-cuts regime. The few that remained open to produce replacement missiles, bombers, or submarines could be monitored using portal-perimeter systems, as is done under the START and INF treaties.

For example, START provides for continuous monitoring of production facilities for mobile ICBMs. In Russia, this is the facility that produces SS-25 missiles and launch canisters. Items leaving the facility must go through a monitored portal, at which point U.S. inspectors have the right to determine, typically through visual inspection, that the items are as declared. Each of the accountable items is given a unique identifier. In addition, the United States and Russia are allowed “suspect-site” inspections of other facilities on an agreed list which in the past produced components (such as rocket engines) that could be used for the covert assembly of mobile missiles.[34] Such arrangements could be extended to facilities that produce silo-based ICBMs and SLBMs.

It might be desirable, especially in the latter stages of a deep-cuts agreement, to monitor and limit the production of nuclear-capable delivery vehicles, even if that type of delivery vehicle had never been used in a nuclear role. For example, it might be desirable to limit the production of space launch vehicles to the number needed for planned space launches (including a reasonable buffer stock). Similarly, the total number of long-range bombers (conventional and well as nuclear) and air-launched cruise missiles (ALCMs) might also be limited. Such restrictions would build additional barriers to break-out, and thereby help to build confidence in the stability of the deep-cuts regime.

Monitoring Warhead Loadings. Verifying the number of nuclear weapons that a delivery vehicle carries or is equipped to carry could be done according to START procedures. To verify SLBM warhead loadings, for example, a short-notice inspection of a submarine base would be requested, and activities at the base would be curtailed until the inspectors arrived. The inspectors would select a sample of missiles to be inspected, the nose-cones would be removed, and the inspectors would count the number of warheads.[35] START I permits the inspected party to shroud warheads and other devices

[34] See Article XVI of the Protocol on Inspections and Continuous Monitoring Activities of the START treaty and Annex 5 to the Inspection Protocol.

[35] Under START I, counting rules were established to assign specified numbers of warheads to specific weapons systems. The U.S. and Russia, however, are allowed to get treaty credit for downloading the weapons systems if the downloading can be properly verified, as described. The on-site inspections under START I have been visual; in principle, they could be done using radiation measurements, but so far such inspections have not been agreed to or done.

on the bus to protect sensitive information. Similarly, START II provides for on-site inspections 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.

Under START I, if the number of permitted missile warheads is more than two less than the original warhead loadings specified in the initial declaration, the old bus must be destroyed and a new one deployed. START II relaxes this last condition on the grounds of economy. To speed reductions, it would be best to adopt the START-II procedures for the initial stages of a deep cuts agreement. The requirement that excess warheads be placed in monitored storage and be verifiably dismantled would give further assurance that the downloading was not easily reversible. In the third stage, the agreement might prescribe that all SLBMs be equipped with a new bus -- either a single-warhead bus or one allowing the launch of an agreed small number of warheads. In this case, the old buses could then be destroyed, and random inspections of SLBMs allowed to assure that the missiles were not equipped with buses for MIRVs.

Confidence in warhead loadings would also be enhanced by limitations on flight testing and exchanges of telemetry data. For example, START prohibits flight tests of MIRVed ICBMs after 2003, and tapes containing all telemetric information broadcast during a flight test must be provided to the other party.[36] A deep cuts agreement should contain similar provisions.

Monitoring Numbers of Delivery Vehicles. Total numbers of bombers, SLBMs, and fixed and mobile ICBMs also could be monitored using START procedures. Under START, for example, Russian mobile ICBMs are given unique identifiers, and each missile and launcher is attached to a particular base. The United States can then request that all the missiles associated with a specified base be returned to the base, and that the roofs of the missile shelters be opened so that the number of missiles can be counted with NTM. The United States would also be able to perform an on-site inspection to assure that the specific, numbered missiles associated with the base are, in fact, the ones that had been recalled. Similarly, Russia can request that the United States display in the open all the bombers of a specified bomber base to allow the counting of the number of bombers at the base.[37] The number of SLBM launchers is readily monitored with NTM.

In most cases, it should be straightforward to apply START procedures to a multilateral deep-cuts agreement. In a few cases, however, special procedures will have to be worked out. For example, China evidently wishes to hide its mobile missiles in caves in a kind of shell game.[38] In this case, special verification arrangements will be necessary to

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[36] Protocol on Telemetric Information of the START I treaty.

[37] See Article X of Inspection Protocol of START I. Under START I, Russian mobile ICBMs and the U.S. MX missile are given unique identifiers. In the case of the Russian ICBMs, the identifiers are spray-painted numbers; in the case of the MX, a metal plate is bolted or riveted on the first stage of the missile. [Jonathan Bowers, On-Site Inspection Agency, private communication, July 23, 1996].

[38] For a discussion of cave basing see e.g. Litai Xue, "Evolution of China's Nuclear Strategy," Chapter 8 in *Strategic Views from the Second Tier*, John C. Hopkins and Weixing Hu, eds. (New Brunswick: Transaction Publishers, 1994).

allow these missiles to be counted without compromising their survivability. One possibility would be to tag each missile and declare all deployment caves, and to allow the inspecting party to request a short-notice inspection of a particular missile or cave. In this way one could verify that declared caves did not contain untagged, undeclared missiles, and that declared missiles were present only in declared caves. Challenge inspections of undeclared sites, together with NTM and monitoring of missile-production facilities, would provide assurance that undeclared missiles did not exist.

Deployments and Operations

The final task for a deep-cuts verification system would be to monitor agreed restrictions on the launch readiness or alert status of nuclear forces, such as the removal of warheads or other key components from delivery vehicles. In general, this could be done in a manner similar to procedures used to monitor warhead loadings. Random, short-notice inspections of bomber and naval bases could verify the launch readiness of the force. For example, an inspection of submarines at pier-side could confirm that the warheads or some other agreed component (e.g., shrouds or guidance systems) needed to support a launch had been removed from the submarine. Continuous or random inspections at declared storage sites could confirm that the warheads or other agreed components remained separated from the delivery vehicles.

It would be desirable to work toward a regime in which the launch readiness of all weapon systems could be verified continuously, but without impairing the survivability of at least a portion of the force. Such a regime would allow all parties to receive constant reassurance the forces of other countries were not being readied for attack. If the warheads are removed and stored at fixed sites, video cameras or on-site inspectors could verify that the warheads remained in storage and that no preparations were being made to remove them. In the case of silo-based ICBMs or pier-side SLBMs, video cameras or special seals could verify that the silo doors or launch-tube hatches had not been opened and that no preparations had been made to reinstall warheads, shrouds, or guidance systems.

As discussed in chapter 4, more complex arrangements would be necessary to verify the launch readiness of systems that depend on mobility to ensure their survivability, such as SLBMs at sea and mobile ICBMs. One possibility would be to equip such systems with tags that could be interrogated remotely and which would verify that an agreed component necessary for launch was missing. For example, the monitoring agency could query a randomly selected mobile missile or submarine at sea, which would signal back that it had not been readied for launch. As another example, an agreement that ballistic-missile submarines would patrol out of range of specified targets could be verified by equipping each submarine with a tamper-proof box that would continuously record its location using an inertial measurement unit. The box could be queried remotely at regular intervals to determine, in a simple "yes" or "no" answer, whether the submarine had remained within the allowed boundaries.[39]

Various measures could be adopted to ensure that such interrogation would not makes at-sea submarines or out-of-garrison mobile missiles vulnerable to attack. For example, the signal could be relayed through a transmitter owned by the country being interrogated so as to conceal the origin of the signal, or a time delay of a few hours could be incorporated into the response to allow the submarine or missile to move to a different location before the location during interrogation was revealed. In addition, the queried side could limit the number of queries to an agreed level, so that there would be no opportunity to locate more than a single submarine or mobile missile at one time..

Conclusion

A new and vital component of the deep-cuts verification system is the comprehensive and verified declaration of all nuclear weapons and stocks of fissile material in the nuclear-weapon states. Confidence in the accuracy of the declarations will have to be built up gradually over several years as the parties allow increasing degrees of transparency, and as the amount of information which is considered sensitive decreases. In the final analysis, however, no conceivable verification regime could provide absolute assurance that the United States or Russia had not concealed a few hundred warheads (or enough material to build a few hundred warheads), or that the other nuclear weapon states had not concealed a few tens of warheads. It is important that residual nuclear forces, together with other political and security arrangements, be designed to deal with the inherent uncertainties that will accompany the very deep cuts we propose.

Another new element of the verification system proposed here are measures to verify the alert status of nuclear forces, to confirm that delivery vehicles are not capable of being launched and are not being readied for an attack. These verification measures will, of course, be closely tied to the specific actions or procedures that are adopted by the parties to reduce the launch-readiness of their forces. The main challenge will be to design the dealerting procedures and corresponding verification measures in ways that would not decrease the survivability of the force, increase incentives for a first-strike, or otherwise lead to an unstable situation during a crisis. Although we have suggested ways in which this might be done, finding the best solution will require detailed analysis by the military establishments of each party, and extensive cooperation between the parties.

Finally, it is interesting to compare the verification regime for our deep cuts proposal with that of the START treaties. In any arms control treaty, two types of threats must be considered: cheating, in which a party violates treaty provisions clandestinely; and break-out, in which a party openly abrogates the treaty. In the case of START, analysts have concluded with virtual unanimity that any militarily significant violation would be detected with high confidence. However, they have pointed to the possibility that either party could break out of the treaties by uploading missiles or bombers. For example, the

[39] Lt. Col. Guy Martelle, On-Site Inspection Agency, private communication, July 25, 1996.

Committee on Foreign Relations of the U.S. Senate noted that Russia could upload each of the 105 SS-19 ICBMs allowed under the treaty from one to six warheads or could equip heavy bombers with more nuclear weapons than specified. The Committee noted that, because the testing and training required to maintain the augmented capability on a day-to-day operational basis would likely be detected over time, “such scenarios would appear to be more suited to break-out than cheating.”[40] The capability of the United States to rapidly increase warhead loadings is much greater under START II than for Russia, generating serious concerns about U.S. break-out potential in the Russian legislature.

With the comprehensive verification system that we advocate, any such preparation for break-out would not be possible. Although a country could legally store thousands of warheads and hundreds of non-deployed missiles under START while preparing for a break-out, it could not do so under our deep-cuts program. Any significant preparation for break-out would be detected, and would itself constitute a violation of the treaty. Any party intending to cheat or break out of the treaty would have to evade verified restrictions along several fronts: on nuclear warheads, on fissile materials, on delivery vehicles, and on operational practices. Thus, although the reductions we advocate are far deeper than those required by START, the comprehensiveness of the verification system should provide a comparable level of assurance against military significant cheating and break-out.

[40] Senate Committee on Foreign Relations, “START II Treaty,” 104th Congress, Exec. Report 104-10, December 15, 1995, p. 35.

Table 7.1. Estimated amount of military fissile material in the nuclear-weapon and threshold states at end of 1994, and the number of nuclear explosives that could be built with this material.

Country	Plutonium (tons)	Wpn-grade HEU (tons)	Warhead equivalents*
Russia	130	1000	100,000
United States	85	650	75,000
France	5	24	3,000
China	4	20	2,500
United Kingdom	3.5	8	1,500
Israel	0.4	---	100
India	0.4	---	75
Pakistan	---	0.2	20
Total	230	1700	180,000

Source: David Albright, Frans Berkout, and William Walker, Plutonium and Highly Enriched Uranium 1996, SIPRI, Oxford University Press, 1997, pp. 399-402.
*Assumes 4 kilograms of plutonium or 12 kilograms of uranium-235 for each fission explosive.

Table 7.2. Facilities in the nuclear-weapon and threshold states that have produced weapons-usable fissile material.

[table attached separately, not included here]

Source: Oleg Bukharin and Frans Berkout, "Occasional Report," ***Science and Global Security***, Vol. 5, No. 1 (1994), p. 123–129.