Will Strategic Submarines Be Vulnerable?

Richard L. Garwin

In view of the increasing emphasis placed upon strategic submarines under the Reagan strategic program announced October 2, 1981, it is of interest to review the prospects for survivability of such submarines in the foreseeable future. This is particularly timely because the Scowcroft Commission has confirmed the U.S. inability to identify a survivable land-basing posture for the MX missile and because the Soviet Union will presumably soon be faced with the vulnerability of its own silo-based ICBM force, whether by reentry vehicles on U.S. ICBMs or from U.S. SLBMs.

Antisubmarine warfare (ASW) techniques and capabilities important for *strategic* purposes are quite different from those which can be employed in *tactical* antisubmarine operations. Strategic offensive submarines are able to carry out their mission—delivering nuclear weapons against the homeland of an opponent—while, at the same time, limiting their own vulnerability by utilizing evasive modes of deployment and operation. Tactical, or attack, submarines, on the other hand, must approach their target—warships, merchant ships, a chokepoint to be mined, or the like—to be successful; this limits their flexibility in operational decisions. Furthermore, the contest between tactical submarines and ASW forces may take place over months or years, involves no trailing of submarines but the kill of submarines essentially on sight, and could be modulated by either side to its own advantage. In a long war of attrition, for example, the naval forces of one side may be kept at home or in sanctuaries, so that the enemy's attack submarines would have no targets. The attack submarines themselves may be kept at home or out of danger if using them were deemed too hazardous because of their vulnerability. In contrast, to be effective and worth contemplating, ASW against strategic submarines would have to threaten to destroy almost all offensive submarines within a few days at most. Otherwise, ASW would be superfluous, since both U.S. and Soviet forces would be vulnerable over a period of months to repeated attacks on their accustomed ports.[1]

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1. This vulnerability over protracted periods is not unique to submarines. Obviously, nuclear attacks on the accustomed bases of strategic bombers (accompanied by fallout and attack on

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Here, I will not consider strategic ASW capabilities which could detect and destroy an opposing force only over a period of weeks, but will look instead at those capabilities which conceivably could pose a threat to strategic submarines over a period of one week or less. One can imagine wars of attrition against strategic submarines, but should such a nightmare actually occur, the logical counter would be to attack enemy military bases with nuclear weapons. In any event, such protracted war scenarios are not particularly relevant for evaluations of possible technological developments that would (newly) threaten the survivability of strategic submarines.

It should be noted at the outset that even the sudden destruction of a substantial fraction of the deployed strategic submarine fleet, taken alone, would not constitute a disabling blow against either U.S. or Soviet retaliatory capability, any more than the planned survival of only 50 percent of the land-based missiles would vitiate that system, or the inability of 50 percent of the strategic bomber fleet to take off or to penetrate Soviet air defense would negate the value of the air-breathing strategic component. Additionally, even potential future ASW capabilities which appear to threaten strategic submarine operations and deployments as such are currently practiced are not a peril if the postulated ASW technique or system could be substantially countered by modifying submarine operations, by countermeasures that could fool the detection system, or by reliable means of counterattacking the ASW system before it had destroyed a substantial fraction of the strategic submarine force.

Some advocate "moving the strategic force to sea" in order to reduce (or reduce the consequences of) actual or perceived vulnerability of land-based ICBMs. Although I believe that even a vulnerable Minuteman force is valuable and non-provocative, and that small, single-RV ICBMs have a good future even under some future SALT agreement, it is true that ICBM-range SLBMs (such as the Trident II [D-5] missile, the MX, or a small ICBM) can now be given accuracy equivalent to that specified for the land-based MX. We shall note later that the SSBN force can be controlled and communicated with about as well as can a land-based force, so the choice between land and sea may well be made on the bases of cost and vulnerability. The latter is the topic of this article.

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other airfields) would lead to attrition of that force over a period of days or weeks. The landing of saboteurs or even fallout in the land-based missile fields would prevent access for maintenance and could degrade their capabilities over a period of weeks or months. All components of strategic offensive forces, thus, share a "use it or lose it" characteristic, over a period on the order of days or months.

As for cost, a recent publication[2] drawing upon work sponsored by the Navy and Defense Department estimated that a system of small submarines (SUM) "is at least $10 billion less expensive than the drag strip (multiple protective shelter basing of MX) for deploying and operating 850 survivable and effective warheads." It noted also the likelihood that the drag-strip deployment "would be even larger and more expensive or require an active and costly ballistic missile defense" actually to provide that number of survivable warheads. This basing mode was ultimately rejected in favor of placing the MX in existing (modified) Minuteman silos. Yet, in attempts to bypass the many problems with land-basing, SSBN systems of the future may contain also encapsulated MX missiles, carried horizontally outside the pressure hull of a small submarine, two or four on each side. Carrying true ICBMs (as opposed to shorter-range missiles), these submarines would find no advantage in moving far from their home ports in the continental U.S. and Alaska, so the Soviet ASW threat within a few hundred miles of U.S. coasts is relevant, as are the special means we might take to counter that threat at such great distance from the Soviet Union and so close to U.S. territory.

The Potential Effectiveness of Current ASW Technologies

For purposes of discussion, potential threats to strategic submarines may be grouped in three categories:

—Those in which deployed strategic submarines are kept within range of an attack weapon; this is known as "trailing."

—Those in which the attacker can narrow the area of uncertainty in which the submarine is deployed to one that is much smaller than the overall potential deployment zone, so that one or more individual search-and-kill platforms (e.g., aircraft) can be directed to a relatively small area to find the strategic submarine and attack it; this is known as "tracking."

—Those in which the entire deployment (or hiding) area must be searched at the beginning of hostilities and strategic submarines could be destroyed only as they were detected, localized, and attacked; this is know as "open-ocean search."

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2. S.D. Drell and R.L. Garwin, "Basing the MX Missile: A Better Idea," *Technology Review*, May 1981.

THE TRAILING THREAT

The potential deployment zones of nuclear-powered ballistic-missile-launching strategic submarines (SSBNs) are limited—with only minor exceptions—only by the necessity to remain within missile range of their targets. In view of the long range of modern submarine-launched ballistic missiles, these potential deployment zones are very large and the problem of locating the SSBNs accordingly difficult.[3] One way of gaining information about the precise location of the target SSBN might be to trail it with nuclear-powered attack submarines (SSNs) from such short ranges that the target submarine would be vulnerable to attack with torpedoes or submarine-launched, rocket-carried nuclear warheads (SUBROC) if an order were given to destroy the SSBN fleet. Indeed, it would be feasible to trail SSBNs from surface ships equipped with an appropriate sonar. However, given the acute interest of an SSBN in knowing whether it (and its whole fleet of siblings) is held in trail, the availability of submarine-deployed towed arrays, the possible existence of "delousing facilities" in the open ocean,[4] and the like, it is inconceivable that a fleet-wide covert trailing operation could be long maintained. Thus, any trailing which occurred might as well be overt (which is much easier technically) and carried out at very short ranges in order to reduce the probability of loss of trail and to facilitate attack upon demand.

Such a trailing vehicle could use imaging sonar systems which project audible pulses (or utilize higher frequencies) to 1 nautical mile or less, which are then reflected strongly by the submarine so that the trailing could be aided by following the submarine image on the sonar. The trailer would thus have advance warning of impending maneuvers by its target and be able to maintain an advantageous position. The well-known variability of the ocean in refracting sound waves gives no protection against such short-range active

3. With Moscow as a target, ocean operating areas (in millions of square kilometers) achievable with various SLBM ranges are: 2,800 km—5.5 million; 4,600 km—19 million; 7,400 km—62 million; 11,100 km—180 million. In this article we have standardized on metric units; for those more comfortable with nautical miles and yards, 1 nmi = 1.85 km; 1 sq nmi = 3.43 sq km; 1 yd = 0.91 m; 1 kn = 1.85 km/hr.

4. The "towed array" is a cable hundreds of meters long with microphones spaced in its interior which can be towed by a submarine or a surface ship to provide a sensitive receiver of sounds generated by submarines or other trailing vessels. In addition to the sensitivity, the array determines the direction of origin of the sound to within one degree or so. The "delousing facility" might be a region of fixed detailed acoustic surveillance provided by the host country so that a submarine can traverse the area to learn whether it has a trailer attached. If the trailer chooses not to enter the area, it loses trail; alternatively, if it continues to trail the submarine, it is detected and subject to harassment or diversion.

sonar trailing, since the refraction of sound in the ocean never exceeds an angle of 15 degrees, and the trailing vehicle could remain (in adverse waters) at a distance from the quarry less than a few times its depth so that the dip of the sound ray exceeds the possible refraction angle. The (acoustic) vision might be distorted, but it would not be blocked.

Continuous active trailing would require at least three trailers per deployed SSBN and an appropriate kill weapon, but the most demanding requirement would be to reliably acquire trail in a time much shorter than the submarine deployment tours of two months or so. Although SSBNs operate from only a few ports, it can by no means be assured that overt or covert intelligence-gatherers outside that port could not detect and identify emerging SSBNs at relatively short range, and assign trailers to them. Presumably, this would not occur in peacetime within the 12-mile (22-km) limit, but unless operational countermeasures were taken, such restraint could not be assured, particularly during crises. Such operational countermeasures could include: potential target SSBNs creeping along their home coasts and unexpectedly dashing for open waters; their emerging in pairs or in the company of friendly SSNs so that the trailers would often choose the wrong submarine; the passing of the potential target submarine through regions of artificially high acoustical noise; and the establishment of zones near the SSBN base in which friendly naval forces would pose a physical hazard to the trailers if they followed the SSBN to this operating area. Trailing also might be deterred by the consequences for political relations between nations involved. Presumably, political tensions would rise sharply if an SSBN fleet were put under active trail.

But finally, if one side made the investment to acquire and operate effective trailing, it could still be countered if the SSBNs under trail ejected explosive charges (of limited lifetime) at times of their own choosing, which would destroy any trailers. It is probably the inevitability and effectiveness of this potential countermeasure, more than anything, which keeps both the U.S. and the Soviet Union from building a fleet of active sonar trailers.

THE TRACKING THREAT

Given the search and kill radius of a homing torpedo (1 km or more), or the range of a rocket-propelled nuclear warhead (20 km or more), the tracking threat differs from the trailing threat (i.e., requires a further step of localization) only if the dimensions of the tracking uncertainty area of a given SSBN exceed about 20 km, so that there is indeed a need to search for the SSBN in an uncertainty region exceeding 1000 square km. On the other hand, given an operating area for some tens of submarines on the order of 20 million square km, searching the entire operating area to destroy every submarine encountered would correspond to a search requirement on the order of 1 million square km per submarine. This reduction from 1 million to 1,000 square km search area is the origin of concern with the tracking threat. Thus, a system which in peacetime could track each deployed SSBN and localize it to an operating area of even 100,000 square km would allow localization and kill with perhaps 1/10th the hunter-killer force required for open-ocean search.

Such tracking systems must be characterized not only by their precision, but also by their "time-late." Even if such a system could gain precise knowledge of the target submarine's location, the information would be useful only if it could be made available to the weapon system to be used for the attack before the target had moved significantly. An acoustic system, for instance, would receive tracking information at a time-late enforced by the travel time of sound in the ocean (a speed of 1.5 km per second). Thus, acoustic systems with detection ranges of 1,000 km have a time-late on the order of 10 minutes, while those with detection ranges of 5,000 km would have a time-late on the order of one hour. During these times, submarines operating at a reasonable ten-knot patrol speed could have moved on the order of 3 or 20 km respectively. Since the submarine can move in any direction at a speed up to 18 km/hr (10 kn) or so, the uncertainty area after ten minutes is 30 square km; after one hour, 1,100 square km; and after two hours, 4,400 square km.

The only existing long-range system capable of tracking and localizing submarines in this way is advanced passive sonar. Arrays of listening devices may be deployed on the ocean bottom and the signals they detect reported by oceanic cable to processing stations on land. The noise radiated by submarines in the frequency range below a few hundred Hz[5] can travel thousands of km with little attenuation. In a noise-free ocean these signals can be used to provide a line of bearing to the source submarine. The detection of a submarine by several such arrays of listening devices (or alternatively its detection at many individual hydrophones spread throughout the ocean) could be used to localize the submarine to an accuracy which under the best of circumstances might be in the range of some tens of km.

Three problems limit these potential capabilities, however. First, the ocean is full of noise coming from many sources including natural origins and

5. One Hertz is one cycle of oscillation per second.

thousands of ships which sound more or less like submarines. The second difficulty stems from the fact that sound in the ocean is refracted strongly by the general reduction of water temperature and compressibility at depth.[6] Thus a submarine which is clearly audible at 700 km may be totally inaudible at 680 km. Third, the technical problem of keeping sensitive equipment working for long periods in a difficult ocean environment vastly reduces the capability one might otherwise assign to such listening systems.

If we assume for the moment the possibility of tracking some fraction of the deployed strategic submarine fleet at long range, what would be the resulting ASW threat?

Submarines could be attacked without further localization by *barraging* the uncertainty area with nuclear weapons delivered by land-based missiles. Because of the time-late of sound propagation and the notional 30-minute flight time of an ICBM (as well as the size of the original uncertainty area of the tracking system), a single warhead would provide only a small kill probability against the target submarine. Submarines exposed to such a threat would be well advised to patrol normally at a depth of about 100 meters, to minimize the lethality of a warhead of a given yield.[7] A 1-megaton warhead descending to optimum depth in the ocean would have a kill radius of about 5.6 km against a submarine at 100-meter depth, and would thus pose a threat to the survival of submarines within an area of about 100 square km. We have noted that perfect localization at acoustic range at a range of 5,000 km corresponds to a time-late of about 1 hour and an uncertainty area of about 1,100 square km. Adding 30 minutes flight time for an ICBM to deliver its warhead leads to the requirement to barrage some 2,300 square km, which would require 2,300/100 or some 23 single megaton warheads to destroy a single undecoyed SSBN detected at 5,000 km range on a perfectly accurate acoustic surveillance system.

6. This results in a complex sound velocity profile which in deep water bends sound rays so that they plunge repeatedly to depths of 3 km or so, returning near the surface at intervals of 50 km.
7. Because the shock wave pressure at the surface of an underwater nuclear explosion is zero (due to the addition of a reflected impulse), submarines are least vulnerable near the surface. Furthermore, in this way the strength of the submarine against high pressures is available for resisting the overpressure of the explosion, whereas if the submarine were operating at maximum depth, a relatively small additional explosive pressure could crush it. The submarine cannot operate *at* the surface because it would be detectable by vision, by the noise produced by cavitating propellers, and the like. Similarly, a nuclear warhead is most effective when it is detonated at an optimum depth; detonation at or close to the surface wastes the explosive energy by venting the bubble produced.

Of course, many nuclear warheads might be employed against such a valuable target as a strategic submarine. If one imagines that a force incorporating 2,000 megatons yield is made available for this ASW activity, then the overall operating area which could be barraged would be about 200,000 square km. Given the deployment of perhaps 30 SSBNs, the tracking system and the resulting barrage would pose a serious threat to their survival only if the accuracy of tracking limited the uncertainty area per submarine to 7,000 square km or less (or if there were an intermediate stage of localization to this accuracy or better). Such a large number of warheads could barrage an uncertainty area generated by 2 hours delay after perfect localization of the submarines, or by a localization accuracy of 50 km (or a combination of the two). This is the magnitude of the threat, if unopposed. Should such a large system capability emerge, it could still be countered by jamming (to deny the detection of valid submarine targets); by decoys (to add to the valid submarine targets a sufficiently large number of apparently valid targets that the opponent could not destroy them all); or by destruction of the detection system.

Over the years, physicists, acousticians, oceanographers, and those interested either in imperiling submarines or in preserving them have learned of the complexity of the ocean. The long-range acoustic path is predictably obstructed by seamounts; the convergence-zone propagation of sound limits the reliability of detection; ocean noise may mask submarine acoustic signatures; submarines have local sensors to enable them to stay in particularly favorable near-surface water layers, those from which the sound cannot propagate to long distance; and submarines can operate in shallow water in which there is *no* good long-range propagation of sound.

These are the fundamental problems which would be faced by any long-range acoustic tracking system, even without the target submarine taking any countermeasures. For the detection of submarines traveling at high speeds (35-55 km/hr), the immense variability of the ocean is less of a problem because the sound radiated at such speed is dominated by the noise of the submarine's propeller. This source of noise becomes negligible at speeds below about 18 km/hr. Thus, SSBNs which are eminently detectable and vulnerable while traversing the broad oceans at very high speeds to reach their operating areas can slow to a discreet patrol speed at which their radiated noise is much reduced.

Long-range detection with intermediate localization to improve accuracy and carry out the attack would require the dispatching of weapon platforms to localize the target submarine. These vehicles could be supersonic aircraft like the Backfire, but they would take several hours to reach the search area. They could also be missile-delivered automatic sensors which would search within the original uncertainty area and then report back by radio to enable attack by other missiles. The localization could proceed by active acoustic means, by directional passive acoustic means, or by a pattern search for the disturbance of the earth's magnetic field created by the heavy steel hull of the submarine.[8]

Furthermore, an attack on strategic submarines with nuclear weapons would spoil the ocean basin for long-range acoustic detection for many hours because of the very intense sound produced by the nuclear explosion itself and its subsequent multiple reflections from the ocean boundaries. Moreover, there would be a substantial problem in categorizing submarines as enemy or friendly, or as SSBNs or SSNs, in partial or unreliable detections in which there might be only a line of bearing rather than a cross-fix by two or more detecting arrays.

There also are potential counters to long-range passive acoustic tracking, including the use of artificial noisemakers to increase the oceanic basin noise. Since even a noisy submarine radiates a total acoustic noise of only 0.1 watt, and quiet submarines in the range of 0.01 watt or less, it would be a trivial matter to provide a long-endurance noisemaker which could transmit a recorded submarine signature for a period of hours or days. The provision of hundreds or thousands of such noisemakers could well eliminate the possibility of detecting submarines in the first place. Some dozens of noisemakers provided with a few-knot mobility could simulate SSBNs themselves, making attack on detected "SSBNs" unprofitable.

Launching the SSBN missiles during the flight time of the land-based missiles used to barrage its operating area would negate the purpose of the attack. The U.S. continually receives information on Soviet missile launches from infrared warning satellites. Unless these satellites were destroyed preemptively, itself a signal of an impending attack, there would be 10 minutes or more warning of a massive barrage attack against submarines. Depending on (or forcing) an ability to launch submarine-based missiles from under an attack is not without its own problems, chief among them being the instability it might introduce into the strategic posture if the submarine missiles have enough accuracy to be thought to imperil ICBM silos.

8. Most submarines can be detected by the magnetic disturbance to a range of 0.5 km, but not exceeding 1 km.

All in all, there seems to be little prospect of a long-range acoustic system which could hold in track a large fraction of an uncooperative SSBN fleet. The possible follow-up localization forces just noted do not at present exist, and in any case could be countered by noisemakers or other means. Further, there seems to be no known detection phenomenon other than acoustics capable of providing signals which could be used to track SSBNs at long distances. Prospects for the discovery of such techniques in the future are discussed subsequently.

THE AREA-SEARCH THREAT

If SSBNs cannot be trailed and killed on command, and cannot be tracked and localized and then destroyed all of a sudden, could their entire operating area be searched and the submarines destroyed as they were found? The detection of submarines by arrays of acoustic sensors can be ignored here, since that possibility is subsumed under the tracking threat. Logically, an area-search threat must involve something which is too expensive or too provocative to use all the time, but which would be capable of searching the entire deployment area in a few days or less and reliably detecting, identifying, and localizing SSBNs so that they may be destroyed. One can imagine the use of short-range sensors on numerous fast-moving platforms such as aircraft to search out a 20-million square km deployment area. If the sensor used were a magnetometer with a sweep width of 1 km, then a single aircraft operating at 400 km per hr would require 50,000 hours to sweep the area. Even a fleet of 100 aircraft would require 500 hours, and there would be no guarantee that either a random or a pattern search of the operating area would find all the submarines, even if the sensor were totally effective. This result is due to the relatively narrow sweep width, which would allow submarines in their normal operations to drift from an as-yet unswept into an already-swept area, and thus to be missed by further sweeping. The result is that 37 percent of the submarines would be undetected after 50,000 airplane-hours of search, 14 percent after 100,000 hours, and so on.

Because of this latter problem, the only significant threat to deployed submarines would arise from active or passive sonar. But if long-range active sonar were used to sweep the operating area, it could be heard far beyond the range at which it could detect the target submarine, allowing the target to evade by operating near the surface or in other areas unfavorable for acoustic propagation, or by maintaining nose-on orientation with respect to the sonar (to reduce the echoing area). The use of passive sonar would give no such indication of sweeping activity. The most effective mobile passive sonar at present is a towed array of detectors which can be towed by surface ships or submarines. In either case, a vessel making a few knots could tow such an array several hundred meters long at appropriate depths, with the capability of detecting rather noisy submarines out to distances of a few hundred km. Sound propagates to that distance, however, only by repeated refraction through the ocean depth, with the previously noted inconveniences of convergence-zone detection. In any case, even a ship with a 300-km passive sonar range could detect submarines only in a neighboring area of 200,000 square km, so that about 100 such ships would be required in even favorable circumstances to obtain single line-of-bearing detections on some fraction of the submarines in the 20-million square km deployment area. Further, in order to exploit these detections, the detected submarines would have to be distinguished from surface ships, and each such contact would have to be explored and attacked successfully. This process could be undertaken by helicopters or fixed-wing aircraft, which were vectored by the ship towing the sonar array. Uncountered, a fleet of some hundred such towed arrays and aircraft could detect relatively noisy submarines and run them down within some hours. Still, because of the complexity of sound travel in the ocean, the result would be a gradual attrition of the strategic submarines, not the near-instantaneous destruction of the SSBN force.

The Effectiveness of Current ASW Technologies

The U.S. is widely credited with having deployed advanced fixed acoustic arrays. The U.S. also has tested and deployed towed arrays and advanced magnetometers. Tactical ASW benefits from the use of sensors and weapons mounted on helicopters and aircraft, as well as from advanced capabilities on surface warships. U.S. capabilities against Soviet submarines are greatly aided by the relatively high noise levels emitted by existing Soviet submarines, but even so the Soviet Union can probably maintain the security of most of its deployed SSBNs against a *preemptive* attack by operating them with moderate caution (e.g., at low speeds) and in ocean regions unfavorable for detection.

Current Soviet capabilities against U.S. SSBNs are believed to be virtually nil—a result of the low noise level emitted by U.S. SSBNs, the failure of the U.S.S.R. to deploy long-range acoustic sensors, and the more primitive state of Soviet computing and signal-processing technology.

U.S. defense leaders, commenting on the security of U.S. SSBNs, have steadfastly maintained that these weapons are highly invulnerable through the 1980s, but might be threatened by some capability not yet foreseen. Former Secretary of Defense Harold Brown in his annual report for Fiscal Year 1981 noted that the Soviet "VICTOR-class nuclear-powered attack submarine remains the most capable Soviet ASW platform. At present, neither it nor other currently deployed Soviet ASW platforms constitute a significant threat to our SSBNs." Secretary Brown in that same report notes that our strategic submarines patrol "virtually unchallenged in the vast ocean areas and present a multi-azimuth and so far untargetable retaliatory capability." He notes that the greater range of the Trident-I missile "considerably enhances survivability of the SSBN force, allowing these 12 Trident backfitted submarines to operate in much larger ocean areas while on-station, thus hedging against the possibility of a Soviet ASW breakthrough." But in the course of arguing in support of a land-based MX deployment, the Secretary and other Defense officials have suggested that there might be an ASW breakthrough which would result in the "oceans becoming transparent," or at least that submarines would be vulnerable to a breakthrough which *did* make the oceans transparent.

In 1980 Secretary Brown expressed confidence that aircraft in plain view of Soviet radars could, by the use of "STEALTH technology," become invisible. It is remarkable that he was at the same time alluding to the possiblity of some future unanticipated Soviet ASW breakthrough, without noting the likelihood of effective countermeasures in the ASW sphere. Commenting on these remarks in 1980, the commander of the U.S. submarine force, Vice-Admiral Charles H. Griffiths, said that the oceans were a great place to hide because "they're becoming more opaque as we understand more about them." Thus, U.S. navy sources in their public utterances give no support to the thought that "the oceans are becoming transparent."[9] The Scowcroft Commission Report of 1983 also shows no concern for strategically significant vulnerability of an evolving SSBN force.

Emerging Technologies

Fundamentally, the detection of submarines involves either a signal *generated* by the submarine itself and received by the detection system or the *reflection*

9. Admiral Griffiths, in September 1981, confirmed to the author that he continues to maintain these views and notes that he was quoted accurately and in context.

by the submarine of a signal from the detection system. The detection of generated signals corresponds to passive systems, such as the passive acoustic detection system previously mentioned. Other potential signals include the detection of radioactive products emitted by the submarine's nuclear reactor, the detection of light emitted by ocean fauna disturbed by the submarine, of gases emitted by the submarine, and the like. The use of reflected signals implies active systems which must be capable both of bringing energy *to* the submarine and receiving the reflected energy. Active sonars are the most commonly known source of such systems, but active magnetometers have also been considered, and the use of lasers to detect objects at depths in the ocean is much discussed.

Normal communications to U.S. SSBNs is via VLF radio transmitters employing large vulnerable towers and antenna systems. The radio waves at 5–16 kilohertz have a wavelength (at 10 kHz) of 30 km; like all waves, they are launched inefficiently from antennas much smaller than a wavelength. However, there is so much static (from distant lightning) in this band that even a small antenna like that on a pocket transistor radio is adequate to pick up enough signal (and static), so that a larger receiving antenna is no better.

VLF radio waves penetrate into seawater a meter or so, and the SSBN patrols at depth at low speed while holding an antenna within a meter or so of the ocean surface; it does this either by trailing a long buoyant cable or by towing a streamlined buoy containing an antenna. Either of these techniques works well but is an operational inconvenience. The VLF transmitters are very vulnerable to nuclear attack, but their function is satisfactorily assumed by TACAMO EC-130 aircraft equipped to transmit VLF signals to the SSBN fleet by a trailing antenna wire many km long. Indeed, the Reagan strategic program, announced October 2, 1981, will put VLF receivers on the bombers of the Strategic Air Command to improve the reliability and survivability of communications with the air-breathing strategic component. Modern technology shows a way to reduce the inconvenience associated with towing an antenna near the surface while the SSBN (whether SUM or Poseidon or Trident) patrols at depth to hide and survive. A "communications fish"[10] weighing 50 kg and powered by a lead-acid storage battery would swim at patrol speed just over the SSBN, a meter or two below the sea surface, receiving the VLF signal in the water and relaying it via megahertz

10. R.L. Garwin, "Fish Ragu (Fish, Radio-Receiving and Generally Useful)," JASON Technical Note JSN-81-64, August 1981.

acoustic link to the submarine below. Such high frequencies are strongly attenuated in the water, so that they would not add to the detectability of the SSBN. The storage batteries would propel the fish all day at a patrol speed of 7 km/hr, or for about an hour at 18 km/hr. A recharged fish would swim up from the submarine as required to relieve the duty fish for recharging. If no VLF signal were received, the SSBN or the fish could put up a microwave antenna for a few seconds (on schedule) to listen to communications from a special system of strategic communications satellites.

The much-commented-upon (but in this case exaggerated) difficulty of *communicating* with submarines implies a great difficulty of active detection. Electromagnetic waves are very strongly absorbed or reflected by seawater, so that radio frequencies from the high audio range (10 kilohertz and up) through the entire microwave range are reflected at the water's surface. Radio waves with frequencies in the low audio range can penetrate some tens of meters into the water, but the very long wave length (3,000 km for 100 Hz) could make it difficult to localize a submarine even if the disturbance caused by the submarine could be isolated from disturbances of waves, whales, ships, and the like, and from lightning-produced ambient noise. Not until the visible range does seawater transmit electromagnetic waves, and even here the absorption of light is extreme, allowing light to penetrate only some 100 meters in the clearest water. Nevertheless, there is much discussion these days of the use of "blue-green lasers" for one-way communication to and detection of submarines.[11]

Blue-green laser ASW would involve the use of satellites or aircraft on which the lasers would be mounted. These would be used to scan the ocean surface (penetrating to a depth of 100 meters or so) and detect disturbances in the received signals. Whether satellites or aircraft were used, clouds would

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11. The color of clean ocean water above coral reefs or white bottom in general indicates to the eye that blue-green light penetrates most effectively. Even so, the penetration is limited, and the light as it penetrates is refracted by surface waves and ripples. The laser light would be sent to one possible submarine location after another in the operating area, scanning that area in the same way that a facsimile machine or a TV screen scans an object or an image. About 1,000 pulses of light per square km would be required, and the presence of a submarine at depth would be indicated by an increase in back-scattered light coming at a time corresponding to the depth of the submarine (for a "white" submarine), a reduction in light from a white or black submarine *beyond* the depth of the submarine, or from a similar disturbance in the signal. The *problems* are to obtain a laser of requisite characteristics, to provide adequate numbers of lasers and platforms (aircraft or satellite), to obtain a useful system in the presence of clouds, and (especially) to persuade the submarines to swim sufficiently close to the surface that they can be detected in this way.

totally vitiate any capability to detect submarines, although any communication function of such lasers could in principle survive passage through clouds. Detailed analysis, independent of progress in laser technology, shows that there is no possibility of strategically significant blue-green laser ASW because even the optimum laser color does not penetrate (in a round-trip) to the comfortable operating depth of existing submarines.

With the advent of fiberoptic transmission of information, the connection of acoustic sensors with information processing stations becomes both more convenient and less costly. Satellite radio relay could be used for similar purposes. Thus, one might imagine short-range direct-path passive submarine detection by bottom-mounted hydrophones covering the entire SSBN operating area. About 500,000 sensors on a 10-km grid could do the job reliably; they of course would have to be monitored in real time. This could be done automatically, but means would have to be taken to ensure that transmission of the acoustic data to the monitoring nation could not readily be impeded, and the whole system would have to be protected against jamming or other disruption. Such a system might be intended for steady operation, or it might be called into operation (aside from tests) only in the event of a crisis or an actual decision to destroy the opposing SSBN fleet. The latter mode might depend on radio transmission to satellites, although such satellites could be jammed by powerful ground-based transmitters. Such a dispersed array of short-range sensors might be countered by the use of jammers or decoys, or by attack on the sensors or their communication nets.

Against passive acoustic ASW, the technologies currently known for reducing radiated noise, for raising the ocean noise level in the region of submarine operations, and the provision of decoys to simulate submarine noise would seem to have the advantage over prospective developments in sensor technology and systems. Jamming and decoys seem also to be considerably cheaper and more rapidly deployable than vast arrays of sensors. Dragging the ocean bottom to cut long-range communication by cable or fiberoptics is an old art.

Conclusion

The oceans are so big that short-range detective devices would be needed by the hundreds of thousands to make the strategic submarine force vulnerable to attack. Long-range detection mechanisms of strategic significance are limited to acoustic detection and are readily countered.

Submarines will always be vulnerable in port, and in small numbers in the open ocean, but a nation with a force of dozens of submarines and significant ocean presence can keep the strategic submarines survivable when deployed. To do this will ultimately require countermeasures such as decoys or jammers, and a continuing awareness of technological developments and deployments.

It seems unlikely that either the U.S. or the U.S.S.R. could hope to achieve a capability for preemptive strike against the other's deployed SSBNs. Consequently an effective strategic doctrine must accommodate the continued capability of each nation to attack the other with SLBMs. Technological advances will likely give those missiles 100-meter accuracy, and communication technologies can provide reliable, timely links to the SLBM fleet. Thus, it makes sense to continue to depend on SSBNs as an important part of the strategic forces.

Although continued invulnerability of strategic submarines does not depend on arms control measures, there are some other benefits of arms control. Thus, a prohibition on the patrol of SSBNs closer than 1,000 km to each nation could ensure the time necessary to allow bombers to leave their bases before they were destroyed by a preemptive SLBM attack. Similarly, a ban on trailing submarines by active sonar would simply save the concern, funds, and forces which would otherwise be devoted to effective countering of the active trailing threat. If sanctuaries for the operation of SSBNs were negotiated, they would be of interest primarily to avoid the loss of SSBNs during limited warfare, in which SSNs might be hunted in the open ocean and SSBNs imperiled.

U.S. strategic doctrine still must reckon with the reality that sufficient resources expended for the destruction of any component of the strategic force could result in its gradual attrition, whether that be land-based missiles, air-breathing weapons such as air-launched cruise missiles, or strategic submarines. Whatever the possibility of such attrition warfare, the U.S. should have a capability to deter or to counter such a threat. Among strategic offensive forces thus far discussed, a fleet of strategic submarines is our greatest assurance of continued invulnerability.