FROM POLARIS TO TRIDENT: THE DEVELOPMENT OF US FLEET BALLISTIC MISSILE TECHNOLOGY

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TRIDENT AT SEA

An American Trident submarine is 560 feet long, or almost twice the length of a football pitch. Each can carry twenty-four missiles capable of delivering nuclear warheads to targets thousands of miles away.[1] Each of these warheads can deliver an explosive yield many times as powerful as the bomb dropped on Hiroshima to within about a hundred yards of its target.[2] This formidable destructive capability is the culmination of over thirty years of technological development, and six generations of missile: Polaris A1, Polaris A2, Polaris A3, Poseidon, Trident I, and Trident II.

Trident submarines on patrol in the Atlantic and Pacific oceans have just one mission, as have had all fleet ballistic missile (FBM) submarines since the first Polaris submarine went on patrol in 1960; that is to be able to launch some or all of their complement of missiles at any time they are required to. To this end, the submarines must remain undetected by potential enemies, forever awaiting a message that they hope will never come.

Various technologies have been brought together to make this possible. The missile itself principally consists of nuclear warheads inside protective reentry bodies,[3] a guidance system, and steerable propulsion. Once fired, it becomes independent and cannot be recalled or destroyed (except for test missiles).

The pattern for FBM patrols was set by Polaris which initially was restricted to the Norwegian Sea because of the missile's short range. Standard practice was for three submarines to form what is called a chain. Each chain would be allocated two target sets that would be 'passed' from one submarine to another halfway through its patrol. The third submarine would be at the support tender ship and would take up the first target set as the first submarine returned from patrol. Thus between them the three submarines provided continuous coverage to two sets of targets.[4] All subsequent FBM patrols, including those with longer range missiles and operating in both the Atlantic and Pacific, have followed the same operational procedure. The chain system, and the possible need occasionally to replace a submarine in a chain, provides a strong rationale for standardisation of the missiles carried by the submarines. All submarines in a chain must be equipped the same as regards warhead numbers, types, and any penetration aids.

During its patrol the submarine's navigation system must be constantly updating its position and heading and providing this information to a fire control system. Over a typical three-month patrol the self-contained inertial navigation system also requires periodic updating from external sources to maintain accuracy.

Communications systems must be continuously listening, waiting for an emergency action message (EAM). This is the command from the National Command Authority (which comprises in the first instance the President and the Secretary of Defense) to fire some or all of the missiles.[5] Unlike most other nuclear weapons in the US arsenal, the warheads carried by the FBM force (and most other naval weapons) are not fitted with permissive action links (PALs) that require a code to activate them.[6] Instead, unauthorised use is prevented by the need to follow a rigid routine involving several people, none of whom individually could sustain the necessary process. However, so long as the original EAM matches the correct format this process should proceed smoothly.[7]

This would then set in motion the preparation of the missiles for launch. Unlike US Air Force land-based ICBMs, the FBM force does not keep its missile guidance systems continuously running. They are maintained at a suitable temperature, but must be 'spun up' from this dormant state when required. The fire control system prepares the guidance system for launch by telling it which way it is pointing and which way is up (the local vertical), and then by feeding it the information needed to fly the correct trajectory to take it from the launch point – provided by the navigation system – to the target. Much of this information depends on land-based computations done at the Naval Surface Weapons Center at Dahlgren, and in the Trident missiles, on extensive mapping of the earth's gravity fields and of the position of stars. Given an assigned target set and the information it is continuously receiving from the navigation system, the fire control system also continuously updates its computations.

Finally, just prior to launch, the missile is switched over to internal power, the final instructions for the guidance system and for warhead detonation are read in, and the guidance system 'goes inertial'. Then, when commanded, the launcher system expels it from the tube in which it has been cocooned during the patrol. After clearing the surface of the water – typically from an almost stationary submarine at a depth of around a hundred feet, though it can be done from the surface – the first stage rocket motor fires and powered flight begins. After a few minutes flight the rocket stages have imparted enough velocity to the warhead-carrying reentry bodies to take them to the target area. Whereas each Polaris could hit only one target, the later FBMs, Poseidon and Trident, use a manoeuvring platform to dispense the reentry bodies onto trajectories that can hit different targets.

At one level, then, the smooth operation of FBM technology has the end result of nuclear warheads detonating at their designated targets; at another, paradoxically, it is exactly the opposite outcome, the absence of nuclear warheads detonating in conflict, which is seen as the successful working of the technology. All this, however, requires a technological system that encompasses far more than just the submarines and missiles. The final few minutes of independent missile flight are the culmination of a technological system, the development of which has required many disparate parts to be put, and kept, in place. Before describing how this technological system was built, and then maintained over the years (in chapters 3 to 8), some basic ideas about the nature of technology and nuclear war need to be introduced.

WEAPONS TECHNOLOGY AND THE NUCLEAR ARMS RACE

Despite the thaw in the Cold War, and associated arms control agreements, nuclear weapons systems like Trident continue to pose an unprecedented threat to human civilization and the ecological health of our planet. The use of even a fraction of current arsenals could cause massive devastation and millions of deaths.[8] As the inscription on an exhibit of a Polaris A3 missile in Washington's National Air and Space Museum chillingly put it: 'Each Polaris submarine contains as much firepower as was used during World War II.' Each Trident submarine armed with Trident II missiles will carry a lot more.

Also, although by no means the most expensive item in most military budgets, nuclear weapons systems have large opportunity costs, especially in terms of their drain on a nation's industrial and scientific resources. Yet nuclear weapons have come to be considered integral to the defence policies of some of the nations that possess them.[9]

Indeed post World War II 'superpower' relations were characterized by rivalry in nuclear weapons. The central Cold War antagonism between the USA and USSR involved their acquisition of a combined total of some 50,000 nuclear weapons by the 1980s. However, quantitative additions to arsenals were not the most worrisome feature of this 'arms race'.[10] Quantitative limits and reductions are relatively easy to negotiate and verify, and small numerical imbalances are not of much 'military' significance at the high levels in question.[11] More disturbing are qualitative 'improvements' in nuclear weapons technology, which are more difficult to curb with arms control and perhaps more threatening to strategic stability.

The main concern is that new technological developments may increase the risk of nuclear war breaking out during a crisis. That is, they may reduce *crisis stability*.[12] In particular, technologies which make a preemptive attack appear more feasible technically, such as improvements in missile accuracy, may increase the temptation to strike first during a serious crisis.[13]

Nuclear-armed ballistic missiles are central technologies in the nuclear confrontation. Their relatively short flight time for 'strategic' use allows only the briefest possible tactical early warning of imminent attack. With flight times of the order of 30 minutes or less ballistic missiles heightened the concern of preemptive nuclear attack by one superpower on the other.

Central to the concern with stability are two different approaches to the targeting of nuclear weapons. The popular conception of nuclear deterrence is that aggression is prevented by the threat of devastating retaliation. Accordingly, nuclear forces sufficient to assure a certain level of destruction should deter. This 'assured destruction' clearly only requires a level of technological sophistication capable of first surviving an attack and then destroying the aggressor's major cities in return. Assured destruction or 'counter-city' deterrence received its clearest *public* articulation in the 1960s by US Secretary of Defence Robert McNamara (and the distinction drawn here by McNamara should be understood as one of public rationalization rather than of changes in the actual warplan). The primary purpose of US nuclear forces were, he argued, 'to deter a deliberate nuclear attack upon the United States and its allies by maintaining a clear and convincing capability to inflict unacceptable damage on an attacker, even were that attacker to strike first'.[14] The assured destruction level to deter the Soviet Union was set at 'the destruction of, say, one-quarter to one-third of its population and about two-thirds of its industrial capacity'.[15]

However, McNamara had earlier emphasised an entirely different view of the way nuclear weapons should be used. In a reaction against the indiscriminate destruction threatened by the nuclear warplans he inherited from the Eisenhower administration's 'massive retaliation' policy, McNamara first shifted US nuclear warplans away from counter-city targeting. Discriminate use of nuclear weapons against military targets was to replace the all-out 'Sunday punch', with cities to be avoided, at least in the early phases of the exchange. McNamara argued that 'basic military strategy in general nuclear war should be approached in much the same way that more conventional military operations have been regarded in the past. That is to say, our principal military objectives in the event of nuclear war ... should be the destruction of the enemy's military forces while attempting to preserve the fabric as well as the integrity of allied society'.[16] Counterforce targeting was not new to the actual warplans, but this rationalization of it as preferable to targeting cities was a novel step.

However, counterforce targeting raises the fear of a disarming, pre-emptive strike in which one side could eliminate the nuclear forces of the other. Should this be possible, or appear possible, it would in principle seem to increase the incentive to use those forces before they are destroyed. Thus vulnerable forces are considered destabilizing because they increase the potential benefits of striking first, as well as the costs of failing to do so.

That this concern is well recognized is clear from the fact that nations have devoted considerable effort to ways of reducing the vulnerability of their own nuclear forces. At the same time, however, they have been equally vigorous in the pursuit of ways to *increase* the vulnerability of enemy forces. This pursuit of counterforce capability, the ability to destroy enemy nuclear forces, has threatened to undermine the stability which nuclear deterrence seemed to offer.

Central to advances in perceived counterforce capability have been the development of multiple warhead technology and improvements in ballistic missile accuracy. The ability to carry several independently targetable warheads on one missile allows a greater 'exchange ratio', thus considerably adding to the potential effectiveness of a pre-emptive attack.[17] Coupled with increasingly better accuracy – itself a much greater contributor to effectiveness against hardened targets than extra explosive yield[18] – this marked a general trend in the ballistic missile forces of both the USA and USSR towards greater 'hard target kill capability'.[19] These changes in technology have paralleled changes in nuclear strategy which have increasingly emphasized counterforce targeting, and in particular the destruction of hardened targets such as missile silos and command posts.

A number have seen this as a distinctive shift from a policy of deterrence based on the threat of retaliation against cities to a more unstable situation where the apparent ability to implement an 'effective' first strike (against fixed, land-based targets) may be technically available.[20] Some see the shift as actively desired, indeed the result of a 'secret agenda',[21] whereas others, more typically, attribute it simply to the inevitable, on-going advance of technology.

Thus Fred Halliday states that 'the possibility of greater accuracy in targeting missiles *led to* the shift from the "countervalue" approach, aiming at cities and economic targets, to one aimed at specific military targets, i.e. "counterforce"'.[22] But can technology be held responsible for this change in nuclear strategy? Or, to put it more generally, does technology determine the nature of society or vice versa? The theoretical issues surrounding this question will be set out in the next chapter.

US FLEET BALLISTIC MISSILES

This study deliberately focuses not on a single generation of a weapon system, but on the evolution of US fleet ballistic missile technology over a period of over thirty years. (Some of the main features of US FBMs are summarized in Table 1.1.) By tracing the parallel development of technology and nuclear strategy during this time it is hoped that a more sophisticated understanding of their interaction can be obtained.

The shift in missile technology and targeting rationale towards counterforce is particularly evident in the US Navy's Fleet Ballistic Missiles. The original Polaris, first deployed in 1960, seemingly provided the ideal deterrent, able to remain submerged and invulnerable at sea and capable of little other than deadly retaliation against Soviet cities as a last resort. Deployed some thirty years later, the latest FBM, Trident II, is claimed to have a combination of accuracy and explosive yield which makes it comparable to the Air Force MX in its high likelihood of destroying hardened targets.

This shift provides the central focus of this study, which will describe the evolution of those parts of FBM technology that most generally relate to the system's perceived strategic capability. It is not possible to cover every aspect of the development of FBM technology here. Instead some technologies – such as navigation and guidance – will play a much greater part in the story than others because of their greater strategic significance.

Table 1.1. *US Fleet Ballistic Missiles*

	Polaris A1	Polaris A2	Polaris A3	Poseidon C3	Trident C4	Trident D5
Length (feet)	28.5	31.0	32.3	34.0	34.0	45.8
Nominal Range (nautical miles)	1200	1500	2500	2500–3200	4000	4000+
Weight at launch (1000s of lbs)	28.8	32.5	35.7	65.0	73.0	c130.0
Year first deployed	1960	1962	1964	1971	1979	1990
No. of warheads	1	1	3 (MRV)	average of 10 (MIRV)	8 (MIRV)	8 (MIRV)
Yield per warhead (kilotons)	600	800	200	40	100	475 or 100
Warhead type	(W47)	(W47)	(W58)	(W68)	(W76)	(W88 or W76)
Guidance system	Mk. 1	Mk. 1	Mk. 2	Mk. 3	Mk. 5	Mk. 6
Approximate circular error probable (nautical miles)	2	2	0.5	0.25	0.12–0.25	0.06

Sources: General data from *FBM facts/chronology – Polaris, Poseidon, Trident* (Washington, DC: Strategic Systems Program Office, 1986) and earlier editions.
Accuracy and warhead yield figures are officially classified and have been deduced from a number of other sources: T. B. Cochran, W. M. Arkin and Milton M. Hoenig, *Nuclear Weapons Databook,* vol. 1, *US Nuclear Forces and Capabilities* (Cambridge, MA: Ballinger, 1984); W. M. Arkin, 'Sleight of Hand with Trident II', *Bulletin of the Atomic Scientists,* vol. 40 (December 1984), 5–6; R. S. Norris, 'Counterforce at Sea', *Arms Control Today* (September 1985), 5–12.

A NOTE ON SOURCES

As well as the open literature, which is extensive, and some archival material, this study draws heavily on interviews with present and former participants in the FBM programme. A full list of those interviewed is given in the Appendix, and where permission was obtained the interviewees are cited by name in the footnotes. No source material, whether it be an interview, archival document or published article has simply been accepted uncritically at face value. In attempting an explanation of technology which takes care to understand the role of social factors, it would be naive to ignore their role in the way people write or speak about technology!

In addition to over fifty interviews carried out directly for this study it has also been possible to draw on some other related interviews carried out by Donald MacKenzie in his work on inertial guidance and navigation technologies. These are also listed in the Appendix.

Interviews were arranged simply by writing to or telephoning the relevant individuals. Once a few key people and organizations had been identified, others 'snowballed' quickly. Simple lack of time meant that it was not possible to interview everyone. However, those interviewed include most of the 'core-set' of major participants in the FBM programme. I am particularly grateful to the Strategic Systems Program Office of the US Navy for their cooperation in arranging interviews (and to Andrew DePrete who was my contact there), as well as to the other organizations and individuals who were helpful.

In these interviews no attempt was made to gain access to classified information, and the study as a whole is based solely on unclassified (and declassified) sources. Perhaps surprisingly this is not an insurmountable obstacle to writing a detailed history of a nuclear weapons system programme. Much technical information is not classified, and where quantitative details are so, it still remains possible to gain adequate qualitative descriptions.

Considerable technical detail can also be found in the open literature, especially in journals such as *Aviation Week & Space Technology*, and for the early period of FBM development, *Missiles & Rockets*. These and other historical accounts have an unfortunate tendency, however, to construct a dichotomy between the 'technical' on one hand and the 'political' or 'social' on the other. Technical accounts are overwhelmingly of the 'B followed A because it was better' variety, in which the social world enters only rarely. Accounts by political scientists, on the other hand, tend to treat the technology largely as a black box, the content of which is not considered especially important.

Nevertheless, although in this vein, Harvey Sapolsky's book remains an excellent source of information on Polaris.[23] Ted Greenwood's account of the development of MIRV technology not only provides one of the best interminglings of the technical and political, but also the best description of the origins of Poseidon.[24] The third book-length account by political scientists of the FBM programme, Dalgleish and Schweikart's discussion of Trident, is less helpful.[25] Numerous other pieces of academic and indeed journalistic writing also provided useful sources of information. Finally, a rich source of information lies in the various Congressional hearings. Most useful for this study have been hearings from the Senate Armed Services Committee Subcommittee on Research and Development, particularly during the 1970s.[26]