Verification

Monitoring Disarmament

EDITED BY
Francesco Calogero,
Marvin L. Goldberger,
and Sergei P. Kapitza

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Verifying START

Steve Fetter (USA) & Stanislav N. Rodionov (USSR)

The recently signed treaty on intermediate-range nuclear forces (INF) has sanctified the "zero option." It has long been understood that it is easier to verify a complete ban on a weapon system than it is to verify a numerical limit. Under a complete prohibition, the sighting of a single banned weapon would constitute clear evidence of a violation. Moreover, a complete ban would eliminate training, testing, and repair activities that could serve as a cover for clandestine weapon deployments or could support a sudden breakout from a treaty.

Although a total ban may be easiest to verify, this is not realistic for many weapon systems. The rhetoric of Reykjavik aside, we will have to live with sizable numbers of several types of nuclear weapons for the foreseeable future. In past agreements, such as the SALT I Interim Agreement and the unratified SALT II Treaty, numerical limits were keyed to objects or practices that could be readily monitored with national technical means (NTM) of verification (e.g., photoreconnaissance and electronic-intelligence satellites). The deployment of new weapons, such as mobile missiles and cruise missiles, will be difficult to monitor using NTM, however. This paper explores various options for verifiably limiting the strategic nuclear arsenals of the superpowers in the context of the current Strategic Arms Reduction Talks (START).

The START proposal would limit the total number of strategic nuclear delivery vehicles (SNDVs)--ballistic missiles and bombers--to 1600. The total number of warhead "points" on these SNDVs would be limited to 6000. (Due to various counting rules to be described later, the actual number of deployed warheads would be substantially greater.) Of these 6000 warhead "points," a maximum of 4900 would be permitted on ballistic missiles.[1]

The Rationale for Verification

Verification is the process of determining the degree to which parties are complying with the provisions of an agreement. Three reasons are often given for verification: (a) to build confidence between parties by verifying treaty compliance, (b) to deter cheating by raising the costs and lowering the benefits of cheating, and (c) to detect militarily significant cheating early enough to protect national security. Each of these plays an important role in treaty verification.

Building confidence

The role of verification in building confidence is often emphasized by advocates of arms control, who see the arms race as caused at least partly by mutual misunderstanding and action-reaction dynamics. Thus, the verification process itself can reduce the apprehensions of both parties by dispelling residual suspicions of noncompliance and by showing ongoing support for the treaty regime. This effort should be cooperative, since parties would have strong incentives to prove that they were observing the terms of the treaty. To serve this purpose, verification systems must have very low false-alarm rates, or else they might have the effect of increasing, rather than decreasing, confidence.

Deterring cheating

Many analysts doubt that parties automatically comply with a treaty just because it is in their interest. Although an agreement as a whole may serve a nation's interests, certain treaty provisions may prove onerous or unattractive, or an unilateral military advantage could be obtained by clandestinely violating the agreement. To deter cheating, a verification system should make the costs of covert activities and the risks of discovery greater than the expected benefits of cheating. If, for example, missiles produced in a covert facility would cost ten times as much as missiles produced in the open, then a country might decide that the marginal military benefits were not worth the cost, just as they might forgo an expensive system in the absence of an agreement. It is important to note that if the penalties for being caught cheating are high enough, then a verification system must merely deny a country high confidence that it could cheat without discovery, rather than provide high confidence that cheating could be detected. The problem with applying these concepts to superpower arms control is that they depend on estimates of costs and benefits which are unknown to the other party.

Detecting cheating

Although some analysts feel that any cheating, no matter how trivial, is significant because it shows dishonesty, the majority feel that it is most important to be able to detect militarily significant cheating soon enough so that the nation's security would not be jeopardized. This is the most common standard against which verification systems have been measured in the past. But what level of cheating is militarily significant?

The answer to this question must take into account the nuclear strategies of both sides, or how and under what circumstances nuclear weapons would be used. If, for example, both superpowers view nuclear weapons solely as deterrents to nuclear attack, then the job of verification would be relatively easy--it would only have to be capable of detecting deployments that could threaten a second-strike retaliatory capability. This might require, for example, a capability to detect the clandestine deployment of thousands of ballistic missiles, as would be needed for successful barrage attacks against mobile missiles, bomber bases, and submarine patrol areas.

If either superpower relies on nuclear weapons for more than just simple deterrence, the job of verification becomes more demanding. For example, NATO currently depends on nuclear weapons to deter a Warsaw Pact invasion. If, on the eve of an invasion, the Soviet Union rolled out hundreds of secretly deployed mobile missiles, some fear that NATO's political will to resist would evaporate, along with the credibility of NATO's threat to escalate to the nuclear level. Another example is the counterforce or "window of vulnerability" scenario, in which one nation uses a fraction of its nuclear missiles to destroy most of the other's intercontinental ballistic missiles (ICBMs) and bombers, leaving the attacked nation with a choice between suicide and surrender. In both of these scenarios, a nation can "lose" even though it retains the ability to destroy the opposing society in a retaliatory blow. Although most such scenarios have serious logical flaws, detecting activities that might make them theoretically possible is a prudent basis for verification requirements.

Cooperative Verification

Verifying numerical limits on objects that cannot be adequately counted with NTM requires a considerable amount of cooperation between the monitored and the monitoring parties. Cooperation is not new--even SALT verification was cooperative in the sense that parties agreed not to interfere with NTM. The degree of cooperation required for START, however, is vastly greater. The verification system for START, which must build ambitiously on the foundation laid by the INF Treaty, would include data exchanges, provisions to enhance NTM, on-site inspections of various types, perimeter-portal monitoring, and perhaps a tagging system of some sort.[2]

Data exchange

The Soviet Union had long refused to disclose the number and location of its weapons. Under pressure from the U.S. Senate, the Soviet Union agreed to divulge the number of weapon systems for the SALT II Treaty. Data exchanges were expanded greatly by the INF Treaty, which required that the location of all weapon production, final assembly, storage, testing, and deployment facilities be declared, as well as the number of weapons at each declared site. The data base is to be updated each time a missile is transferred from one facility to another. The START agreement can be expected to require similar exchanges of data on all limited weapon systems.

On-site inspection

Until recently, the Soviet Union had been even more adamant in refusing to permit on-site inspections (OSIs), claiming that OSIs were unnecessary to verify compliance and that they would be used to gather intelligence. The Peaceful Nuclear Explosions Treaty proved, however, that the Soviet Union would permit OSIs if they were necessary to obtain an agreement that was in its interest. The INF Treaty, which permits several different types of OSIs, illustrates this dramatically.

Immediately after the signing of the INF Treaty and the exchange of data, "baseline" OSIs were conducted by both sides to verify the accuracy of the data exchange. In just three months, every declared site was visited--a rate of about two inspections per day. The elimination process is also subject to on-site inspection to verify that legitimate missiles are actually being destroyed. During this three-year process of elimination, up to 60 short-notice inspections can also be requested to verify the updated data base. The destruction of all missiles at a particular site is verified during "close-out" inspections. A START agreement, which would encompass many times more declared sites and missiles to be destroyed, would also require many more OSIs than INF.

Suspect sites

The INF Treaty lacks provisions for inspecting sites other than those that are declared. This was considered reasonable for INF, since the missiles were banned completely; any remaining stocks could not be tested and would therefore not be considered reliable. In a START treaty, however, legal missiles will remain to mask the possible presence of a covert stockpile of missiles. To deter the possession of secret stockpiles, it would be valuable to be able to request a short-notice inspection of any facility that is suspected of covert activities banned by the treaty. There are two problems, however: there are many highly sensitive facilities that neither side would want inspected, and such inspections are highly unlikely to turn up evidence of a violation.

The first concern is that suspect-site OSIs would be used at pretext for gaining entry to secret facilities. Some analysts claim that parties would be deterred from such behavior because they would fear reciprocal requests; others are not so sure. This problem could be ameliorated by allowing inspections of suspect sites only when evidence is first presented of a possible violation. The request would then be like the request for a search warrant in the United States, for which the police must present evidence of possible illegal activities before they are allowed to conduct a search. This would be unacceptable, however, because the nature of the evidence might reveal how it was obtained (thereby jeopardizing intelligence sources), and no impartial court is available to judge the worth of the evidence. Alternatively, one could set rules for sites that would be open to inspection. For example, only buildings that are large enough to hide treaty-limited items need be inspected. The United States and the Soviet Union could make a list of an agreed number of sites (perhaps 100) that would not be open to inspection. This list could be confidential; indeed, the list need not even be revealed to the other party unless an inspection was requested at one of these sites. One could, for example, deposit the lists in a safe that would require both parties to open. Critics could, of course, claim that all the cheating would occur in sites that are off-limits.

The second concern is that inspections of suspect sites would never turn up evidence of a violation, because inspections that could turn up such evidence would be refused, perhaps by claiming that the suspect site was a sensitive military facility. Although this is undoubtedly true, there are still two excellent reasons to do OSIs: the granting of inspection requests builds confidence by showing that cheating is not taking place (at least at those sites), and the possibility of having to refuse a request--which would be tantamount to a confession of guilt in the eyes of many--would help deter cheating.

Perimeter-portal monitoring

A "perimeter" is a fence around a facility that forces all traffic through a "portal," where the traffic is monitored for treaty-limited items. Perimeter-portal systems are usually associated with production monitoring, but they could be used to monitor the flow of treaty-limited items through any facility. Consider, for example, monitoring the production of missiles. When a missile stage leaves the production facility, the monitored party could declare it and the missile count would be incremented. If an object large enough to be a missile stage passes through the portal but the monitored party does not declare it, inspections would be permitted to ensure that the object was not a missile stage.

One of the stages of the SS-20 intermediate-range ballistic missile (IRBM) that was banned by the INF Treaty is similar to a stage of the SS-25 ICBM. Because of this similarity, a perimeter-portal monitoring system was established at Votkinsk, where SS-25s are assembled, to verify the absence of SS-20 assembly. For purposes of reciprocity, a similar system was also built in Magna, Utah, where the solid-rocket motors for the U.S. Pershing II had been produced. The perimeter-portal system at Votkinsk is of direct significance for START, since the rate of SS-25 assembly will inevitably be monitored.

Enhanced NTM

NTM are constantly becoming more powerful: photoreconnaissance satellites can resolve smaller objects, more wavelengths are being collected, and so on. The usefulness of NTM can be enhanced even more if the monitored party cooperates by making treaty-limited items and activities available for observation. SALT II did this in a modest way by banning deliberate interference with NTM (camouflage, encryption of certain data, etc.) and by specifying procedures to make the destruction or dismantling of certain items easily observable with NTM. The INF Treaty expanded on this by allowing each side a fixed number of opportunities to request that the other side openly display its missiles at a given site. START will undoubtedly adopt these procedures, and future treaties could extend these techniques still further. One could, for example, request that a particular attack submarine surface within a given amount of time to verify that it was not operating in agreed "keep-out" zones. Requests would be limited, and the response time would be long enough so that exact deployment patterns need not be revealed.

Tags and seals

Tags and seals are not used in the INF Treaty, but they might find several uses in a START agreement. A tag is an unreproducible label that is affixed to a treaty-limited item.[3] Tags need not be unremovable, but they must indicate that they have been moved or tampered with. Tags can be unique, like a fingerprint or serial number, or they can be identical, and simply indicate that a particular item is part of the allowed inventory. Tags have the virtue of converting a numerical limit into a ban on untagged items: the observation of a single untagged item would be *prima facie* evidence of a violation. Seals could be used with or without tags to indicate, for example, that a cruise-missile canister had not been opened.

Table 1. U.S. and USSR strategic nuclear forces in 1989, using the proposed U.S. START counting rules

Type of SNDV	Delivery Vehicle	Number of SNDVs	Number of Warheads
	United States		
ICBMs		**1000**	**2450**
Silo-based	Minuteman II	450	450
	Minuteman III	500	1500
	MX (Peacekeeper)	50	500
SLBMs		**640**	**5632**
16 Poseidon	Poseidon C3	256	2560
12 Poseidon	Trident I C4	192	1536
8 Trident	Trident I C4	192	1536
Bombers		**360**	**1872**
ALCM-carriers	B-52G/H (98/70)	168	1680
Penetrating	B-52G/H (69/26)	95	95
	B-1B	97	97
	TOTAL	*2000*	*9954*
	Soviet Union		
ICBMs		**1386**	**6412**
Silo-based	SS-11	420	420
	SS-13	60	60
	SS-17	138	552
	SS-18	308	3080
	SS-19	350	2100
Rail-mobile	SS-24	10	100
Road-mobile	SS-25	100	100
SLBMs		**934**	**3372**
16 Yankee I	SS-N-6	256	256
1 Yankee II	SS-N-17	12	12
22 Delta I & II	SS-N-8	280	280
14 Delta III	SS-N-18	224	1568
4 Delta IV	SS-N-23	64	256
5 Typhoon	SS-N-20	100	1000
Bombers		**175**	**805**
ALCM-carriers	Bear H	70	700
Penetrating	Bison/Bear	105	105
	TOTAL	*2495*	*10589*

Table 2. Hypothetical U.S. and USSR strategic nuclear forces in the late-1990s after START reductions

Type of SNDV	Delivery Vehicle	Number of SNDVs	Number of Warheads
		United States	
ICBMs		**565**	**1445**
Silo-based	Minuteman III	215	645
Rail-mobile	MX (Peacekeeper)	50	500
Road-mobile	SICBM	300	300
SLBMs			
18 Trident	Trident I/II	432	3456
Bombers		**193**	**1057**
ALCM-carriers	B-52H	96	960
Penetrating	B-1B	97	97
	TOTAL	*1190*	*5958*
Land-attack SLCMs			
Nuclear	TLAM-N	758	758
Conventional	TLAM-C/D	2643	----
		Soviet Union	
ICBMs		**714**	**3000**
Silo-based	SS-18	154	1540
Rail-mobile	SS-24	100	1000
Road-mobile	SS-25	460	460
SLBMs		**324**	**1896**
5 Typhoon	SS-N-20	100	1000
14 Delta IV	SS-N-23	224	896
Bombers		**200**	**1100**
ALCM-carriers	Bear	100	1000
Penetrating	Blackjack	100	100
	TOTAL	*1238*	*5996*
Land-attack SLCMs			
Nuclear	SS-N-21	?	?
	SS-N-24	?	?

Strategic Nuclear Delivery Vehicles

At present, there are three basic types of strategic nuclear delivery vehicles: ICBMs, submarine-launched ballistic missiles (SLBMs), and intercontinental bombers. In addition, long-range sea-launched cruise missiles (SLCMs) could be used for strategic attacks. Although START may impose some restrictions on SLCMs, they will not be counted as SNDVs under the agreement. Several other methods of weapon delivery--ballistic missiles based on airplanes or surface ships, ground-launched cruise missiles, and de-orbited satellites--are banned by existing treaties.

Table 1 gives the approximate strategic balance as of 1989, and Table 2 presents a hypothetical strategic force for the United States and the Soviet Union that would be consistent with START. The reductions required by START are substantial: a total of about 3,000 ballistic missiles and 80 submarines would have to be destroyed or dismantled. Even after these reductions, the superpowers would retain a total of nearly 2,500 SNDVs, a sizable fraction of which may have to be inspected periodically to verify warhead loadings. This section reviews the key verification problems for each type of delivery vehicle and evaluates possible solutions.

Intercontinental Ballistic Missiles

ICBMs are land-based ballistic missiles with ranges usually in excess of 10,000 km. ICBMs are big: even the smallest (the proposed U.S. Midgetman missile) is 12 meters long and weighs about 15 tons. The largest missiles, each of which is armed with up to ten multiple independently targetable reentry vehicles (MIRVs), are over 30 meters long and weigh more than 150 tons. ICBMs are produced and assembled in large, distinctive facilities that are easily identified by photoreconnaissance; it would be very difficult to produce ICBMs in a covert facility. Moreover, ICBM tests are readily detected and monitored by various satellite systems; full-scale clandestine testing is impossible.[4] ICBMs are now based in three ways: in silos, on roads, and on railroads.

Silo-based ICBMs

Until recently, all ICBMs were deployed in silos. Silos are heavily reinforced concrete missile launchers that are flush with the surface of the ground; they are easily spotted by photoreconnaissance. Since they take more than a year to build, the rapid deployment of a large number of additional silos is unlikely. Although silos are easily counted, they may not provide a good measure of the strength of the ICBM force for two reasons: (a) the number of ICBMs that could be launched in an attack may not be equal to the number of silos, and (b) the capabilities of silo-based missiles might be increased secretly.

Nondeployed missiles

The first worry is the possible existence of extra missiles that could be launched in an attack. The number of missiles produced is normally much larger than the number employed; the extra missiles are used for tests or for spares. For example, of the 220 MX missiles that have been built by the United States so far, only 50 are deployed; 21 are for tests, 99 are spares, and 50 are for a still-unauthorized later deployment.[5] Soviet practices are not well known; many analysts think that they build fewer spares than the United States because they replace their missiles more often.[6] The number and location of nondeployed missiles must be declared under START, but they will not be counted against the treaty limits.

The reuse of silos was a concern in the 1970s. SALT II banned the storage of extra missiles near silos and the testing of rapid reloading and firing of ICBMs. These provisions are verifiable using NTM. If significant quantities of extra ICBMs are stored away from silos, it still may be possible, in the first weeks of a crisis, to erect extra missiles on open ("soft") launch pads for use in a first strike. (Since the missiles would be very vulnerable, they could not be used for much else.)

One possibility is that declared stockpiles of nondeployed missiles could be launched from soft pads. This possibility is most troubling for solid-fuel, cold-launched, canisterized missiles such as the Soviet SS-24 and SS-25 and the U.S. MX and Midgetman missiles. If declared storage sites are monitored under the treaty, however, prompt warning of any attempt to use these missiles could be obtained. It would take at least several days--and probably several weeks--to assemble a significant force from such stocks. A remotely-monitored perimeter-portal system around each storage site would be more than sufficient to provide the necessary warning.

Another possibility is that nondeployed missiles at certain secret locations would not be declared under the treaty. An OSI might be requested at such a site, but only if the monitoring party knew where to look. It should be noted that ICBMs cannot simply be piled up in warehouse like a cord of wood - one small fire could blow the building and it contents sky high. But special storage for ICBMs would be recognizable; these sites undoubtedly have already been identified. Deceptive storage is possible, but size of ICBMs (especially Soviet silo-based ICBMs such as the SS-18) makes this difficult. Deceptive storage may also increase the chance of an accident that would reveal such cheating.

A third possibility is that new ICBMs could be produced covertly, although the production of ICBMs would be very difficult to hide, and full-scale flight-tests

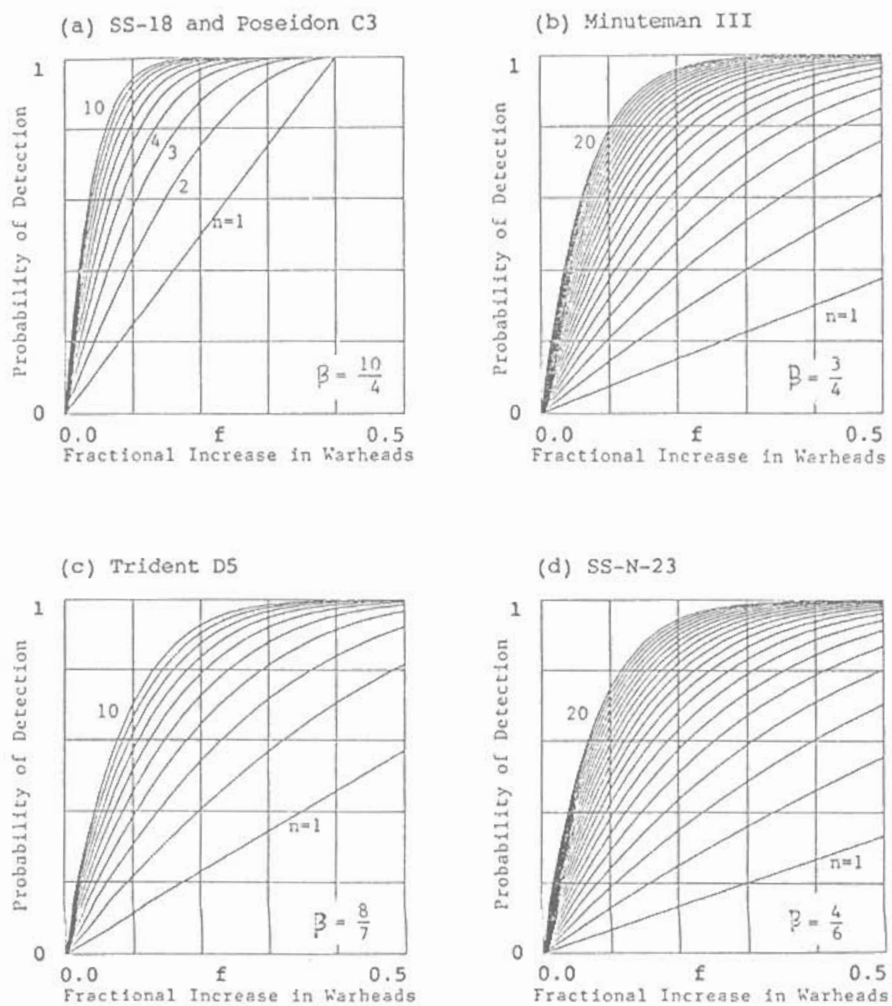

Figure 1. The probability of detecting a given increase in the number of missile warheads as a function of the number of OSIs.

would be essential to ensure their reliability. The test-flights of covertly produced missiles might be hidden among those of legal missiles; if this was sufficient cause for concern, legitimate missiles could be tagged and random on-site inspections of tests performed to verify that the missile stages to be tested had valid tags. The United States and the Soviet Union have already agreed to prenotification of ballistic missile launches;[7] it would only be necessary to send an inspection team at random intervals to observe a fraction of the tests. Observing 20 percent of ICBM launches would, for example, give a 90 percent probability of detecting at least one in a program of ten illegal test launches.[8] Even four such inspections per year would prevent high confidence in escaping detection.[9]

It is relatively easy to verify a reduction in the number of silo-based ICBMs. As mandated by the SALT II Treaty, the silos are simply destroyed by an explosion. And, as specified by the INF Treaty, the missiles can be crushed, burned, exploded, or destructively tested in the presence of inspectors. The magnitude of the elimination program dictated by START would probably require special environmental controls to limit pollution.

The problem of nondeployed missiles exists independent of START. In the absence of an agreement, the United States would face, as it has for decades, the possibility that substantial numbers of nondeployed missiles could be erected on soft pads during a crisis. It is not clear how the START reductions would make this possibility more ominous, for although the U.S. force would be smaller under START, the risk of such deployments presumably would be made smaller as well.

Fractionation limits

The second worry is that the number of warheads on a missile ("fractionation") could be increased surreptitiously, or that less-capable missiles could be exchanged for a more-capable variety. These problems were resolved in SALT II by counting each missile as having the maximum number of warheads that the missile had been tested with, and by assuming that each silo contained the most capable missile ever deployed in that type of silo.[10] If there were any doubts about the type of missile stored in a particular silo, these could be easily resolved by a few random OSIs or by enhanced NTM (pulling a randomly selected ICBM from its silo under the observation of photoreconnaissance satellites).

The counting rule for fractionation may present future problems for both sides. The SALT II and proposed START counting rules credit the Soviet SS-18 ICBM as having 10 warheads, although some U.S. analysts claim that it could be deployed with as many as 14 warheads without additional flight testing.[11] If the entire SS-18 force were so equipped, the number of SS-18 warheads would be increased by 40 percent, but the total number of ICBM warheads would be increased by only 20 percent.[12] The U.S. Minuteman III ICBM, which is credited with three warheads under the counting rules, has been tested with up to seven warheads.[13]

The probability of this relatively modest increase can be made negligible by permitting a few random OSIs to verify fractionation limits. For example, just one inspection per year would detect a 20 percent increase in SS-18 warheads 50 percent of the time (assuming that it would take about one year to upgrade the SS-18 force). Three inspections per year would detect such small increases with almost 90 percent confidence. Figure 1a shows the relationship between the fractional increase in the number of warheads, the number of inspections, and the probability of detection.[14]

In the simplest scheme, one could pick a missile at random, remove the shroud, and count the number warheads on the bus. Since the environment inside the shroud is carefully controlled to protect delicate equipment inside, some feel that the shroud could not be removed without seriously disrupting the normal operation of the missile force. Surely one or two such inspections could be permitted without too much trouble. Some analysts claim that sensitive information about the warheads, decoys, penetration aids, and the bus might be revealed during an OSI; if so, the bus could be draped with cloth and the warheads counted through the cloth. If one bus is stacked on top of another, however, the problem of determining the number on the bottom would remain.

If removing the shroud is too intrusive, portable radiation detectors probably could be used to count warheads by detecting radiations emitted by the fissile material in the warheads.[15] Such techniques could also be used to verify the number of warheads on stacked buses. Although it would be much more complicated, radiography could also be used to determine the number of warheads, or fissions could be induced in the fissile material with a neutron or photon source.

The problem of verifying fractionation could become particularly acute if the superpowers agree, in a subsequent agreement, to reduce the number of MIRVs on existing missiles to decrease first-strike incentives. "De-MIRVing" would be much cheaper than building new single-warhead missiles (at least in the short term). But even if de-MIRVing could be verified, a substantial reduction in the number of warheads on existing missiles would not be a good idea, because the warheads could be replaced rapidly. Richard Garwin has suggested using seals to ensure that dummy weights remain in unused bus positions, but these could, of course, be removed whenever the monitored party decides to abrogate the treaty.[16] The old MIRVed buses might be destroyed and replaced by smaller buses, but covert storage or production of the old bus would not be difficult. One would presumably want to flight-test samples of the covertly produced buses, and this would be nearly impossible without observation. Still, we believe that de-MIRVing is acceptable only when the maximum possible increase in the number of warheads is not militarily significant, as would be the case with the SS-18 force after START.

Mobile ICBMs

Mobile ICBMs are exactly like their silo-based counterparts, except that they are carted about the countryside by truck or train to avoid surprise attack. Because there is no fixed silo to use as a surrogate measure of the number of missiles, production and inventory controls are vital to mobile ICBM verification. The Soviet Union has produced both road- and rail-mobile ICBMs, and the United States has plans to build a road-mobile or a rail-mobile system (and perhaps both). Because mobile missiles are relatively new, few have been produced and intelligence about production rates should be good. The Soviet Union is proposing a limit of 800 mobile launchers and 1,600 mobile-missile warheads for START, but the United States is likely to insist on a lower number--probably 500 to 800 warheads.[17]

Road-mobile ICBMs

Since 1985, the Soviet Union has deployed about 100 road-mobile single-warhead SS-25 missiles. The United States is developing a similar road-mobile system, the Midgetman or small ICBM (SICBM), but deployment is uncertain. Road-mobile ICBMs are carried on large transporter-erector-launchers (TELs). Upon receiving warning of an attack, the TELs would disperse from their operating bases. To be effective (and not to cause undo alarm during a crisis), dispersal should be practiced regularly.

In the START talks, the United States and the Soviet Union have agreed on several aspects of mobile-missile verification. First, they have agreed that road-mobile ICBMs would normally be kept at relatively small main operating bases, each containing a limited number of missiles. The United States has suggested an area of 25 square kilometers for the operating bases; the Soviet Union has suggested 100 square kilometers. The SS-25 missiles are stored in garages with sliding roofs; the number of such shelters at an operating base would be limited to the number of missiles based there. A limited fraction of the missiles could be dispersed outside the main operating base at any given time. A larger fraction could leave the base for military exercises or training, but advance notification would be necessary and an OSI could be requested after the exercise. In addition, each party would have a limited number of requests for enhanced observation with NTM that the monitored party could not refuse. Under the INF Treaty, the United States can request that the Soviet Union remove the roofs from such garages at a given site for observation by photoreconnaissance satellites. The request must be fulfilled within six hours, and the missiles must remain exposed for twelve hours.

The verification of numerical limits on mobile ICBMs could be accomplished through controls similar to those developed for the SS-20 and Pershing II IRBMs in the INF Treaty. First, the initial inventory would be established with a data exchange that declared the location of all missiles and TELs. As mentioned above, the United States should be able to have higher confidence in the initial inventory of SS-25s than it had in the number of SS-20s, since the SS-25 is newer, fewer are deployed, and the assembly of SS-25s is being monitored at Votkinsk. Baseline OSIs at each declared facility would then verify the initial inventory. Thereafter, the monitoring party would be notified of all movements of missiles from one facility to another. Elimination of excess missiles and TELs could be accomplished through OSI or enhanced NTM.

Second, perimeter-portal systems would be installed at all solid-rocket-motor production plants. Production controls would be very effective for missiles not yet produced (such as the SICBM) or that have been produced in relatively small quantities (such as the SS-24 and SS-25). Since the covert production of ICBMs would be difficult, the problem is mainly one of verifying that all missiles produced before production controls began were declared.

The usefulness of any undeclared stockpiles could be limited by tagging all declared missiles. Short-notice OSIs could verify that declared facilities contained only legitimate, tagged missiles. Undeclared missiles would then have to rust away in storage or risk exposure. Tags might even reduce the need for on-site inspections. If, for example, perimeter-portal systems were installed at deployment areas, objects large enough and heavy enough to be a missile would have to have to display a valid tag to pass through the portal without further inspection. Large objects that are not missiles would be subject to further inspection using video cameras or radiography, all of which could be done remotely or with minimal on-site presence.

Rail-mobile ICBMs

The Soviet Union has just begun deployment of the SS-24 rail-mobile missile, which can carry up to ten warheads. The United States has plans to deploy 100 rail-mobile MX missiles, each with ten warheads. Verification of limits on these missiles could be accomplished in much the same way as limits on road-mobile ICBMs: missile trains would be restricted to main operating bases; the number of shelters per base would be no greater than the number of declared trains per base; shelters would not be longer than a normal train; a fraction of trains could leave the bases for exercises, training, and maintenance; there would be opportunities for enhanced monitoring with NTM; and perimeter-portal systems would be installed at missile production and assembly facilities.

Verification may be easier for rail-mobile missiles as compared with road-mobile missiles. The location of all rail lines is well known, and the missile-carrying cars can be distinguished from normal cars (they have twice as many wheels). Sensors, such as a light beam perpendicular to the track or seismic sensors, could be placed at choke-points in the rail network to detect missile cars.

Every time a missile car was detected, a valid tag would be expected on the missile car. The tag could be read without stopping the train by using an infrared transceiver. Storage, maintenance, and testing facilities could be monitored in the same way. To be useful, missile storage facilities would have to be located on a rail spur, which makes the detection of covert facilities relatively easy.

Submarine-Launched Ballistic Missiles

Numerical limits on SLBMs are relatively easy to monitor. The number of nuclear ballistic missile submarines (SSBNs) is well known, and the number of launch tubes on each SSBN is easily verified by photoreconnaissance. Moreover, unlike ICBMs, the number of SLBMs that could be used in a nuclear attack is limited to the number of launchers, since SSBN cannot be reloaded quickly.

The START limits will require both superpowers to reduce the number of SLBM warheads they deploy. There are three ways to do this: (a) reduce the number of submarines; (b) reduce the number of missiles per submarine; or (c) reduce the number of warheads per missile.

The first option--reducing the number of submarines--is the easiest to verify and would result in the greatest decrease in operating costs. It is the least desirable option for strategic stability, however, because the survivability of the SLBM force is roughly proportional to the number of SSBNs at sea. Under the START proposal, only 17 or 18 fully loaded Trident submarines could be deployed, of which 10 to 12 would be at sea at any one time--about half the number deployed and at sea today.[18] Although the U.S. Navy decided upon a force not much larger than this (20 Tridents) in the absence of arms control restrictions, going to an even smaller number of SSBNs in a future agreement would not be prudent.

The second option--reducing the number of missiles per submarine--could be easily verifiable. One could, for example, fill some fraction of the launch tubes with concrete and weld the covers shut under the observation of photoreconnaissance satellites or on-site observers. Better still (although much more costly), a section of the submarine containing several launch tubes could be removed, and the two halves of the submarine welded back together. In this way, the survivability of the SLBM force would not be reduced by arms limitations, and rapid breakout from treaty restrictions would be eliminated.

The third option--reducing the number of warheads per missile--is harder to verify, but it is cheaper than removing launch tubes and might be less destabilizing than reducing the number of SSBNs. A reduction in fractionation could be verified as discussed above for ICBMs, except that SLBMs would have to be lifted from their launch tubes and probably removed from their canisters for inspection. This should not be too objectionable, however, because the number of inspections would be limited.

Three SLBMs--the U.S. Poseidon C3, the U.S. Trident D5, and the Soviet SS-

N-23--are capable of carrying more warheads than the proposed START counting rules allow. The proposed START counting rules credit the Poseidon C3 with ten warheads, the Trident D5 with eight warheads, and the SS-N-23 with four warheads. Although the average loading of the Poseidon C3 is ten warheads, it has been tested with as many as 14 warheads; this is relatively unimportant for START, however, because Poseidon missiles and submarines are being replaced by Tridents. The Trident D5 was designed to carry up to 15 warheads,[19] but it has been tested with only eight so far; it is unclear whether it will ever be tested or deployed with more than eight warheads. The status of the SS-N-23 is somewhat of a mystery: although early reports credited the missile with ten warheads,[20] it will be counted as having only four under START.

Assume, for the sake of argument, that the SS-N-23 could be equipped with ten warheads without further flight testing. How many OSIs would be needed to provide assurance that a militarily significant increase in SLBM warheads had not secretly occurred? If all the SS-N-23s were outfitted with ten instead of four warheads, the increase in the START-constrained SLBM force would be less than 70 percent.[21] Five random OSIs would give 90 percent confidence that the total increase in the SLBM force was no more than 25 percent, and 50 percent confidence that the increase was no more than 10 percent (see Figure 1d). If future SS-N-23 deployments are smaller, or if less than ten warheads can actually be placed on a SS-N-23, then fewer inspections would be necessary for the same degree of confidence.

If all Trident D5 missiles are secretly equipped with 15 warheads, the total increase in the SLBM force would be 50 to 90 percent.[22] If the United States deploys Trident D5 only on the next 9 to 10 submarines built, a 25 percent increase in the SLBM force could be ruled out with 90 percent confidence by three random on-site inspections; the same number of inspections would rule out a 10 percent increase with almost 50 percent confidence.

One should note that if missiles are not accurate enough to destroy hardened targets, the degree of fractionation is not militarily significant. No currently deployed SLBM has such accuracy; SLBMs are assigned to the destruction of soft targets, such as cities or bomber bases. The area that can be destroyed by a warhead is proportional to its equivalent megatonnage (the megatonnage raised to the two-thirds power). For a given throwweight, the equivalent megatonnage of a missile is roughly independent of fractionation. For example, the Trident D5 is said to be capable of carrying eight 475-kt warheads or fifteen 100-kt warheads. Although the total throwweight is approximately the same in both cases, the combined destructive potential of the fifteen smaller warheads is less than that of the eight larger warheads. The destructiveness of a missile can only be increased by increasing the throwweight, which decreases the range of the missile.

In the absence of accurate SLCMs, the verification of fractionation limits would probably be unnecessary. The next generation of SLBMs - the Trident D5 and possibly the SS-N-23 - are, however, attaining the accuracy needed for attacks on hardened targets. It is unfortunate that the missiles for which fractionation is important are precisely those for which there is uncertainty. Unless intelligence analysts can convince themselves that the Trident D5 and SS-N-23 cannot accommodate more warheads than the counting rules allow without additional testing, then some OSI is probably necessary, though certainly no more than three to five inspections (0.1 to 0.3 percent of the total SLBM force) per year.

Strategic Bombers

Like ICBM silos and SSBNs, strategic bombers are fairly easy to count with photoreconnaissance satellites; the problem is determining their capabilities. There are five main problems in bomber verification: (a) distinguishing between nuclear-capable and conventional bombers; (b) distinguishing between strategic and tactical nuclear-capable bombers; (c) distinguishing between strategic bombers equipped with air-launched cruise missiles (ALCMs) and those that are not; (d) counting the number of ALCMs on each ALCM-equipped bomber, and (e) distinguishing between nuclear and conventional ALCMs.

Nuclear vs. conventional

To comply with the START limits on strategic bombers, the United States would prefer to assign older strategic bombers to conventional roles rather than destroy them. The Soviet Union has proposed deploying such conventionally armed strategic bombers at certain airfields where nuclear weapon storage would be banned; all strategic bombers at other airfields would be considered nuclear-capable. If for some reason this proves unacceptable, perhaps random on-site inspections could confirm that conventional strategic bombers are not nuclear-capable (e.g., the fire-control system would be different in a nuclear-capable bomber). Without such OSIs, it might be feared that these bombers could be loaded with nuclear weapons during a crisis.

Strategic vs. tactical

The distinction between strategic and tactical is usually based on the range of the aircraft. Strategic bombers typically have an unrefueled combat radius of more than 7,000 km. With in-flight refueling, however, tactical bombers could be used for strategic attacks. In the SALT II talks, the United States claimed that the Soviet Backfire bomber, which has an unrefueled combat radius of 4,000 km, should be counted as a strategic system because it could reach the United States with in-flight refueling. The Soviet Union subsequently agreed not to deploy the bomber in a strategic mode and to limit its rate of production, but this did not satisfy critics in the U.S. Senate. Even without refueling, tactical bombers could be used for strategic attack if they were equipped with long-range ALCMs. The best solution to this problem is to ban the testing and deployment of ALCMs on all tactical aircraft.

ALCM-carrier vs. penetrating bomber

Under the START proposal, bombers equipped to carry ALCMs will be counted differently from those carrying only bombs and short-range attack missiles (SRAMs). But how does one distinguish between the bombers that carry ALCMs and those that do not? SALT II resolved this question by requiring ALCM-carriers to have functionally related observable differences from non-ALCM carriers. This worked well for the B-52 bombers, which were modified to carry ALCMs under their wings. It does not work, however, for bombers that carry ALCMs internally--there is no functionally related observable difference between a B-1B bomber carrying ALCMs internally and a B-1B carrying only bombs and SRAMs. In fact, the B-1B is equipped with a rotary launcher that can hold any combination of ALCMs, bombs, and SRAMs.

The most verifiable solution to this problem is simply to limit each type of bomber to an ALCM or non-ALCM role. The United States, for example, could use nuclear-capable B-52s only as ALCM carriers and B-1Bs (and later B-2s) only as penetrating bombers; the Soviet Union could use Bear-H as an ALCM carrier and Blackjack as a penetrating bomber. If this limits the flexibility of the strategic bomber forces too much, one could resort to random short-notice on-site inspections to verify that particular B-52 or Bear-H bombers are not equipped to carry ALCMs.

Number of ALCMs per bomber

Verification of the number of ALCMs on each bomber is best accomplished through counting rules, just as the fractionation of ballistic missiles is limited with counting rules. In the START talks, the United States has proposed counting each bomber as having ten ALCMs. The Soviet Union, on the other hand, would like to count each bomber as having the maximum number of ALCMs for which it is equipped (eight for Bear H, 12 for B-52, and 24 for B-1B).[23] Although the Soviet approach seems more logical, a B-1B is not 2.4 times more potent or threatening than a SS-18 or MX missile. Moreover, the average ALCM loadings would likely be substantially less than the maximum.

If a counting rule of less than the maximum number is unacceptable without verification, short-notice OSIs could be used to verify actual ALCM loadings.

Only a few inspections per year would be necessary. As with de-MIRVing, however, breakout from such constraints would be quick and simple. A limit on ALCMs that is substantially less than the maximum loading might be supplemented with production and inventory controls on the ALCMs themselves, but this is unlikely to be worth the trouble since the clandestine production, storage, and testing of ALCMs could be difficult to detect.

Nuclear vs. conventional ALCMs

There are now no ALCMs armed with conventional warheads. The United States wants to keep this possibility open, and does not want START to limit conventionally armed ALCMs. To solve the verification problems this would create, the United States and the Soviet Union have agreed that all currently deployed ALCMs would be considered nuclear, that any new conventionally armed ALCMs would be distinguishable from nuclear-armed ALCMs, and that all dual-capable ALCMs could be carried only by strategic nuclear bombers. If all of these conditions can be met (and it is not clear that they can be), then there should be few verification problems.

Sea-Launched Cruise Missiles

Long-range land-attack nuclear SLCMs have only been deployed since 1984. At that time, the United States introduced the Tomahawk, a subsonic missile less than 6 meters long and half a meter in diameter and weighing only about 1,500 kilograms. The Tomahawk can be configured as an anti-ship missile (TASM) or as a land-attack missile (TLAM). The land-attack missile is dual capable; that is, it can be armed with either a nuclear or a conventional warhead. The United States plans to deploy about 600 TASMs and 3,300 TLAMs by 1993; about 760 of the TLAMs will be armed with nuclear warheads.[24] In all, nearly 4,000 Tomahawks will be deployed on some 200 surface ships and attack submarines.

The Soviet Union deployed its first long-range land-attack nuclear SLCM, the SS-N-21, in 1988. The SS-N-21 is similar to the Tomahawk, although it is not believed to have a conventionally armed variant. It appears that the deployment of the SS-N-21 will be limited to attack submarines; only about 60 have been deployed so far. The Soviet Union has also tested a larger, supersonic SLCM, the SS-NX-24, but claims that it has no plans to deploy the missile.

There are numerous problems with SLCM verification: (a) the as-yet undetermined structure of an agreement limiting SLCMs; (b) distinguishing long-range from short-range missiles; (c) distinguishing nuclear from conventionally armed versions; (d) the difficulty of production controls and the problem of rapid breakout; and (e) the incompatibility of SLCM controls with the U.S. Navy's policy of neither confirming nor denying the presence of nuclear weapons on naval vessels.

What to limit?

Although the United States and the Soviet Union have agreed not to include SLCMs as strategic nuclear delivery vehicles in START, they have so far not agreed about how SLCMs should be limited, if at all. The United States has suggested that both sides simply make nonbinding declarations of their plans for the deployment of long-range nuclear SLCMs. The Soviet Union wants a formal limitation as part of a START treaty. The Soviet Union has suggested limits of 400 long-range nuclear SLCMs and 600 long-range conventional SLCMs; it has also indicated that an overall limit of 1,000 missiles with freedom to mix between nuclear and conventional versions would be acceptable. The United States has adamantly refused any restriction on conventionally armed SLCMs. The most likely compromise is a limit on long-range nuclear SLCMs only, with the limit set at 400 to 800 missiles. Perhaps 600 nuclear SLCMs--10 percent of the START warhead limit--would be a satisfactory compromise.

Long-range vs. short-range SLCMs

The distinction between long-range and short-range SLCMs is meant to distinguish land-attack missiles, which might be used in strategic attacks, from anti-ship missiles, which would not. Current anti-ship SLCMs have ranges of less than 600 kilometers; therefore, the Soviet Union has proposed limiting only those SLCMs with ranges greater than this. This presents problems, however, because the range of some anti-ship weapons could be increased substantially. Because nuclear warheads are lighter and smaller than conventional warheads, and because nuclear-armed versions require smaller and less-accurate guidance systems, more fuel can be carried on a nuclear SLCM. The nuclear TLAM, for example, has a range five times greater than that of the TASM, even though their airframes are identical. Moreover, the range of several Soviet SLCMs could be increased by 50 percent simply by using a more-efficient turbofan engine rather than the cheaper turbojet now in use.[25]

Since cruise missile tests are difficult to monitor using NTM, cooperative measures to enhance verification, such as the advance announcement of the time and place of all tests, should be included in an agreement. This would facilitate the verification of range limitations. Limits could be extended to include all nuclear SLCMs regardless of range, but this would only shift the difficulty from verifying range to distinguishing conventional SLCMs from nuclear SLCMs.

Nuclear vs. conventional SLCMs

As mentioned above, the U.S. land-attack SLCMs are dual capable. Observed from the outside, the conventional version is indistinguishable from the nuclear version. Although the Soviet SS-N-21 and SS-NX-24 are believed to carry only nuclear weapons, the medium-range anti-ship SLCMs mentioned above are dual-capable. If an agreement limits the total number of SLCMs, with freedom to mix between conventional and nuclear versions, then dual capability poses no verification problem. Such an agreement, to which the Soviet Union has indicated it would be amenable, could be verified by a combination of data exchanges, perimeter-portal monitoring of production and loading, tagging, and on-site inspection to verify that the total number of long-range SLCMs was within the limit.

If, as the Soviets prefer, there is a sublimit on the number of nuclear SLCMs, or if, as the Americans prefer, there is no limit on conventional SLCMs, then there will have to be some means of distinguishing nuclear from conventionally armed missiles. After final assembly, those SLCMs declared to be conventionally armed could be radiographed through the canister to ensure that they were not nuclear armed or nuclear capable. All canisters could be tagged before leaving the final assembly facility, and those containing conventionally armed SLCMs would be sealed with a tamper-revealing seal. The seal would not interfere with the operation of the missile in any way--it would only indicate that a conventional missile had not been swapped for or converted into a nuclear version.

A possible loophole in this scheme is that conventional SLCMs might be quickly converted into nuclear SLCMs. The U.S. Navy has stated that this is not possible with the Tomahawk - the missile must be returned to the factory for all maintenance. The Soviet Union may accept this at face value. The ease with which the Soviet dual-capable SLCMs can be converted is unknown. Unless major structural changes must be made, it is hard to see why conversion would be impossible at sea. It might be possible to satisfy the monitoring party that conversion is difficult by releasing certain design information. Alternatively, one could divide the warhead compartment of conventional SLCMs with baffles welded to the airframe, with the spacing between the baffles too small to accommodate a nuclear warhead but sufficient to contain conventional submunitions. Some missions may, however, require a unitary high explosive.

Rapid breakout

Even under the best controls, rapid breakout from treaty limitations would be possible. As mentioned above, secret cruise missile production facilities and secret tests would be difficult to detect. Cruise missiles are produced and assembled in rather undistinctive buildings. Covert storage and testing would be much easier for cruise than for ballistic missiles. Stockpiles of secretly produced nuclear SLCMs could be stockpiled for quick delivery to aircraft carriers, and helicopters could distribute the missiles to ships and submarines.

No-confirm-no-deny

SLCM verification would be greatly simplified if certain ships could be declared SLCM-free, or at least declared free of nuclear SLCMs or long-range nuclear SLCMs. But any revelation that nuclear SLCMs are or are not on certain ships, whether through declarations, data exchanges, or on-site inspections, would be incompatible with the neither-confirm-nor-deny (NCND) policy of the U.S. Navy. The NCND policy, which states that the United States will neither confirm nor deny the presence of nuclear weapons on U.S. ships, was promulgated to facilitate the use of ports in countries that would object to the presence of nuclear weapons. The Soviet Union does not have a comparable problem. This problem could be minimized by keeping the data exchanges and the results of OSIs confidential.

Possible solutions to the SLCM problem

There are several ways to frame the SLCM "problem." The most simplistic is to view it solely as an impediment to achieving a START agreement. To solve the SLCM problem in this narrowest sense--that is, to remove it as an obstacle to START--one must know why the Soviet Union wants restrictions on SLCMs. Alternatively, one can understand the SLCM problem from a more theoretical point of view: do SLCMs enhance or detract from crisis stability and arms race stability? What kind of SLCM arms control regime would improve stability?

The United States maintains that the characteristics of nuclear land-attack SLCMs make them ill-suited for preemptive attack. They have limited ranges (about 2,500 kilometers) and they are slow (about 850 kilometers per hour). Only those SLCM-equipped ships or submarines that were within 2,000 kilometers of Soviet borders could participate in an attack. This distance is greatly reduced for attacks on targets in the interior of the Soviet Union. Flying at top speed, SLCMs would take nearly three hours to reach their targets.

The planned number of U.S. nuclear SLCMs is not large (760), and would not represent a substantial increase in U.S. forces even after the START reductions. Moreover, the United States plans to distribute its nuclear SLCMs more-or-less uniformly among nearly 200 surface ships and attack submarines: an average of less than four SLCMs per platform. It would be extremely difficult to coordinate an attack using such a large number of dispersed platforms, half of which (the attack submarines) are difficult to communicate with. Thus, SLCMs appear to be ideally suited for tactical missions and retaliation, not preemptive strategic attack.

This is why many U.S. strategists view them as a stabilizing contribution to deterrence.[26]

Most Soviet analysts do not agree that SLCMs are stabilizing. While they acknowledge that current SLCMs are slow, dispersed, and not excessively numerous, future versions may travel at much higher speeds (the United States is developing a supersonic cruise missile) and, without a suitable arms control agreement, SLCMs may become much more numerous in the future. In addition, these analysts claim that the small size of SLCMs makes them ideal for sneak attacks. SLCM launches are very difficult to detect, as are SLCMs in flight. A small SLCM attack might occur without warning, disrupting command and control centers and delaying retaliation long enough to permit the near-complete destruction of ICBMs and bombers. This scenario is a bit far-fetched, since SSBNs at sea would survive and could retaliate. It is also risky, since detection of the slow-flying SLCM attack would disastrously upset the strategy. Still, the option might look more promising than the alternatives to a leader deep in crisis.

The primary purpose of arms control is to decrease the incentives of striking first, and thereby decrease the probability that a crisis would escalate into nuclear war. SLCMs make a first-strike both more and less attractive: more attractive because they could be used for a precision sneak attack; less attractive because they constitute a slow-flying, survivable nuclear deterrent. It would be nice if a SLCM force could be configured so that the latter capabilities could be attained without the former, but this is impossible, since a surprise attack would require only dozens of nuclear SLCMs. If we are worried about the possibility of a surprise attack, then a total ban on nuclear SLCMs is required. There are good reasons for the United States to favor a ban, since it has a much greater proportion of coastal targets that would be vulnerable to SLCM attack than the Soviet Union. Compared to the alternatives, a ban on nuclear SLCMs would be relatively easy to verify. Since the superpowers already have more than enough survivable retaliatory weapons, a ban probably enhances stability, and is the best solution to the SLCM problem in the broadest sense. But since the United States appears committed to deploy nuclear SLCMs, and since the Soviet Union has already indicated that a limit on nuclear SLCMs would be acceptable, it is not a solution to the SLCM problem in the narrow sense.

The most likely structure of a SLCM agreement is a limit of 400 to 800 nuclear SLCMs, with no limit on the number of conventional SLCMs. How would this be verified? As with ballistic missiles, all SLCM production, storage, maintenance, testing, and deployment areas would be declared in an initial data exchange. Baseline OSIs would establish the initial inventory, and perimeter-portal monitoring at assembly facilities would keep track of the production rate and tag missiles as they exit. A perimeter-portal system would also be installed at the facility where nuclear warheads are mated to the airframes and the completed, ready-to-fire missile is placed in a canister. As missiles exit the facility, canisters are tagged. All missiles declared to be non-nuclear are radiographed to ensure they do not contain nuclear weapons and that they are not nuclear capable, after which their canisters are sealed with a tamper-revealing seal. Loading SLCMs on ships could be confined to a limited number of declared ports; loading and unloading SLCMs anywhere else would be banned. A perimeter-portal system could then be installed at designated ports to ensure that only legal SLCMs are being loaded and unloaded. A few random on-board inspections each year could ensure that only legal SLCMs are deployed. The location and time of all cruise missile tests would be declared; on-site observers at a few randomly selected tests could verify that only legal missiles were being tested, and that range limitations on shorter-range missiles were being observed.

Although very extensive, these verification arrangements are not airtight. Cruise missiles could be produced secretly and flown out to ships during a crisis. Future long-range conventional cruise missiles could be designed to be easily converted at sea to carry nuclear warheads. At this juncture, however, these possibilities are remote. In the case of the Soviet Union, at least, it is simply not credible to assume that a country that has not produced more than a few SLCMs in the open could manufacture, test, and ready for deployment large numbers of these missiles in secret. Indeed, this possibility seems so remote that the verification scheme described above could be relaxed considerably without losing confidence in the ability of the U.S. to verify Soviet compliance.

Notes

1. For a review of START, see Robert Einhorn, "Strategic Arms Reduction Talks: The Emerging START Agreement," *Survival*, July/August 1988, pp. 387-401.

2. For a review of INF verification procedures and their relation to START verification, see Jeremy K. Leggett and Patricia M. Lewis, "Verifying a START Agreement: Impact of INF Precedents," *Survival*, July/August 1988, pp. 409-428.

3. For an in-depth discussion of tags, see 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.

4. Clandestine static firings are possible, and could be used to assess the reliability of aging stocks of clandestine missiles. Static firings alone would *not* be sufficient to assess the reliability of clandestinely produced missiles. Static firing would be useful only when full-scale testing of allowed stocks of the same missile is possible.

5. U.S. Congress. House Committee on Armed Services. *Breakout, Verification, and Force Structure: Dealing with the Full Implications of START*. 100th Congress, 2nd session, 24 May 1988, p. 36.

6. The number of spare missiles is already a source of contention. The U.S. Defense Intelligence Agency (DIA) believes that the Soviet Union under-reported the number of nondeployed SS-20s under the INF Treaty; the CIA disagrees. The Soviet Union reported 405 deployed and 245 nondeployed missiles; DIA believes that the numbers of nondeployed and deployed missiles were about equal. *Ibid.*, p. 3.

7. Agreement Between the United States of America and the Union of Soviet Socialist Republics on Notifications of Launches of Intercontinental Ballistic Missiles and Submarine-Launched Ballistic Missiles, reprinted in *Arms Control Today*, July/August 1988, pp. 20-21.

8. The probability of detecting at least one of n illegal tests is equal to one minus the probability of all n tests escaping detection. The probability of all n escaping detection is equal to $(1 - p)^n$, where p is the probability of detection per test. In the example given in the text, $1 - (1 - 0.2)^{10} = 0.89$.

9. The United States conducts about 30 to 40 test launches per year; the Soviet Union may test twice as many. Inspecting 4 of 80 tests (5 percent) would give a 40 percent chance of detecting at least one in a program of ten tests, a 23 percent chance of detecting at least one of five tests, and a 10 percent chance of detecting at least one of two tests.

10. The latter rule presented problems for the U.S. SALT II delegation, because Minuteman II missiles are deployed in silos that are identical to those in which the Minuteman III (and now, the MX) is deployed. In accepting the rule but agreeing not to apply it to the Minuteman II, the Soviets acknowledged the "informational asymmetry" between the United States and the Soviet Union. See Strobe Talbott, *Endgame: The Inside Story of SALT II* (New York: Harper and Row, 1979), pp. 114-115.

11. The SS-18 has been tested with a maximum of 10 warheads, but one test included the simulated release of two additional warheads. The geometry of the bus suggests 14 warhead positions, and tests already performed with various combinations of 10 or fewer warheads probably would be sufficiently to ensure reliability with a full load of 14 warheads.

12. Assuming the Soviet Union maintains 154 SS-18s and 3,000 to 3,300 ICBM warheads.

13. Article IV of the SALT II Treaty (Part 10, First Agreed Statement) states the Minuteman III was tested with a maximum of seven reentry vehicles, although in a following Common Understanding it is stated that the United States has never deployed Minuteman with more than three warheads. The tests occurred in 1975 under the Air Force "Pave Pepper" program.

14. This relationship can be represented by the equation $p = 1 - (1 - \beta f)^n$, where n is the number of inspections, p is the probability of detecting a violation, f is the fractional increase in warheads, and β is the number of permitted warheads divided by the maximum number of extra warheads. For the SS-18 example in the text, $n = 3$, $f = 0.2$, and $\beta = 10/(14 - 10) = 2.5$, which gives $p = 0.88$.

15. See Steve Fetter, Robert Mozley, O.F. Prilutskii, S. Rodionov, R.Z. Sagdeev, and Marvin Miller, "Detecting Nuclear Warheads" *Science and Global Security*, Vol. 1, No. 3-4 (in press).

16. Richard Garwin, "Tags and Seals for Verification," *The Council for Arms Control Bulletin*, No. 40 (October 1988), p. 4.

17. Both the proposed rail-mobile MX and road-mobile SICBM systems would consist of 500 warheads. The latest U.S. Air Force proposal is to convert the 50 silo-based MX to rail-mobile mode and to build 300 road-mobile SICBM. George C. Wilson, "Air Force Acts to Break ICBM Impasse," *The Washington Post*, 24 March 1989, p. A1, A6.

18. Each Trident submarine carries 24 missiles, and each missile carries 8 warheads, for a total of 192 warheads per submarine. Thus, 17 Tridents would carry 3,264 warheads. When the Soviet Union proposed a sublimit of 3,300 SLBM warheads (to match the

corresponding limit on ICBMs), the United States objected, but claimed that it would in any case not deploy more than 3,300 SLBM warheads. Some analysts assume a force of 18 Tridents under START; indeed, the construction of the 18th Trident has already been authorized by Congress.

19. Richard Halloran, "Navy Trident 2 Missile Explodes In Its First Underwater Test Firing," *The New York Times*, 22 March 1989, p. 1.

20. *Soviet Military Power* (Washington, DC: Department of Defense, 1987), p. 33.

21. This assumes a total Soviet SLBM force of 1600 to 1900 warheads under START, and that the Soviet Union builds no more Typhoon submarines. The five Typhoons already built will count as 200 warheads each under START, leaving at most 600 to 900 warheads for 144 to 224 SS-N-23 SLBMs on 9 to 14 Delta IV submarines. Six extra warheads on each SS-N-23 would then amount to 864 to 1,344 extra warheads, or 54 to 71 percent of the total allowed force. The Soviet Union is unlikely to allocate more than 1900 warheads to their submarine force, since this would require even larger cuts in the ICBM force. If the Soviet Union builds more Typhoons, the SS-N-23 problem would become less significant.

22. The percentage depends on whether the eight existing Trident submarines equipped with Trident C4 missiles are backfitted with Trident D5 missiles.

23. *The Military Balance: 1988-1989* (London: International Institute for Strategic Studies, 1988), p. 211.

24. Valerie Thomas, "Verification of Limits on Long-range Nuclear SLCMs," *Science and Global Security*, Vol. 1, No. 1-2 (in press).

25. The Soviet Union has only 280 turbojet-powered SLCMs with ranges of 550 km (SS-N-12 and SS-N-19).

26. For examples of this view, see Linton Brooks, "Nuclear SLCMs Add to Deterrence and Security," and Henry C. Mustin, "The Sea-Launched Cruise Missile: More Than a Bargaining Chip," *International Security*, Vol. 13, No. 3 (Winter 1988/89), pp. 169-174, 184-190.