Chapter 5

SMALL SUBMARINE BASING OF MX

Chapter 5.—SMALL SUBMARINE BASING OF MX

Page

Submarine Basing of Strategic Missiles .. .167

Nontechnical Considerations 167

Technical Choices Leading to Small Submarines 169

Description and Operation of the Small Submarine System. 170
- **Introductory Remarks. 170**
- **Overview 171**
- **Communications System and Operational Procedures 173**
- **Submarine Navigation and Mapping Needed for High Missile Accuracy .. .174**
- **Missile Guidance Technologies 175**

Vulnerability. 176
- **Tactical and Strategic Applications of Antisubmarine Technologies 177**
- **Theory of Open Ocean Barrage 178**
- **Open Ocean Barrage With No Information** About Submarine Locations 179
- Open Ocean Barrage After Detection of Snorkeling Submarines 180
- Searches With Technologies That **Observe Nonsnorkeling Submarines. .182**
- **Increased Range Acoustic Technologies. 184**
- **Increased Radar Search Using Satellites. 186**
- **Countermeasures to Radar Satellites .. .189**
- **War of Attrition 189**
- **Van Dorn Effect 190**
- **Theory of Trailing. 191**
- **Establishment of Trail at Port Egress. . .193**
- **Establishment of Trail Using Large Area Open Ocean Search 196**
- **Diesel-Electric Propulsion Technology. .197**
- **Nuclear Electric Propulsion 198**
- **Concluding Remarks on the Vulnerability of Submarines 199**

Page

Factors Affecting the Accuracy of Land- and Sea-Based Missiles 199

Accuracy of Small Submarine Based MX .. 202

Accuracy of Star-Tracker-Aided Inertially Guided MX 205

Degradation in Accuracy After a Submarine Navigation Fix. 206

Inertial Guidance Aided by Radio Update .207

Time on Target Control. 208

Responsiveness of the Submarine Force. . .209

Endurance of Force. 210

	Page
Cost and Schedule	210
System Size.	212
Final Sizing Consideration	213
Location and Description of Bases.	213

TABLES

Tab/e No.		Page
21.	SubmarineObservables	177
22.	Acoustic Sensors forSubmarine Detection	177
23	Nonacoustic Sensors for Submarine Detection	177
24	Operational Factors Affecting Radar Search of Submarine Deployment Areas.	182
25	Miss Sensitivities toInitial Errors for ICBMTrajectories.	201
26	Comparisonof Hard Target Kill Capabilities of Sea-Based MX With Design Requirements of the Land-Based MX	203
27	Small Submarine 10-Year Lifecycle cost.	211
28	Number of Submarines Required To Keep 100 MX Missiles Continuously on Station v. Submarine In-Port Time	213
29	Estimated Characteristics of the Small Submarine Refit Site and the Trident Refit Site.	214

FIGURES

Figure No.		Page
67,	Nuclear and Nonnuclear Powered Submarines of Different Size	171
68	Encapsulated MX Missile	172
69	MX-Carrying Diesel-Electric Small Submarine.	173
70	Sequence of Events During the Launch of an Encapsulated MX Missile.	173
71	Number of Weapons Required to Destroy Submarines That Have Been Sighted Prior to a Preemptive Attack	179
72.	Potential Deployment Area Given 1,000- and 1,500-nmi Operating Ranges	180
73.	Large Area Search With Technology That Can Only Detect Snorkeling Submarines.	181
74.	Sources of Reverberation That Limit the Capability of High-Powered Active Sonars.	183
75.	Potential Whale Sonar Targets	185
76.	Fishing Vessel Monitoring,	187
77.	Ground Track of Radar Search Satellite	188
78	Van Dorn Effect	191
79	Active Acoustic Search for a Submarine That Has Dispensed Decoys Which Simulate a Reflected Sonar Signal From a Submarine Hull.	194
80	Passive Acoustic Search for Submarine That Has Dispensed Decoys Which Simulate the Sound of a Submarine	195
81	German Type 2000 Submarine	197
82	Factors Affecting the Accuracy of a Ballistic Missile.	200
83.	Down Range and Cross Range Errors of a Ballistic Reentry Vehicle at a Target	202
84.	Accuracy of Inertially Guided Sea-Based Missile at Different Ranges From Targets.	202
85<	Accurary of Star-Tracker-Enhanced Sea-Based Missile as a Function of Range From Target	206
86,	Ocean Areas That Provide Adequate Line-of-Sight View of Ground Beacons on Continental U. S., Aleutian Islands, Alaska, and Hawaii	208
87	Ocean Areas That Provide Adequate Line-of-Sight View of Ground Beacons on Continental U. S., Aleutian Islands, Alaska, Hawaii, and Selected South Sea Islands.	209
88	Small Submarine Program Schedule.	211

Chapter 5

SMALL SUBMARINE BASING OF MX

SUBMARINE BASING OF STRATEGIC MISSILES

Strategic missiles are based on submarines because submarines can be hidden in vast expanses of ocean, thereby gaining a high degree of survivability. Currently, the United States takes advantage of the survivability of submarnes to deploy the Polaris, *Poseidon,* and Trident I missiles. Unlike attack submarines, whose primary mission is to protect convoys or attack enemy shipping, these ballistic missile carrying submarines seek to avoid surface ships and remain undetected, available for strikes against enemy targets on command. The object of basing MX on submarines would be to take advantage of the same survivability that has been demonstrated by experience gained with the *Polaris* and Poseidon systems. One major question addressed in this chapter is whether this survivability can be expected to continue into the 1990's

MX has been conceived as a land-based intercontinental ballistic missile (I CBM). The land-based ICBM has historically had greater accuracy, flexibility of targeting and rapidity of response than that of sea-based missiles. As a land-based ICBM, the MX missile is expected to set still a new standard in each of these attributes relative to previously deployed land-based missiles. The second technical question that is to be addressed in this chapter is the extent to which this new standard of attributes could be preserved if the MX were instead based on submarines.

Deploying the MX at sea rather than on land would also raise questions about how important it is to mix and balance the different attributes of nuclear forces to best deter war. The different points of view are summarized here, but these issues cannot be resolved by technical analysis.

This chapter begins by noting some of the principle rationales and drawbacks of submarine basing of MX. Some of these issues, while clearly relevant, are just as clearly not technical issues per se. The following sections attempt to more closely define and analyze technical and operational issues that bear on the problem of submarine deployment of a large, flexible, counterforce ICBM like MX. The conclusions of these technical analyses are summarized in the last section.

NONTECHNICAL CONSIDERATIONS

Much of the interest that has been shown in submarine basing of MX is motivated by the perception that the survivability of a future submarine force is likely to be insensitive to the nature and size of the Soviet ICBM force. As long as the Soviets are not able to develop an ability to localize and track submarines, the only conceivable way they could preemptively attack the submarine force with ICBMS would be to randomly barrage suspected submarine operating areas. If the Soviet ICBM force were to grow in its ability to deliver large amounts of megaton nage, submarine operating areas could merely be expanded in size to counter such a threat. I n addition, the Soviets could gain no additional ability to threaten the survivability of submarines through improvements of accuracy technology or through fractionating the warheads on existing or new ICBMS. Thus, provided that submarines maintain their ability to hide in vast expanses of ocean, there would be little or no way to threaten their survivability with either a substantial expansion, or with technical improvements, of Soviet ICBM forces. A decision to deploy the MX missile at sea in submarines would therefore negate the effectiveness of the Soviet ICBM force as a means of threatening the MX missile. This decision could diminish the political leverage that the

Soviets have bought with their modernized ICBM force by removing their ability to threaten a major U.S. strategic weapon system.

A perspective that argues against the basing of MX on submarines holds that moving missiles off the land will result in fewer disincentives to an adversary who is contemplating the use of, or the threat of using, nuclear weapons as a means of extracting political concessions from the United States. This perspective views the basing of strategic missiles on land as insurance against political blackmail. An adversary who attempts to gain political advantage by threatening U.S. strategic systems with nuclear destruction would, in effect, be forced to threaten targets on American soil. Land-basing would make the price of attempts to gain political leverage in this manner very high, thus decreasing the likelihood of such blackmail.

Some who argue this way also believe that the United States would lack the resolve to respond to Soviet threats unless it was clear that the continental United States was threatened with nuclear attack, They fear that such lack of resolve could make nuclear war easier for an adversary to contemplate, thereby making it more likely.

Others disagree with these perspectives and argue that there is a beneficial effect of removing potential targets from the continental United States. Since there would be no clear gain in an unsuccessful attack against a survivable sea-based system, there would be no incentive to attack strategic systems. They argue that a land-based system that presents a serious threat to Soviet military systems could invite attack if a crisis deteriorated to the point where Soviet decisionmakers believed war was unavoidable. In such a circumstance, Soviet decisionmakers might attempt to limit damage to their own systems by striking first. If a submarine-based system were untargetable, a rational Soviet decisionmaker would be denied such a choice. Thus, submarine basing would have the stabilizing effect of forcing a wait-and-see attitude on decision makers during periods of international crisis.

A potentially serious drawback of basing MX missiles on submarines is that the system could share a common mode of failure with Trident and Poseidon if an unforeseen antisubmarine warfare capability emerged in the next 20 years. Since the United States, with its substantial commitment to undersea warfare, has been unable to identify or project any threat to ballistic missile submarines, the significance of such a potential drawback is difficult to evaluate.

Another potential drawback is that a submarine-based system would require highly skilled and trained personnel that are not currently available in the Navy. In order to meet additional manpower needs, training centers would have to be established and recruiting efforts would have to be expanded. If the civilian economy was healthy, competition for trainable people could make it difficult to attract them into the Navy. It could also be difficult to retain personnel once they have developed skills because of the attraction of lucrative civilian jobs.

'Submarine construction presents somewhat different problems from that of surface ship construction. Past experience indicates that if shipyards do not demonstrate a good deal of competence constructing surface ships, they will have very great difficulties constructing submarines. Since the volume available for equipment and crew in a submarine is very small relative to that available on surface ships, construction must be carefully planned so that components can be put into cramped locations in the proper sequence. Quality control is also important since equipment and components may be subjected to extreme conditions during the course of submarine operations.

Constructing a new fleet of MX-carrying submarines would be a major undertaking. Three shipyards not currently engaged in submarine construction would probably be needed to construct submarines if the full fleet is to be deployed by 1992 or 1994. Each shipyard would have to be provided with a small team of people experienced in submarine construction to help it make an orderly transition to submarine construction. Lack of experience in submarine construction could result in program delays if the shipyards had not been carefully chosen for their efficiency and competence or if they did not have adequate guidance on submarine construction techniques

Delays could occur in other submarine construction programs as well, if the base of special materials required for submarine construction were not expanded to meet increased demands. It is also possible that if problems developed within the MX submarine program, talent, effort, and funding might also have to be diverted from those programs.

Other problems could arise with other elements of the project due to the timing of the missile development program If missile development were delayed a year by design changes required for sea basing, it would be ready for deployment in 1987 The design, development, and construction of a new class of submarines could in theory be expedited to produce lead ships by late 1987, but this appears unlikely. If the program proceeded at a rate more characteristic of recent strategic weapons programs, the lead ships would not be deployed until 1990. The missile could therefore be ready for deployment several years before there are means to deploy the missile. It would be necessary to keep missile scientists, engineers, and managers available for the testing and monitoring phase of the missile deployment. These individuals might have to be retained at great cost until the deployment is far enough along to assure that unforeseen problems had not emerged.

These perspectives, among others, involve judgments of a nontechnical nature and will not be addressed further in this chapter. Instead the focus will be on assessing the technical strengths and weaknesses of a sea-based MX system that was optimized to perform the missions usually ascribed to ICBMS.

TECHNICAL CHOICES LEADING TO SMALL SUBMARINES

If an MX-carrying submarine force is to be specifically optimized to capture as many attributes of the land-based ICBM as possible, there are two attributes of the land-based I C BM that suggest small submarines carrying a few missiles are preferable to large submarines carrying many missiles These attributes of the land-based missile are

1. flexibility of targeting that does not compromise survivability of unused missiles in the force, and
2. diversity in failure modes with the other legs of the Triad

Flexibility refers to a weapons system's ability to select and carry out preplanned attack options, or attack options that are subsets of preplanned attack options It also includes the ability to carry out ad hoc attacks against targets that may be on the National Target Data Inventory List or targets that are specified only in terms of geographical location

Since a large ballistic missile submarine carries military assets capable of delivering enormous destruction against an adversary's targets, it is itself a target of considerable military importance, I f the submarine's position were to become known in wartime, there would be a substantial incentive to attempt to destroy it.

If a flexible tar-getting strategy were adopted for a submarine force, submarines might be ordered to fire a limited number of missiles at enemy targets. The firing of these missiles could potentially reveal the position of the submarine to enemy surface ships at great distances, to space-based sensors, radar systems, and possibly even sonar systems. The expected postlaunch survivability of a missile-carrying submarine is therefore quite different from that of its expected prelaunch survivability The flexible use of this force could therefore result in attrition that would compromise its ability to continue the war or force termination of the war

If flexibility of targetting is specifically desired in a submarine force, it would be necessary to make the survivability of remaining missiles as independent of previously launched missiles as possible. This **could be** done **if the submarine force was made** up of a large number of submarines each carrying a small number of missiles. If this were the case, then the wartime loss of submarines that placed themselves at risk by launching only a few of their missiles would not result in the loss of a large number of remaining unused missiles. The force would therefore be able to carry out limited nuclear attacks without compromising its ability to carry out subsequent massive strike missions.

Another reason that submarine-based strategic weapons have been less flexible than land-based ICBMS in the past is that communications with submarines have historically not been as good as those achievable with land-based systems. As will be discussed later in this chapter, flexibility in targetting could be achieved with the current submarine force if a conscious decision were made to acquire certain kinds of communications capabilities and to adopt certain operational procedures.

Diversity in failure modes with other legs of the Triad is a more difficult attribute to discuss, since it involves making judgments about threats that have not yet been identified. If the MX missile were deployed on small submarines, it seems more probable that it would share a common failure mode with other submarine-based systems than would a land-based system. The likelihood of such a breakthrough must be considered remote in the absence of any scientific evidence to support such a possibility. However, if an unforeseen antisubmarine capability developed in the future, it is possible there could be quantitative and/or qualitative differences between sea-based ***Trident/Poseidon*** submarine forces and submarine-based MX that could make the threat less effective against such diverse types of submarines. Small, slow-moving submarines would in fact have certain signatures that are different from those of larger, faster moving submarines. In addition, a fleet of many submarllnes poses both a qualitatively and quantitatively different set of operational problems to an antisubmarine force than does a fleet of a few submarines. With this in mind, it could be argued that a fleet of MX-carrying submarines would increase the diversity of strategic nuclear forces, making it less likely that a **single technology** could threaten all three legs of the Triad.

DESCRIPTION AND OPERATION OF THE SMALL SUBMARINE SYSTEM

Introductory Remarks

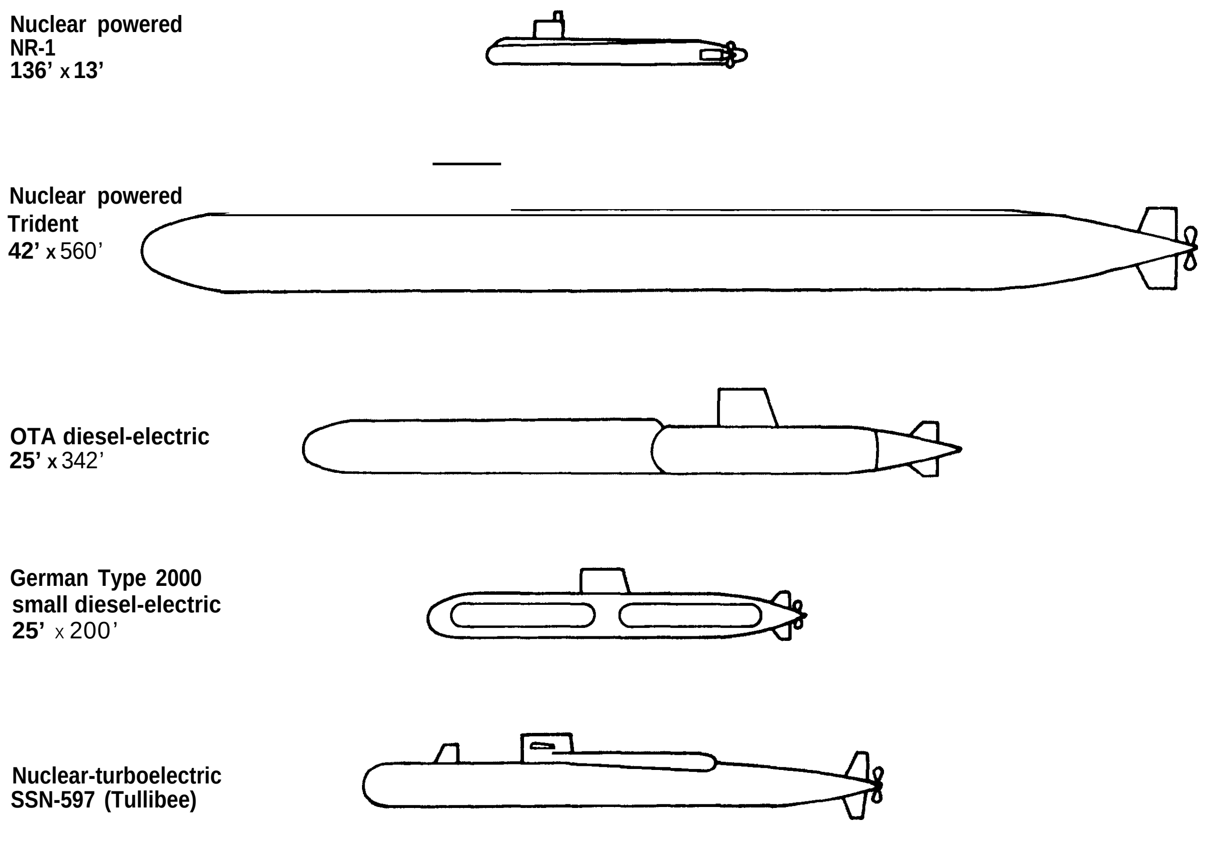
If the MX were to be deployed on a fleet of submarines, there would **be many engineering and operational tradeoffs that would have to be made if the fleet was to be an effective weapon system. 1 n order to establish conservative bounds for what is likely to be achievable,** OTA has postulated a system of submarines, operational procedures, and communications that is specifically optimized to attain ICBM-like flexibility and responsiveness while still basing MX on submarines. The system concept to be described and evaluated is based on off-the-shelf technologies, and Navy operational experience and practices wherever possible. However, it should be expected that if a national decision were made to deploy MX on submarines, many technical features of a new system of MX-carrying submarines would likely be different from those postulated for OTA'S analysis of small submarine basing. A new class of submarines would have to be designed and built. New and different procedures would also be evaluated and developed for the submarine operations. Such a vast enterprise as the design, **construction, and** deployment of a new and modern strategic weapon svstem could result in a system with features different from the system that will be discussed here

Overview

The submarine system to be described uses a combination of communications, navigation, and guidance technologies aimed at maximizing flexibility of targeting, rapidity of response, and missile accuracy. Submarine operational procedures are set up to allow submarines to carry out launch orders issued by the National Command Authorities (NCA) rapidly. There would always be enough submarines to carry 100 alert MX missiles for delivery of highly accurate warheads against Soviet targets. It is believed that these submarines, while at sea, would be untargetable and impervious to Soviet preemptive actions (this issue is discussed fully in the next section) This submarine force is therefore optimized to carry out missions similar to those commonly ascribed to ICBM forces.

The basing system would consist of a force of 51 moderate-sized (see fig. 67) diesel-electric submarines each of which is armed with four MX missiles. The submarines could also be powered with small, low-enrichment

Figure 67.—Nuclear and Nonnuclear Powered Submarines of Different Size



SOURCE: Office of Technology Assessment

nuclear reactors. During normal operations, 28 submarines would be continuously at sea, In periods of crisis or international tension, submarines in refit (but not those in extended refit or in overhaul) could be surged from port to raise the at-sea numbers to 38 to 40. This deployment would provide an additional 400 warheads on station.

The MX missiles would be carried in steel capsules approximately 80 ft long and 10 ft in diameter (see fig. 68), The capsules would be carried outside the pressure hull on the top side of the submarine's hull (see fig. 69).

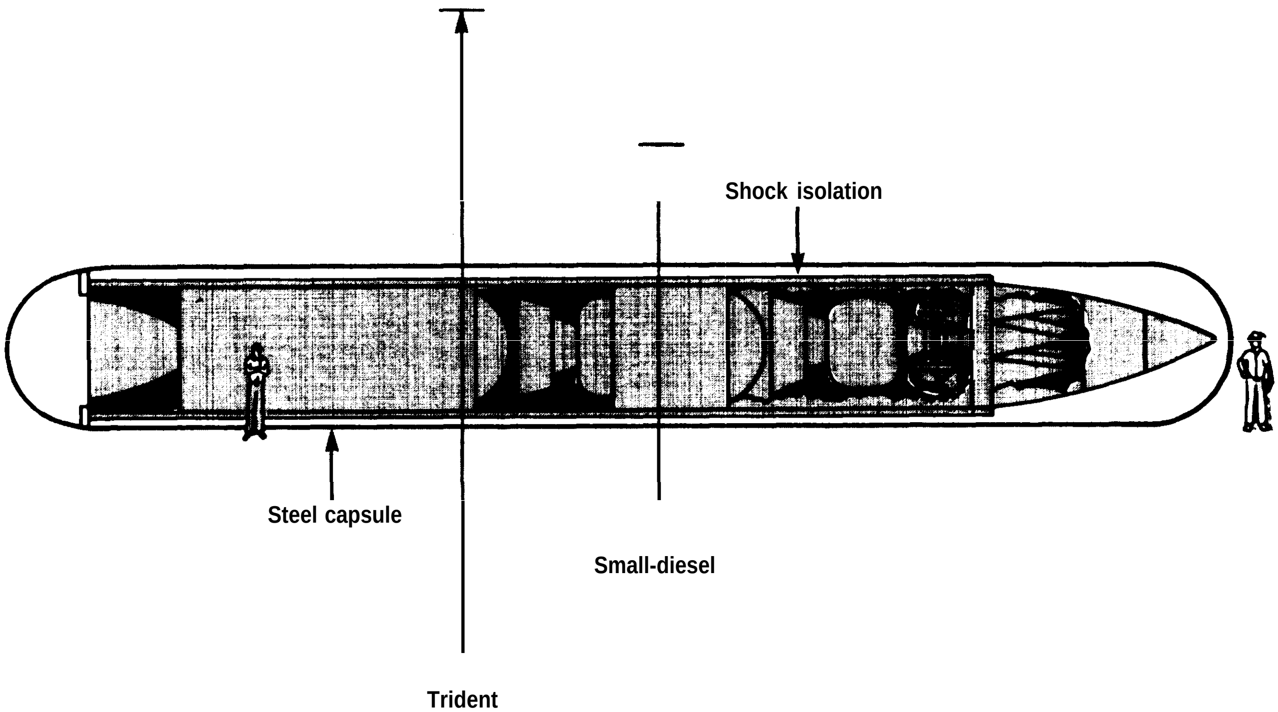
On a launch command (see fig. 70), hydraulic actuators would open doors on the submarine's fairings and straps within the fairings would release the capsule. Soft ballast would then be blown from the front end of the capsule causing it to rise and rotate toward the vertical. Upon sensing the ocean surface, the top and bottom caps on the capsule would be cut free, the missiles motors would ignite, and the thrust of the first stage motor would propel the missile from the capsule.

After missile flyout, a flotation collar and/or drag surface would deploy from the empty capsule to slow its descent into the ocean. This wou Id lower the risk of a COllision between the expended capsul e and the submarine.

The submarines would deploy from dedicated bases in Alaska and on the east and west coasts of the continental United States, Each base would, on the average, have 5 to 6 submarines in port at al I times. The submarines would be at sea for 60 days and in port for refit and logistic support for 25 days.

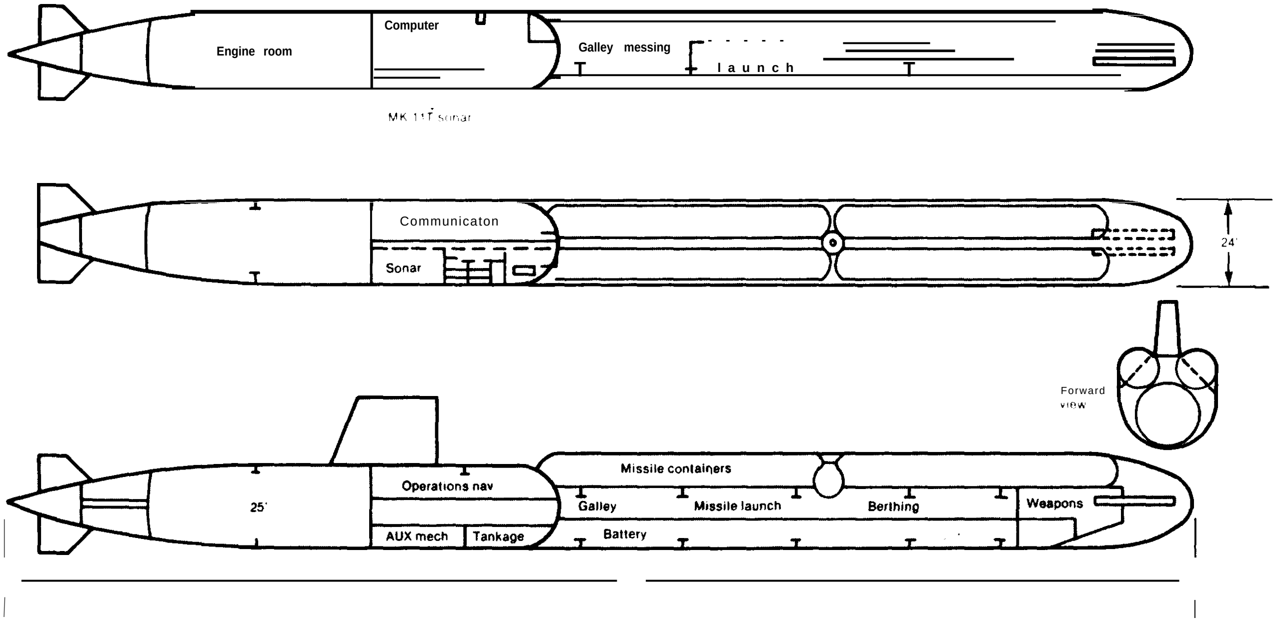
The submarines would typically operate as far as 1,000 nautical miles (nmi) from port. They would be designed to have sufficient speed and endurance to operate at still greater distances from port (1 ,500 nmi or more) if such operations were deemed desirable. Each submarine would have an advanced submarine

Figure 68.—Encapsulated MX Missile



SOURCE. Off Ice of Technology Assessment

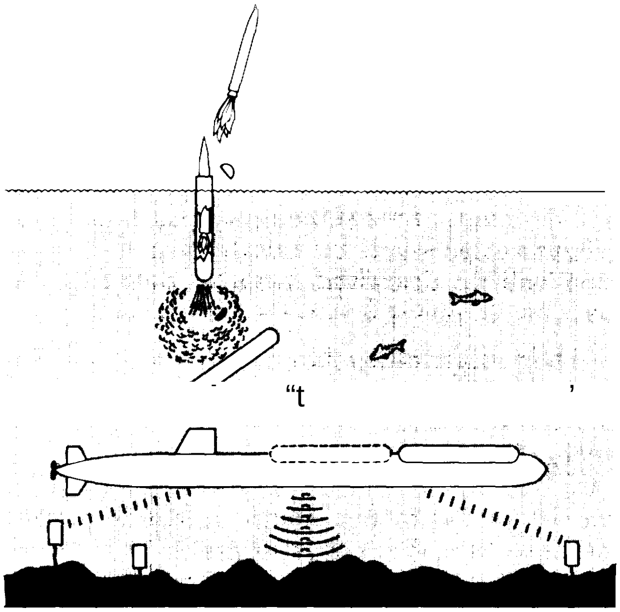
Figure 69.— MX"Carrying Diesel. Electric Small Submarine[a] (3,300 tons submerged displacement)



[a]Submarlne design developed by consfdenng the characteristics of the most recent U S,.bwlt diesel submarines, the SS580, the SSG557 GROWLER Class REGULUS mlssl le submarine, current technology represented In the Federal Republ IC of Germany submarine designs (H DW Type.209 and Type-2000 **designs), and other advances demonstrated In Swedwh and Nethedand designs Proven technologies incorporated Into design are maximum quletlng achewable by sound fsolation, a(r coupling of** electrtc drive motor to screw shaft, faster recharging at lower snorkel noise levels, Increased battery capacity, microprocessor monitoring and management of power systems, and smaller crew size

SOURCE Off Ice of Technology Assessment

Figure 70.—Sequence of Events During the Launch of an Encapsulated MX Missile



SOURCE Office of Technology Assessment

inertial navigation system (E SCM/SINS), a velocity measuring sonar (VMS), an acoustic system for interrogating prepositioned transpenders, and equipment for taking fixes on the Global Positioning System (GPS) and LORANC.

Missile accuracy would be maintained mainly with onboard submarine navigational equipment. This equipment would occasionally be updated with the G PS or a covert system of acoustic transponder fields. If the GPS were destroyed by enemy action, the occasional navigational updates would be done with the acoustic transponder fields.

Communications System and Operational Procedures

The communications system and operating procedures would be configured so that the submarines in peacetime would constantly be receiving communications from NCA through trailing wire antennas and/or buoys that would constantly receive shore to submarine very low frequency (VLF) communications. In addition, the submarines could also be in two-way communications with NCA using a covert, rapid and reliable high-orbit satellite transponder link. This link would allow for the submarines to report back to NCA and make possible high data rate reception of information for rapid retargetting of the force.

Since shore-based **VLF stations would probably be destroyed** if there was enemy preemptive action, communications with the submarines would then be maintained via survivable airborne VLF relays, that could immediately replace shore-based VLF stations. These airborne relays would maintain radio silence and would be continuously airborne unless they were needed to replace shore-based VLF transmissions. Emergency Action Messages (EAMs) could be routed from NCA, through either the shore-based VLF stations, or the airborne VLF relays, to the submarines. (Today these airborne relays are known as TACAMO aircraft. TACAMO is an acronym for Take Charge And Move Out).

If there was a need for high data rate retargetting, or for two-way communications, designated submarines would be ordered via the VLF radio link to prepare for high data rate or two-way communications. In order to do this, the submarines would erect a mast above the ocean surface to permit communication through the high-orbit satellites mentioned earlier.

If there was a need for the submarine to report back to NCA, the submarine could beam a message through the satellite using a 5-inch dish antenna which would be mounted on a mast.

The probability of an adversary detecting or intercepting such transmissions would be very low for the following reasons. The radio **frequencies used** by the satellites would be in the extremely high frequency (EHF) radio band and would have a wavelength of order several millimeters. Because the wavelengths are so small, EHF signals would be collimated into an extremely tight beam by the 5-inch dish antenna. Only receivers in the path of the beam could receive the transmissions from the submarine. Since the dish antenna would also be highly directional for receiving satellite signals, it would be effectively impossible to jam incoming signals from the satellite.

The satellites could be survivable against satellite attacks. The high-orbit satellites could be put in five times geosynchronous orbits (almost halfway to the Moon) and would be very difficult to attack, even using large space boosters.

Earth-launched interceptors would take 16 to 18 hours to reach the satellites, During this period, the satellites could be maneuvered while they are out of sight of Soviet ground-tracking stations, forcing the space boosters to make course changes beyond their propulsive endurance. If there was an extended period of conflict and the United States did not want to keep repositioning these satellites, the ground-tracking stations could be destroyed and the satellites could be repositioned for a final time.

Submarine Navigation and Mapping Needed for High Missile Accuracy

In order to have high missile accuracy, the missile guidance system must have accurate information on the missile's initial velocity, position, and orientation immediately prior to launch. This information can be obtained from navigation systems on the submarine and from gravity maps of the submarine operating areas. These systems will be briefly described here and will be discussed again in detail in the section on missile accuracy.

The submarines would maintain accurate information on their position using an advanced submarine inertial navigation system ESGM/SINS. They could also measure their velocity very accurately using a VMS. This information would be fed to the missile guidance system prior to launch so that errors in missile accuracy due to velocity and position uncertainties would be minimal.

ESCM/SINS could be reset by making navigational fixes on the GPS. If the satellites were destroyed by enemy action, the navigation system could instead be updated using any of 150 covert acoustic transponder fields.

The acoustic transponder fields would be layed by submarines while on normal patrols. Typically, such operations would take several hours. After laying a transponder field, the submarine would determine transponder positions using the ESGM/SINS or the GPS. The transponder field could be turned on using an encrypted acoustic signal that could be sent from the submarine or by a small, powered, underwater drone deployed by the submarine, Small boats could later use an encrypted acoustic signal to command the transponders to release their anchors and float to the surface for retrieval. In this way, the transponder fields could be constantly shifted if the need arose.

Orientational information for the missile guidance system would be obtained with the aid of gravity maps of submarine operating areas. These maps would be generated using satellites, surface ships, and possibly submarines to measure gravity anomalies near the surface of the ocean and in space.

Missile Guidance Technologies

There are three sets of missile guidance technologies that could be used to maintain high accuracy from sea. These are:

1. pure inertial guidance,
2. star-tracker-aided inertial guidance, and
3, radio-aided inertial guidance.

The strengths and weaknesses of these systems will be described in more detail in the section on missile accuracy.

Pure inertial guidance would essentially be similar to that of the land-based missile, with some of the methods of performing missile guidance calculations modified for sea basing.

Star-tracker-aided inertial guidance would be similar to that of the land-based system but with the aid of a star tracker to help correct for position, velocity and orientational guidance errors that accumulate during missile flight. These corrections are done by sighting on a star and comparing the star's measured position to that of its expected position. The Trident I missile uses a star tracker and experience with this missile has demonstrated that this technology is very reliable and effective as a means of obtaining high accuracy with sea-based missiles.

Radio-aided inertial guidance depends on radio beacons to correct for position, velocity, and orientational guidance errors that occur in missile flight. These corrections are done by sighting on a system of radio beacons.

The system of radio beacons used by the missile could be either on satellites (the GPS) or on the surface of the Earth (such a system has been called a Ground Beacon System (CBS) or an Inverted Global Positioning System **(IGPS)**

If a submarine-based system used radio-aided inertial guidance as a means of maintaining high accuracy, a GPS guidance fix could be taken by missiles launched anywhere within the deployment area. **In the event of** outage of the GPS, which could occur if the satellites were attacked, the secondary land-based IGPS could be used to maintain the missiles' accuracy. However, if the ground radio beacons are used, the missiles might have to be launched within 400 to 500 miles of the ground beacons in order to get good enough line of sight contact to maintain missile accuracy.

The system of ground radio beacons could be deployed along the coast of the continental United States and Alaska. There would be a large number of such beacons and a larger number of decoys to make it costly for the Soviets to attack the beacons.

If the GPS were destroyed, and a launch order was issued, some submarines might not be close enough to the continental United States to use the radio ground beacons. If time permitted, NCA could direct the remaining submarines to redeploy to areas within the coverage of the ground beacons or direct them to any of 150 presurveyed acoustic transponder sites in the open ocean. The submarines could obtain extremely accurate measurements of both position and velocity at these presurveyed sites. Missile accuracies achieved from these transponder fields could be slightly degraded relative to that achievable with the aid of the radio beacons assuming that the missile was only inertially guided (i. e., the missile does not have a star tracker). If there was not enough time to redeploy to acoustic transponder fields, missiles could be launched with position and velocity information from the ESGM/SINS and VMS submarine systems. Under these conditions, missile accuracy would be degraded still further.

VULNERABILITY

The vulnerability of the force of submarines to Soviet countermeasures depends on the nature and capability of the weapons systems that would be deployed, the strategy of their application, and the amount of resources that might be committed against the submarine force.

Potential threats to the submarine force fall into several broad categories:

1. barrage attack using nuclear weapons;
2. large area searches, followed by barrage attack;
3. large area searches, followed by attacks using surf ace ships or aircraft;
4. nuclear explosion generated giant waves (Van Dorn Effect); and
5. trailing of the submarine force, followed by simultaneous attacks on all the submarines.

A barrage attack is a pattern bombing attack, using nuclear weapons. In its simplest form, it is a random pattern bombing of ocean areas in which the Soviets suspect submarines are operating.

A variation of the barrage attack is an area search followed by a barrage attack. If an adversary possessed a search technology that was only able to locate submarines approximately over an extended period of time, then only those areas of ocean in which the approximate locations of submarines were known would be attacked. if the area in which the submarines are localized was small enough, it is possible that the barrage could result in the destruction of the submarine force.

If an adversary possessed still better search technologies, capable of localizing submarines well enough to send out surface ships or planes to attack the submarines, it would be possible to sink the entire force of submarines with conventional weapons or a very small number of nuclear weapons.

Still another way that a force of submarines might be attacked is to detonate large nuclear weapons in sufficiently deep water to generate gigantic waves, If the waves were large enough and the water shallow enough the waves might tumble the submarines, causing sufficient damage to sink them or render them inoperable. The phenomenon associated with the generation of such large waves with nuclear explosions is called the Van Dorn Effect.

If an adversary's ability to search large areas rapidly was inadequate for attacking the force by limited barrage or with surface ships or planes, he might instead choose to trail all the submarines. once a significant fraction of the submarines were under trail, they could then be attacked at a prearranged time, resulting in the destruction of the submarines and their missiles,

A barrage attack against the entire operating area would require more than 30,000 high-yield nuclear weapons. If the high-yield warheads on the missiles were replaced with a larger number of smaller warheads (i.e., if the adversary fractionated his force) the area of ocean that could be barraged would be no greater.

If the adversary instead chose to generate gigantic waves by detonating large nuclear weapons in deep ocean waters, the submarines would not be damaged unless they were in certain shallow water areas on the Continental Shelf.

All other means of attacking the force of submarines depend on an ability to detect and localize, or trail, submarines with varying degrees of success. Table 21 lists possible observable that in principle accompany the presence or operation of a submarine, Sensing technologies that could potentially detect the presence of the observable listed in table 21 are listed in tables 22 and 23. These technologies were examined as possible methods for detecting and localizing a fleet of slowly patrolling dispersed ballistic missile submarines. All these technologies were found to fall into one of two broad categories: sensing technologies that do not appear to offer any possibility of detecting submarines effectively enough to be able to threaten the submarine force by area search or trailing; and sensing technologies that could be spoofed, confused, or rendered useless with inexpensive and easy to implement countermeasures.

Tactical and Strategic Applications of Ant i submarine Technologies

it should be noted that many sensing technologies of great use in tactical antisubmarine operations are of little use in the strategic role.

Table 21 .—Submarine Observable

Acoustic radiated sound
Acoustic reflected sound
Heat (infrared signatures, surface scars from snorkeling submarines, hydrodynamic transport of reactor heat to ocean surface)
Electromagnetic disturbances
Ocean surface effects (Bernoulli hump, snorkel or periscope wake, trailing wire wakes, microwave reflectivity of the ocean surface)
Hydrodynamic wake effects (salinity, temperature, conductivity, density, etc.)
Erosion and corrosion products
Chemical Effluents
Irradiated elements in sea water
Magnetic field disturbances
Optical reflectivity (blue-green lasers)
Luminescence
Biological disturbances of marine life

SOURCE Office of Technology Assessment

Table 22.—Acoustic Sensors for Submarine Detection

Submarine sonar systems
- **Active sonars**
- **Passive sonars**
  - **Conformal arrays**
  - **Hull-mounted arrays**
  - Towed arrays

Fixed array networks
- Passive (sonobuoys and arrays)

Surface ship sonars
- Active
  - Standard ship sonars
- Semiactive
  - High-power low-frequency transmitters in combination with long-towed arrays
- Passive
  - Hull-mounted arrays
  - Towed arrays

Plane, ship, or helicopter deployed sonobuoys
- Active
- Semiactive
  - Sound source plus receivers
- Passive

Helicopter sonars
- Dipping sonars

SOURCE Office of Technology Assessment

Table 23.—Nonacoustic Sensors for Submarine Detection

Infrared systems
- Snorkeling scars
- Reactor heat

Optical systems
- Visual observations
  - Snorkles or masts
  - Wakes
  - Near surface effects
- Blue-green laser

Synthetic aperture and pulse compression radars
- Surface roughness
- Snorkels or antennas
- Hydrodynamic wakes
- Bernoulli hump

Sniffing devices
- Snorkeling effluents

Magnetic anomaly detectors
Passive microwave radiometers
- Surface roughness
- Hydrodynamic wakes

Electromagnetic detectors
Turbulence sensing systems
Trace element detectors
Activation product detectors

SOURCE Office of Technology Assessment

For example, an attack submarine that is moving at high speed in order to position itself to attack a battlegroup or convoy may be making tens or hundreds of times more noise than that made by a slow-moving ballistic missile submarine. The close proximity of the fast-moving hostile submarine and the large amounts of noise associated with highspeed operations makes the attack submarine susceptible to detection by the battlegroup. If the attack submarine is detected by a passive sonar and it is not possible for the sonar operator to determine the range of the submarine from the battlegroup, a plane or helicopter equipped with a magnetic anomaly detector could be sent out along the direction of the sonar contact to localize the submarine. The aggressive tactics required of the attack submarine result in the submarine increasing its detectability while simultaneously bringing itself within close range of potential adversaries. This circumstance is completely different from that of the ballistic missile submarine.

Theory of Open Ocean Barrage

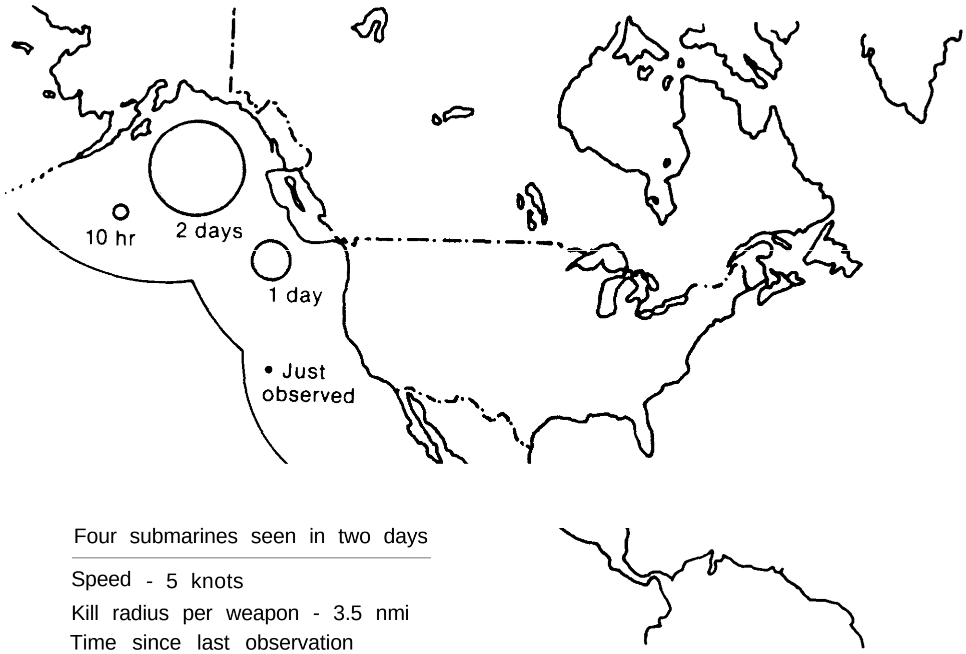
A barrage attack is a pattern bombing attack, using nuclear weapons, of ocean areas in which the Soviets suspect submarines to be operating. I n the absence of information on the locations of submarines, they would have to barrage millions of square miles of suspected operating area. It is also possible that the Soviets would attempt to gain information on the approximate whereabouts of submarines by using large area search techniques. If, for instance, each submarine in the force could be contacted and localized once a day, during the process of a large area search, then the approximate locations of the submarines would be known within a 24-hour sailing distance of those contact points.

Figure 71 illustrates just such a circumstance. This diagram illustrates the results of a postulated large area search in the Gulf of Alaska that results in the observation and localization of four submarines in a period of 2 days. Upon observing a submarine, the search aircraft notes its location and continues on its search pattern. The submarine is assumed to be patrolling at 5 knots and may be moving in any direction from the point of contact. The result is that the submarine's location is known with less and less certainty as the submarine continues its patrol. I n the diagram, the area of uncertainty associated with the most recently observed submarine is represented by a point. The smallest circle represents the area of uncertainty generated by a submarine observed 10 hours earlier. The next larger circle illustrates the area of uncertainty of a submarine observed the day before and the largest circle represents the area of uncertainty associated with a submarine observed 2 days before.

The ability to perform such large area searches is based on considerably more than just the dedication of military assets, A technology must exist that gives a sufficiently high search rate so that the mean time between submarine localizations is small relative to the time needed for the submarine to generate an area of uncertainty sufficiently large to be impossible to barrage. For example, if a search technology existed that, on the average, was able to localize every submarine i n the force every 24 hours, then each submarine would on the average be be localized within a circle of radius 120 miles (see fig. 71 for an illustration of the size of the l-day area of uncertainty generated by a submarine assumed to patrol at an average speed of advance of 5 knots). The submarine would, on the average, be known to be somewhere within a circle of area 45,000 nmi 2. If the kill radius of a nuclear weapon is of order 5 nmi, then 500 to 600 weapons would be required to assure that the submarine was destroyed.

Of equal importance to large area search capability is a low false alarm rate. If one false alarm were generated per hundred thousand square miles searched, there would be 20 to 30 additional targets that would have to be attacked that were not submarines (assuming the deployment area was of order 2 million to 3 million mi^2). If the average submarine contact rate were still every 24 hours but there were, in addition, 20 to 30 false alarms among the targets, 10,000 to 15,000 nuclear weapons would

Figure 71.—Number of Weapons Required to Destroy Submarines That Have Been Sighted Prior to a Preemptive Attack



Four submarines seen in two days

Speed - 5 knots
Kill radius per weapon - 3.5 nmi
Time since last observation
Just observed -1 RV
10 hr, 7,800 nmi², 196 RVS
1 **day,** 45,000 nmi², 1,130 RVS
2 days, 181,000 nmi², 4,500 RVS

SOURCE: Office of Technology Assessment

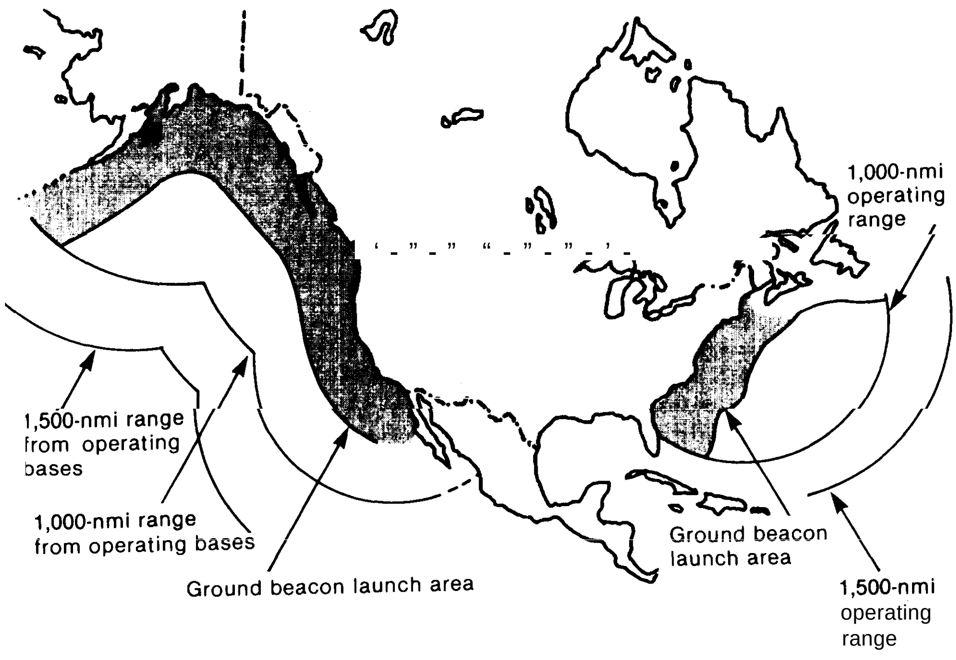
be required to cover the false alarms. Thus, the false alarm rate must be very small or it will be difficult to narrow down the number of targets to a manageable level.

Finally of significance in the barrage attack is the number of warheads available to the adversary for purposes of barrage. If the number of weapons grows to a large enough number, it may be necessary to expand the submarine operating areas or create decoys to increase the number of false targets observed in an area search. For conceptual purposes, an approximate rule of thumb would be 20,000 to 25,000 nuclear weapons are required to barrage a million square miles of deep ocean operating area. I n shallow water, the kill radius associated with the underwater detonation of a nuclear weapon is considerably smaller than that in deep water. There is between 70,000 and 90,000 mi² of Continental Shelf area (excluding the Continental Shelf of the Gulf of Mexico but including the shelf area of the Gulf of Alaska) available for submarine operations; a pattern bombing attack of these areas would require between 25,000 and 30,000 nuclear weapons because of the smaller kill radius.

Open Ocean Barrage With No Information About Submarine Locations

The submarines would operate **in an area** of **ocean sufficiently** large so that a significant fraction of them could not be damaged by pattern bombing with nuclear weapons. The deployment areas near the east and west coasts of the United States and the Gulf of Alaska are shown in figure 72. The outer boundaries in the figure are 1,000- and 1,500-nmi arcs from Narragansett Bay, R. I., Anchorage, Alaska, San

Figure 72.—Potential Deployment Area Given 1,000- and l,500mmi Operating Ranges



SOURCE: Office of Technology Assessment.

Diego, Cal if., and the Miller Peninsula, Wash. The exact boundaries of this area could vary significantly with choice of base siting and operational procedures. The operational area would be of the order of 2 million to 31/2 mill ion miles.

In testimony given to Congress, Garwin and Drell have suggested that a strategic nuclear weapon detonated at the proper depth in deep water might destroy a submarine at a distance of 5 miles. According to this estimate, an underwater nuclear detonation could destroy submarines within an area of ocean of about 75 mi^2.

Garwin and Drell have also stated that this damage range could be considerably smaller if the submarine were operating at a shallow depth. If an open ocean barrage were attempted, a large number of missile launches would be observed on early warning sensors. The submarines could be ordered via the VLF radio l ink to move to shallow depths where the effects of underwater nuclear explosions would be much shorter range. If this movement were to occur, the effectiveness of the barrage would be substantially reduced relative to the numbers quoted in the paragraph above.

Assuming the Soviets could deliver as many ICBM warheads against MX-carrying submarines as they could against a land-based MX system (i. e., 2,300 warheads) and the submarine damage range is 5 nmi, submarines operating with i n an area of 200,000 miles of ocean could be destroyed or rendered inoperable by a nuclear barrage attack. This attack would result in the loss of two to three submarines and their missiles if the submarine operating area was limited to only 3 m i l l ion mi^2.

Open Ocean Barrage After Detection of Snorkeling Submarines

If a sensing technology with a very high search rate and a very low false alarm rate were available, it is conceivable that submarines could be contacted often enough that the entire operating area would not have to be barraged in order to sink the submarines. Assume a search technology capable of detecting submarines only when they are snorkeling. This device could be a passive sonar detecting the diesel engine tonals or an airborne radar detecting a snorkel mast. If 50 submarines were uniformly dispersed within **3** mill ion mi^2 of ocean, one submarine could be expected in every 60,000 nmi^2.

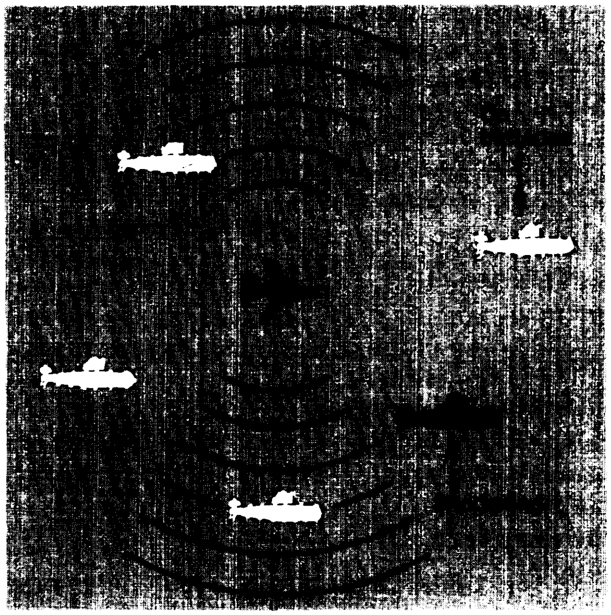
Figure 73 illustrates the concept of a large area search as it would apply to an aircraft searching for snorkeling submarines, since the sonar ship would be unlikely to detect a submarine operating on batteries. The same diagram could apply to a sonar ship. Although the sonar ship would move more slowly than an aircraft, it is possible that its detection range would be greater. The result might be that both the sonar ship and the aircraft could have the same search rate. As illustrated, if the search platform passes within detection range of a submarine, the submarine may not be snorkeling and would therefore not be detected.

Also worthy of note is that the submarine could have the ability to counterdetect the search platform before the search platform is close enough to detect the submarine. This discovery could occur if the search platform is a fast-moving surface ship (that makes a lot of noise) or a radar plane (that emits a signal that is detectable at a greater distance than the signal reflected from the snorkel).

In order to develop a more quantitative picture of the possible outcome of a determined large area search effort, the following assumptions are made about a large area search effort:

1. a search technique is available that can search 14,000 nmi^2 per hour, This method might be an aircraft that flies at 350 knots and can observe snorkels at 20 nmi on either side of its flight track or a long range sonar system that is towed at 14 knots and can detect snorkeling tonals at 500 nm i in each direction;
2. submarines snorkel 10 percent of the time;

Figure 73.—Large Area Search With Technology That Can Only Detect Snorkeling Submarines



SOURCE: Office of Technology Assessment

3. the probability of detecting a submarine when it is in range is 50 percent;
4. the number of false detections is infinitesimal relative to the number of valid detections, even though extremely large regions of ocean are being searched rapidly; and
5. there are 100 units searching the 3-million-nmi deployment area 24 hours per day 365 days per year.

These assumptions lead to a detection rate of one submarine every hour by the 100 searching units in the 3-million-nmi2 deployment area.

If the position of each of these submarines was recorded, then 1 hour after being detected a submarine could be anywhere within a 5-mile radius of its original position. At **2** hours the distance will have grown to 10 miles, at 3 hours 15 miles, and so on.

The Soviet Union could then pattern bomb each area determined by the patrol radius of a previously sighted submarine. If nuclear weapons with kill radius of 5 **miles** were used, one weapon would be needed to guarantee the destruction of the submarine seen 1 hour earlier, four weapons would be needed for the one seen 2 hours earlier, nine for the one seen **3** hours earlier, sixteen for 4 hours, and so on. To destroy 20 submarines, 2,870 weapons would be needed, 5,525 would be needed to destroy 25 submarines and 9,455 weapons would be needed to destroy **30 submarines.**

It should be noted that passive sonars would not be able to localize submarines at such great distances since fluctuations in sound transmission in the ocean make measuring distances impossible. Cross fixing with multiple units would almost never occur because of fluctuations **in the acoustic transmission of sound** in the ocean. It would be a common circumstance that the sound would reach one of the sonar units, but not the other.

If the units were aircraft searching with radar, they would have to make long transits in order to remain on station. The aircraft would have to transit from bases to the submarine deployment areas, search the areas, transit back home, and be refueled and repaired for the next transit out. In order to maintain one aircraft on station continuously, three to six aircraft would be needed. Some typical base loss factors (i. e., the number of platforms needed per platform continuously on station) are shown in table 24 for turboprop aircraft transiting from Soviet bases to operating areas.

Finally, it is absolutely necessary that false alarm rates be extremely low in spite of the fact that vast areas of ocean must be searched at a very high rate. As will be illustrated in the discussion to follow, even low or moderate false alarm rates would render the most effective area search useless.

Searches With Technologies That Observe Non snorkeling Submarines

It is conceivable that a search could be performed using a technology that was able to detect the presence of a submarine whether or not it is snorkeling. Such technologies might involve the use of active acoustic technologies or magnetic anomaly detectors. The nature of these technologies is that they are short range. For purposes of discussion it will be arbitrarily assumed that the detection range of these technologies would be about 5 miles. This assumption should not be taken as a true estimate of capabilities since that would depend on the acoustic properties of ocean areas, magnetic storms, sensitivity of sensors, properties of the target submarine, etc.

Since the sensors being discussed in this case do not require the submarine to be snorkeling to be detected, all submarines within the detection range of the sensor could be assumed to be detected. If it is assumed that an aircraft must travel more slowly for magnetic

Table 24.—Operational Factors Affecting Radar Search of Submarine Deployment Areas[a]

Operating area or naval facility	Soviet naval or air base	Distance (nmi)	Time on station (hours)b	Transiting time (hours)c
Norfolk	Murmansk	4300	Not possible	—
Norfolk	Cuba	870	6.6	4.1
Charleston	Murmansk	4600	Not possible	—
Charleston	Cuba	610	7.2	2.9
San Diego	Petropavlosk	3600	0.2	16.9
Seattle	Petropavlosk	2800	2.1	13.2
Northwest Atlantic	Cuba	1400	5.4	6.6
Northeast Pacific	Anadyr	2300	3.3	10.8

[a]Time on station and transit assumes BEAR bomber configured or long-range Surveillance.
[b]High altitude transit followed by low altitude search
[c]Transit speed of 425 knots Transit times Include transit 10 search area and transit back to base.

SOURCE. Off Ice of Technology Assessment detection (say 100 knots) then it would be able to detect every submarine within a 5-mile radius of it as it moves along, This assumption means the aircraft could search a 1,000 nmi area each hour it is operating (assuming a probability of detection of one when a submarine is encountered), In order to achieve the same detection rate that the aircraft in the earlier example achieved, 7 platforms equipped with magnetic anomaly detectors would have to be substituted for each of the radar aircraft. Thus, it would require 700 aircraft on station continuously, which means a fleet of 2,100 to 4,200 aircraft dedicated only to search of the deployment area. If weather did not interfere with the search and submarines did not take advantage of surveillance data supplied through VLF channels to avoid search platforms, then 5,525 warheads might be needed in addition to these forces in order to destroy half of the postulated force of 50 submarines.

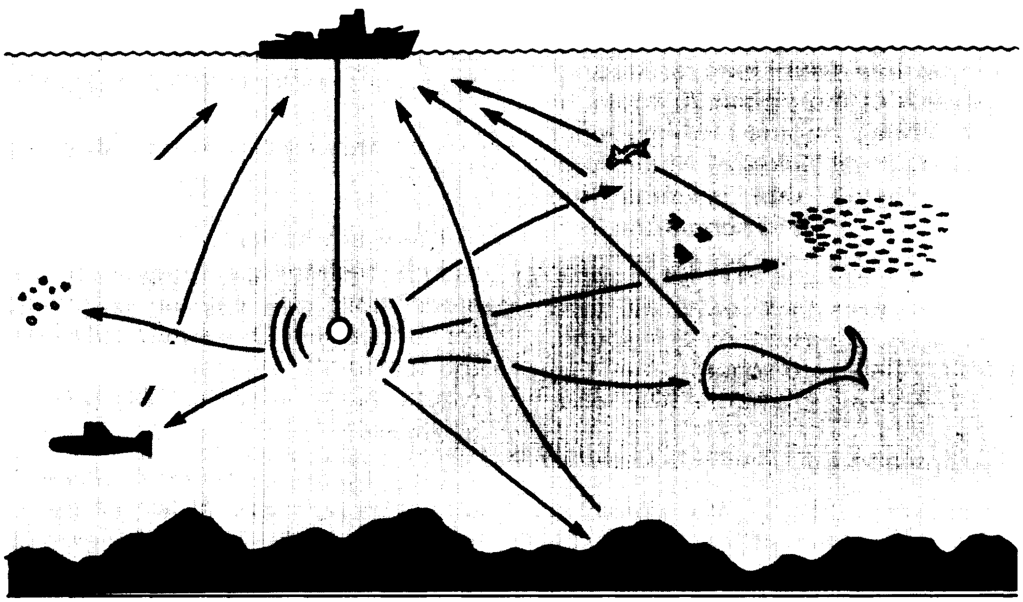
Active acoustic search might be substituted for passive. Since the range assumed is 5 miles, and ships might travel at only 20 knots, it would require 35 ships to replace every radar plane in the first example (assuming a probability of detection of one if a submarine is within the detection range)

A serious problem associated with active acoustic search would be the problem of false targets. Simply stated, a false target is an underwater phenomenon that generates a sonar signal similar to that of a submarine. The existence of false targets generates an additional complexity in the large area search problem that can catastrophically degrade the effectiveness of the search effort:

1. nonsubmarine targets may be incorrectly identified and tracked as possible submarine targets, and
2. submarine targets may be incorrectly identified as nonsubmarine targets,

Figure 74 illustrates the circumstance of an active acoustic search, The surface ship has a sound transducer that emits sound that scatters off objects in the water. Unfortunately for the searcher, sound not only bounces off the submarine, but it also bounces off temperature boundaries in the water, bubbles, plankton,

Figure 74.—Sources of Reverberation That Limit the Capability of High-Powered Active Sonars



SOURCE: Office of Technology Assessment.

schools of fish, the ocean bottom, and the ocean surface. 1 n particular, the sound that reflects back and forth between the surface and the bottom of the ocean results in an extended and very intense echo. Since the surface area of the ocean floor and ocean surface are so great relative to the surface area presented by a submarine target, the initial sound impuulse of the sonar returns like the deafening echo from the walls of a cavern From the point of view of the sonar operator, each sound pulse is reflected by a myriad of false targets and deafening echoes from the "walls" of the ocean, From this set of confused data, sound reflected from the hull of a submarine must be identified from sound reflected from other "false targets" that could potential l y be submarines.

Figure 75 is a chart of the number of whale targets over 30 ft in length per 1,000 nmi that could potential ly be mistaken for sonar targets in the Western North Atlantic during the month of September, Of all biological targets in the ocean, whales are the most difficult to distinguish from submarines on sonar. These marine animals resemble submarines in size, speed, acoustic characteristics, and certain modes of behavior. When two or more whales occur together, as they frequently do, they represent a very significant sonar target, Under normal conditions whales swim at 4 to 8 knots, well within the range of submarine patrol speeds, and may flee from manor natural" predator-s at speeds of more than 20 knots I n addition to returning submarine like sonar echoes, the power-fultail flukes of whales produce swimming sounds that resemble the screw (i e , propeller) noise of a submarine

Smaller fish can also have very large sonar cross sections because they have air-filled swim bladders that intensely reflect sound. When these fish collect into schools, they can present very convincing submarine-like sonar signals.

If the submarine is moving, the reflected sound from the hull will be slightly shifted in frequency relative to sound reflected from stationary objects in the water. The frequency shifted sound might be separable from other sounds provided the submarine didn't slow down to reduce the the size of the frequency shift. If the sonar platform speeded up in order to get a higher search rate, the sound reflected from the "walls" of the ocean would be shifted in frequency. This would make it very difficult t. separate the frequency shifted "echo" from real signals generated by moving targets.

If a submarine counterdetected an adversary performing an active acoustic search, the submarine could also turn toward or away from the source in order to reduce the amount of reflected sound from the hull. The sound reflection would be reduced because the intensity of sound reflected back toward the sound source would be roughly proportional to the cross sectional area the submarine presents to the source. Since the cross sectional area would be reduced by about a factor of 10, the sound reflected back to the acoustic searcher would also be reduced by a factor of 10 In addit ion, since the f rent or back of the submarine has a more highly curved surface than the side, sound will be more diffusely reflected from the front or back of the submarine then it would be if it were reflected from the side. This same principle of reducing detectability by causing reflections to be diffuse is a l so of use in lowering the radar cross sections of aircraft.

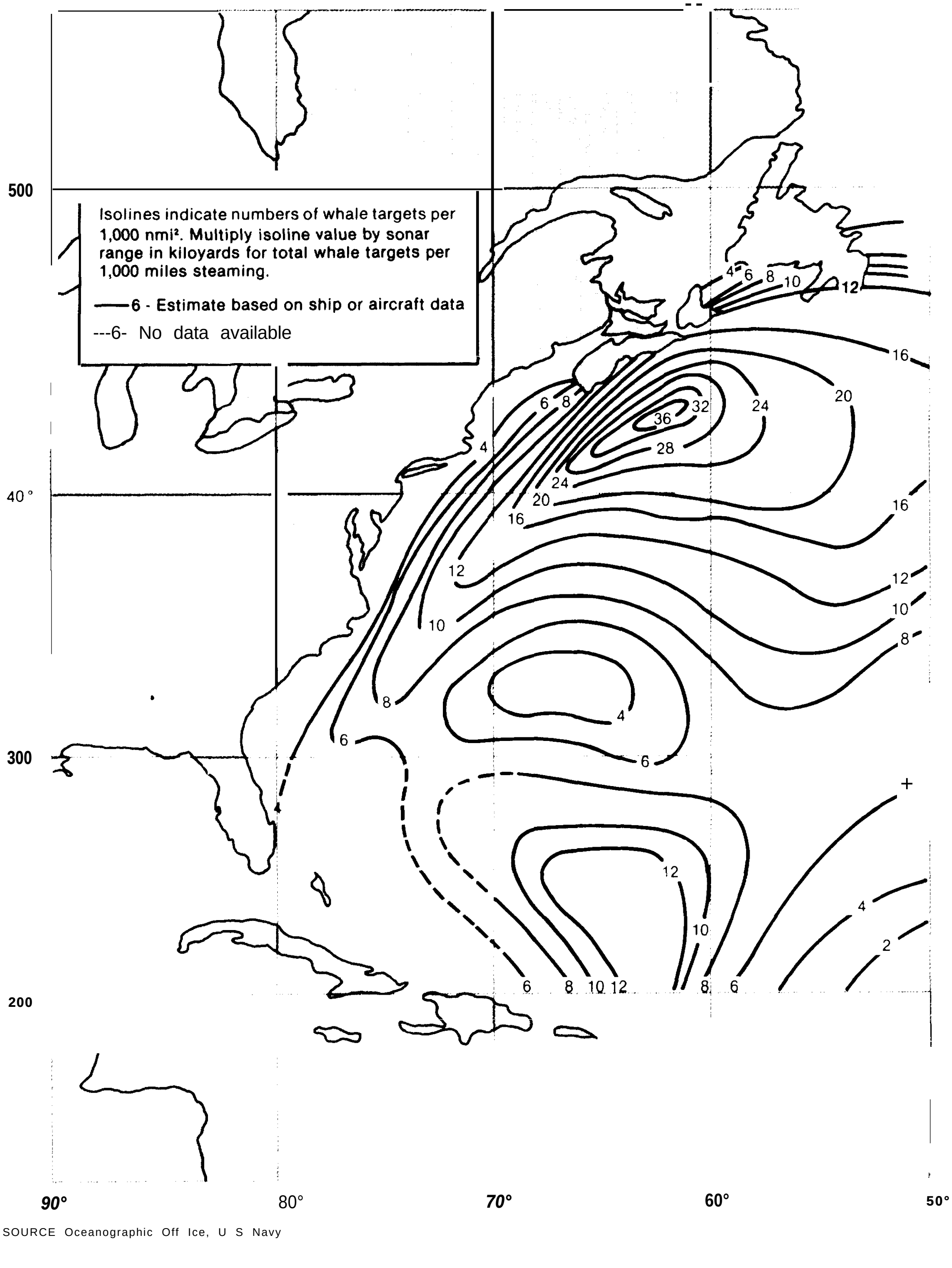
Thus, there are many problems of both a technical and operational nature that seriously hamper active acoustic technologies as a means of searching out submarines.

Increased Range Acoustic Technologies

There are basically two ways that acoustic search technologies might in principle be made more efficient for long-range searches for submarines. One way would be to increase the sensitivity of passive acoustics, the other would be to increase the power of active acoustics.

Unfortunately, the more power that active acoustics puts into the water, the more sound reverberates through the ocean blinding the ability of the acoustic system to the small signals from a submarine. Active acoustics can

Figure —Potential Whale Sonar Targets (Western North Atlantic)



SOURCE Oceanographic Off Ice, U S Navy

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be very effective against submarines at short range, simply because the signal from a nearby submarine is so much more intense than background signals. However, as the submarine moves away from the active sonar, its intensity will drop at least with the fourth power of range. Thus, if the submarine is twice as far away, the signal from it will be 16 times weaker ($2^4 = 16$*). The background reflections from the ocean surface and bottom will not change. Hence, it becomes more and more difficult to distinguish reflections from the hull of the submarine from the unwanted ocean reverberations. Increasing the power of the sonar only increases the unwanted reverberation along with the wanted signal, Thus, the nature of sound propagation in the ocean presents a fundamental limit to the increased capability of active acoustics.

Passive acoustics has similar barriers to increased performance. Passive acoustic sonars must discriminate the sound of a submarine from all the other sounds in the ocean. The total radiated acoustic power of some foreign modern submarines is measured in milliwatts. In a calm sea, the sound from one of these submarines at 100 yd would be equal to that of ocean wave and shipping background. No matter how one improves the quality of detectors and signal processing, the quietness of modern submarines and the noisiness of the ocean set fundamental barriers on the capability of long-range sonars against slowly patroning submarines,

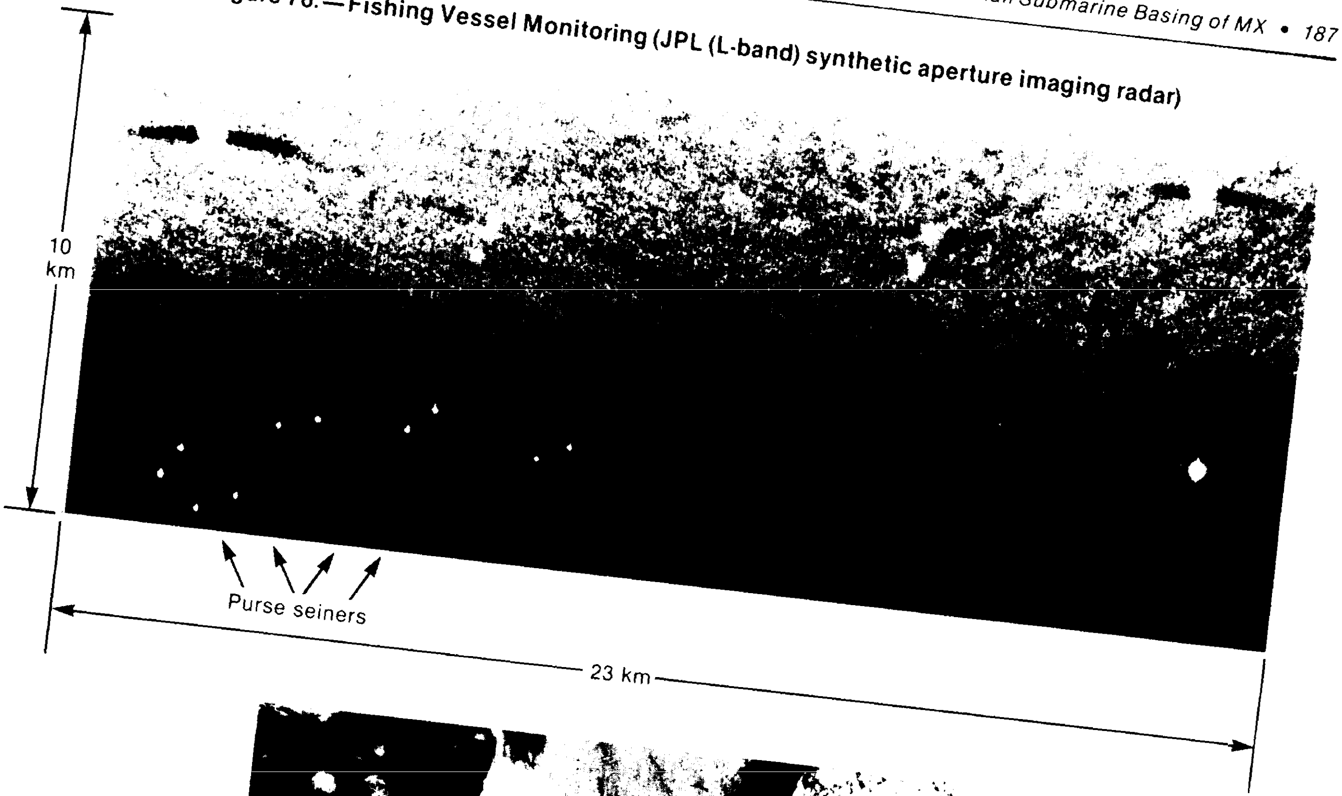
* The fourth power law comes about as follows Sound emmitted from the sonar source and sound reflected from the submarine on the average spread sphericaly at short range The intensity of a sound wave that spreads spherically frorn a source point Will decrease as the square of the distance from that point The intensity of found that ultimately arrive back at the search platform is first diminshed by a factor of distance squared before reaching the submarine, and then diminished by another factor of distance squared after it is reflected by the hull of the submarine Thus, as the distance between the submarine and the the search platform Inc reases, the Intensity of the signal that ultimately arrives back at the search platform diminishes at least as fast as the fourth power of that distance. If the effects of sound absorption are also include, the intensity of the signal received from the submarine will decreased even faster fourth power law as the distance between submarine and search platform increases

Increased Radar Search Using Satellites

Since large area search against snorkeling submarines is likely to be limited by the endurance of aircraft and range of radars, it is conceivable that other more exotic platforms could be used for large area search. A high-resolution radar (i. e., synthetic aperture radar) has been flown on a satellite (*Seasat-A* had an L-band (25-cm wavelength) synthetic aperture radar) that has obtained a resolution of 25 m from altitudes of order 500 nmi. In principle, significantly higher resolutions are possible. *Seasat* was able to observe ships on the surface of the ocean with sufficient accuracy that image processing could result in crude identification of ship characteristics. *Seasat* was, under certain conditions, also able to observe the hydrodynamic wakes of ships and the surface roughness of the ocean. Remarkable pictures of internal ocean waves, that impress themselves through hydrodynamic coupling on the roughness of the oceans surface, have been observed from *Seasat* radar reflectivity data. It is reasonable to expect that higher resolution radars can and will be built that could be capable of observing snorkeling submarines.

As an example of the surveillance capability of a low resolution synthetic aperture radar system, two photographs obtained through the courtesy of M. L, Bryan of the Jet Propulsion Laboratory staff are presented in figure 76 Photograph A was taken in the Bering Sea Test as part of the Fisheries **Imaging** Radar Surveil lance Test Program. This photograph wa' taken using an airplane equipped with an L band synthetic aperture radar. The small spot on the lower left portion of the photograph are small japanese fishing boats operating a purse seiner (a large vertically suspended fishing net and the larger bright spots are mother ships Photograph B was taken on Seasat *A* orbi 1291. It is the area off Newport Beach an Orange County in southern California. Th white streaks in the photograph are probabl ships. The bright and dark areas of ocean ar due to the changing roughness of the ocea surface and the angle of the radar return. Tl- multi ridged structures within some of th-

Figure 76.—Fishing Vessel Monitoring (JPL (L-band) synthetic aperture imaging radar)



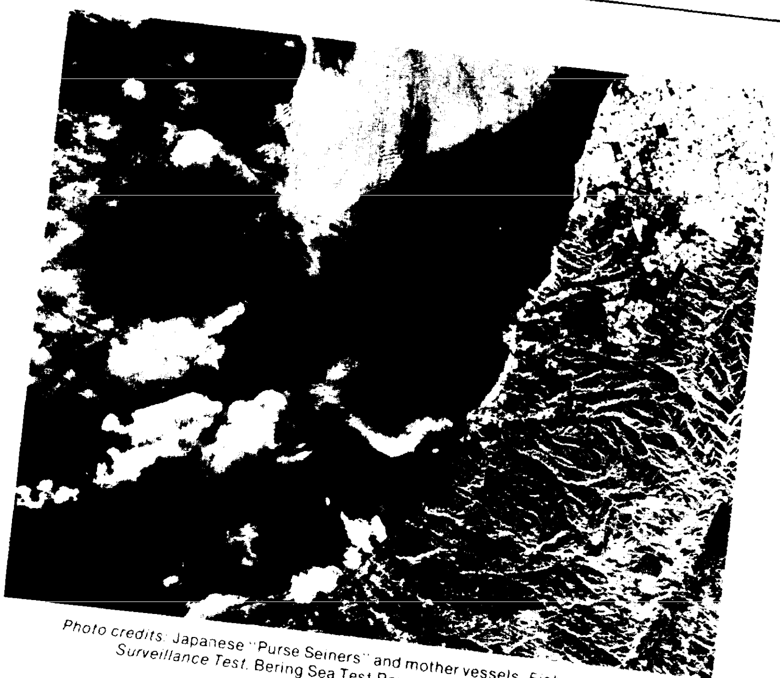


Photo credits: Japanese "Purse Seiners" and mother vessels. *Fisheries Imaging Radar Surveillance Test,* Bering Sea Test Report, NASA courtesy of M. Leonard Bryan, JPL Technical Staff.

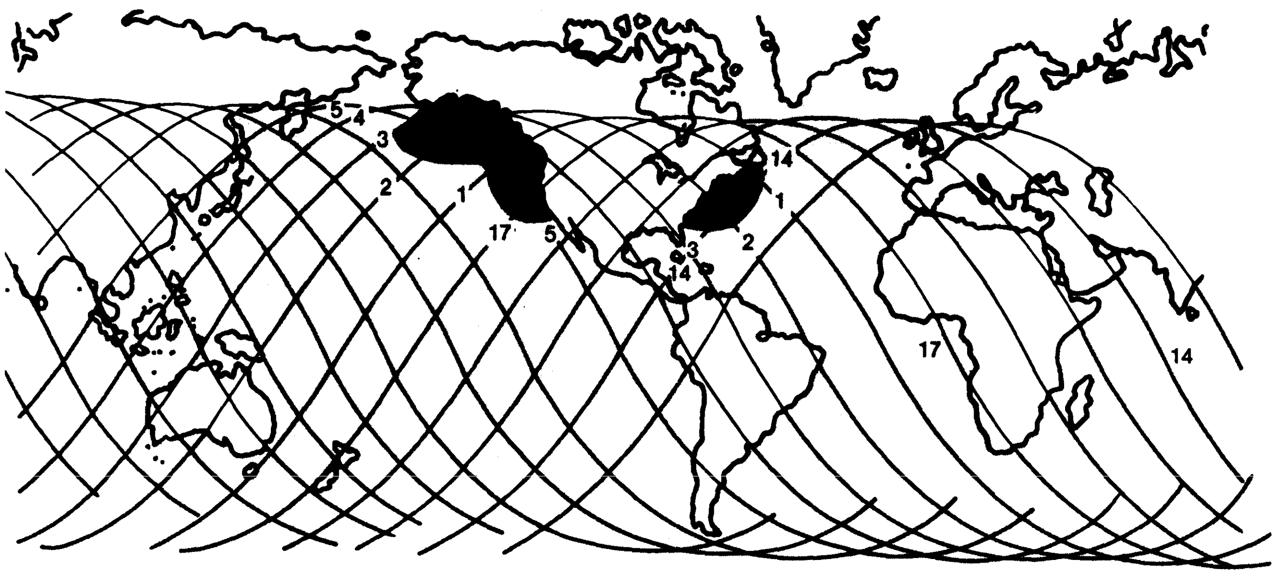
Seasat-A synthetic aperture radar photograph bright regions are surface manifestations of internal ocean waves that result in changes of the surface roughness and the radar reflectivity.

A high-resolution radar system searching a vast and constantly shifting ocean surface could have a very high false alarm rate due to random waves reflecting additional intensity, In addition, the capability of the radar would also vary dramatically with the sea state (i. e., size of waves and roughness of the ocean), since the ocean surface creates an intense background of reflected clutter that can be very difficult to filter out.

The false target rate due to random wave motion might be dramatically reduced by having the radar "repoint " at the suspicious target. However, such a radar would require considerably greater amounts of signal processing in a technique already limited by signal processing capabilities. Nevertheless, it is prudent to assume that signal processing and radars could be sufficiently improved to observe snorkeling submarines with a high degree of confidence.

Figure 77 shows the ground track of a satellite that is at an altitude of 162 nmi and whose orbit is inclined at 600 to the equator. This orbit is similar to that used by the Soviet Cosmos 954 radar satellite that entered the upper atmosphere over Canada on January 24, 1978 (the actual orbital inclination of Cosmos 954 was 65 O). Note from the figure that the satellite coverage is predictably intermittent. [luring the 1.5-hour satellite period the ground track advances 22.50 on the Earth below and the search pattern shifts to the west (note the orbits labeled one, two and three). After 16 cycles the satellite arrives over the same point on the Earth's surface but it will only have

Figure 77.—Ground Track of Radar Search Satellite



60° inclination
160-170 nmi altitude
1.5-1.6 hr period

SOURCE Off Ice of Technology Assessment

overflown the deployment area on six or seven orbits The satellite would spend about 4 to 5 minutes over the deployment area during each of the six to seven orbits. Thus, one satellite spends no more than 25 to 35 minutes per day over the deployment area. If two satellites are in the same orbit but separated in phase by 180 ", they would follow one another by 45 minutes (i e , by half of the 90-minute orbital period) .Thus, for six or seven orbits a day, satellites would be over the deployment area once every 4s minutes Six to seven orbits translates to 9 hours per day (six orbits times 1 5-hour orbital period) when satellites could be expected overhead every 45 minutes If two other planes of orbits with two satellites each are staggered so they will not overlap the first plane of two satellites, then eight satellites would be required to cover the deployment area 8 minutes every 90 minutes. Covering the area for 16 minutes every 90 minutes would require 12 satellites and 32 minutes out of every 90 minutes would require 24 satellites. It would thus appear that in order to cover the deployment area 30 percent of the time, of order 24 satellites would be required.

If an eight-satellite constellation of radar satellites was placed in orbit to cover the deployment area, submarines could not snorkel for periods of longer than 40 minutes before it **would be necessary to** secure snorkeling to hide from a satellite. If 150 minutes of snorkeling were needed every day, eight satellites would force the submarines to snorkel for four periods of 40 minutes each and 16 satellites would drive the submarines to eight or nine periods of 18 minutes each. I f observation by a constellation of eight radar satellites had to be avoided, the normal 150 minutes continuous snorkeling period would have to be extended by 12 to 16 minutes due to the three to four periods (of length 4 minutes each) the satellites would be overhead. For 16 satellites the period could be extended to 180 minutes and for 32 satellites it could be extended to more than 200 minutes. The submarines would therefore have to be designed so they could snorkel for many successive short intervals. Current diesel-electric submarines may not be capable of this type of operation (modern submarines may be able to interrupt snorkeling for periods as short as the necessary 4-minute periods without serious losses in snorkeling efficiency, but data on such procedures are not currently available) The power management system of the small submarine might therefore have to be configured so that the submarines could snorkel efficiently for short periods of time interrupted by still shorter periods of battery operation. This approach would allow them to avoid surveillance from a constellation of radar satellites and would only marginally affect the overall length of the snorkeling period.

Countermeasures to Radar Satellites

If radar satelites were **considered to** be a serious enough t h r-eat, Garwin and Drell have suggested that the ocean could be seeded w i t h radar reflecting objects that would be indistinguishable from snorkels

If many false snorkel targets were deployed in waters near the continental United States, it could make it easier for Soviet diesel-electric submarines to operate in U. S waters because U.S. naval forces could have as much d if ficulty distinguishing false snorkels as would the radar satellites. If the snorkels could not be designed to be distinguishable to U.S. naval forces, but not to space-based radars, such a strategic countermeasure could disrupt our own tactical operations.

Another possibility would be jamming the radar satellites from ground- or sea-based stations. However, jamming could have international implications. Since the intermittent nature of the satellite orbits makes avoidance of detection straightforward, neither of these countermeasures would likely be preferable to intermittent snorkeling.

War of Attrition

As mentioned in the introductory remarks to this section, the strategy associated with a given surveillance capability, coupled with availablemilitary resources, could affect the outcome of a preemptive attack on the force of submarines. It is therefore possible that the surveillance capability postulated in the section on Open *Ocean Barrage After Detection of Snorkeling Submarines* could be used to fight a "war of attrition" rather than attacking in one massive barrage. A "war of attrition" approach to destroying the submarine force would simply involve immediate attacks on the submarines whenever a snorkeling submarine is observed. The outcome of this type of attack would be considerably different from the method discussed earlier of constant surveillance followed by a massive barrage attack. The time period over which the attack would take place would be days or weeks, rather than fractions of an hour Nevertheless, in order to assess the seriousness of such a threat, it is useful to get a sense of that time sca l e.

Let us assume that the Soviet Union is able to keep 100 planes on station over a northwest Atlantic operating area. This deployment would require the commitment of a fleet of between 300 and 600 planes constantly flying the 1,400 nmi transits to and from the operating bases in Cuba. Assume for simplicity that all the submarines are operating in a 3-million-mi operating area in the Northwest Atlantic. Then as estimated in the previous section, one submarine should be observed every hour of operation.

For purposes of discussion, assume that each time a submarine is sighted it is attacked and sunk, and continental based U.S. forces do not react to this action at any point during the process. It could then be expected that approximately half the force of 50 submarines would be destroyed in the first day. Since there now would be half as many submarines distributed throughout the deployment area, the rate at which submarines would be contacted and destroyed the next day would drop by two. This would then result in half the surviving submarines (about 12 submarines) being destroyed in the next day of operation. On the third day, the rate of contacts would drop again by two and only six submarines would be left. This kind of circumstance is called a "war of attrit ion" and was very successful against submarines in the North Atlantic during World War I 1.

Another possibility is that a submarine is observed once every hour but only ha If the time the attack on the submarine results in its destruction. Then one fourth of the submarines are destroyed the first day (about 12 submarines), another 9 are destroyed during the second day's operations, 7 the third day, 6 the fourth day, 4 the fifth day, etc. Thus, 5 days of operations results in the destruction of 38 of the 50 submarines as compared to the previous example where 43 submarines were destroyed in three days (it would take 7 days to destroy 43 submarines using the assumptions in the current example).

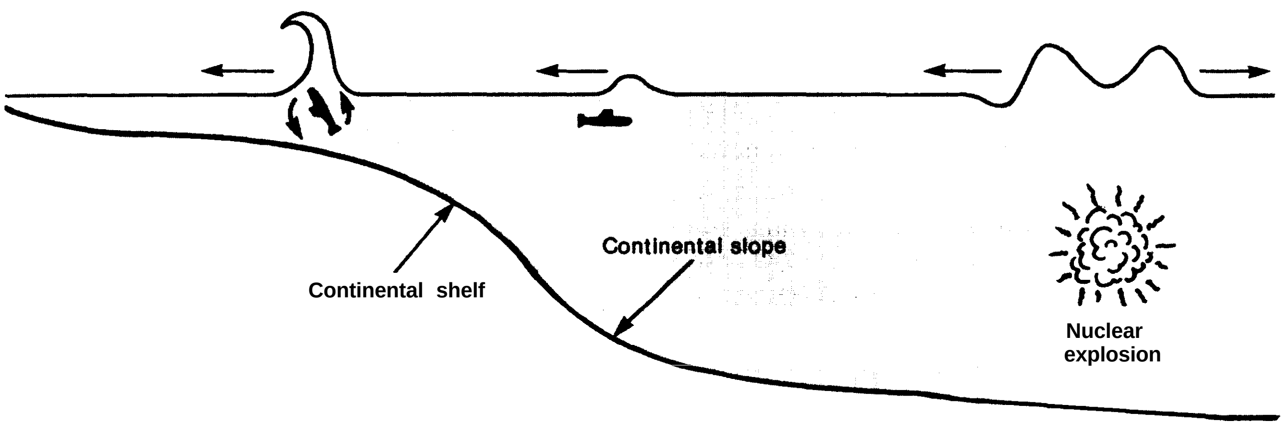
The "war of attrition" scenario would require that the planes carry sufficient armaments to engage and sink submarines with a high probability. It would also require that large relatively defenseless surveillance craft could continuously transit the 1 ,400-mile route between Cuba and the submarine operating areas, carrying out attacks on U. S, submarines in airspace near the coast of the continental United States, unopposed by American air and sea forces Another assumption is that submarines could not, and would not, defend themselves with the aid of decoys or underwater to air missiles,

Van Dorn Effect

The Van Dorn Effect is the creation of extremely high ocean waves over large areas of a continental shelf by an appropriately placed multi megaton nuclear detonation. The physical basis for the Van Dorn Effect is as follows (see fig. 78). A wave created by an underwater explosion in uniform, deep water will diverge raidially until it moves into shallow water. when the water becomes shallow enough the wave energy is funneled into a smaller volume of water and the wave height grows in height relative to the height it would have had in deep water. The shape of the Continental Shelf off the eastern coast of the United States is sufficiently steep for an absolute increase in wave height.

There is considerable uncertainty associated with the generation of Van Dorn waves. The

Figure 78.—Van Dorn Effect



SOURCE Office of Technology Assessment

curvature, steepness, and bottom characteristics (i e , sand or rock) of the continental slope could effect the size and formation of waves at different areas of the coast. The degree of underwater motion that submarines are likely to be able to tolerate without losing their abllity to launch missiles if also uncertain.

If a submarine were in sufficiently shallow water, the water motion at the bottom of these giant waves would make it unlikely that the submarine would survive in good enough condition to be able to launch ballistic missiles If the submarlne were operating off the Continental Shelf, the water would always be deep enough that the Van Dorn Effect would not be a threat The Van Dorn Effect is therefore not a problem for submarines operating off the Continental Shelf

Because the nuclear explosions would have to be generated in sufficiently deep water to generate Van Dorn waves in the shallow water, there would be several hours' warning before the arrival of these waves It any submarines were operating in water too shallow to escape the effect, and a Van Dorn attack were diagnosed quickly, several hours would be available for NCA to decide to launch missiles at risk.

Theory of Tra ling

It is conceivable that a c etermined adversary could review the method of continuous surveillance followed by barrage and determine that the likelihood of success is small The adversary might be particularly discouraged after a review of the diversity, effectiveness, and cost of countermeasures relative to that of his search and destroy effort It might therefore be concluded that an effort to continuously trail the submarine force might be more likely to meet with success.

To successfully trail a submarine, it is necessary to have a device capable of sensing the submarine with sufficient effectiveness that some estimate of the position of the submarine relative to that of the trailer can be maintained. It is also necessary that the device be difficult to spoof or jam and that it not be susceptible to simple countermeasures.

There are very few observable associated with the presence and operation of submarines that can be used to detect and track them. The most effective and reliable of these, like magnetic anomaly detection, tend to be very short range and cannot be operated too closely to a platform (like a surface ship or submarine) that has its own magnetic signature. Longer range techniques (like sonar) tend to be subject to the constantly changing acoustic properties of the ocean. Acoustic trailing operations are further complicated by the possibility that the submarine could move into sound ducts, channels, and shadow zones, as a means of suddenly "disappearing" from the view of the trailer. These ubiquitous sound ducts, channels, and shadow zones are created by in homogeneous ocean waters.

A final serious problem confronting the trailer is the possibility the submarine will deploy decoys, jammers, and/or spoofers to further complicate the problems of the trailer. Nevertheless, it is useful to examine some of the possibilities of trailing as a threat to the force of small submarines.

The problem of trailing the submarine force can be broken into three major areas of analysis:

1, initiating the trail,
2. maintaining the trail, and
3. destroying the submarine.

Once the submarine is within a few thousand yards, it is assumed that it can be destroyed with a probability of one with conventional means. This extraordinarily optimistic assumption presumes that the submarine under attack takes no evasive actions and uses no devices to confuse homing torpedoes or other devices and that the weapon used against the submarine is 100-percent reliable.

According to these assumptions, the success or failure of the trailing operation would only depend on the ability to establish trail, and the ability to maintain trail for a long enough period of time that a significant fraction of the submarine force is on the average localized, Two extreme cases are useful to examine in order to understand the significance of an ability to establish and to maintain trail as separate elements of the trailing problem:

1, The probability of establishing trail is one, but the mean time a trail is held varies,
2. The probability of establishing a trail is small, but the trail, once established, is not broken for the remainder of the submarine's at-sea period,

In case 1, for example, if the submarines were always picked up successfully as they egressed from port, then the average number of submarines under trail would be equal to the percentage of time each submarine was held in trail during its patrol. For instance, if the submarines had a 60-day at-sea patrol and the trail could be maintained for a period of 10 clays, then one-sixth of the submarines would be, on the average, under trail.

In case 2, the fraction of submarines successfully trailed is determined by the number of submarines for which a trail was successfully initiated. In this case, if a trail were successfully established on egress from port one-sixth of the time, and maintained for the entire at-sea period, then one-sixth of the fleet would be under trail at all times,

If one combines case one and two, and assumes that one-sixth of the submarines have trails established on them as they egress from port, and one-sixth of those submarines are maintained on trail (because they are trailed on the average for 10 days out of 60), then one-thirty-sixth of the submarines (i. e., less than 3 percent) can be expected to be under continuous trail. It is clear that both the ability to maintain trail and the ability to establish trail are extremely important if there is to be any possibility of maintaining contact with a significant fraction of the force,

A more complete analysis of the trailing plroblem would include probabilities that trails are established, broken, and reestablished. In the assessment that includes the possibility that a lost trail is reestablished, the possible use of multiple sonars and magnetic anomaly detectors, surface ships using active and passive sonar systems, etc., must also be included. In such a case, if the target submarine is recontacted by a search unit other than the trailing unit (perhaps by a helicopter) the probability that the search unit successfully hands the contact back to the trailing unit (which would have to be a ship or submarine i n order to have endurance similar to the target) must also be included in the analysis). Simulations accounting for such complexity have been performed. The models are technically complex and the results of the analysis are consistent with conclusions drawn from insights gained by examining cases 1 and 2. Since no new insights are gained with the additional complexity, and the models are mathematically complex, these models will not be presented or discussed here.

Establishment of Trail at Port Egress

In order to establish a trail, it is necessary to know the whereabouts of the submarine within a sufficiently small area of ocean that the submarine can be localized well enough to begin trailing operations. As discussed in other sections, no technology has been identified that appears to provide the ability to effectively search large areas of ocean. Given this circumstance, the trailer would have to seriously consider attempting to trail at port egress, where submarines are initially localized, if there is to be any hope of success.

The trailer would have to use either an acoustic or nonacoustic sensing technology to detect and follow the submarine. This sensing technology would have to be both reliable and difficult to counter. Since trailing operations would have to be initiated at port egress, where substantial U.S. assets would be available to help assure egress, the sensing technology would also have to be unjammable and resistant to spoofing from electronically equipped tugboats, submarines, or surface combatants that might aid in the egress.

The trailing of one submarine by another could be viewed as somewhat similar to the trailing of a plane by a homing missile. The homing missile would either have to passively sense some observable of the aircraft like heat from the engine, or actively illuminate the aircraft as with a radar. If the trailing missile is heat-seeking, the aircraft can disperse flares which the missile is unable to distinguish from the aircrafts engines. If the missile is radar-seeking, the aircraft can disperse chaff to create false radar targets to confuse the radar. Another measure could simply be to jam the radar (which, depending on the radar, might not be so simple). Still another measure would be for the aircraft to dispense a self-powered decoy that would retransmit the radar signal from the trailing missile in a way that would make the plane and the decoy indistinguishable to the radar. Such a device (called the Quail) was deployed in limited numbers during the 1960's on B-52s as an aid for use in confusing Soviet radars.

Such ideas have been applied in naval warfare as well. During the Battle of the Atlantic, the Germans deployed an acoustic horning torpedo called the Zaunkoning. The Allied countermeasures was to have convoy escorts stream noise emitting "Foxers" to create false targets and jam the acoustic homing torpedo's sensing system.

If there were an attempt to trail a submarine using passive sonar, for instance, trail could be broken through the clever use of a "Foxer''-like device. Such an operation could be done as follows: A submarine being trailed may deploy a small device that makes a sound similar to the submarine. As the submarine proceeds forward, the device could be slowly played out behind the submarine, making it appear to the trailer that the submarine is moving more slowly than it actually is. The trailer would then have to slow down in order to avoid risking a collision, resulting in an increased distance between the trailing and the trailed submarines. The device could also slowly increase the intensity of the simulated submarine sound, further convincing the trailer to increase his distance between him and his potential adversary. At the appropriate time, the line could then be cut or the trailing device shut off. The trailer would only know that the submarine had disappeared from sonar contact.

A most likely technology of use to a trailer would be an active or passive sonar. Active sonar at close range can be quite reliable (remember the distance to the fourth power signal to noise relation). A problem with active sonar is that the trailer is more vulnerable to attack than the trailed, since the sonar is broadcasting its own position.

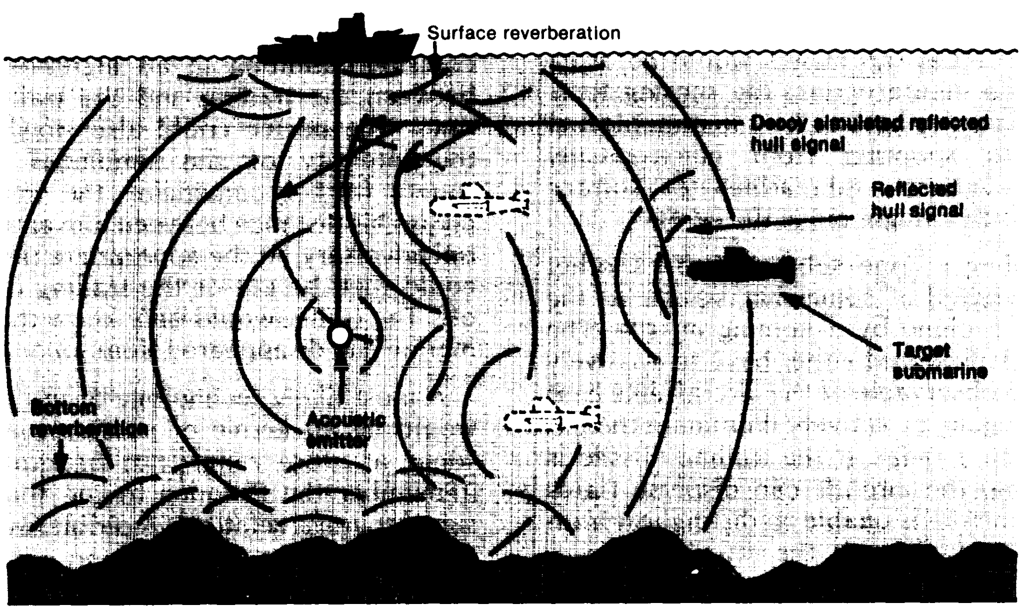
Passive sonar is preferable to active since the trailer does not make himself quite so vulnerable to preemptive action or countermaneuvers. However, if the submarine is quiet enough, it will be exceedingly difficult to trail by passive means.

Figures 79 and 80 show another means of making it difficult to establish trail against a submarine using either active or passive sonar. The submarine (or accompanying tugboats from the port) could deploy small torpedo-like devices (similar, in principle, to the radar confusing Quails deployed by B-52s). These devices could be equipped with small tape recorders which simulate the sound of a submarine. Electrical coils could simulate magnetic and other signatures and a transponder mounted on the device could simulate the reflection of sound from the hull of a submarine. If the need arose, devices like these could not only be carried on submarines to aid in breaking trails, but they could be deployed in large numbers each time a submarine attempted egress from port. Devices deployed from the port could be preprogrammed to behave like submarines and could regularly be recovered after each egress operation. Simple, inexpensive, and recoverable devices could be constructed using either battery or fuel cell technology to simulate submarines egressing from port. The fuel cell device could be programed to behave like a submarine using an inexpensive microprocessor and would have great endurance. The device could be used to deceive trailers for days, if an operational need for such a capability arose. At some preprogrammed point it could turn around and come back to port for recovery.

Still another possible device that could prove useful against a trailer using active sonar would be a device similar to the German pillenwerfer. The pillenwerfer was a device used by German U-boats during World War II. The U-boats could eject this device during the course of an engagement and create a dense underwater cloud of bubbles. Since sound would be intensely reflected by the pillenwerfer bubble screen, active sonars could mistake the cloud for a submarine or could not observe the submarine maneuvering behind the screen to escape.

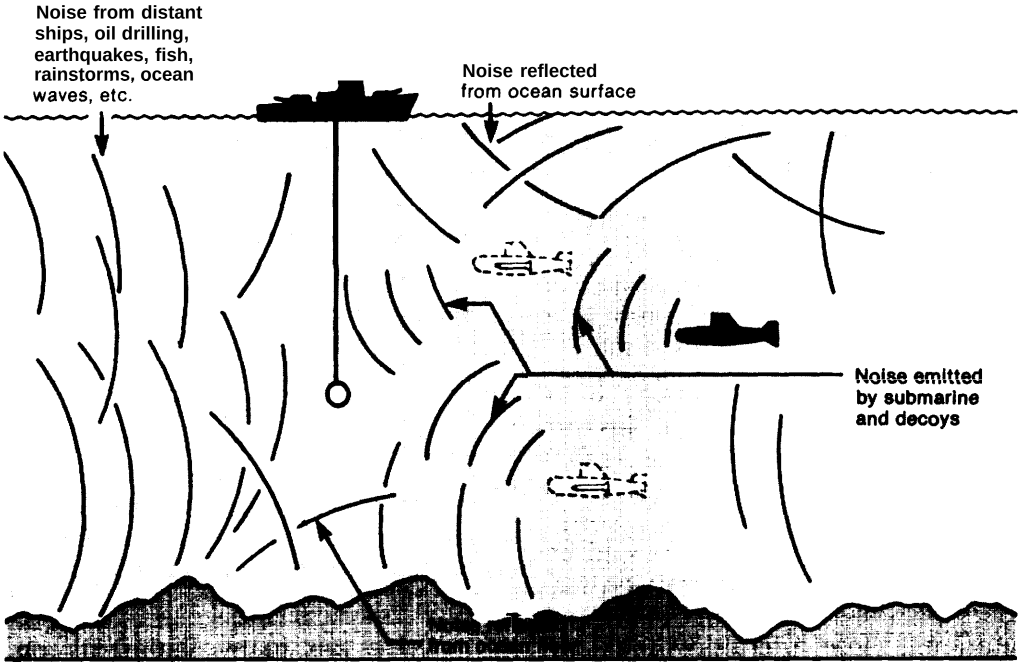
Attempting to establish trail on a submarine egressing from a home port requires not only

Figure 79.—Active Acoustic Search for a Submarine That Has Dispensed Decoys Which Simulate a Reflected Sonar Signal From a Submarine Hull



SOURCE: Office of Technology Assessment.

Figure 80.–Passive Acoustic Search for Submarine That Has Dispensed Decoys Which Simulate the Sound of a Submarine



SOURCE: Office of Technology Assessment

"spoof proof" sensing devices with sufficient range and reliability for "a trailing operation, but the technology must be difficult to jam. Jamming, while not as elegant as the method of decoys, is at least as effective a means of "delousing" submarines as they egress from port. This could be accomplished with small surface ships or preemplaced sound projectors. If the trailers are using devices like magnetic anomaly detectors, relatively modest-sized coil devices capable of distorting the local magnetic field could be emplaced in the egress region or towed by small ships. These would, in effect, be magnetic jammers.

Still another tactic available for port egress operations might be to use the 12-mile limit to force the adversary to spread himself thin. The submarines could proceed up or down the coast well within territorial waters before proceeding into the open ocean. Since the submarine would be in noisy shallow coastal waters, it would be undetectable from outside the territorial limit. The adversary would virtually have to commit thousands of ships to attempt to establish trail on port egress.

Finally, the logistics of establishing a picket in order to pick up egressing submarines should not be neglected. Assets stationed outside a port in order to try and pick up egressing submarines would have had to transit from home ports. This would mean that each ship would have to spend a period of time covering the port access looking for egressing submarines, a period of time transiting back to home ports for resupply and repair, and a period of time transiting back again to cover the port. Enough ships and/or submarines would have to be committed at all times to the port watch so that all the entrances, exits and coastline which submarines could use for egress operations from the port would be continuously covered. There must also be enough excess ships or submarines on station so that all suspicious contacts can be prosecuted until they are determined to be false targets.

It should be clear that egress from port has such a rich diversity of countermeasures and technologies that it can effectively be considered a nonexistent threat to any well-run submarine force.

Establishment of Trail Using Large Area Open Ocean Search

Since egress from port has such a variety of operational countermeasures and technologies that favor the egressing submarine, an adversary may instead choose to combine a large area search with trailing vessels at sea.

Again, for purposes of illustration, it is assumed that 300 to 600 long-range aircraft equipped with radars that allow for a 14,000 nmi2 per hour search rate transit from Cuba to a 3-million-nmi^2 deployment area in the Northwest Atlantic. This fleet of aircraft would be large enough to maintain 100 aircraft on station, 24 hours per day. Between transit and search operations, these aircraft would consume more than 1.5 million gal of aviation fuel per day. As postulated earlier, such a search might produce a radar contact with 1 of the 50 assumed submarines on the average of once an hour. This contact would occur when the submarine was snorkeling so the submarine would have detected the radar signal and could be presumed to recognize it had been sighted.

If the Soviets have, in addition, 1,000 ships evenly distributed over the 3-mill ion-nmi^2 operating area, one ship will on the average be able to patrol a 3,000-nmi^2 area of approximately 30-nmi radius. Assuming the ship is, on the average, capable of arriving at the area of contact within 1 1/2 to 2 hours and the submarine has moved in a random direction at 10 knots after being detected, the ship will have to search an area of 700 to 1,2oO nmi^2 by the time it arrives in the vicinity of the aircraft radar contact. If the ship has sonar device with a 2- or 3-mile range and can search at 10 knots, it will be able to search about **40** to 60 nmi^2 within the first hour of arrival at the location where the submarine was first sighted. If the submarine is not found within the first hour of search, it will have traveled another 10 nmi from the point of sighting and would be somewhere within an area of 2000 to 3,000 nmi2.

The probability of the ship picking up the submarine would be of order 0.03 to 0.08 and would vary dramatically with how fast the ships arrive at the point of aircraft sighting. Assuming that the probability of the ship establishing trail is 0.08, then on the average, 2 of the 50 submarines would be picked up on trail each day of operation.

If the submarine were equipped with 10 decoys, it could then attempt to break trail in the following manner. If trail is established, a single decoy could be released by the submarine, giving the trailer a one in two chance of choosing the correct target. If the correct target is chosen, another decoy could be released. Thus, by the time the submarine had released its tenth decoy, the probability that trail is maintained would be about one in a thousand (2^{10} = 1,024).

There are many variations on the open ocean search followed by trailing. These variations include the use of helicopters operating from the on-station search ships and the use of multiple ships converging on sighting locations. The assets that must be committed by an adversary, under optimistic assumptions of good weather and capable reliable sensors, is enormous relative to countermeasures. I n the above case, the 50 submarines equipped with 500 decoys are able to remain untrailed by an adversary who has committed a fleet of 300 to 600 long-range surveillance aircraft, 1,000 surface ships, and sensors that surpass the performance capabilities of what is likely to be achievable.

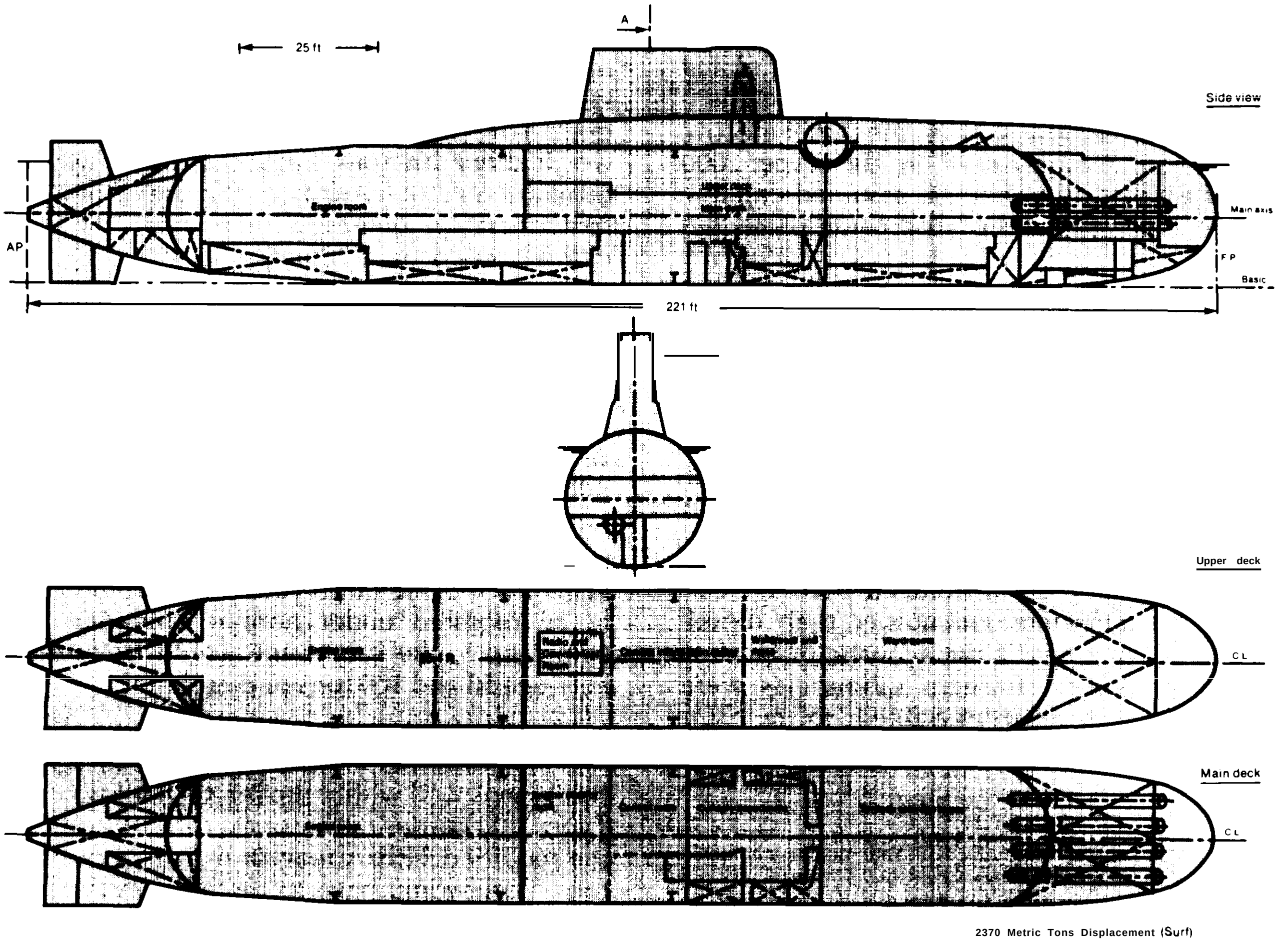
As is indicated throughout the discussion on vulnerability, opportunities for obtaining information on the location of snorkeling submarines are far greater because of the increased noise output associated with snorkeling and the fact that a snorkel mast is exposed above the ocean's surface. Detailed analysis indicates that long-range passive detection of modern snorkeling submarines would not be a threat to the survivability of the force. Analysis indicates that nonacoustic search techniques that might be able to detect snorkels will also not seriously affect the survivability of a fleet of diesel-electric ballistic missile submarines deployed within 1,000 to 1,500 nmi from the continental United States and Alaska.

Nevertheless, as remote sensing improves and satellite surveillance becomes more complete, it is possible that concern about the need to snorkel could arise. It is therefore of interest to describe some features of modern diesel-electric propulsion systems and compare them to another proven propulsion technology — nuclear propulsion.

Diesel-Electric Propulsion Technology

The diesel-electric propulsion system in the German-type 2000 powerplant is an example of proven capabilities in modern nonnuclear submarines (see fig. 81). The submarine is designed to snorkel using four 1,400 RPM high-speed diesel-driven generators simultaneously. When configured as an attack boat, it will snorkel less than 90 minutes out of 24 hours (assuming it snorkels with a 6-knot speed of advance and patrols on batteries at 5 knots). If the submarine were configured as a strategic weapon submarine instead, additional power would be

Figure 81.—German Type 2000 Submarine



SOURCE: Office of Technology Assessment

consumed due to increased hydrodynamic drag on the missile fairings and added load due to the strategic weapon system and the missiles. The snorkeling period with these additional loads would be about 2'A hours per day (i.e., the submarine would snorkel about 10 percent of the time). The submarine carries 960 batteries which are energy-managed by a microprocessor. The propulsion motor has a maximum output of 7,500 kW and is double mass isolated from the hull for silencing. The motor is air coupled to the shaft (for silencing) and the shaft drives a seven-blade skewback propeller. When configured as an attack submarine, this boat has a top speed close to 25 knots (which can be maintained for about 1 hour).

When operating on batteries, any modern diesel-electric submarine will, for all practical purposes, be close to acoustically undetectable by passive means. Thus, the diesel-electric technology demonstrated in the Type 2000 would easily fall within the assumed capabilities of the vulnerability discussion presented earlier.

Nuclear Electric Propulsion

Small submarines that use nuclear propulsion might have survivability superior to those powered by diesel-electric systems. * However, this would depend on the nature of any unforeseen future threat that might emerge and is therefore dissicult to analyze.

It is generally acknowledged that nuclear-powered submarines are noisier than diesel-electric submarines. If the acoustic outputs of nuclear-propelled strategic submarines were large enough to result in a threat to their survivability (and they are not), proven technology exists that would permit them to be equally quiet.

Since the coastally deployed strategic submarine has modest power requirements relative to those needed by longer range faster and more versatile submarines, it is possible to use an inexpensive self-regulating TRIG A-type nuclear reactor as a power source alternative to diesel-electric propulsion. The power system would employ fully developed reactor technology used in conjunction with standard hardware and electronic components. Because of the self-regulating features of this type of reactor (and, in fact, any small low enrichment reactor), the safety and control systems on the reactor would be very simple. The reactor would be natural circulation and conversion to electricity could be accomplished using thermoelectric modules (about 4 to 6 percent conversion efficiency is within proven technology). The reactor, with its shielding, would weigh about 100 tons. Since the reactor would generate electricity without the use of moving parts (neither generators or pumps), the submarine would be as quiet as an electric-powered submarine and would never have to snorkel.

The submarine could carry 550 tons of batteries as does the Type 2000 submarine since it would need extra propulsion power on occasion. It would therefore have high-speed capability similar to the Type 2000 until the batteries were drawn down. Quick recharging would be done with the aid of diesel-driven generators. Since quick recharging would rarely be required under normal operating circumstances, the submarine would carry only between 50 and 100 tons of diesel fuel.

The weight budget of the Type 2000 submarine indicates that a small submarine design of this type is well within proven technology. The Type 2000 carries close to 300 tons of fuel and the modified TRIGA reactor weighs about 100 tons. Care would have to be taken in the submarine design to account for differences in weight distribution dictated by a single large component like a reactor.

A specific system design and the fabrication of a prototype would be required before a

'It IS hard to say that a coastally deployed, small strategic sub marine would be more or less survivable if it were nuclear powered since its survivability would not depend on an ability to maintain high speeds for extended periods of time, as might be the case with attack submarines In addition, since the coastally deployed submarines would always be relatively near the continental United States, they would not have long transits to and from patrol areas In any case, the survivability of either diesel-electric and the nuclear-powered units would be so high that the choice of propulsion system need not be of serious concern reactor unit could be brought into service. If reactors were then produced at a rate of at least six units per year, it would cost less than $20 million (1981 dollars) per unit. This figure would add only a marginal cost to the submarine.

If a decision were to be made to deploy MX missiles on small submarines, such a propulsion system would clearly be a competitor with diesel-electric propulsion, both in terms of survivability and cost. This deployment would have to be considered by any design group tasked with the problem of designing an MX-carrying system of small submarines.

Concluding Remarks on the Vulnerability of Submarines

Antisubmarine warfare techniques and methods is an area of high sensitivity due to concerns about security. For this reason, the numbers used in this section in conjunction with specific search technologies should in no way be construed as indicating the state of the art with regard to the sensing technologies discussed. What this discussion has sought to do is provide the reader with a sense of the richness, diversity, and complexity that accompanies both submarine technologies and operations. It should also be noted that all technologies that could in principle or in practice be used as a means to find submarines have not been discussed. However, the conclusions that can be drawn about the survivability of strategic submarines from the present discussion in fact vastly overstate the vulnerability of these systems.

FACTORS AFFECTING THE ACCURACY OF LAND- AND SEA-BASED MISSILES

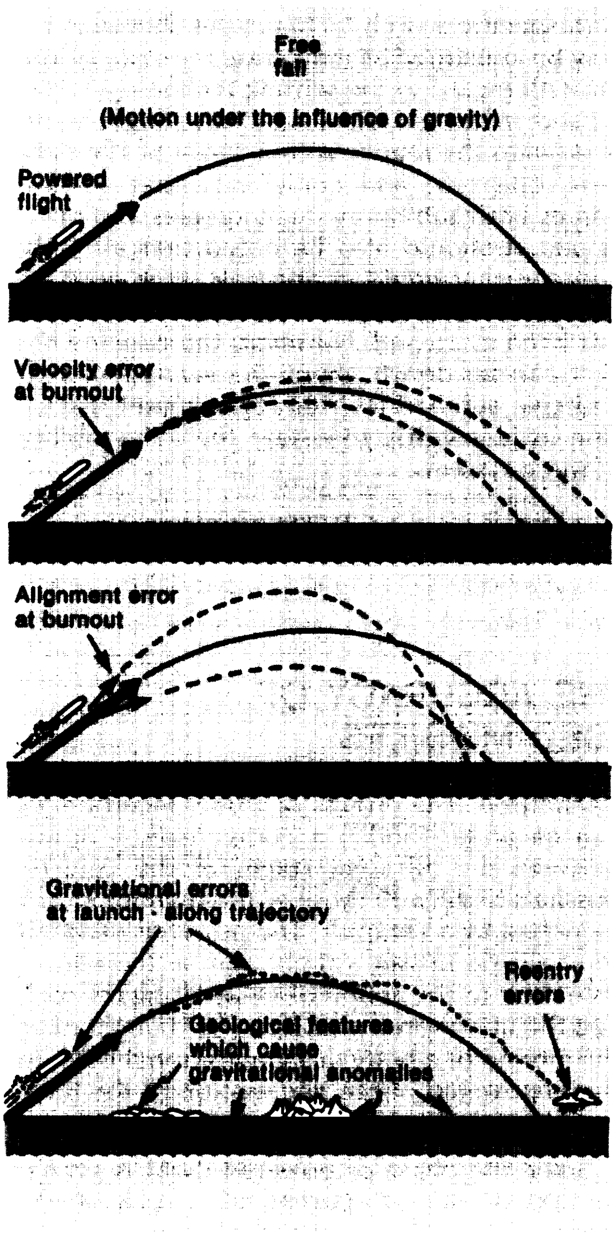
In this section, some of the factors that play a role in determining the accuracy of land- and sea-based ballistic missiles are presented in order to establish a context for discussion in the sections that follow.

A ballistic missile is a device that is accelerated to a velocity sufficient to reach a target or set of targets without further propulsion. Intercontinental range ballistic missiles (missiles with a range of order 6,000 miles) generally undergo powered flight for a period of 5 to 10 minutes. Once powered flight is complete, the missile's upper stage and reentry vehicles float toward a target, or a set of targets, under the influence of gravity in the near vacuum of space. In the final portion of the flight, the reentry vehicles enter the upper atmosphere and are subjected to very strong aerodynamic forces before finally arriving at targets.

During the initial stages of powered flight, guidance errors can be introduced by uncertainties in the missile's velocity, position, and orientation. The effects of these uncertainties can be understood if a comparison is drawn between the different stages of the ballistic missile's flight with those of the flight of a rock launched by a catapult. The powered phase of the ballistic missile's flight can be thought of as similar to the action of catapulting the rock and the unpowered phase can be thought of as the motion of a body in a gravitational field. In the unpowered phase, the motion of the body is entirely determined by the force of gravity.

Since the phase of powered flight is similar to that of the catapulting of a rock, if the missile is almost on course after the engines have burned out, but the magnitude of its velocity is slightly in error, it will fall short or long of the target (see fig. 82). If the missile velocity is correct but the missile is slightly misaligned from its intended direction, it will also miss the target. In addition, even if the missile is properly alined and has the correct speed, if its launch point is moved with respect to the target, the missile will again miss its target.

Figure 82.— Factors Affecting the Accuracy of a Ballistic Missile



SOURCE: Office of Technology Assessment

The effects of uncertainties in the gravitational field also influence the missile's accuracy in the early stages of powered flight. When the missile is initially launched, the forces that determine the motion of the missile are due to the thrust of the rocket's engines and the gravitational field of the Earth (aerodynamic forces are neglected here for simplicity). If the gravitational field is not known in detail, the missile will end up, after launch, with a slightly different direction and velocity than originally intended. Since this change occurs early in the missile's flight, a slight misalignment in direction, or uncertainty in velocity, accumulates into a much larger target miss as the missile floats for great distances along its trajectory. As will be explained later in this section, these velocity and direction errors can be introduced due to lack of knowledge of the Earth's gravitational field, as well as due to imperfections in different elements of the missile system. If unaccounted for, these errors can accumulate into significant miss distances at the target.

After the missile's engines are turned off, its motion is determined by the gravitional field of the Earth. If the gravitational field is different from that which is expected, the reentry vehicle will not follow the trajectory that has been planned for it. For this reason, the missile guidance system must have data on the nature of variations of the Earth's gravitational field along the trajectory to the target.

Still later in the missile's flight, the reentry vehicle enters the upper atmosphere and begins to decelerate violently (this process usually begins at about 100,000 ft for a warhead flown at intercontinental ranges), In this stage of flight, wind and rain can have an effect on the reentry, as well as uneven ablation, body wobble, or misalinement. Errors that occur in guidance during this stage of ballistic missile flight are called "reentry errors. "

Missile accuracy is generally defined in terms of the circle of equal probability (also called the circle error probable) or CEP. The CEP is the radius of a circle that is drawn around the target in which, on the average, half of the reentry vehicles fired at the target fall. There are two geometric contributions to the CEP. The first is called the cross range or track error. This error is a measure of the miss distance perpendicular to the direction of the missile's motion at the target. The second geometric contribution to the CEP is the down range or range error, that is the miss distance along the direction of the missile's motion at the target.

Table 25 shows the different contributions to target miss for a missile which depends on pure inertial guidance at a range of 5,500 nmi. This table gives some indication of the importance of initial errors in position velocity, and alignment in determining the missile's CE P. Each of these error components contributes to the down range and cross range errors as the square root of the sum of the squares (see fig. 83). The CEP is then 0.59 times the sum of the down range and cross range errors.

The major factors that contribute to the accuracy performance of any inertially guided intercontinental range ballistic missile (missiles of nominal range of 6,000 nmi) can be broken into the following categories:

1. uncertainties in the initial position, velocity, and orientation of the missile at launch,
2. boost phase guidance errors due to inertial sensing errors, and inertial computational errors,
3. thrust termination errors at the end of the boost phase,
4. velocity errors imparted to reentry vehicles during deployment by bus,
5. gravity anomaly errors,
6. uncertainties in the position of targets (targeting errors), and
7. atmospheric reentry errors.

Although the magnitude and importance of each of these factors in determining missile accuracy will vary (with missile design, missile range, weather conditions over the target area, and the quality of gravitational data over the flight trajectory of the missile), all but two of these factors are in principle the same for both land- and sea-based missiles.

Factors 1 and 5 account for most of the difference in accuracy of land- and sea-based systems.

Since sea-based missiles are constantly in motion, the missile must be provided with accurate information on its position, velocity, and orientation. This necessity requires a navigation system capable of providing information to the missile before it is launched. The quality of this navigational data will affect the performance of the missile.

The quality of gravitational data near the launch points of land- and sea-based missiles may differ. If this is the case, this too will affect the accuracy performance of the missile.

Table 25.—Miss Sensitivities to Initial Errors for ICBM Trajectories

Error Component		Miss Sensitivities		
		Units	Down Range	Cross Range
Initial Posit ion Error	Down range	m/m	1	0.0
	Cross range	m/m	0.1	0.7
	Vertical	m/m	5.4	1.3
Initial Velocity Error	Down range	m/(cm/see)	40	9
	Cross range	m/(cm/see)	2	10
	Vertical	m/(cm/see)	22	6
Initial Alignment	Level	m/arcsec	46	21
	Azimuth	m/arcsec	6	24

"These values apply to a 5500 nmi minimum energy trajectory CEP = .59 (Down range error + cross range error),

SOURCE. "Guidance System Application of MX Basing Alternatives" by Major G B Green/SAMSO and L N Jenks/TRW

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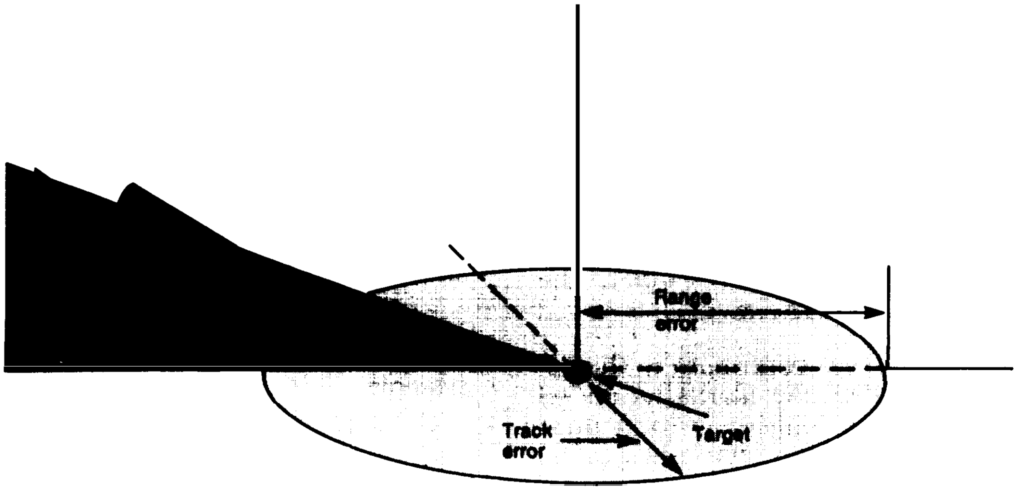
Figure 83.—Down Range and Cross Range Errors of a Ballistic Reentry Vechile at a Target



SOURCE: Office of Technology Assessment.

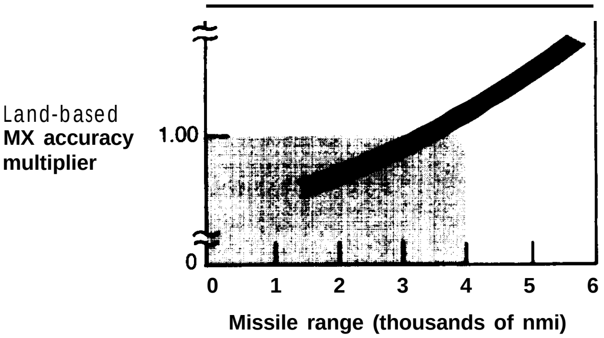
ACCURACY OF SMALL SUBMARINE BASED MX

The object of having a missile with great accuracy is to have the ability to place warheads sufficiently close to very hard military targets so that there will be a high probability of destroying them. The ability to do this will in general depend on the nature and the quality of the guidance technology used by a missile system and the range of that missile from its targets.

The MX, as designed, is a purely inertial guided missile. In the following presentation the accuracy of a sea-based MX that uses purely inertial guidance will be discussed next, and the accuracy of a sea-based MX that uses inertial guidance in conjunction with radio beacons will be discussed last.

Figure 84 is a graph of the CEP accuracy multiplier for a sea-based MX with pure inertia l guidance. A CEP accuracy multiplier of 1.0 on the graph means that the expected CEP of the missile at that range from target will be equal to the engineering-design requirements for the land-based MX. A CEP multiplier of 1.5 means that the CE P at that range will be 1.5 times that of the design requirements of the land-based MX, and so on. At present, it appears likely that the land-based MX will have a smaller CEP than that set for its design requirements, so a CEP multiplier of 1.0 does not necessarily mean accuracy equal to a land-based MX. The graph assumes that the submarine's position is known within a few meters and that it would use a velocity measuring sonar to measure its

Figure 84.—Accuracy of Inertially Guided Sea-Based Missile at Different Ranges From Targets



SOURCE: U.S. Navy.

velocity. None of the above assumptions present any operational problems for the submarine fleet (for reasons that will be discussed later) and so this graph can be considered a good operational representation of achievable accuracies at different ranges from targets.

In order to illustrate the significance of range from target effects for the small submarine-based MX missile, table 26 lists a number of cities in the Soviet Union in regions that also may have targets of military interest. The number in the upper part of each of the boxes in the table is the range from one of the three submarine deployment areas to targets within the regions surrounding these cities. In the lower part of each box the expected hard target kill capability of a sea-based MX is compared to that of the hard target kill requirements for the land-based missile. It should be kept in mind that the accuracy requirements set for the land-based MX result in very large single shot kill probabilities against targets of great hardness. In fact, the single shot kill probabilities used to compile table 26 are sufficiently large that differences described as "slightly better, " "comparable," and "slightly worse" r-nay not be of military significance (see Classified Annex for numerical details).

If targets in the region around Novosibirsk were to be attacked, warheads would have to travel roughly 3,700 nmi to reach their targets. The graph in figure 83 indicates that for that range, warheads fired from the Gulf of Alaska could have an expected accuracy at the target Slightly better than the design requirements set for the land-based MX. Missiles fired from the Northeast Pacific deployment area would have slightly worse accuracy than that of the land-based design requirements and missiles fired from the Northwest Atlantic deployment area would have still worse accuracy than those from the Pacific area.

The significance of a slightly improved or degraded hard target kill capability becomes still less significant for hard targets which merit attacks with more than one warhead. If, for instance, a single warhead fired from one submarine operational area had a probability of 0.95 of destroying a particular hard target and a second warhead fired from a different submarine operational area had a 0.85 kill probably against the same target, a 2-on-l attack would still have a greater than 0.99 probability of destroying the target being attacked. This means that cross targeting could be performed from different operational areas with considerable flexibility.

This point is applicable even for targets in areas that are extremely far from al l of the submarine operating areas. Even though these tar-

Table 26.—Comparison of Hard Target Kill Capabilities of Sea-Based MX" With Design Requirements of the Land-Based MX

	Relative hard target kill capability		
Range to target from launch area	Gulf of Alaska	Northwest Atlantic	Northeast Pacific
Moscow	4,200 Comparable	3,900 Slightly better	4,500 Comparable
Semipalatinsk	4,000 Slightly better	5,200 Slightly worse	4,700 Slightly worse
Vladivostok	3,000 Slightly better	5,800 Worse	3,900 Slightly better
Novosibirsk	3,700 Slightly better	4,800 Slightly worse	4,400 Comparable
Minsk	4,100 Slightly better	3,600 Slightly better	4,600 Comparable
Irkutsk	3,400 Slightly better	5,200 Slightly worse	4,200 Slightly better
Tashkent	4,600 Comparable	5,600 Worse	5,500 Worse
Tyuratam	4,500 Comparable	4,900 Worse	5,200 Worse

a Numerical values available in the Classfied Annex

SOURCE: Office of Technology Assessment

gets are at very great distances from all the submarine operating areas, and accuracy degrades with distance from target, such targets will still be subject to successful attacks from sea-based missiles in the late 1980's and early 1 990's.

The most extreme test of the system capability shown on table 26 are targets in the region surrounding Tashkent, in the extreme southern region of the Soviet Union (Tashkent is about 200 miles from the Soviet Union's border with Afghanistan). Single warheads fired from the Gulf of Alaska would have to travel about 4,600 nmi to targets in that region and would have single shot kill probabilities comparable to the design requirements set for the land-based MX. Missiles fired from the other two operating areas would have to traverse much greater distances (about 5,600 and 5,500 nmi). The probability of destroying hard targets in this region with a 2-on-1 attack using missiles from *any* combination of submarine operating areas would differ by only a few percent. Thus, even in the extreme case of very distant hard targets, 2-on-1 targeting would result in an almost indistinguishable difference in capability to destroy very hard targets of importance.

If the targets were to be made still harder in an attempt to increase their survivability against sea-based warheads with the yield accuracy combinations used to construct table 26, it might be possible to gain several percent more survivability against 2-on-1 attacks. The small gains introduced by such a program, would be enormously costly and could be wiped out by additional possible improvements in accuracy.

Table 26 assumes that all missiles fired against targets work, that is, it is compiled under the assumption of 100-percent missile reliability. If missile reliability is not better than the single shot kill probabilities, missile reliability will be more important a determinant of the hard target kill capability than accuracy. In the opinion of OTA, single shot kill probabilities from sea-based missiles could be so high by the 1990's, that missile reliability, not accuracy, will be the dominant factor determining hard target kill capabilities.

The guidance technology assumed in table 26 assumes minimal changes to the MX missile guidance system. The MX computation techniques used by the guidance system would have to be optimized for sea basing rather than land basing and high frequency gravitational data of the quality expected to be available in the late 1980's or early 1990's would have to be known within a 200-nmi radius of the launch point. In addition, the data summarized in table 26 assumes that the submarine would know its position to several meters and would use a velocity measuring sonar to update its velocity. Analysis performed by OTA indicates that the use of velocity measuring sonars does not introduce either operational or vulnerability problems for the MX-carrying submarines. However, if the GPS were destroyed, the satellites would not be available for position update immediately prior to missile launch. If the submarine did not take satellite position update several hours prior to launch, knowledge of its position would be sufficiently degraded that the accuracy curve presented in figure 84 could not be achieved against distant targets. This potential problem is, however, easily solved by proper force management.

If antisatellite boosters or launches were detected from American early warning sensors, the submarines could be informed over VLF channels that an attack on the satellite navigation system could be in progress. In response to this, the submarines would immediately proceed to update their navigational systems in the hours before the intercepts. While performing the satellite fix the submarines could simultaneously issue a "ready" signal to NCA via the Deep Space Millimeter Wave Satellite System. Since the submarines would be under orders to avoid all shipping at all times, it would be extremely unlikely that a submarine could not take a fix within the time period before loss of the satellites.

In the unlikely event that one or two submarines were unable to take a fix before hostil-

ities began, they could immediately proceed to the nearest acoustic transponder field. This would take the submarine between 2 to 3 hours. If a launch order were given during this period of time, submarines with sufficiently accurate guidance data could be in a position to launch without risk to the ship. Any submarine that had not reported a "ready" signal could immediately have its target package reassigned to one of the other submarines on station. This could be done using VLF channels if it only required reassignment of a prepackaged option or it could require the high data rate satellite l ink if ad hoc targets which are not listed on the National Target List are to be attacked. This force management procedure could therefore guarantee that the submarine force could strike targets on short notice with very high accuracy.

ACCURACY OF STAR-TRACKER-AIDED INERTIALLY GUIDED MX

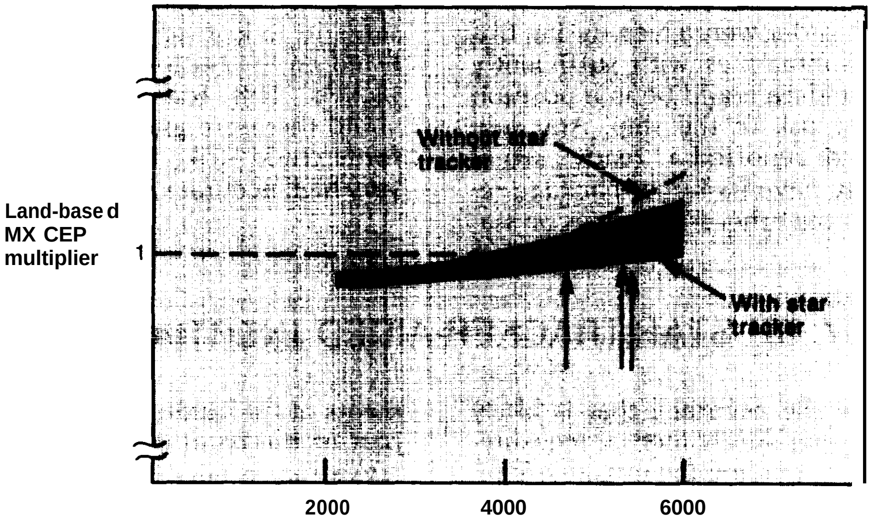
Heretofore only the accuracy that is likely to be attainable using purely inertial measurements as a means of guiding the missile is considered. We now consider the additional accuracy that could be attainable if the inertial guidance system is updated using some form of external reference. First the use of star trackers is discussed, and then the use of radio beacons, as means of updating the missile's inertial guidance system in order to obtain higher accuracy at greater ranges.

It is possible to mount a device on the missile guidance platform that will allow it to take a fix on a star after it leaves the atmosphere. This technique is currently being used on the new TRIDENT I missile and would be a more significant modification to the MX missile guidance system than that assumed in constructing table 26, Such a modification could delay the deployment of the missile by a year and cost several hundred million dollars. However, as will be discussed in the section on schedule, the submarines design and construction schedule should pace the missile development. Delays in the research and development of the missile would therefore not be likely to affect the date that the first missiles could be put to sea.

The broad band in figure 85 shows a conservative estimate of the band of possible accuracies versus range for an MX-like missile which has been fitted with a star tracker, As in figure 84 the accuracy multiplier is defined with respect to the engineering design requirements of the land-based MX missile. The upper part of the band is the accuracy versus range curve that is very likely to be achieved in the late 1980's or early 1990's. The three vertical arrows define the distances to Tashkent from the Gulf of Alaska, Northeast Pacific, and Northwest Atlantic deployment areas. As can be seen from the graph, it is very likely that all targets in the Soviet Union could be attacked in the late 1980's or early 1990's from all submarine operating areas with accuracies marginally better or worse than that of the engineering design requirements of the land-based MX. The lower part of the band represents a conservative estimate of what is possible in the late 1980's **or early** 1990's if the advanced MX inertial measurement unit is used in conjunction with a star tracker. If this level of performance is reached, all targets could be covered from all deployment areas with CEPs at least as good as the engineering design requirements of the land-based MX,

For purposes of reference to the earlier discussion, the dashed line plotted in figure 85 shows the accuracy multiplier versus range for an MX missile guided without the aid of a star tracker. The hard target kill probabilities used to construct table 26 and discussed earlier in this section are derived from this curve. Since the addition of a star tracker to the inertial guidance package helps reduce certain range-dependent guidance errors during the early stages of flight, the star tracker aided inertially guided missile displays a weaker degradation

Figure 85.—Accuracy of Star-Tracker=Enhanced Sea= Based Missile as a Function of Range From Target



SOURCE: U.S. Navy

of accuracy with range relative to that of the purely inertial guided MX.

It should be noted that the star tracker accuracy versus range curve shown in figure 85 is derived on the basis of assumptions about the availability and capability of certain technologies relevant to guidance, quality of navigational data at the time of launch, and knowledge of geophysical data around the launch point and along the missiles trajectory. The assumptions are as follows:

1. An Improved Submarine Inertia! Navigation System (SINS) and/or accurate initial position and velocity data at time of launch. Accurate data at time of launch could be obtained with the aid of: acoustic transponders, velocity measuring sonars, and the Global Positioning System.
2. Introduction of gravity gradiometers on submarines and/or quality high frequency gravity data within 200 nmi of the launch point. It is expected that these technologies and data will be available in the period of the late 1980's to early 1990's.

DEGRADATION IN ACCURACY AFTER A SUBMARINE NAVIGATION FIX

Because a star tracker enhanced, inertial guided missile is able to obtain navigational information by sighting on stars during its flight, its accuracy at range is not as sensitive to navigational uncertainties introduced by the continuous motion of its launch platform, as is the case with a purely inertial guided missile.

It is expected that submarine inertial navigation systems will be considerably improved even relative to their currently impressive capabilities. Improvements in inertial guidance technologies, gravitationaly mapping and the use of star trackers on missiles is expected to dramatically lengthen the time needed between navigational updates of the submarine inertial guidance system. I n the 1990's, navigational updates would not be required for days or even weeks in order to maintain sufficient capability to attack very hard targets from sea.

INERTIAL GUIDANCE AIDED BY RADIO UPDATE

The two sets of accuracy data so far discussed are based on improvements in inertial guidance technologies that are used in missiles and in submarines, and on improved geodetic and gravitational data.

Another set of guidance technologies that could be used to obtain high accuracy with sea-based missiles without precise navigational data at launch and extensive gravitational mapping is a system based on inertial guidance aided by updates from radio navigation aids.

Radio updates could be taken with the aid of the GPS. They could also be taken with the aid of a system of ground radio beacons CBS (also refered to as an Inverted GPS), that could be emplaced on the continental United States. In the event that the GPS is attacked using antisatellite weapons, the GBS could provide backup radio navigation aids to the missiles in flight. Unlike the GPS, the CBS would only operate during a crisis, and could be made costly to attack by constructing many radio beacons and decoys.

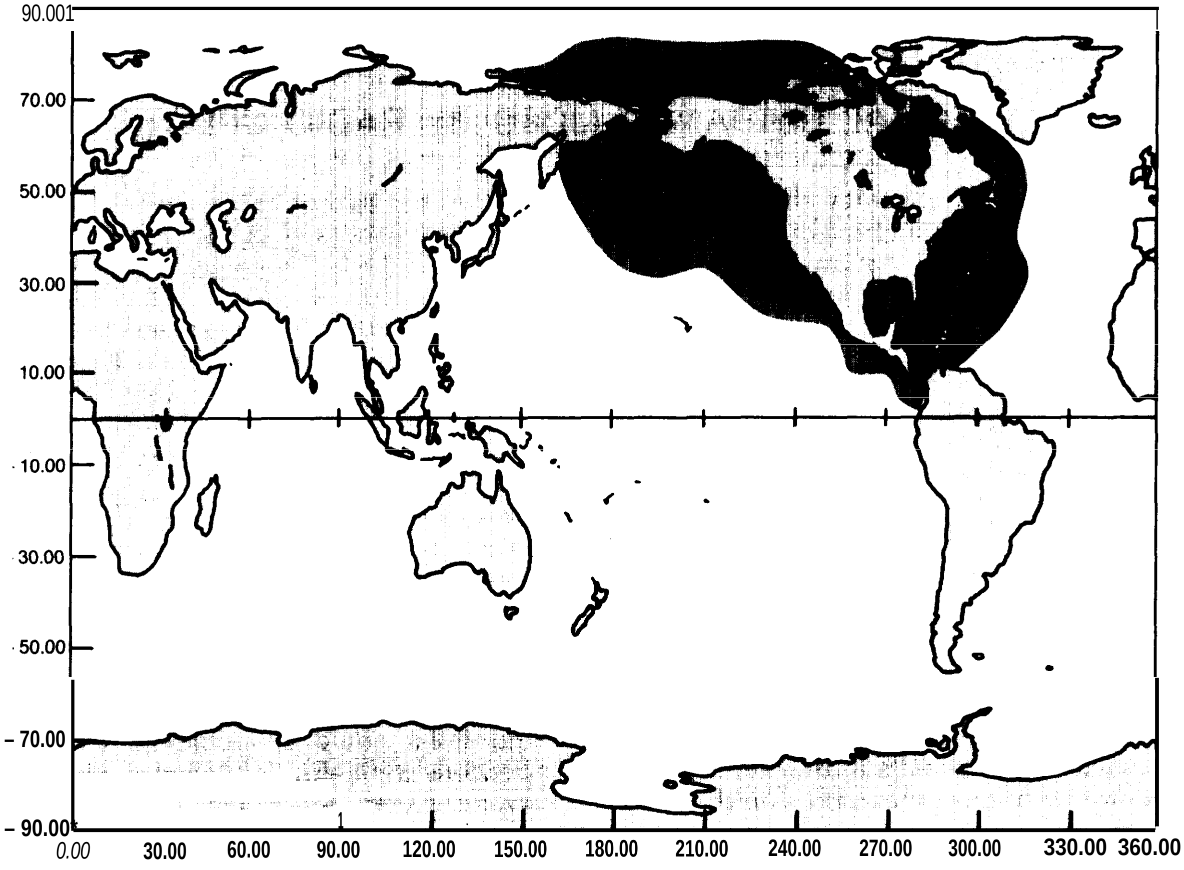
The sea-launched missile could radio update its inertial guidance system in three different ways, The missile could take a navigational fix using GPS to update its inertial guidance system before it deploys its reentry vehicles from the missile's post boost vehicle (i. e., the missile's bus). In the event of outage of the CPS, the navigational fix could instead be taken using the ground beacons. I f the GPS were destroyed and the ground beacons were used as a backup system, it would be necessary to take a radio fix through the ionosphere. This radio fix might be disrupted if there were nuclear detonations occurring in the ionosphere. In order to avoid disruptions of this type, a radio fix could be taken before the missile reaches the bottom of the ionosphere, perhaps at an altitude of about 50 miles.

The first two of these methods should provide MX accuracy at all ranges from Soviet targets. If the GPS were used, missiles could be launched from anywhere in the submarine deployment area. If the ground beacons were used, system accuracy would be degraded if the submarines were not with in 700 to 900 nmi of the continental United States. This degradation would occur due to errors introduced into the navigational update by poor line of sight geometry on the ground beacons. Figure 86 shows the areas of ocean from which a CE P multiplier of one could be achieved if ground beacons were emplaced on the continental United States, Alaska, Hawaii, and on the Aleutian Islands. Figure 87 shows the additional Pacific area from which the same CEP multiplier could be achieved if the ground beacons were also emplaced on the islands of Wake, Guam, Kwajalein, Palau, and Tafuna, Samoa.

If the ground beacons were used to update the missile guidance system before the missile reached the ionosphere (this update could be necessary if the GPS system had been destroyed and the ionosphere was disturbed by the detonation of nuclear weapons) the submarines would have to be within 400 to 500 miles of the continental coast if a radio update is to be possible before the lower ionosphere is reached. Using this method of update, a CE P multiplier of 1.0 to 1.5 that of land-based MX might be achievable. Unfortunately, calculations on this type of update have not been performed in detail and a more accurate assessment of the capability of this type of update is not available.

In summary, a sea-based MX could be guided using purely inertial measurement technologies or with inertial measurement technologies updated by sighting on stars or radio beacons. The star trackers offer a great

Figure 86.—Ocean Areas That Provide Adequate Line-of-Sight View of Ground Beacons on Continental U. S., Aleutian Islands, Alaska and Hawaii



SOURCE: Office of Technology Assessment.

advantage in that they are a self contained element of the missile and have been demonstrated to be highly reliable. Radio beacons on satellites, and on land, also can be used for updating the missile's inertial guidance system.

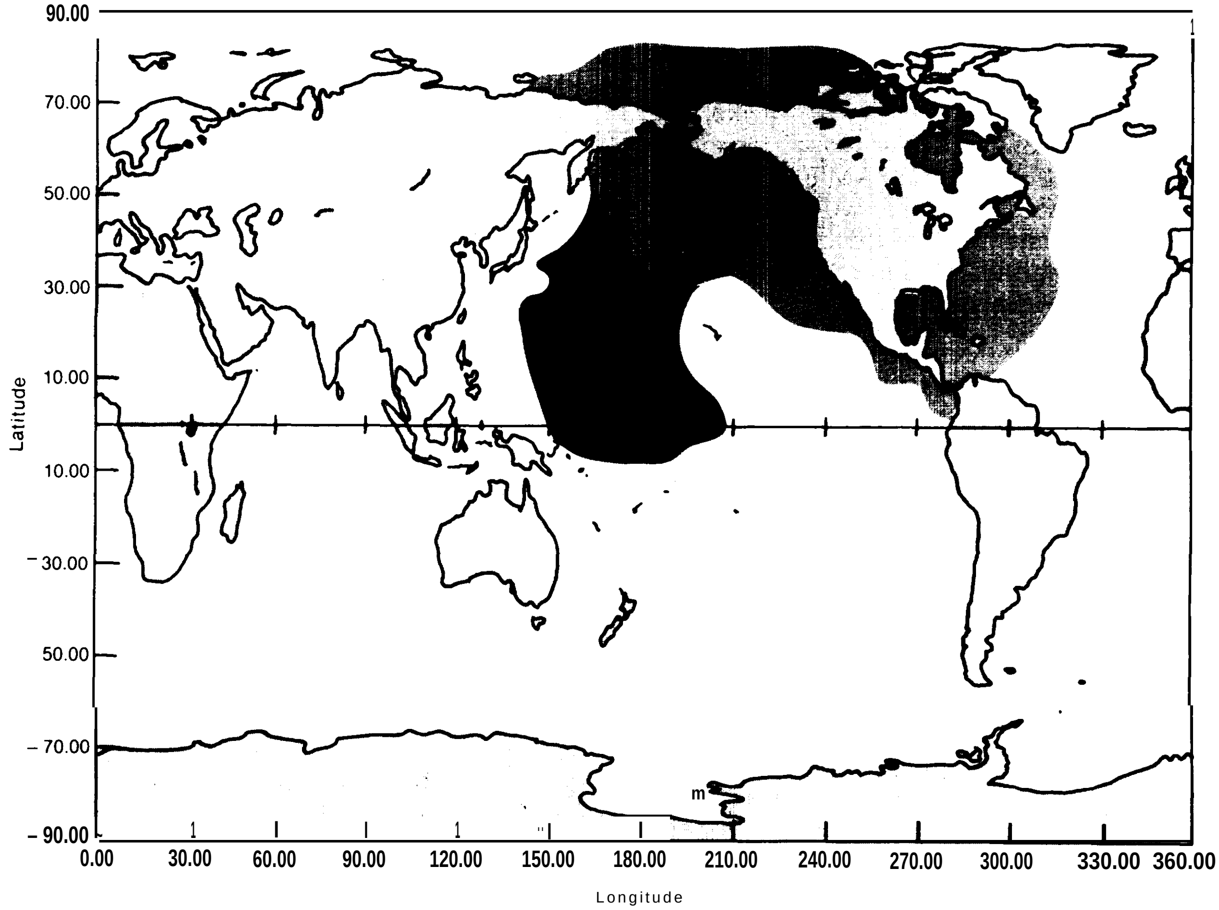
By deploying a large enough system of ground beacons and decoys as a backup to the satellite beacons, the risk from Soviet countermeasures could be kept small.

TIME ON TARGET CONTROL

If the submarine system is to attack hard targets with more than one warhead, there is a need to control the time at which warheads arrive at targets with a high degree of accuracy. This control is needed so that the detonation of the first warhead will not interfere with the arrival the second warhead.

Since the small submarine would carry missiles in external capsules that would be launched at different depths under different operational conditions, the exact time at which a missile flew out of the capsule could possibly effect the arrival of warheads at targets. In practice, this problem could be

Figure 87.—Ocean Areas That Provide Adequate Line"of-Sight View of Ground Beacons on Continental U. S., Aleutian Islands, Alaska, Hawaii, and Selected South Sea Islands



SOURCE Off Ice of Technology Assessment

solved by assigning each missile a time at which warheads are to arrive at targets. Uncertainties in launch time could then be compensated for by changing the missile's trajectory (i.e., the missile trajectory could be slightly lofted or depressed relative to the planned trajectory). Care would have to be exercised in the design of the fire control and guidance package to assure that this could be done.

RESPONSIVENESS OF THE SUBMARINE FORCE

The responsiveness of the submarine force is determined by the speed with which an Emergency Action Message (E AM) could be transmitted to the force and the time required for the submarines to launch their missiles. The calculation of trajectories to target sets must be performed for both land- and sea-based missiles if targets are reassigned to a missile without warning. The time necessary for these calculations wou Id be of order a few minutes and would not be a factor I ikely to delay a launch.

Therefore, the two time periods that would dominate the ability of the submarine force to respond rapidly to an EAM would be the time period needed to receive the EAM and the time period needed to prepare the submarine for the launch of missiles. The EAM could be received in a pre- attack or transattack period within a few minutes. If the submarines were ordered to execute a preplanned strike, all data necessary for the strike would be available at the reception of the EAM and the time required to initiate the strike would be determined by the time that could be needed to bring the submarines to launch depth. This time could be several minutes.

If the ordered attack were not a preplanned option, there could be two different categories of target sets chosen, those that are stored in the guidance computer and those that are designated ad-hoc in terms of their latitude, longitude and height of burst. If the target list required a high data rate link, the VLF link would not be appropriate. In this circumstance, a coded message would be sent over VLF for a particular submarine, or group of submarines, to come to depth and copy a new target list using the EHF satellite l ink Alternatively, if the submarine force were diesel-electric powered (rather than nuclear powered), the fraction of the force that was snorkeling could receive the ad-hoc targets as well. After recept ion of data, which would take only a minute or two over the EHF link, the submarines could immediately prepare for launch by proceeding to launch depth, provided the strategic weapon system is configured to directly accept and validate the data from the satellite link. Launch of the missiles could take place shortly thereafter. The rapidity of response of the system could therefore be of order 10 to 15 m i nutes

ENDURANCE OF FORCE

I n the event of a protracted nuclear exchange, surviving IC BMs might be required for strikes weeks or months after an initial exchange. These forces would be executed from surviving command and control centers using whatever communications channels were available.

The survival of command and control channels and the availability of communications channels during a protracted nuclear exchange is a common problem for both land- and sea-based forces. However, the endurance of the ICBMS themselves would differ with the basing mode.

The small submarine could be constructed to have an at-sea endurance of more than 90 days without support from tenders. It is assumed, based on U.S. Navy operating experience, that a normal submarine patrol would last for 60 days. This assumption means that for 30 days after an initial attack, no submarines would have to return to port. About 5 percent of the missiles at sea would be lost due to missile failures during this time. Sixty days after an initial exchange, about half the force would still be capable of remaining at sea. If the missiles were not operated in a dormant mode (so that they could be fired on a minute's notice rather than on an hour's notice) about 10 percent of the missiles could be expected to have failed at the end of 60 days. Thus, 9 weeks after an initial attack, the submarine force could deliver about 400 warheads against an enemy. By 12 weeks after an exchange, the number of operational missiles at sea would have diminished to zero.

COST AND SCHEDULE

The small submarine basing concept is envisioned as a fleet of 51 diesel-electric submarines, each of about **3,300** tons submerged displacement. Each submarine would be capable of carrying four externally encapsulated MX missiles. The submarines would be manned with a crew of about 45 members and would operate within 1,000 to 1,500 nmi of three bases. One of the bases would be located on the east coast of the continental United States, another would be on the west coast, and the third would be located on the coast of Alaska.

The acquisition cost of the system of submarines, bases, navigational aids, and related operational and support equipment is estimated to be about $32 billion (fiscal year 1980 dollars). An operating and support cost of $7 billion is estimated for a 10-year system lifecycle, The total cost of the system is estimated to be about $39 billion. The details of this cost estimate at the major subsystem level is presented in table 27.

The deployment schedule for a system of small submarines is shown in figure 88. This schedule would vary with the degree of commitment the nation makes to a new strategic weapon system. If the commitment is such that slippage is not allowed due to unforeseen technical setbacks, funding cuts, environmental law suits, or other actions that could require congressional action, an initial operational capability (IOC) in the middle of 1988 could occur. It could even be possible to have a lead ship by the end of 1987, but this would require a very high degree of national commitment. A more realistic estimate based on a review of military programs over the past decade would place IOC in 1990. If IOC occurred in 1988, full operational capability (FOC) could be achieved in late 1992. If the more realistic estimate of a 1990 IOC occurs, FOC would occur in early 1994.

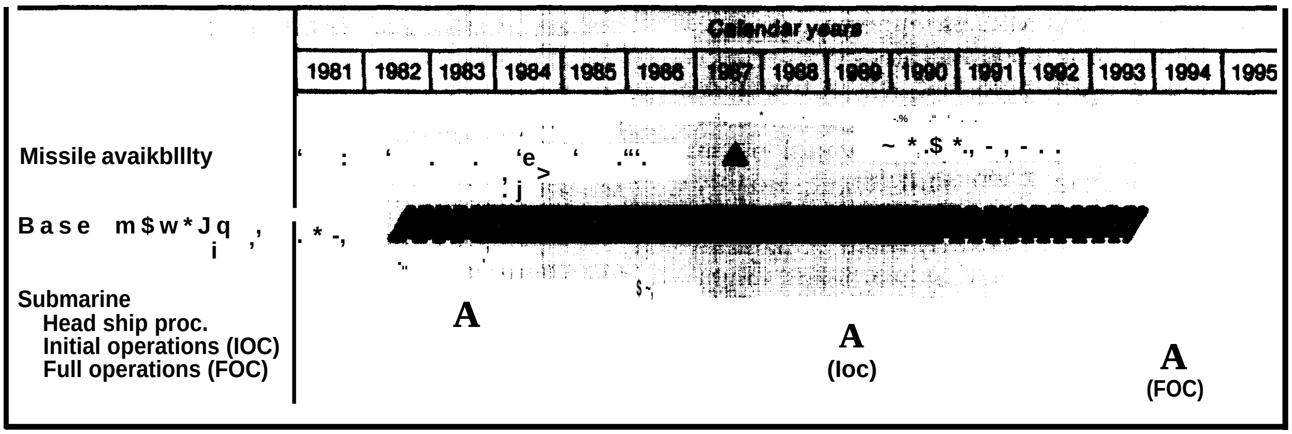
It should be noted that the costing of the submarine system assumes Navy procurement

Table 27.—Small Submarine 10-Year Lifecycle Cost (billions of fiscal year 1980 constant dollars)

Cost element	Number	cost
RDT&E:		
Submarine	—	$0.422
Missile	—	6.056
Sws	–	0.400
Capsule	—	0.257
Navigational aids	—	0.090
Total RDT&E		$7.225
Procurement:		
Submarine	51	$ 6.682
Basing	3	7.240
Missile	470	5.419
Sws	51	2.397
Capsule	521	1.725
Navigational aids	1,500/3,000	1.399
Total procurement		$24;862
Total acquisition		$32.087
Operating and support:		
IOC to FOC		$ 2.392
FOC to year 2000		4.868
Total operating and support		$=.160
Total to year 2000 LCC		$39.247
Average acquisition $/submarine,		$0.629
Average LCC/submarine to year 2000		0.770
Average acquisition $/deployed missile		0.157

SOURCE Off Ice of Technology Assessment

Figure 88.—Small Submarine Program Schedule



SOURCE Office of Technology Assessment

practices for the MX missiles. In order to have 100 missiles alert at sea at all times 470 missiles are obtained. The land-based Air Force baseline procures 330 missiles. The additional missiles are obtained since it is assumed that Navy experience developing sea-based missiles would apply to the MX if it were deployed at sea. These missiles would be used in an extensive program of testing and evaluation similar to that of the Trident/Poseidon programs.

It should also be noted that three bases are included in the costing. Since the submarines postulated for this system would have a considerable at-sea endurance, it would be possible to deploy them from two bases instead of three. However, each of the bases would have to be larger in order to handle additional submarines. These bases would normally service nine to ten submarines instead of six to seven.

SYSTEM SIZE

The number of submarines acquired was chosen so that 100 MX missiles would be available at sea for retaliation against the Soviet Union regardless of preemptive actions on their part. The choice of 100 surviving missiles was arrived at using the following reasoning:

The number of small submarines required for a sea-based MX system is determined by the perceived need to be able to attack a predetermined number of targets after any enemy action. The number of targets that the United States could attack after a Soviet first strike would depend on the number of missiles that survive such an attack.

It is assumed that all at sea-submarines would effectively survive an ICBM attack. This assumption is based on a review of the capabi1ities of antisubmarine technologies and forces. A barrage attack is not considered a significant threat for the following reasons:

The Air Force MX/MPS baseline has 200 missiles hidden among 4,600 shelters. For purposes of analysis, it is assumed that half of the land-based MX force will survive a determined Soviet attack. This assumption would mean that no more than 2,300 hard target capable warheads landed in the MX/MPS fields close enough to shelters to destroy them. A barrage attack with this number of warheads might result in the destruction of one to two submarines at sea. This does not represent a significant attrition of the submarine force.

The number of small submarines required to maintain 100 missiles at sea in an "up" status is determined by the number of missiles per submarine Mps, the fraction of missiles in an "up" status Fmu the fraction of the time a submarine is at sea during a patrol cycle Fas the fraction of submarines that are in overhaul or on restricted availability For and the fraction of submarines that are expected to survive an at-sea attack Fss. The total number of small submarines N required to maintain 100 missiles is then given by:

$$N \quad \frac{100}{\quad}$$

where

N = the total number of submarines required to deliver 1,000 RVS

Mps = the average number of missiles per submarine

F = the fraction of submarines in overhaul or restricted availability

t ,,. = the traction of time submarines are at sea during a patrol cycle

F_{mu} = the fraction of missiles In an "up" status at sea

$F_{\backslash\backslash}$ = the fraction of the at sea submarines surviving after an attack

Since the missiles would be in capsules external to the hull of the submarine, they could not be serviced while the submarine is at sea. Hence, the failure of a missile at sea would put it in a down status for the remainder of the at-sea patrol.

The fraction of missiles available at sea during a patrol period of T days will be:

1 S T – (It

where 7 is the mean t l me **between failure** of the missile and the is the length of time of the submarines is on patrol

Since each submarine will spend T days at sea and TIP days in port, the at sea availability of the submarine during a normal patrol cycle Is:

$$F_{I\backslash} \quad \frac{}{T + ,,,}$$

If a submarine spends 12 months in overhaul or in restricted availability during each 5-year operating period, then $_{o}$= 0.8.

Table 28 presents the number of submarines that would be required to maintain 100 missiles on station for different patrol periods at sea and for different times in port for refit. It is assumed that 100 percent of the submarines survive preemptive enemy action and that 20 percent of the submarine force is either undergoing overhaul or is in restricted availability. The numbers in parentheses assume 15 percent of the submarines are in overhaul or restricted availability instead of 20 percent. Thus, if it proved feasible to perform refit operations in 18 days (instead of OTA'S assumed 25 days) and to have 15 percent of the submarines in overhaul and extended refit, it would be possible to maintain 100 missiles on station with a fleet of 41 submarines, rather than the 51 submarines assumed by OTA. The at-sea factor is the fraction of the submarine force that is always at sea. It is defined as:

at-sea factor = F<,, (1 – F,,)

An at-sea factor of 55 percent is assumed in order to estimate the total number of required submarines. This factor is also used to estimate the number and size of base facilities required for servicing submarines between patrols.

In order to provide 100 at-sea missiles (or alternatively 1,000 surviving warheads) at all times, the at-sea reliability of the missiles must be factored into the sizing of the fleet. It is projected, from engineering requirements, that 95 percent of the missiles at sea would be in an up status for a fleet of submarines with an at-sea patrol of length **60** days.

Table 28.—Number of Submarines Required To Keep 100 MX Missiles Continuously on Station v. Submarine In-Port Time

Patrol period (days).	40	50	60
Number of submarines at sea .	26	26	27
Total submarine force size:a			
12 days in port	42 (40)	41 (38)	40 (38)
15 days in port	45 (42)	43 (40)	41 (39)
18 days in portb	47 (44)	45 (42)	43 (41)
21 days in port	50 (47)	47 (44)	45 (45)
24 days in portc	52 (49)	49 (46)	46 (44)

a Total force numbers assume that 20 percent of att submarines will be in extended refit or overhaul and are therefore unavailable Numbers in paren theses assumes 15 percent of the force in overhaul or extended refit.

b Naval Sea Systems Command estimates minimum time in Port required for refit IS 18 days.

c OTA assumes 25 days in port for refit and handling of missiles

SOURCE Off Ice of Technology Assessment

FINAL SIZING CONSIDERATION

In the final sizing of the system, it was assumed, in order to establish a conservative cost estimate, that 10 percent of the missiles might not function on a launch command and it would be necessary to maintain more than 100 "up" missiles at-sea. This assumption added 4 submarines to a procurement which would otherwise have been 47. The costs of procuring, operating and supporting additional crews, missiles, capsules, and strategic weapons systems is of the order of $1 billion to $2 billion.

LOCATION AND DESCRIPTION OF BASES

Base selection was limited to the continental United States since the submarine force is designed to operate in deep ocean areas adjacent to the continental United States.

The perceived need for responsiveness, flexibility, and weapon system effectiveness dictated that the submarines be able to move rapidly to acoustic transponder fields to maintain accuracy in the event of outage of the GPS. A very large operating area would spread the acoustic transponder fields over a large area of ocean, resulting in possible execution delays due to long transits to transponder fields. In addition, time on station could be maximized without the need of a submarine with a high transit speed. It should be noted, however, that none of the above considerations truly dictate a need for such a limited deployment area.

The Gulf of Mexico was rejected as a deployment area for the following reasons: diesel-electric submarine technology has achieved a level of quieting that would not restrict the submarines to acoustically shallow water even if a large-scale advanced passive sonar threat emerged. The acoustically shallow water of the Gulf of Mexico therefore offered no clear survivability benefits to offset the range/payload/accuracy missile performance penalties associated with that deployment area.

It is assumed that a detailed review of possible base locations would be made if there was a decision to deploy a fleet of small submarines. In order to provide a basis for estimating costs, three base locations on the east and west coasts of the continental United States and Alaska were assumed. These are:

- Anchorage, Alaska
- Puget Sound Area, Wash.,
- Narragansett Bay, R. 1.

Each of the sites has problems of its own. The arctic winters, long winter nights, and extreme weather at the Anchorage site would pose problems clearing ice, loading and off loading missiles, maintaining and refitting submarines, and supporting crews at the base. The Puget Sound area already has a Trident base (Bangor, Wash.). Construction at the Narragansett Bay site could be delayed due to competition for the land from the Rhode Island Government.

Other possible secondary sites could be:

- San Diego, Cal if.,
- Charleston, S. C.,
- Kingsbay, Ga.

These possible sites also offer their own problems. San Diego would be unlikely to provide enough waterfront area without displacing existing Navy operations. Charleston and Kingsbay could be too far south for the most efficient deployment of submarines in the northern coastal areas of the Atlantic.

Since SSBN fleet support is shifting to Kingsbay, waterfront area may become available in Charleston for submarine support in Charleston while MX support might be provided at the new SW FLANT facility at Kingsbay. Tradeoff studies would have to be performed in order to evauate the sensibility of these options.

In order to develop a conservative estimate of the size, number, and cost of facilities at the small submarine base, an analysis of the *Trident* base facility at Bangor was made. Approximately 85 to 90 percent of the land required for the base is dictated by explosive weapons safety requirements and facilities for handling strategic weapons. It was assumed that the amount of land required scaled with the number of strategic weapons on the base. This number includes the missiles on the submarines, missiles stored for operational tests, and missiles stored for demonstration and shakedown operations. These assumptions lead to the conclusion that 4,450 acres would be required for the base. other assumptions could lead to a smaller less costly base but they would only be justified if a more detailed feasibility analysis could be performed.

The size of the base arrived at for the costing analysis is approximately 500 acres larger than a base sized in an earlier study of small submarine basing performed by the System Planning Corp. for the Navy. Table 29 compares the estimated small submarine base with the *Trident* base at Bangor.

Table 29.–Estimated Characteristics of the Small Submarine Refit Site and the Trident Refit Site

	Small submarines	Trident
Total area (acres)	4,450	8,397
Waterfront length (feet)	11,630	4,248
Number of submarines in port	5/6	3
Number of explosive handling wharfs	1	2
Number of refit berths	4/5	3
Drydockets/graving docks	1	1

SOURCE Off Ice of Technology Assessment.