Science & Global Security, 1989, Volume 1, pp.27–57
Photocopying permitted by license only
Reprints available directly from the publisher

Printed in the United States of America

Verification of Limits on Long-range Nuclear SLCMs

Valerie Thomas[a]

Arms control negotiators have identified a number of problems in verifying limits on long-range nuclear sea-launched cruise missiles (SLCMs). These are the difficulties of counting deployed SLCMs, of distinguishing nuclear from non-nuclear SLCMs, and the possibility of secret production or stockpiles.

On-site inspection measures to monitor either a limit or a ban on nuclear SLCMs could include inspection of: ships and submarines where SLCMs are deployed or being loaded; production facilities; maintenance operations; and storage sites. While verification plans that involved either very few inspections or, at the other extreme, frequent inspections of ships and submarines might be acceptable, a reasonably effective verification plan with an intermediate level of intrusiveness is also possible. This would include monitoring of the production and maintenance of any non-nuclear long-range SLCMs and any nuclear long-range SLCMs not banned by the agreement. Tagging of these missiles to allow identification at subsequent inspections at shore-based maintenance depots would significantly decrease the probability that undetected SLCMs could be deployed or that non-nuclear SLCMs might be covertly converted to nuclear.

THE CONTEXT OF THE SLCM VERIFICATION PROBLEM

Sea-launched cruise missiles (SLCMs—pronounced *slick-ems*) have become a serious problem for nuclear arms control. To some extent, this is a

a. The author is a research associate at the Center for Energy and Environmental Studies, Princeton University, Princeton, NJ 08544

This paper was written under the auspices of the Cooperative Research Project on Arms Reductions, a joint project of the Federation of American Scientists and the Committee of Soviet Scientists for Peace and Against the Nuclear Threat

consequence of their physical attributes: they need not be deployed in special launchers; they are relatively small and easy to transport and conceal; and there are both nuclear and non-nuclear versions.

The US long-range SLCM—the Tomahawk—comes in non-nuclear land-attack and antiship versions, and in a nuclear land-attack version. It has been deployed on attack submarines for launch from torpedo tubes and from vertical launch systems, and on surface ships in Armored Box Launchers and in vertical launch systems.

The Soviet long-range SLCM, known in the US as the SS-N-21, has been reported to be nuclear only and to be deployed on submarines for launch from torpedo tubes and from specially designed launchers. A supersonic SLCM, the SS-NX-24, is under development. Further details of the US and Soviet SLCM programs are given in appendixes 1 and 2.

Although the United States and the Soviet Union have agreed to "establish ceilings on [SLCMs], and to seek mutually acceptable and effective methods of verification of such limitations,"[1] they have yet to find common ground. Soviet negotiators have said that the START (Strategic Arms Reductions Talks) Treaty must include verifiable limitations on SLCMs, and have proposed a system of intrusive verification measures. The US has proposed only a nonbinding "declaration of intent" on SLCM deployment, with no verification measures.[2]

A central factor in this impasse is the asymmetry between the SLCM programs of the two countries: US deployment of long-range SLCMs is far larger. The United States has about 1,500 Tomahawk SLCMs and plans to deploy about 4,000. Of the 4,000, more than 80 percent are to be non-nuclear, though nearly identical in appearance to the nuclear version. The Tomahawk is deployed on both surface ships and submarines: by the mid-1990s about 200 vessels are intended to have them. In contrast, reports indicate deployment of Soviet long-range SLCMs on only a few submarines.

Therefore, at present, limits on long-range SLCMs would constrain the United States more than the Soviet Union. And, because US SLCMs are deployed throughout the US Navy, on-site inspection of deployed SLCMs would involve greater numbers and types of US ships than Soviet ships.

US government statements about the intractability of the verification of SLCM limits seem to derive less from concern about the threat from Soviet SLCMs than from apprehension about restrictive limits on US

SLCM deployment and intrusive verification arrangements. There is special concern also that intrusive verification might threaten the US Navy's policy of "neither confirming nor denying" the presence of nuclear weapons on any particular ship.

Even intrusive arrangements would not, however, completely eliminate the uncertainties of SLCM verification. Some on-site inspection could be helpful, but increasingly intrusive measures would provide diminishing returns, as has been stated by some members of the US House Select Committee on Intelligence,[3]

> We face a painful dilemma.... We must consider frankly whether major cumulative arms control risks are more or less dangerous than an absence of real or theoretical restrictions on Soviet military power.... The current refrain is that treaties must and will be "verifiable".... Politicians and the public must realize, however, that there is no way we could afford to develop collection capability providing 100 percent certainty that the Soviets are or are not violating major arms limitations. And even with unlimited funding, such capabilities often would not be achievable....
>
> Since so many key weapons and capabilities will be difficult to monitor, treaties truly focusing only on clauses monitorable with high confidence often will be virtually irrelevant and almost certainly will not reduce the overall threat, because military buildup easily could be diverted to nontreaty categories.

This paper will focus on limits on long-range nuclear SLCMs, though auxiliary limits—on non-nuclear SLCMs, short-range SLCMs, and ALCMs—will also be considered. The purpose is to provide the technical information necessary to understand the feasibility and implications of various plans for SLCM verification, and to provide the information necessary to judge the risk of clandestine treaty violations.

SLCM VERIFICATION PROBLEMS

The main SLCM verification tasks are to ascertain the number of SLCMs produced or deployed and to distinguish between nuclear and non-nuclear SLCMs. One must also take into account the possibility of conversion from non-nuclear to nuclear, of transformation of ALCMs or large short-range SLCMs into long-range SLCMs, and of secret production and storage.

The Counting Problem

Nuclear SLCMs are difficult to count because they can be launched from standard torpedo tubes and other multipurpose launchers. Thus the number of potential SLCM launchers is much larger than the number of nuclear SLCMs likely to be deployed. The similarity of US nuclear and non-nuclear SLCMs is a further complication.

Similar difficulties arise for the counting of air-launched cruise missiles (ALCMs), in that more ALCMs could be deployed on long-range aircraft than actually will be deployed. At the START negotiations, it is proposed that verification of ALCM limits be accomplished by designating certain bomber aircraft to be nuclear ALCM carriers and crediting each of these aircraft with a specific number of nuclear ALCMs according to agreed "counting rules." A similar approach might be used for nuclear SLCMs.

This approach could work fairly well for Soviet SLCMs, assuming that they all can be counted as carrying nuclear warheads and as long as their deployment remains limited to a relatively small number of submarines. The SS-NX-24 is so large that its launchers will be unique and recognizable by satellites. The SS-N-21 is smaller and can, in principle, be launched from any standard 533-millimeter torpedo tube but in fact has reportedly been deployed for torpedo launch on only the most modern Soviet attack submarines. This may be because the SS-N-21, like the US Tomahawk, requires a sophisticated fire-control system, available only on new or refitted submarines. Assuming the SS-N-21 deployments are limited to submarines, each type of submarine from which the SLCM has been tested might be counted as carrying some number of SLCMs for each torpedo tube.

Designing counting rules for US SLCM deployments is more complicated, because of the variety of US SLCM launchers and because most US SLCMs are non-nuclear.

In addition to torpedo tubes on attack submarines, the US Navy has developed three other types of SLCM-capable launchers (see figure 1): the Armored Box Launcher (ABL) and Vertical Launch System (VLS) for surface ships; and the Capsule Launch System (CLS), which is being installed on new *Los Angeles*-class submarines. The ABL and CLS hold only Tomahawk SLCMs, and, in each case, the number of launchers is externally visible and could be counted from satellites (see figures 2 and 3). The number of VLS launchers can also be counted, but, because VLSs also carry the Standard surface-to-air missile and will carry the ASROC antisubmarine depth charge (see figure 4), the US might be reluctant to have all VLSs counted as carrying SLCMs.

The most serious complication with the counting-rule approach to US SLCMs, however, is that only one in five US Tomahawks is planned to be nuclear. Counting rules for SLCMs could therefore significantly overestimate the number of US nuclear SLCMs.

Another approach to the counting problem is to implement a system of on-site inspections. Monitoring of SLCM production facilities and maintenance and storage sites would allow direct verification of the number of nuclear SLCMs. Spot-checks of SLCM launchers on ships and submarines could directly verify limits on nuclear SLCM deployments.

A ban on nuclear SLCMs would essentially eliminate the counting problem. While verification measures might include some inspection of SLCM launchers, the primary compliance information would be provided by monitoring of the destruction of all nuclear SLCMs, and observation of the elimination of all nuclear SLCM support facilities and activities.

The Warhead Switching Problem

It is possible that a non-nuclear SLCM could be transformed into a nuclear SLCM by replacing the warhead. Through such a procedure, a missile which had been designated as non-nuclear could later become nuclear. At present, conversion between conventional and nuclear versions of the US Tomahawk would be a complex operation. According to Admiral Hostettler, then director of the Joint Cruise Missile Project in the US Department of Defense,[4]

> The current cruise missile is a highly complex vehicle which was not designed for field maintenance. Each missile is thoroughly tested before it leaves the factory and remains intact until it is fired or returned for recertification in 30–36 months. During the period the missile is in the fleet, electrical continuity is maintained. To change a variant from conventional to nuclear or vice versa would require replacement of the entire front one-third of the missile. Nuclear surety requirements would dictate a complete retest of the missile requiring each ship be outfitted with highly sophisticated test equipment and highly trained technicians to interpret the results. Clearly, this is beyond the scope of normal Navy maintenance concepts, and will be performed only at shore-based depots. The capability to modify variants in the fleet is not planned for the Tomahawk.

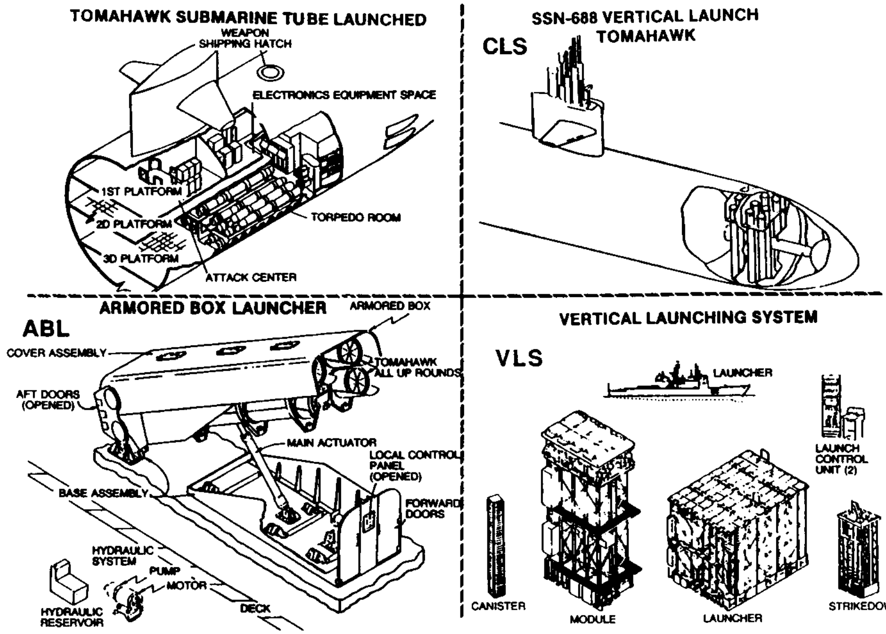

Figure 1: US Tomahawk Launch Systems

Source: Cruise Missile Project, US Navy

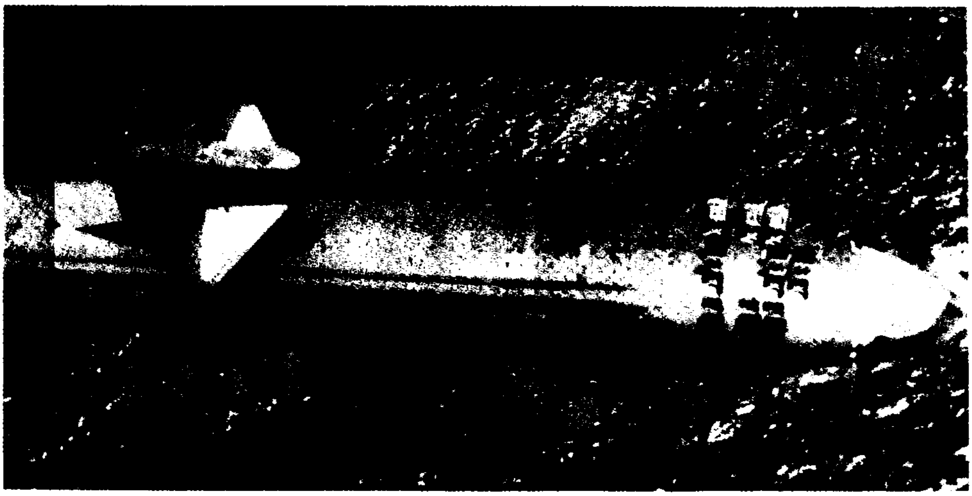

Figure 2: Open Tomahawk CLS Hatches on a *Los Angeles*-class submarine

Source: US Navy

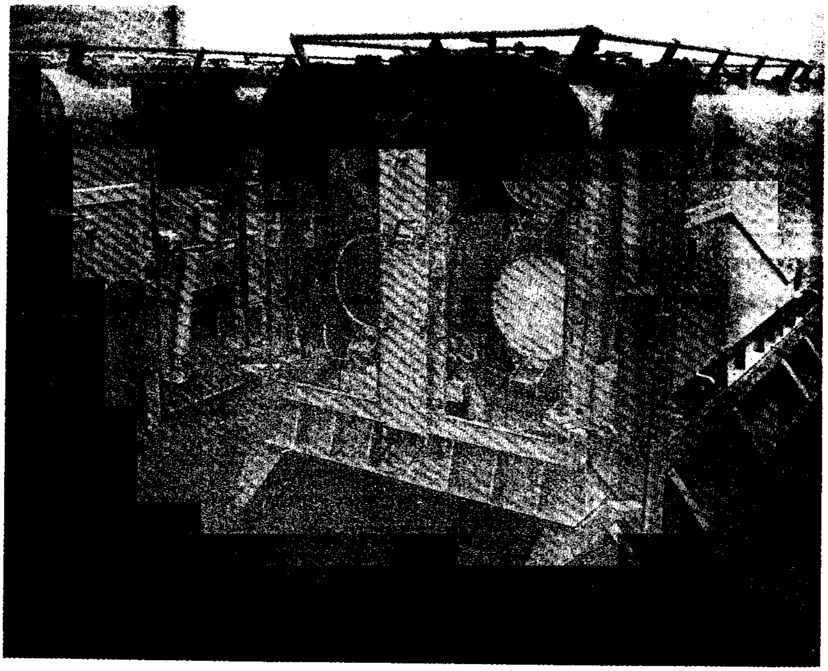

Figure 3: Armored Box Launcher

Source: Cruise Missile Project, US Navy

Figure 4: Standard missile being loaded into VLS

Source: Martin Marietta

In the future, transformation of non-nuclear weapons into nuclear weapons might become easier. The United States' Lawrence Livermore National Laboratory (LLNL) has developed an "insertable" nuclear warhead for other missile systems. If an insertable nuclear warhead were developed for the cruise missile, conventional cruise missiles could quickly be converted to nuclear. An insertable nuclear warhead was considered for the short-range Harpoon cruise missile; the idea was rejected primarily for arms control reasons.[5] Agreement not to deploy an insertable nuclear warhead system would be useful.

If warhead switching is taken to be a serious problem for SLCMs, occasional inspections of designated non-nuclear SLCMs could ensure that nuclear warheads had not been installed. However, even this would not remove the potential for warhead transfer, since nuclear warheads could be installed after breaking out of the treaty.

The ALCM Problem

In principle, ALCMs and SLCMs differ only in their launch platforms; it therefore might be possible for ALCMs to be launched from SLCM launchers with only minor modifications. If so, a cruise missile designated to be an "ALCM" could be used as a SLCM.

The US ALCM, however, is not designed to be launched from Tomahawk launchers. Specifically, the diameter of the US ALCM is 69.3 centimeters, compared to 53 centimeters for the SLCM. Therefore the US ALCM is too wide to fit in the standard 533-millimeter torpedo tube or other current SLCM launchers.

However, the Soviet ALCM and SLCM may be more similar.[6] It may be that the Soviet ALCM could be launched from SLCM launchers with only minor modifications. A compatible system of ALCM and SLCM limits would remove any advantage of switching from one category to another.[7]

The Short-Range SLCM Problem

During the Senate hearings on SALT II, it was pointed out that the range of Soviet short-range SLCMs could be upgraded by the substitution of better guidance systems and more efficient propulsion systems.[8] The SS-N-12 and SS-N-19 have a range of 550 kilometers, just short of the usual 600-kilometer definition of "long-range" and are, in fact, larger than the SS-N-21 long-range SLCM (see appendix 2). In contrast, the US short-range cruise missile, the Harpoon, has a range of only about 100 kilometers and is only 34 centimeters in diameter and 4.6 meters long.[9] Although some increase in range is possible, it is too small to have the 600-kilometer-plus range of "long-range" SLCMs.

The range of a missile depends on the efficiency of its engine, the amount of fuel carried, and the weight of all missile parts. An older missile could be upgraded by substitution of a more efficient engine, or by use of a lighter warhead. Non-nuclear warheads can be considerably larger and heavier than nuclear warheads. Replacing a non-nuclear warhead with a nuclear one may not only reduce the payload weight, but may also increase space available for carrying fuel. This is why the range of the US nuclear Tomahawk (2,500 kilometers) is so much longer than the range of the non-nuclear land-attack Tomahawk (1,300 kilometers). Without knowing more about Soviet short-range SLCMs, however, it is difficult to judge the plausibility of substantial increases in range.

In any case, it is likely that testing would be necessary for a significant upgrade; these tests might be picked up by national intelligence sources.[10]

The problem of distinguishing short-range SLCMs from long-range SLCMs could be eliminated by limiting shorter-range SLCMs as well.

The Problem of Secret Production or Stockpiles

It is possible that SLCMs could be produced and stored secretly. In principle this is a problem for limits on any weapon system, but it is more relevant for SLCMs because, while ballistic missile production facilities tend to be distinctive, and identifiable by satellite reconnaissance, cruise missile production facilities do not have distinctive visual characteristics. SLCM storage sites could be even less conspicuous than production facilities.

The possibility of excess production at declared production facilities could be addressed by on-site monitoring at these facilities. The possibility of secret production sites could be addressed by provisions for challenge inspections, which could be particularly useful at production sites for similar weapons.

Challenge inspections of suspected storage sites could also be established. Although the reliability of challenge inspections is limited by the difficulty of identifying likely "clandestine storage sites," challenge inspections do provide a mechanism for checking a suspected treaty violation that might have been indicated but not clearly established by intelligence information.

SLCM VERIFICATION APPROACHES

Three approaches to verification of limits on long-range nuclear SLCMs will be considered below, in order of the intrusiveness of inspections.

Minimum Inspection

A minimum inspection approach would rely primarily on data exchanges, satellite reconnaissance, and other intelligence to monitor treaty compliance. Data exchanges could detail the number of SLCMs produced and deployed, and, if nuclear SLCMs were not banned, the number of nuclear SLCMs on each ship and submarine. The approximate number of deployed long-range SLCMs might be estimated with reasonable confidence, but confidence in the number of these that were non-nuclear would be more difficult to achieve. Because the Soviets have not deployed a non-nuclear long-range SLCM, current Soviet deployments are relatively easy to monitor.

The minimum inspection approach is analogous to proposals for verifying limits on ALCMs under the START treaty.

This approach also corresponds to a situation in which nuclear SLCM deployments were to be reduced or eliminated by nonbinding declarations. In the context of a treaty, minimum inspection might be most acceptable if nuclear SLCMs were banned.

Intermediate Levels of Inspection

A significant improvement in information on the SLCM arsenals could be achieved by monitoring declared production facilities and maintenance facilities.

Any SLCMs to be destroyed would be destroyed in the presence of inspectors. For any remaining missiles, inspections would occur at the production site for new missiles or at the maintenance site for old missiles. At the first inspection, each missile could be tagged for future identification, and possibly sealed. On subsequent inspections—the end of every maintenance cycle—SLCMs would be inspected to check that only tagged missiles passed through the maintenance depot, and that the type of warhead, either nuclear or non-nuclear, matched the tag.

In the US, SLCMs are brought back for maintenance once every three years. On this schedule, after three years all SLCMs would have been inspected and tagged, and they would be reinspected at three-year intervals. Since in the US depot maintenance is done at the production facilities, monitoring need only occur at the two production sites.

There are a number of variations of this approach: challenge inspections of suspected production sites might be allowed, or all SLCMs might be brought in for an initial inspection and tagging when the treaty came into force. But the essential feature that distinguishes this from a maximum inspection approach is that there would not be regular inspections of ships, submarines, or ports. The plan could be strengthened by data exchanges on the number of SLCMs deployed on each vessel—possibly not distinguishing nuclear from non-nuclear. This database would support national technical means of verification, since any missile spotted out of place would be evidence of a violation.

There is an obvious shortcoming of this method: there is no guarantee that all SLCMs will be brought to the designated maintenance site. But if the treaty were to be violated in secret, two separate sets of SLCMs and associated production and maintenance facilities would need to be maintained: the tagged and the untagged. Such a violation would be a complex undertaking, involving several facilities and many people, and would be considerably more difficult to conceal than if the missiles were not tagged.

Maximum Inspection

A maximum inspection approach would include inspections of ships and submarines, and the monitoring of SLCMs from manufacture to elimination.

A version of the maximum inspection approach was proposed by the Soviet government as follows: SLCM production and warhead installation facilities would be subject to "portal-perimeter" monitoring, where missiles could be tagged and sealed. Inspectors would be stationed at ports to monitor loading of SLCMs into ships and submarines. Suspect sites on land would be subject to challenge inspection. SLCM deployment would be restricted to two types of submarine and one type of surface vessel. Limited inspections of other ships and submarines in ports might be allowed to verify the absence of cruise missiles.[11]

In the United States, this would involve inspection of two SLCM production sites, 16 Tomahawk Naval Ordnance Facilities, about 200 ships and submarines, and any sites chosen for challenge inspection.[12] In the Soviet Union the number of sites to be inspected would be fewer, with fewer than 10 SS-N-21 SLCM submarines reported so far.

This is the most intrusive arrangement that has been considered. But even with so much inspection, there are possibilities for undetected violation or for sudden breakout from the treaty. The primary violation scenarios are: 1) Some previously manufactured SLCMs might not be declared; 2) Secret production; 3) Even if non-nuclear SLCMs were sealed to deter conversion to nuclear, the conversion could be done if the treaty were broken.

WHICH VERIFICATION APPROACH IS BEST?

For some other weapon systems the choice is clear: those for which there is a technical method of verification that is inexpensive and highly effective. For example, limits on submarine-launched ballistic missiles (SLBMs) can be verified with high confidence by counting the launch tubes on each submarine while it is under construction. Although a reconnaissance satellite is expensive, it would be financed by its primary mission—military reconnaissance. There are few costs or trade-offs in SLBM verification.

But this is not the case with SLCMs. Because it is difficult to count the number of SLCMs on ships and submarines or to distinguish nuclear from non-nuclear SLCMs by national technical means, direct verification requires on-site inspections. The disadvantages of such measures in terms of cost, bureaucratic politics, and collateral risks to national security may be significant.

On-site inspection measures cannot totally preclude violations, but would constrain those that are most plausible. Specifically, such measures could counter every plausible violation except a secret, undeployed stockpile. For this type of violation, national technical means and other intelligence would remain the primary sources of information.

Under the minimum inspection option, involving only counting rules, the Soviets would have no direct way of checking that the 3,000 or so supposedly non-nuclear US Tomahawks did not in fact carry nuclear warheads.

The US might also find the minimum inspection option problematic. Although, for the immediate future, the US might not face the difficulty of distinguishing Soviet nuclear SLCMs from their non-nuclear counterparts, the Soviets may deploy non-nuclear long-range SLCMs in the future. In addition, although adequate estimates might be made of the number of SS-N-21s deployed for torpedo-tube launch in each SLCM-carrying submarine, it would be more difficult to determine which submarines were capable of launching the SS-N-21, or how many SS-N-21s had been produced and were available for deployment.

On the other hand, at present the United States does not even want to limit nuclear SLCMs and has not shown particular concern over Soviet SLCM deployments. The disadvantages of on-site inspection may continue to be seen as outweighing the advantages of direct verification of SLCM limits.

The advantage of the intermediate inspection regime, in which the SLCM production and maintenance sites would be monitored, is that it provides a method of significantly reducing the probability of clandestine production and deployment of SLCMs, without involving the inspection of ships, submarines, or primary naval facilities. The level of intrusiveness is comparable to that agreed to in the INF treaty, in that it allows portal-perimeter monitoring of declared production sites, but might not provide for challenge inspections of undeclared, "suspect" sites.

Tagging of SLCMs would greatly enhance the value of inspections under the intermediate regime. However, details of tagging remain to be worked out. US national laboratories have developed tags that could be used for many arms control purposes, but no preferred tag design for cruise missiles has yet been agreed upon. The tag must not only work technically, but also must meet the requirements of the US Navy, the US intelligence community, and, of course, the Soviet government. Tags have not been emphasized in Soviet verification proposals; Soviet interest in or willingness to accept particular types of tags remains to be tested.

The advantage of the maximal inspection approach, involving on-site inspection of deployed SLCMs, is that it allows direct verification. On-site inspection of three types of US SLCM launchers (ABLs, VLSs, and CLSs) could readily determine how many of the launchers contained nuclear SLCMs, and could be done from the exterior of the ship or submarine (see appendix 3). For SLCMs in submarine torpedo rooms, inspectors would have to go inside the submarine, which would be much more intrusive than an external inspection. The alternative proposed by the Soviet Union, monitoring of loading and unloading at ports, would avoid internal inspections, but would require inspectors to be present at all ports that handle SLCMs, and would require the monitoring of every loading and unloading. Such monitoring would not preclude the possibility of clandestine SLCM unloading at unmonitored ports.

Although neither the minimum nor the maximum inspection approach is inherently unreasonable, the intermediate approach would provide a considerable degree of verification without unduly burdensome inspections.

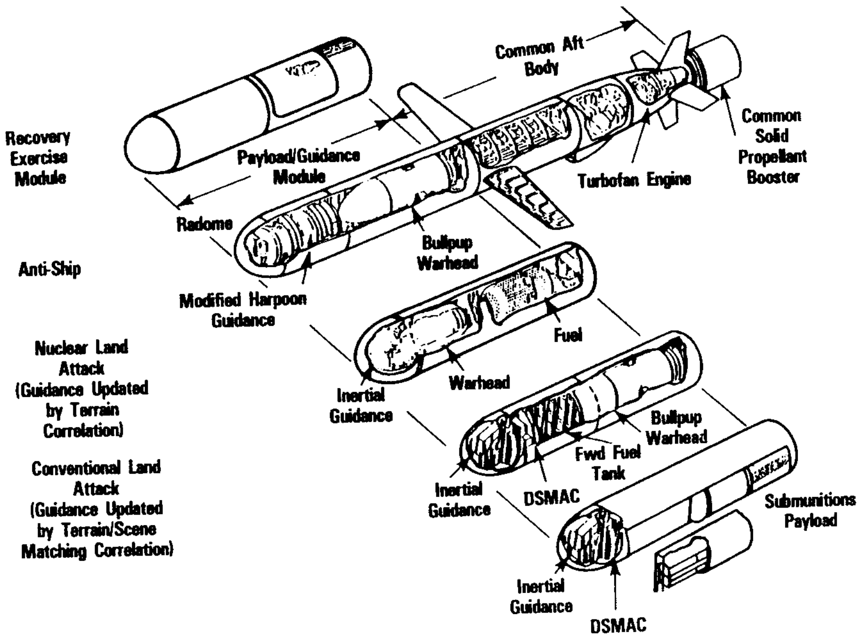

Figure 5: Tomahawk Variants

Source: Cruise Missile Project, US Navy

APPENDIX 1: US SLCMS

The United States' long-range SLCMs are called Tomahawks. They are all 5.56 meters long and 53 centimeters in diameter. The internal differences of the Tomahawk variants are shown schematically in figure 5. Notice that the nuclear version, the TLAM-N (Tomahawk Land Attack Nuclear), has a smaller warhead than the non-nuclear versions—the TLAM-C (Tomahawk Land Attack Conventional), TLAM-D (Tomahawk Land Attack dispensed submunitions), and TASM (Tomahawk AntiShip Missile)—so that the nuclear version has room for an additional fuel tank. There is also a short-range, non-nuclear SLCM, the Harpoon. Table 1 shows the characteristics of each type of US SLCM. Notice that more than four times as many non-nuclear Tomahawks as nuclear are planned. Tomahawk deployment is planned for about 100 surface ships and 100 submarines by the mid-1990s, as shown in table 2.

The guidance system of all three land-attack versions uses TERCOM (TERrain COntour Matching), which compares terrain profiles gathered by a radar altimeter with computer-stored contour maps. The nuclear version has an accuracy (CEP) of

Table 1: Planned US Tomahawk Cruise Missile Deployment*

Type of vessel	Number of vessels	Launcher type	SLCMs/ vessel
Battleship BB-66 *Iowa class*	4	8 ABLs	32
Destroyer DD-963 *Spruance class*	7	2 ABLs	8
Destroyer DD-963 *Spruance class*	24	1 VLS	37
Guided missile destroyer DDG-51 *Burke*	29	2 VLSs	16
Guided missile cruiser CG 47 *Ticonderoga*	22	2 VLSs	19
Guided missile cruiser *nuclear*	5	2 ABLs	8
Submarine SSN-719 and later *Los Angeles*	37	CLS, torpedo tubes	20
Submarine SSN-688-718 *old Los Angeles* SSN-637 *Sturgeon* SSN-671 *Narwhal* SSN-685 *Lipscomb*	70	4 torpedo tubes	8
Submarine SSN-21 *Seawolf* (planned)	30	8 torpedo tubes	50+

* Bernard Blake, ed., *Jane's Weapon Systems 1987-88* (New York: Jane's Publishing, Inc.) p.487. Statement of Rear Admiral William C. Bowes, USN, director, Cruise Missile Project, before the Defense Subcommittee, House Appropriations Committee, 21 April 1988. Statement of Rear Admiral Stephen J. Hostettler, USN, director, Joint Cruise Missile Project, before the House Armed Services Committee, DoD Authorization Hearings for FY 1985, part 2, p.361, 14 March 1984.

Table 2: US Sea-launched Cruise Missiles

Type	Mission	Number planned*	Number bought*	Range *km*	Warhead	Guidance
TLAM-N	Land attack	758	350	2,500	Nuclear *~200kt*†	TERCOM
TLAM-C	Land attack	1,486	600	1,300	HE *unitary*	TERCOM/ DSMAC
TLAM-D	Land attack	1,157	80	1,300	HE *multiple submunitions*	TERCOM/ DSMAC
TASM	Antiship	593	475	460	HE *unitary*	Radar
Harpoon‡	Antiship	1,876	1,148	110	HE	Radar

* As of early 1988. Information provided by the Cruise Missile Project, US Navy.

† Thomas B. Cochran, William M. Arkin, and Milton M. Hoenig, *Nuclear Weapons Databook, Volume 1: US Nuclear Forces and Capabilities*, (Cambridge, Massachusetts: Ballinger, 1984), p.79.

‡ As of 1985. *Report on Arms Control Limitations on Deployed Nuclear Armed SLCMs and their Verification*, DoD, March 1985 (Report in response to request of the Conference Committee on the FY 1985 Defense Authorization Bill, concerning arms control verification for SLCMs).

Table 3: Tomahawk Launchers

Type	Launchers/ unit	Location	Other weapons	Vessel type
Armored box launcher (ABL)	4	Above deck	None	Battleships Cruisers Destroyers
Vertical launch system (VLS)	61 or 29	Internal, top flush with deck	Standard ASROC	Destroyers Cruisers
Capsule launch system (CLS)	12	Outside inner pressure hull	None	*Los Angeles* 719 and later
Torpedo tubes	4 tubes per sub	Torpedo room (sub interior)	Torpedoes Harpoon Decoys	Attack subs (*Los Angeles* etc.)

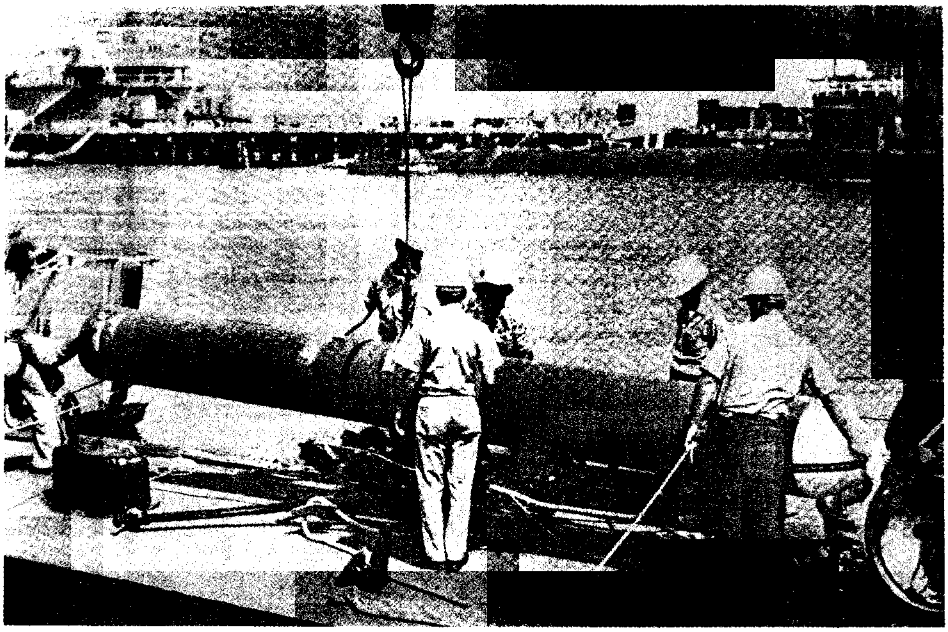

Figure 6: Torpedo Launch Tomahawks Being Loaded Into Submarine
Source: Cruise Missile Project US Navy

250 feet.[13] In the non-nuclear versions, guidance is supplemented near the target with DSMAC (Digital Scene Matching Area Correlator), which compares optically sensed scenes with images stored in the guidance computer. This brings the accuracy to within 25 feet, or perhaps 10.[14] DSMAC is not included in the nuclear version, apparently because such accuracy is not needed for nuclear weapons.[15]

Tomahawks are housed in four different types of launchers: the Armored Box Launcher (ABL) and the Vertical Launch System (VLS) on surface ships, and the Capsule Launch System (CLS) and torpedo tubes (torpedo rooms) on submarines. These are shown in figures 1, 2, 3, 4, and 6, and described in table 3.

APPENDIX 2: SOVIET SLCMS[16]

SS-N-21

The SS-N-21 is the first long-range Soviet SLCM. It is a development of the AS-15 air-launched cruise missile (deployed in Bear H bombers), and is essentially the same missile as the SSC-X-4 ground-launched cruise missile, banned by the INF Treaty.[17] The SS-N-21 missile is not believed to exist in a conventionally armed version. It is 6.4 meters long and 0.5 meters in diameter, small enough to be launched from standard 533-millimeter torpedo tubes. This makes it the smallest Soviet SLCM; yet its range is the longest, due to an advanced turbofan propulsion system. Earlier types of Soviet cruise missiles have less efficient turbojet engines, or solid-fueled rockets for the very short-range antiship missiles, as shown in table 4.

Testing of the SS-N-21 was reported in December 1987; the missiles were launched from an Akula-class submarine.[18] A single Victor III submarine with a cylindrical structure forward of the sail has also been reported as an SS-N-21 trials ship.[19]

The first deployment of the SS-N-21 was reported in January 1988, on a refitted Yankee submarine.[20] (The Yankee is an old ballistic missile submarine from which the launch tubes have been removed and which has been dismantled

Table 4: Soviet Sea-launched Cruise and Short-range Antiship Missiles

Missile	Year introduced	Range *km*	Launchers* deployed	Length† *m*	Diameter† *m*	Propulsion	Warhead	Launchers§
SS-N-2c	1959	80	36	6.5	0.7	turbojet	HE	surface ABL
SS-N-3	1960	460	256	11.7	1.0	turbojet	dual	surface ABL sub CLS
SS-N-7	1971	60	88	7.0	0.5?	solid fuel	dual	sub CLS
SS-N-9	1968	100	230	8.8	?	solid fuel	dual	surface ABL sub CLS
SS-N-12	1973	550	144	11.7	1.0	turbojet	dual	surface ABL sub CLS
SS-N-19	1980	550	136	10–12	1.0	turbojet	dual	surface VLS sub CLS
SS-N-21	1988	2,224	60#	6.4	0.5	turbofan	nuclear	sub CLS? torpedo
SS-N-22	1981	100	68	9.0?	?	solid fuel	dual	surface ABL
SS-NX-24	–	3,000?	(12)	13.0	1.0	?	nuclear	sub CLS

* *The Military Balance 1987–88*, (International Institute for Strategic Studies: Launcher numbers, 7/87); *Soviet Military Power 1987*; US Naval Institute Military Database. Dimensions of SS-N-12 and -19 are given as the same as SS-N-3 as they are said to be similar missiles.

† *Jane's Weapon Systems, 87–88*

‡ Barton Wright, *World Weapons Database Volume I: Soviet Missiles*, (Lexington Massachusetts: Lexington Books, 1986)

§ Indicates most similar US SLCM launcher. ABL refers to above-deck launcher; CLS refers to dedicated single launchers in submarines; and VLS to launchers below deck of surface ship.

\# Assuming 20 launchers on the Yankee, 3 Akulas with 6 tubes each, 2 Sierras with 6 tubes, and guessing 10 tubes for the Mike. Tube numbers from Norman Polmar, *Guide to the Soviet Navy*, 4th edition, (Annapolis: Naval Institute Press, 1986).

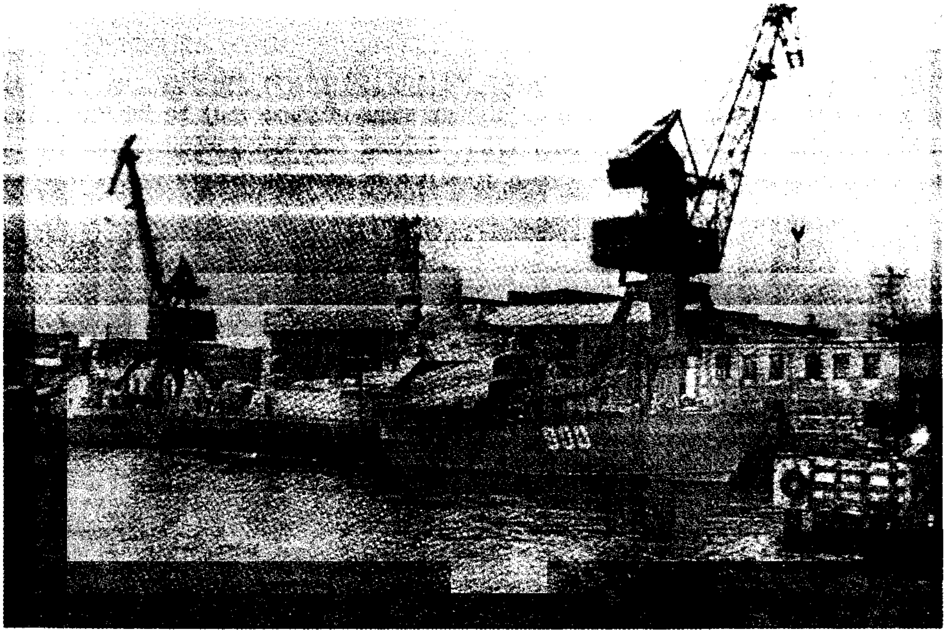

Figure 7: SS-N-9 Launchers and Loading Apparatus

Source: Norman Polmar

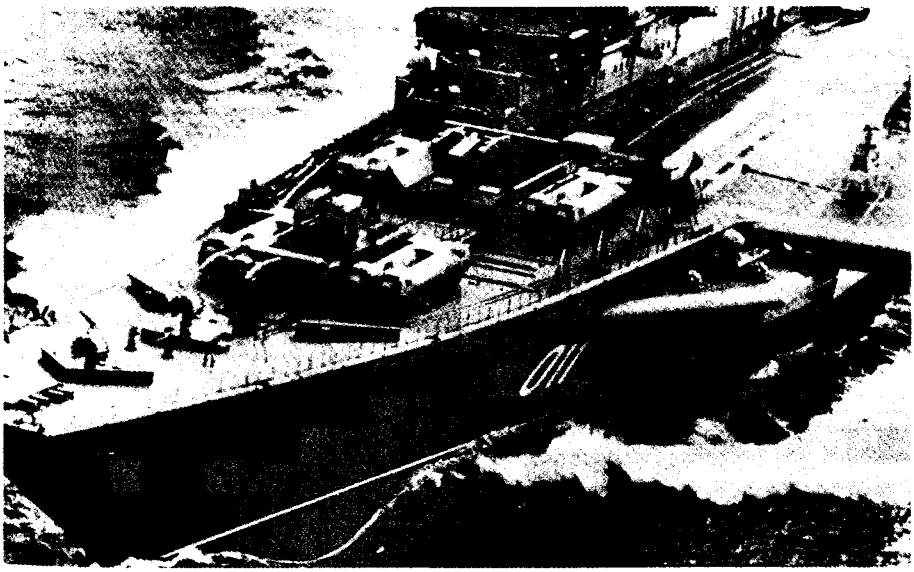

Figure 8: Four twin SS-N-12 Launchers on Soviet Carrier Minsk

Source: Jane's Information Services

and reconfigured to carry cruise missiles.) Norwegian defense officials estimated that the submarine can carry between 20 and 40 cruise missiles. At least 12 Yankee submarines are being refitted, though some of these may be for the larger SS-NX-24. The refitted Yankee submarine, dubbed the "wasp-waisted Yankee" or the Yankee Notch, is identifiable by a 10-meter increase in length and a 3-meter longer and reshaped fin.

Deployment of the SS-N-21 has recently been reported on three Akula class submarines, two Sierra class submarines, and one Mike class submarine, from which the missiles would be launched from torpedo tubes.[21] These are the most modern attack submarines of the Soviet Navy; all have been deployed since 1983.[22] There has been no indication of plans for deploying the SS-N-21 on surface ships.[23]

SS-NX-24

The SS-NX-24 is a large (13 meters × 1 meter) supersonic cruise missile. It is too big for a standard torpedo tube, so it will need a dedicated launcher. It has not yet been deployed, though it has been flight-tested from a reconfigured Yankee class submarine.[24]

The Soviet Navy is thought to be building a new cruise missile submarine specifically designed to carry the SS-NX-24, which is expected to be launched within the next year.[25] The SS-NX-24 is not reported to have a conventionally armed version.

Limits on deployment of the SS-NX-24 could be monitored by counting the number of launchers by satellite reconnaissance; on-site inspection would not be necessary.

Shorter-range Missiles (< 600 kilometers)

The Soviet Union has a variety of short-ranged sea-launched cruise missiles. The main types are denoted by the US as the SS-N-2, -3, -7, -9, -12, -19, and -22. All of these have a range of less than 600 kilometers; all are considered to be anti-ship, not land-attack weapons.[26] The SS-N-2 does not have a nuclear warhead; the others are thought to have both nuclear-armed and non-nuclear versions. The longest ranged of these are the SS-N-12 and SS-N-19, with ranges estimated at about 550 kilometers.

Figure 7 shows the SS-N-9 launchers and loading apparatus. Figure 8 shows the SS-N-12 launcher. As shown in these figures, many Soviet SLCMs are deployed in launchers that can be identified and counted using satellites. If these weapons were to be limited by arms control, counting the total number deployed should not be a major problem, though distinguishing nuclear from non-nuclear would require on-site inspections.

Limits on these systems have not been discussed at the START talks. But they could pose a verification problem for an agreement limiting long-range SLCMs, because the range of some may be difficult to verify.

APPENDIX 3: SLCM MONITORING METHODS FOR ON-SITE INSPECTION

For any treaty limiting SLCMs, satellite reconnaissance and all other available sources of intelligence would be available to monitor treaty compliance. Data exchanges concerning SLCM deployments and practices would also clearly be helpful in treaty verification. There is, however, a range of options available for on-site inspection. Possibilities include on-site monitoring of deployed SLCMs, monitoring of storage sites, and monitoring of production and maintenance sites. Inspection could be one-time-only, or on a continuing basis at specified sites, or on demand at numerous possible sites. Tags, seals, and fissile- material detectors could be used to discriminate between nuclear and non-nuclear weapons, and to identify previously declared missiles.

Detection of Nuclear Warheads

Nuclear SLCMs can be distinguished from non-nuclear SLCMs either passively, by detection of radiation spontaneously emitted by the warhead fissile material, or actively, by exposing the warhead area to gamma rays or neutrons and measuring the scattered, transmitted, or induced radiation. Detectability of nuclear warheads depends on the warhead design, the method of detection, the sensitivity of the detectors, and any material between the warhead and the detector that might shield the radiation.

The simplest method is passive detection of neutrons or photons emitted by the warhead. The study by Fetter et al.[27] considers four hypothetical nuclear warhead types.

The conclusion is that the neutrons from an unshielded warhead with a plutonium core could be detected with a portable neutron detector at a distance of on the order of ten meters with a detection time of a few minutes. Using larger but still moveable detectors for longer times (tens of minutes), such warheads might be detected at distances on the order of 100 meters.[28] For warheads with depleted uranium tampers surrounding the fissile core, the gamma-ray emissions from uranium-238 would be detectable at distances on the order of 10 meters using portable equipment.

However, warheads that do not contain plutonium or depleted uranium may not be detectable by passive means. Such a warhead might be made with a core of highly enriched uranium and a tungsten tamper. Or, since it is plutonium-240, not plutonium-239, that emits almost all of the neutrons from weapon-grade plutonium, it may be possible in principle to make a warhead from highly purified plutonium, in which the plutonium-240 concentration is reduced to less than 0.01 percent, to avoid passive detection.[29]

In addition, shielding reduces the detectability of a nuclear warhead. To prevent detection by a portable detector aimed at the weapon for one minute from a distance of one meter, neutrons from a weapon-grade plutonium warhead could be shielded with a layer of lithium hydride 20 centimeters thick. Similar reduction of the gamma-ray signal from a depleted uranium tamper would require a layer of about 4 centimeters of tungsten.[30] These figures indicate that nuclear warheads can be hidden within ships, rooms, and even large boxes, but that it could be difficult to put shielding within a missile canister to disguise the presence of a nuclear warhead containing either plutonium or depleted uranium-238.

An active detection method is radiographic analysis—the measurement of transmission of neutrons or gamma rays through the missile. The transmitted radiation has a different range in different materials. Gamma rays have a significantly longer range—and high-energy neutrons have a significantly shorter range—in carbon, aluminum and iron than in highly enriched uranium.[31] Therefore the amount of radiation transmitted through the missile could indicate the presence or absence of fissile material.

A third detection method is to measure the products of induced fission. Using a portable neutron source, fission can be induced, creating a detectable flux of delayed neutrons or photons from any of the weapon models considered out to distances of more than 10 meters. However, shielding could be as effective in preventing active detection as it is in preventing passive detection.[32]

At a portal monitoring station, such as at a production or maintenance facility, any of these methods might be used to distinguish nuclear from non-nuclear SLCMs. It would, of course, be crucial to minimize the possibility of shielding. Use of both passive detection methods and transmission radiography could indicate the presence of shielding.

If SLCMs on ships and submarines are to be monitored, procedures for fissile material detection would have to be carefully designed. It is time-consuming to remove SLCMs from their launchers, so it would be more convenient to make all measurements with the SLCM in its launcher. In this case transmission measurements would not be possible, since the radiation source and radiation detector must be on opposite sides of the missile.

Passive detection may be the most practical method. To minimize shielding, there should be nothing but air between the missile canister and the radiation detector. For the ABL, the surface ship VLS, the submarine CLS, or similar launchers, this can be accomplished by opening the hatches of the launcher (see figures 2, 3, and 4). Monitoring could be done by inspectors on the deck of the ship or possibly from helicopters hovering over the launchers. But to monitor SLCMs in torpedo rooms, it would be necessary, because of shielding effects, to take the detectors into the torpedo room. It might therefore be easier to monitor torpedo-launch SLCMs at port during loading (see figure 6). To check that no warheads specially designed to elude passive detection were deployed, SLCM canisters could occasionally be removed at random for radiographic examination.

Tags

Tags could simplify monitoring. A tag is any unique identifier that can be permanently affixed to a SLCM; an acceptable tag must be incapable of being forged. (Although part of the tag might be a seal to prevent its removal, the term "seal" will be reserved for devices to prevent or reveal the opening of a missile or missile canister.) A tag could identify a missile as one of a designated number, indicating that it did not come from a secret stockpile or production facility. The tag could also indicate whether the SLCM was nuclear or non-nuclear.

Tags could be installed during a baseline inspection of deployed missiles or at the production facility. During subsequent inspections, each SLCM would be checked for its tag, to ensure that it was a declared missile. If SLCMs are to be inspected while in canisters, the tag would need to be placed on the canister rather than on the missile itself. Any missile not associated with a tagged canister would be evidence of a violation. If SLCMs are to be inspected while in their launchers, the tag should be visible through the opened door of the launcher (see figures 2, 3, and 4).

Many types of tags are possible. Tags could be based on an intrinsic property of the missile or canister, such as details of surface features, or a tag could be an item that is applied to the missile. For example, Sandia National Laboratory has developed a tag made of clear plastic embedded with particles of micaceous hematite. For each angle of illumination there is a different pattern of reflections. The tag can be read with a special reader consisting of a still video camera and a number of lights. Readings can be compared with data stored on a computer floppy disk.

Electronic tags are also feasible and are under development.

A measure similar in effect to tagging would be to declare the position of all SLCMs and to announce all missile movements, as is required for the missiles being eliminated under the INF Treaty. Then inspectors could verify by random, short-notice site visits that the announced numbers of missiles were at the designated sites. If SLCMs were found during a challenge inspection at an undeclared site, they would clearly be in violation of the treaty. This declaration method would require more comprehensive revelation of SLCM locations than would tagging, but it has the advantage of reduced technical complexity.

Seals

A seal is a device that would prevent or reveal opening of a missile or missile canister. Seals could deter or indicate installation of nuclear warheads into non-nuclear SLCMs.

Non-nuclear SLCMs or their canisters could be sealed and tagged as nuclear or non-nuclear either at production facilities or during initial on-site inspections. During subsequent inspections, a broken seal might indicate that the missile had been tampered with. That missile could be subject to more detailed inspection, including monitoring for the presence of fissile material.

In the United States, SLCMs are returned for maintenance every 30–36 months. Seals would have to be removed at this time. Portal-perimeter monitoring could be established at these maintenance facilities: inspectors would check the seals and tags of incoming SLCMs, inspect the missiles after maintenance (to verify that all SLCMs designated non-nuclear were indeed non-nuclear), and reapply the seals and tags.

Seals made with fiber-optic bundles are routinely used by the International Atomic Energy Agency to safeguard nuclear materials. A variety of other designs for SLCM seals are possible.[33]

Inspection of Deployed SLCMs

Monitoring of deployed SLCMs would involve monitoring of weapons on ships and submarines or at ports. Allowing access to ships, submarines, and naval facilities raises the possibility of revealing military secrets. It also brings up the problem (for the United States at least) of maintaining a policy of "neither confirming nor denying" the presence of nuclear weapons on particular ships. These problems might be reduced by careful design of the inspection procedure.

The least intrusive inspection arrangement would be to restrict inspections to ships in port, and to restrict ship-board inspections to the vicinity of designated SLCM launchers (or to weapons removed from these launchers). This is the least effective combination, however, because of the possibility of weapons hidden elsewhere on the vessel, and the possibility of transfer of nuclear weapons to a ship during a subsequent undisclosed visit to another port.

Alternatively, to avoid any actual on-board inspection, inspectors could monitor the loading and unloading of designated SLCM carriers. This is an important component of a Soviet proposal for SLCM verification.[34] Inspection teams stationed at key ports would inspect and count each missile before it was loaded onto a ship or submarine. Equipment that could be used to load missiles at any other site, including at sea, would be banned.

Despite its advantages, this arrangement could result in a greater number of inspections than on-ship launcher inspections. While port monitors would inspect every loading, launchers could be checked only at infrequent random intervals.

The ABL sits above deck, carries four SLCMs, and does not carry other weapons. If the doors of the ABL were opened, inspectors could check tags on the missile canisters (see figure 3). Nuclear versions could be identified either by a special tag or by fissile material detection.

The VLS presents more of a problem, since it also stores other weapons. It is built into the ship so that the tops of the launchers are flush with the deck. Much of the VLS capacity is to be taken up by the (non-nuclear) Standard missile; it will also house a new, non-nuclear version of the ASROC (antisubmarine rocket). The VLS system is designed for reloading at sea, though the accompanying crane is only strong enough to transfer the Standard and ASROC missiles, not the heavier Tomahawk. The VLS hatches could be opened for inspection; a SLCM in its canister may look different from other weapons (see figure 4, showing reloading of the VLS system).[35] It might also be possible to remove weapons from the VLS system for detailed inspection, but this would be more time-consuming and more complex than simply looking into the launcher.

The CLS is a vertical launch system that will be built into attack submarines and will house 12 Tomahawks. Since it is outside the inner pressure hull of the submarine, it cannot be reloaded from inside the submarine. The CLS will be dedicated to SLCMs and could be inspected fairly easily by opening its hatches from the exterior of the submarine (see figure 2).

US (and Soviet) SLCMs are also deployed in attack submarine torpedo rooms for launch from torpedo tubes (see figure 6). In a US attack submarine torpedo room there is room for about two dozen weapons.[36] Not all of this space is likely to be taken up by Tomahawks: other torpedo-room weapons include torpedoes, the short-range Harpoon cruise missile, and decoys for antisubmarine warfare. Determination of the contents of a torpedo room would require access to the interior of the attack submarine. Because of the unwillingness of the US Navy (and perhaps the Soviet Navy) to allow inspections of submarines, monitoring of the loading and unloading of submarines, as the Soviets have proposed, could be the preferable alternative.

Under current US plans, SLCMs will be the only nuclear weapon deployed in SLCM-capable launchers. The US does not have a nuclear torpedo; the nuclear SUBROC, which can be launched from submarine torpedo tubes, is being phased out, and the new version of the ASROC, designed for the VLS system, is non-nuclear.[37] Therefore, if arrangements were made to allow detection of nuclear weapons in SLCM-capable launchers or being loaded into torpedo rooms, any US nuclear weapon detected could be counted as a nuclear SLCM.

Monitoring of deployed nuclear SLCMs would allow inspectors to determine that no more than the allowed number were deployed. However, because SLCMs can be stored on land, the number of deployed nuclear SLCMs might be increased rapidly in a "breakout" from a treaty limit.

On-Site Production Monitoring

The role of production monitoring depends on the contents of the agreement. If SLCMs were to be produced while the treaty was in effect, production monitoring would allow inspectors to count the number of SLCMs produced. If SLCMs were to be inspected again at a later time, a unique tag could be put on each SLCM at the production facility. If non-nuclear long-range SLCMs were being produced, inspectors could verify that only non-nuclear warheads were installed. If short-range SLCMs were being produced, inspectors could verify that only the designated engines and warheads were installed.

In the United States, Tomahawk SLCMs are produced by General Dynamics Convair Division in San Diego, California, and by McDonnell Douglas in Titusville, Florida. Figure 9 shows Tomahawk production at General Dynamics. The warheads of the non-nuclear Tomahawks are installed at these facilities, but the nuclear Tomahawks are shipped from the factory without warheads. Nuclear warheads are manufactured by the Department of Energy and are installed at naval weapons facilities, of which there are about 16.

Fissile-material detectors would therefore not be able to distinguish non-nuclear SLCMs from prenuclear SLCMs at US production facilities, even though there are internal structural differences. However, each non-nuclear SLCM could be subjected to fissile-material inspection (just to make sure) and its canister

Figure 9: Tomahawk Final Assembly

Source: General Dynamics, Kearney Mesa, California tagged and sealed, so that on subsequent inspection it could be identified as non-nuclear. Canisters containing the prenuclear SLCMs could be tagged as identified nuclear SLCMs. These canisters would be opened later, at a naval weapons facility, for warhead installation. This procedure could be monitored, though this might not be considered necessary since these missiles would already be tagged as "nuclear."

Challenge inspections might be employed to deter or detect clandestine production. Cruise missile production facilities do not have particularly obvious external features to aid their discovery by satellite reconnaissance. Nevertheless, SLCM manufacture would probably be easiest to hide in facilities that turn out similar products, such as ALCMs, drones, SRAMs (short-range attack missiles), and the Harpoon in the United States, and similar systems in the Soviet Union. Shipment of missile parts in and out of such facilities would not be unusual, nor would employment of a specialized work force or use of specialized machinery.

What would constitute a production violation must be clearly defined. Simple limits on missile size would not be sufficient, because a large missile does not necessarily have a long range. For example, the long-range SS-N-21 is actually the smallest Soviet SLCM (see table 4, appendix 2). But short-range cruise missiles could be distinguished from long-range on the basis of a combination of size, engine, and other design features.

Some of this information may be considered secret. In particular, the US is developing an advanced long-range non-nuclear cruise missile, which may incorporate special materials to decrease radar observability. The United States may be reluctant to permit inspection of these facilities.

Inspection procedures might be designed to minimize some of these problems. For example, the technology used for large but short-range missiles is probably old, so little risk would be taken in demonstrating the inefficiency of the missile. Small, short-range missiles, such as the Harpoon, may rely on sensitive technology, but their size in itself demonstrates that they are short-ranged.

As already noted, effective production monitoring might be difficult if not impossible if ALCM and SLCM production were not both limited by compatible treaties.

Inspection of Storage Sites

Sixteen naval ordnance shore facilities have been selected to support the US Tomahawk: six supporting Atlantic Fleet Units and ten supporting Pacific Fleet Units.[38] Requirements include waterfront facilities, magazines suitable for the storage of high explosives, security facilities, and facilities for intermediate maintenance. The Soviet Union may have fewer support facilities for its long-range SLCMs, because they have fewer ports and fewer long-range SLCMs.

Monitoring of such storage sites could be continuous portal-perimeter monitoring or it could be limited to periodic inspections. A typical naval base is a large facility supporting a variety of naval activities. Continuous portal monitoring at these facilities would be a major undertaking, which might be complicated by other naval operations at the same facilities.

The Soviet Union has proposed that facilities suspected of storing clandestine cruise missiles be subject to challenge inspections. Certain highly sensitive facilities, such as military command posts or intelligence centers would be exempted from inspection.[39]

The usefulness of challenge inspections would depend on the likelihood of receiving information on possible clandestine storage sites. Storage sites for nuclear weapons might be distinguished by extra security and extra fences, but it would be difficult to distinguish storage sites for nuclear SLCMs from storage areas for other nuclear and non-nuclear naval weapons.

Monitoring of Maintenance Sites

In the US, SLCMs are returned to the production facilities for "depot maintenance" once every three years.[40] During maintenance, it would in principle be possible to exchange warheads or increase the range of short-range SLCMs. Portal-perimeter monitoring could ensure that all already deployed SLCMs were tagged and that subsequently only tagged missiles were returned and that the proper numbers of nuclear and non-nuclear missiles were maintained.

Intermediate maintenance may be conducted at naval bases or on submarine tenders. To reduce concern over warhead exchange, these facilities might be opened to inspection. Alternatively, non-nuclear SLCMs could be kept in sealed containers that were to be opened only at the designated depot maintenance sites.

NOTES AND REFERENCES

1. Joint US-Soviet Statement, Washington Summit, 10 December 1987.

2. Dan Oberdorfer, "Mixed Results Cited in Arms Talks," *Washington Post*, 21 April 1988, p.A33.

3. *Intelligence Support to Arms Control*, Report by the Permanent Select Committee on Intelligence, House of Representatives, November 1987, dissenting views of Reps. Hyde, Cheney, Livingston, McEwen, Lungren, and Shuster, pp. 33–39.

4. Admiral Hostettler, director, Joint Cruise Missile Project, 8 March 1985. Senate Armed Services Committee, DoD Authorization Hearings FY 1986, part 7, p.3875.

5. Fred Hiatt and Rick Atkinson, "Insertable Nuclear Warheads Could Convert Arms," *Washington Post*, 15 June 1986, p.A1; letter from John Engehart, *Proceedings of the US Naval Institute*, February 1987, pp.19–20.

6. "Naval Report: Extent of Soviet Submarine Power," *Jane's Defense Weekly*, 3 December 1988, p.1409.

7. Testimony of Ambassador Maynard W. Glitman, 26 January 1988, INF Treaty Hearings, Senate Foreign Relations Committee, part 1, p.150.

8. Testimony of Harold Brown, Secretary of Defense, 23 July 1979, Senate Armed Services Committee, SALT II Hearings, 1979, part 1, p.48; testimony of Ambassador Ralph Earle, 30 July 1979, ibid., part 2, pp.507–510, 535–536.

9. Thomas B. Cochran, William M. Arkin, and Milton M. Hoenig, *Nuclear Weapons Databook, Volume 1: US Nuclear Forces and Capabilities*, (Cambridge, Massachusetts: Ballinger, 1984), p.188.

10. Ambassador Glitman, INF Treaty Hearings, Senate Foreign Relations Committee, part 1, 26 January 1988, p.150.

11. R. Jeffrey Smith, "Soviets Seek Cruise Data Verification," *Washington Post*, 23 July 1988, p.A1.

12. As of early 1988. Information provided by the Cruise Missile Project, US Navy.

13. Testimony of Commodore Roger F. Bacon, 14 March 1984, House Armed Services Committee, DoD Authorization Hearings FY 1985, part 2, p.392. CEP—circular error probable—is the radius within which half of the missiles would fall.

14. Testimony of Richard Perle, 16 February 1988, Hearings on the INF Treaty of the Senate Foreign Relations Committee, part 3, p.435,

15. Testimony of Admiral Stephen J. Hostettler, 13 March 1985, House Armed Services Committee, DoD Authorization Hearings, FY 1986, part 2, p.517.

16. For background on Soviet SLCM programs, see Joel Wit, "Soviet Cruise Missiles," *Survival*, November/December 1983.

17. Testimony of Admiral Crowe, USN, chairman, Joint Chiefs of Staff, 4 February 1988, INF Treaty Hearings, Senate Foreign Relations Committee, part 2, p.268.

18. Edward Neilan, "Soviet Cruise Missile Tested in Sea of Japan," *Washington Times*, 28 December 1987.

19. Norman Polmar, *Guide to The Soviet Navy* (Annapolis, Maryland: Naval Institute Press, 1986), 4th edition.

20. Tønne Huitfeldt, "Soviet SS-N-21 Equipped with 'Yankee' in Norwegian Sea," *Jane's Defense Weekly*, 16 January 1988, pp.44–45; "Soviets Get Around Arms Treaty by Updating Arms on Older Subs," (Reuters) *Washington Times*, 13 January 1988, p.9.

21. "Naval Report: Extent of Soviet Submarine Power," *Jane's Defense Weekly*, 3 December 1988, p.1409. The Mike subsequently sank. "42 Die as 'Mike' Submarine Sinks," *Jane's Defense Weekly*, 15 April 1989, p.629.

22. *Soviet Military Power: An Assessment of the Threat 1988* (Washington DC: US Government Printing Office) p.85.

23. FY 1986 Arms Control Impact Statement, (Washington DC: Government Printing Office, 1985) p.64.

24. Bernard Blake, ed., *Jane's Weapon Systems 1987–88* (New York: Jane's Publishing Inc., 1987), 18th edition, p.115,116; *Soviet Military Power 1987*, p.37.

25. "Soviet Intelligence: Developments in Submarine Forces," *Jane's Defense Weekly*, 12 November 1988, p.1233.

26. FY 1986 Arms Control Impact Statement, p.84.

27. S. Fetter, V. Frolov, M. Miller, R. Mozley, O. Prilutsky, and R. Sagdeev, "Detecting Nuclear Warheads," *Science & Global Security*, to be published.

28. ibid.

29. ibid.

30. A spherical shell of tungsten (density 19.2 g/cm^3) with an inner diameter of 22 centimeters and weighing 600 kilograms, as discussed by Fetter et al., has a thickness of about 4 centimeters. The warhead need not be entirely surrounded by tungsten, only over those angles accessible by the detector.

31. ibid.

32. ibid.

33. Dennis L. Mangan, *Hardware for Potential Unattended Surveillance and Monitoring Applications* (Albuquerque, New Mexico: Sandia National Laboratory, January 1988), Report SAND87-2840.

34. R. Jeffrey Smith, "Soviets Seek Cruise Data Verification," *Washington Post*, 23 July 1988, p.A1.

35. Paul W. Stiles, "An Alternative to VLS UnRep," *Proceedings of the US Naval Institute*, December 1987, p.129.

36. Norman Polmar, *The American Submarine* (Annapolis, Maryland: Nautical and Aviation Publishing, 1981), p.151.

37. A nuclear variant of the Sea Lance submarine-launched antisubmarine missile is under consideration. If approved, it could be ready for deployment in the mid 1990s. Report of the Secretary of Defense Frank C. Carlucci to the Congress, (Washington DC: US Government Printing Office, 17 January 1989).

38. Statement of Rear Admiral William C. Bowes, director, Cruise Missile Project, House Armed Services Committee, DoD Authorization Hearings FY 1989, 21 April 1988. These sites include the Naval Weapon Station in Earle, New Jersey, shore facilities in Yorktown, Virginia, and New London, Connecticut, and the Naval magazine facility in Guam, all of which will support Tomahawk submarine operations. Four submarine tenders have also been upgraded to handle submarine-deployed Tomahawks. House Armed Services Committee, DoD Authorization Hearings FY 1987, p.970: these include the USS *Fulton* (AS-11) and the USS *McKee* (AS-41).

39. R. Jeffrey Smith, "Soviets Seek Cruise Data Verification," *Washington Post, 23 July 1988, p.A1.*

40. Admiral Hostettler, director, Joint Cruise Missile Project, Senate Armed Services Committee, DoD Authorization Hearings FY 1986, part 7, p.3875. Statement of Rear Admiral William C. Bowes, director, Cruise Missile Project, before the Defense Subcommittee of the House Appropriations Committee, on the Tomahawk Weapon System, 21 April 1988.