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A COMPARISON OF THE POLARIS AND HARDENED AND DISPERSED MINUTEMAN WEAPONS SYSTEMS

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SPECIAL PROJECTS OFFICE
BUREAU OF NAVAL WEAPONS
WASHINGTON 25, D.C.

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SUMMARY

This study presents comparisons of the Polaris and hardened and dispersed Minuteman weapons systems. Included are a comparison of the relative stage of development of the two weapons systems, a quantitative cost effectiveness comparison, and qualitative comparisons based on important considerations not readily expressed quantitatively. In addition, the validity of the hardened site concept is discussed, and questions are posed concerning Minuteman development progress.

The results of the comparisons show Polaris to be superior to hardened and dispersed Minuteman in all respects. Polaris is in a more advanced stage of development; it is superior on the basis of the cost effectiveness criterion; and it is superior from the point of view of other important criteria. Moreover, there are strong grounds for questioning the validity of the hardened site concept. If the concept is not valid, as appears probable, the effectiveness of the hardened and dispersed Minuteman weapon system would be further degraded drastically.

The comparison of the relative stage of development shows Polaris to be far ahead of Minuteman. Polaris is operational now. It has been proved out by extensive flight testing and by actual operational patrol. Minuteman is in a relatively early stage of development. A number of important technical problems remain unsolved. There has been no flight test, and it appears that the operational schedule will be hard to meet.

The cost effectiveness comparison is based on the assumption that the yield, accuracy, reliability and penetrability (ability to penetrate anti-missile defenses) are the same for both Polaris and Minuteman. In

the case of Polaris an on-station factor of 62 per cent and a survivability factor of 100 per cent are assumed. These values are independent of enemy ICBM force levels. In the case of Minuteman, an on-station factor of 100 per cent is assumed, and survivability is expressed as a function of the number of Soviet ICBMs expected to be delivered. These inputs are used along with carefully developed costs to derive values of the final measure of cost effectiveness--the system cost per surviving on-station missile per year.

The cost effectiveness comparison shows Polaris to be superior to Minuteman for all reasonable assumptions concerning Soviet ICBM force levels. In addition, it shows that the degree of the superiority can be expected to increase as time passes. These results are shown graphically in Figure 3, page 19 .

An enemy attack against Minuteman would bring great collateral damage to the United States. An attack against Polaris at sea would not.

Minuteman does not provide diversification when considered along with manned bombers, Titan and Atlas. The Soviet can counter hardened and dispersed Minuteman by producing more of the ICBMs he is already serially producing to counter the other fixed-based systems. The Soviet cannot now counter Polaris. Future trends are such that fixed-based systems will become easier to counter, while the Polaris system will remain non-counterable.

Reliance on Minuteman as a primary strategic weapon system would lead directly to a spiraling arms race; reliance on Polaris would not.

The hardening of missile sites, even to 300 psi, cannot assure survival against enemy weapons of high yield and accuracy. Furthermore, it is not clear that the hardened Minuteman sites can withstand a 300 psi attack and still remain fully operable. On the contrary, there are good reasons for believing that they cannot. In any case, the United States cannot afford to rely on the hardening concept.

As a result of the study it is concluded that:

1. Polaris is superior in all important respects to hardened and dispersed Minuteman.

2. The superiority of Polaris over hardened and dispersed Minuteman can be expected to increase in the future.

3. The United States cannot afford to rely on Minuteman and the hardened site concept as its primary strategic missile system.

4. Polaris should be selected over hardened Minuteman as the primary strategic missile system of the United States.

COST EFFECTIVENESS COMPARISON

Introduction

The purpose of this study is to compare the Fleet Ballistic Missile System (Polaris) and the Minuteman System (Hardened and Dispersed). Before proceeding to the details of this comparison, however, several general remarks regarding the two systems are in order.

The Polaris weapon system is operational now. The missile has been proved out and its performance characteristics--range, yield, accuracy and reliability--are assured. Over 92 flight tests, including twelve from submerged submarines, have been conducted. The George Washington, carrying sixteen missiles, has already completed a patrol, and the Patrick Henry is now on station. Other submarines are soon to follow. By July, 1962, when it is hoped that Minuteman will first become operational, nine Polaris submarines (144 missiles) will be operational.

In contrast to this advanced state, Minuteman is in a comparatively early stage of development. A number of important technical problems remain to be solved. As yet, no complete missile flight test has been conducted. In order to meet plans for Minuteman squadron activation dates, design freeze on most items must occur by June, 1961. At that time only 5 flight tests (3 pad and 2 silo launches) are scheduled to have been made. Hence, missile performance figures used in cost effectiveness comparisons and other discussions remain largely conjectural. It has not been demonstrated that design performance can be attained on schedule.

A similar situation exists with respect to costs. Since the Minuteman development is not completed and no production units have been delivered, cost estimates are necessarily subject to considerable error. Experience shows that early cost estimates are usually low. For example, in the MS-3 submission of October, 1959, the Air Force estimated the unit initial investment cost of the Minuteman weapon system at the 600th missile production point to be $1,156,000. In the MS-4 submission of November 1960 this same unit cost was reported to be $2,196,000, an increase of some 90 per cent. In the same period, the estimated ystem annual operating cost per missile showed an increase from $291,000 to $505,000, an increase of about 73 per cent.

Despite these gaps in the knowledge of the cost and effectiveness of Minuteman, comparisons need to be made now in order that the national security will not be jeopardized by inaccurate or wasteful decisions as to programs and force levels.

Methodology

The cost effectiveness of any strategic weapon system may be assessed by considering the following factors:

1. Cost.
2. Lethality: The destructive effectiveness of the weapon--a function of weapon yield and accuracy.
3. Penetrability: The probability that the weapon will successfully penetrate enemy defenses.

4. Reliability: The probability that the weapon will function as designed.

5. On-station percentage: The average per cent of the force expected to be on-station and ready to retaliate.

6. Survivability: The probability that a weapon will survive a postulated enemy attack in condition to retaliate.

In comparing the cost effectiveness of two strategic missile systems, such as Polaris and Minuteman, the problem is greatly reduced if some of these factors can be equated. In this comparison, the lethality, penetrability and reliability of the two weapons systems are assumed to be the same. This permits use of a simplified procedure as follows:

1. A careful determination of the costs of the two systems expressed as system cost per missile per year.

2. Modification of these costs to take account of on-station percentage and survivability. This results in development of the system cost per surviving on-station missile per year, which is the measure of cost effectiveness.

3. Comparison of the cost effectiveness measure of the two systems for a range of postulated enemy ICBM force levels.

Determination of Costs

A vital factor in making a valid cost effectiveness comparison of weapons systems is that the costs to be included should be comparable for each weapon system. Many different combinations are possible as to which costs will or will not be included. A recent Air Force cost effectiveness comparison described the costs to be included in the following words:

> "To provide a cost comparison of Polaris and Minuteman the initial investment cost and the annual operating cost for both systems was estimated so that a 5 year on-station cost per missile could be determined. Research and Development costs for both systems were excluded. The initial investment costs for Polaris included the submarine, operational missiles, spare missiles and training missiles, a proportionate share of the submarine tender and other directly associated costs. For Minuteman, the cost included operational missiles, spare missiles, training missiles, the hardened silo, ground support equipment, base facilities and other directly associated costs in the same manner as for Polaris." (1)

The items listed for inclusion comprise a reasonable basis upon which to estimate the costs of the two weapons systems. However, it is inaccurate to prorate all of these items on a five year basis. That time period is correct for missiles; however, the cost of long life items such as submarines, tenders, launch sites and control centers, base facilities and ground support equipment is properly prorated over a longer time period. Moreover, the actual cost figures selected for each of the items must be very carefully chosen to insure that a comparable basis is used for both systems.

(1) Air Force presentation of 18 November, 1960 in the CNO Briefing Theater.

The cost inputs used in this comparison are shown in Figure 1 and Tables I, II and III. Figure 1 shows the elements that have been included in costing the two systems. Table I specifies the time periods used for each element in prorating costs. Table II shows the development of the system cost per missile per year for Polaris, and Table III shows the same for Minuteman. The figures of both Table II and Table III are further substantiated in Appendix A.

COMPARABLE COSTS INCLUDED

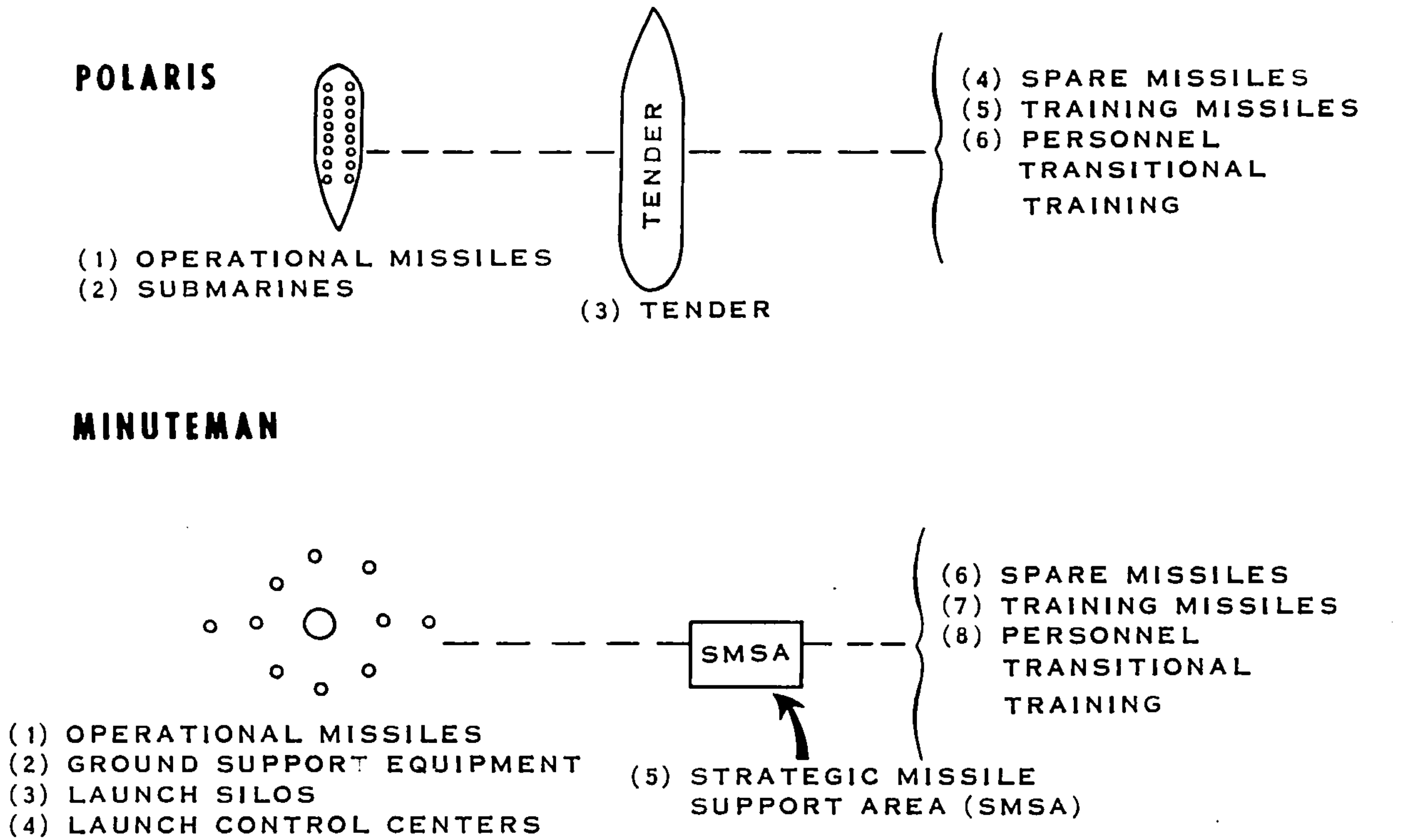


FIGURE 1

TABLE I

COSTS AND PRORATION PERIODS TO BE INCLUDED

POLARIS Cost Item	Period (yrs)	MINUTEMAN Cost Item	Period (yrs)
Initial Investment Costs		Initial Investment Costs	
Operational missiles	5	Operational missiles	5
Spare missiles	5	Spare missiles	5
Training missiles	2½	Training missiles	2½
Submarine	15	Missile launch silo	15
Submarine tender	15	Launch control center	15
Personnel transitional trng	15	Base Facilities (SMSA)	15
		Ground Support Equipment	10
		Personnel transitional trng	15
Annual Operating Cost	1	Annual Operating Cost	1

TABLE II

POLARIS COSTS
(15 years)

	Millions of Dollars
Initial Investment Cost (per submarine)	
Submarine	106.521
1/9 Tender (61.241/9)	6.805
Operational missiles (1 set of 16 missiles for each 5 year period or 48 missiles @ 1.121)	53.808
Spare missiles (at rate of 33 per cent or 16 missiles @ 1.121)	17.936
Training missiles (two per submarine each 2½ years or 12 missiles @ 1.121)	13.452
Personnel transitional training	0.600
Annual Operating Cost	
15 years @ 3.211	48.165
Total for 15 years	247.287

System cost per missile per year $= \frac{247.287}{(15)(16)} = \$1.030$ M

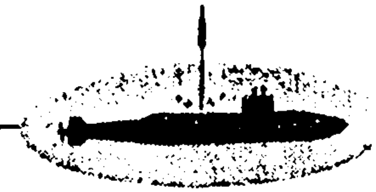


TABLE III

MINUTEMAN COSTS
(15 years)

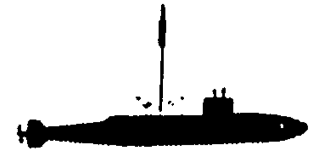
	Millions of Dollars
Initial Investment Cost (per 50 missile squadron)	
Launch complex (silo, control center, paving, electrical, land) (50 units @ 1.169)	58.450
Operational missiles (50 each 5 year period @ 2.203)	330.450
Spare missiles (at rate of 10 per cent @ 2.203)	33.045
Training missiles (12.5 per cent each $2\frac{1}{2}$ years @ 2.203)	82.613
Ground support equipment (50 units @ 1.635)	81.750
Base facilities (SMSA) (1/3 of one SMSA @ 2.000)	.667
Personnel transitional training (50 units @ .082)	4.100
Annual Operating Cost (per 50 missile squadron)	
15 years x 50 missiles @ .505 per missile per year	378.750
Total for 15 years	969.825

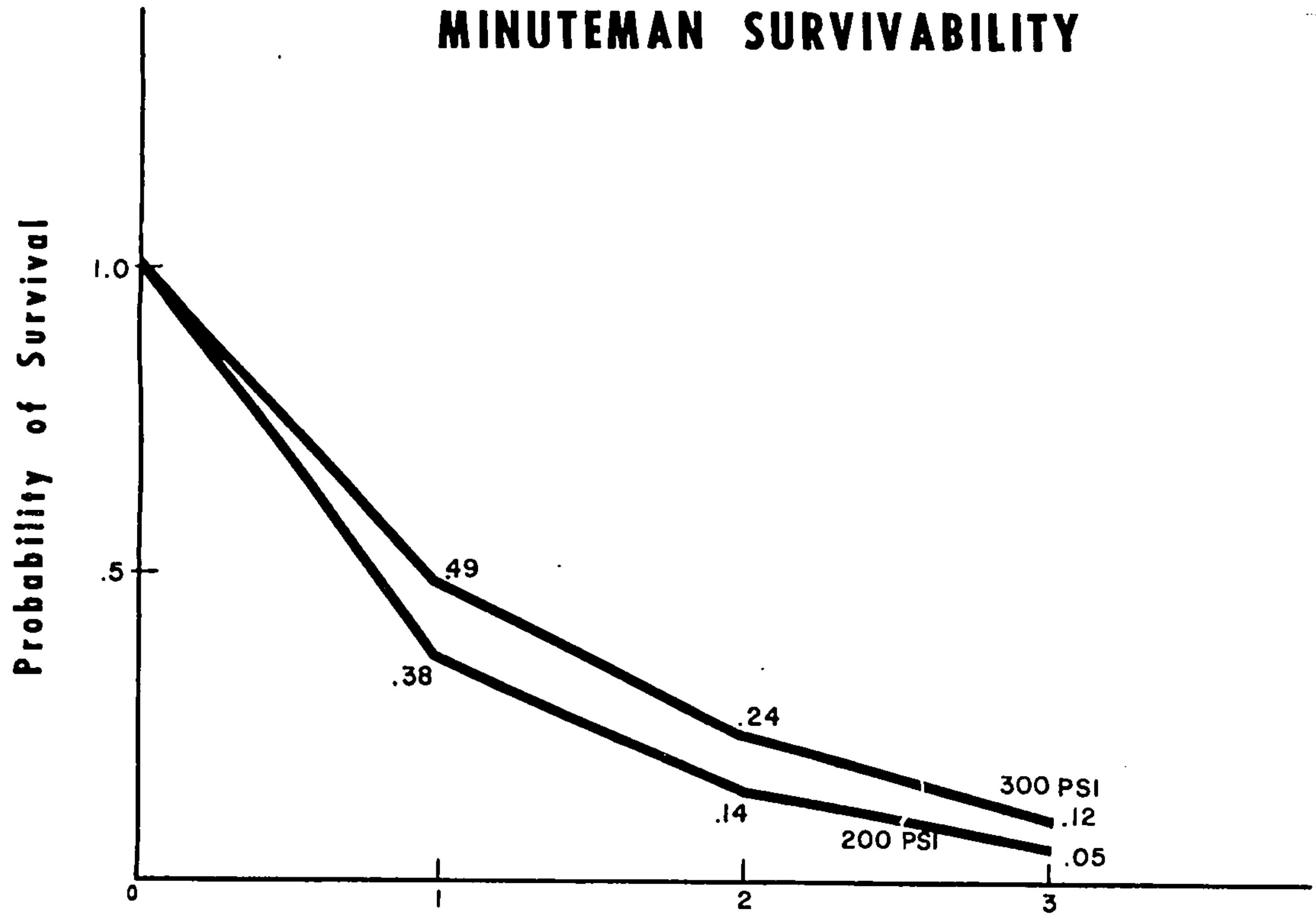
System cost per missile per year = $\frac{969.825}{(15)(50)}$ = $1.293M

Modification of Costs

The cost per missile per year for each weapon system was converted to a cost-effectiveness measure by modifying it to take account of on-station percentage and survivability. In the case of Polaris an on-station factor of 62% and a survivability factor of 100% were assumed. These values are independent of enemy ICBM force levels. In the case of Minuteman, an on-station factor of 100% was assumed, but survivability had to be expressed as a function of the number of Soviet ICBMs expected to be delivered in a surprise attack.

The survivability of Minuteman sites was calculated for a postulated enemy attack employing missiles having the characteristics of the TITAN II. The planned yield of 10 MT and an accuracy of .75 NM CEP (AF Ballistic Missile Accuracy Report, AFBMD-TR-60-177 of 1 September 1960) are taken as attacking weapon characteristics. The probability of site survival as a function of the number of successfully delivered Russian missiles was computed and is plotted in Figure 2 for site hardnesses of 200 psi and 300 psi overpressure.





NUMBER OF SOVIET MISSILES DELIVERED ON A MINUTEMAN SILO (10 MT, 0.75 NM CEP—SAME AS FOR TITAN II)

FIGURE 2

Results

The results of the cost effectiveness comparison are shown graphically in Figure 3. These results may be summarized as follows:

1. On the basis of the cost effectiveness criterion, Polaris is superior to hardened Minuteman whenever the Soviet can strike at least one out of every four Minuteman silos with one ICBM each.

2. As the relative position of the enemy in-force level improves above this minimum of one deliverable ICBM per four Minuteman missiles, the degree of superiority of Polaris increases.

a. If the enemy can deliver one ICBM against each Minuteman missile, Polaris is about twice as good as Minuteman.

b. If the enemy can deliver two ICBMs against each Minuteman missile, Polaris is more than three times as good as 300 psi Minuteman and about six times as good as 200 psi Minuteman.

3. The competitive position of Minuteman, in terms of the cost-effectiveness criterion, degrades rapidly if a hardness of 300 psi cannot be achieved (see page 29).

Cost Effectivness Comparison

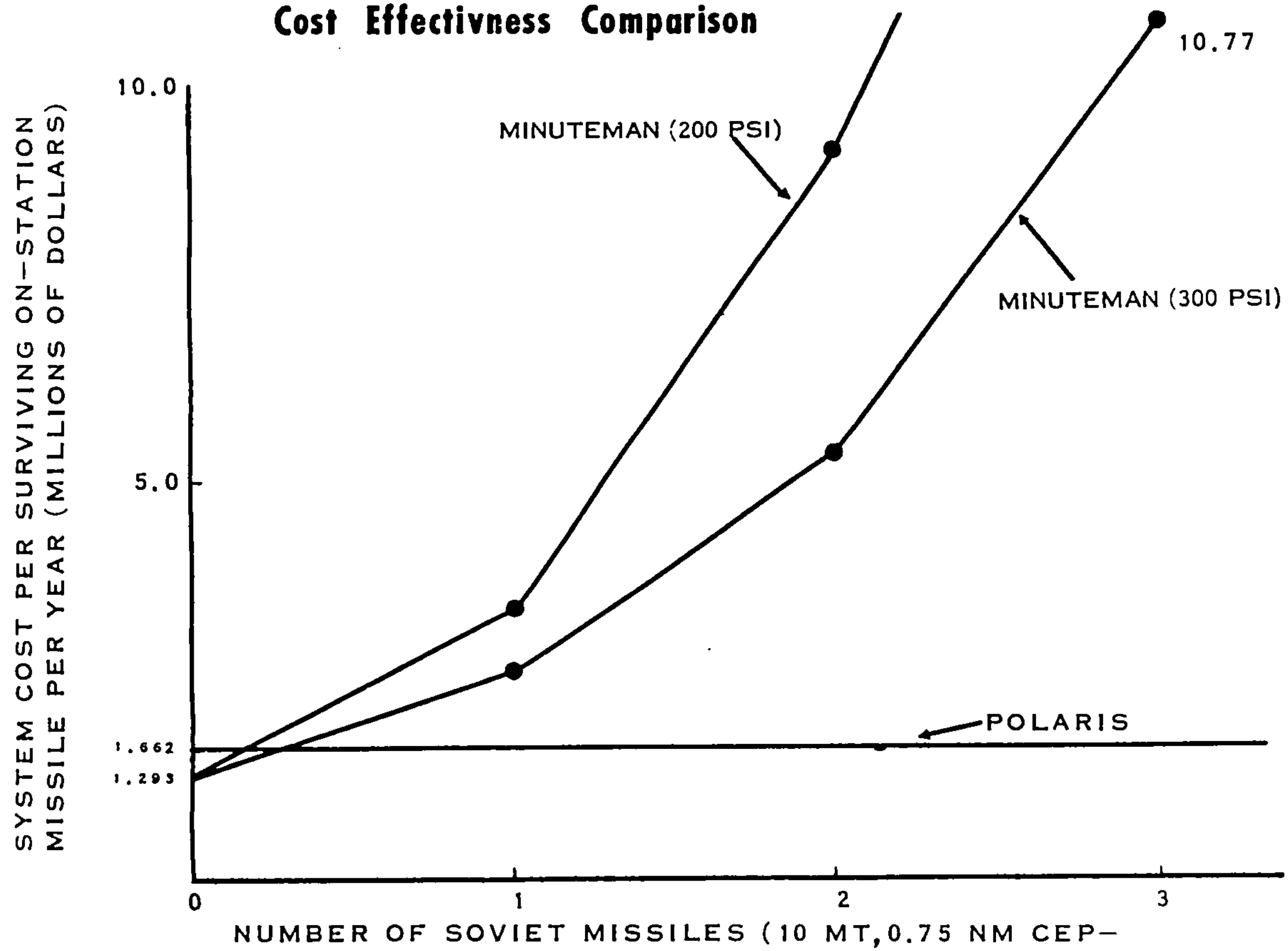


FIGURE 3

IMPORTANT CONSIDERATIONS NOT INCLUDED IN THE COST EFFECTIVENESS COMPARISON

Comparisons Using Other Criteria

A cost effectiveness comparison, when accurately carried out, is an effective aid in judging the relative worth of deterrent weapons systems. For example, the preceding section has shown the clear superiority of Polaris over Minuteman on the basis of the cost effectiveness criterion. However, it should be recognized that a cost effectiveness comparison does not tell the whole story. There are other considerations, equally important, which are not accounted for in a quantitative cost effectiveness measure. Among these are:

1. the degree to which a weapon system draws the enemy attack upon the United States

2. the magnitude of the counter effort a weapon system imposes on the enemy

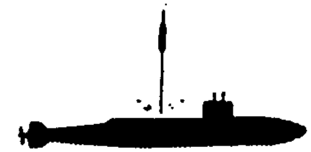
3. the degree to which a weapon system promotes an upward spiraling arms race

Any comprehensive comparison of weapons systems must take note of these considerations.

Any rational enemy surprise nuclear attack against the United States would necessarily include an attack against the strategic forces of the United States. That is the only way the enemy could reasonably expect to avoid a devastating retaliation. Hence, it is axiomatic that strategic forces located in the United States at the time of an enemy surprise attack will draw enemy blunting fire to the United States. Similarly, United States strategic forces located at sea at the time of an enemy surprise attack will not draw any enemy blunting fire to the United States. These factors point up the great superiority of Polaris over Minuteman when the weapons systems are compared on the basis of their tendencies to draw enemy fire upon the United States.

The degree to which collateral damage to the United States would be influenced by the location of the strategic forces is illustrated in Figure 4. This figure shows the pattern of radioactive fallout that would accompany a postulated enemy attack against U. S. military targets. A comparable pattern would accompany an enemy attack against Minuteman sites. Comparable attacks against Polaris forces at sea are not feasible for the Soviet. However, even if attacks were attempted on a sporadic basis, such attacks would produce no radioactive fallout or other nuclear weapons effects on the continental United States. In other words, an attack against Minuteman would bring great collateral damage to the United States while an attack against Polaris at sea would not.

The United States is committed to a "strike-second" strategic military policy. This gives the Soviet the initiative as to whether strategic nuclear weapons will be brought into active combat. It also essentially reduces the question of whether the Soviet can counter United States strategic forces to the question of whether he can, by a massive initial onslaught, prevent large-scale retaliation. Upon the Soviet answer to this question may hinge the choice between nuclear war and peace.



Fallout Pattern 24 Hours after a Postulated Attack Against the United States

FIGURE 4

It is feasible for the Soviet Union to counter reasonable numbers of hardened and dispersed Minuteman missiles. Knowing the exact, unconcealed, non-moving position of the Minuteman missiles, the Soviet would have only to allocate enough strike-first missiles of his own to assure destruction of the Minuteman missiles. He has or will have operational ICBMs of the required performance; he will have them in significant quantity, as he is in serial production. There is no basis for assuming that the stockpile of Minuteman -- still in R and D -- can ever overtake the Soviet ICBM stockpile in numbers. Thus, the Soviet ability to destroy Minuteman will continue to exist, even if the U. S. engages in a "numbers race".

It is not now feasible for the Soviet Union to counter the Polaris weapon system. There is little likelihood that it ever will be. The Polaris nuclear submarine patrolling in unknown locations -- submerged, concealed, and moving -- is an extremely elusive target. It cannot be seen. It cannot be detected by radar. If the enemy should succeed in detecting a Polaris submarine by sonic means -- an unlikely eventuality -- he would still have to localize and destroy the submarine to remove its effectiveness. This would not be easy, since the Polaris submarine possesses sonic detection deveices, nuclear maneuverability and arms for self-defense. The probability is negligible that Polaris can be countered by any Sovie t attempt to attack Polaris forces at sea.

The Soviet Union does not have to develop a new weapon system to counter hardened and dispersed Minuteman. The same weapon that counters SAC, Atlas, Titan or any other fixed-base strategic weapons system -- the ICBM -- can be used to counter hardened and dispersed Minuteman. Thus, the hardened and dispersed Minuteman, contrary to much current publicity, would not provide real diversity or "mix" to the arsenal of strategic weapons systems of the United States. It is just another fixed-base system, counterable by the same weapon as the others -- a proven enemy weapon now in serial production.

On the other hand, Polaris is unique among strategic weapons systems. Neither the Soviet ICBM nor the Soviet bomber fleet can touch the patrolling Polaris submarine. Any attempt to mount a serious counter would require the creation of a vast ASW network. This would take time and great expenditures of research effort and money. Even then, it would have a small chance of success.

In short, it is feasible for the Soviet Union to counter hardened and dispersed Minuteman by producing more of the ICBMs she has already developed and is already producing to counter SAC, Atlas and Titan; it is not feasible for the Soviet Union to counter Polaris. Future trends are such that fixed-based systems will become easier to counter, while the Polaris system will become more difficult to counter.

The foregoing discussions point up the fact that reliance on hardened and dispersed Minuteman, or any fixed-based deterrent weapon system, can be valid only if the reliance is based on superior quantity. That is, the only way the United States can be certain that Minuteman will be able to retaliate following a surprise enemy nuclear attack is to be sure that there are more Minuteman missiles than there are enemy ICBMs to attack the Minuteman missiles. To ensure this would require a spiraling arms race. There would be no end in sight.

It is apropos to consider the lengths to which such a spiraling arms race could lead. The Air Force now proposes to procure Minuteman missiles in fiscal years 1963 and 1964 at a rate of about 500 missiles per year. This is in addition to SAC, Atlas and Titan force levels. There is no reason to suppose that the Soviet Union will not produce ICBMs at a comparable rate. If the United States should place prime reliance for deterrence on Minuteman, as the Air Force has suggested, and allow itself to be drawn into a spiraling arms buildup at the rate of 500 missiles per year, the result would be that shown in Table IV. The United States would buy 15,000 missiles in 15 years. At the end of the period, the United States would be procuring missiles at the rate of 2000 missiles per year. There would still be no escape so long as the United States continued to place prime reliance for deterrence on Minuteman. Not only would this be prohibitively expensive and of doubtful ultimate value, but it might well lead to increased risk of accidental initiation of a nuclear holocaust.

Some other important factors to be noted in comparing Polaris and Minuteman are the following:

1. In the case of Minuteman, enemy defenses and warning systems may be designed to cover only the limited directions from which United States based ICBMs can come. Defenses against Polaris cannot be so reduced.

2. In the event of an enemy raid against the Minuteman system some missiles would require retargeting to get best coverage. Currently, this retargeting process requires approximately 6 hours for changes of target bearing in excess of approximately one degree. During this time period, on station force levels would remain subject to attack. In contrast, Polaris can be retargeted in about 2 minutes.

3. Weapons systems in submarines are much less subject to sabotage than is a fixed ICBM system.

4. A Polaris submarine at sea is invulnerable to covert BW or CW attacks. A fixed, land-based ICBM system could be covertly attacked by BW or CW agents.

5. The invulnerability of Polaris missiles permits them to be held in reserve at sea, if desired. They could well hold the balance of power after an initial nuclear exchange.

6. The SSB(N) can be hidden or exposed according to the political effect desired.

Validity of the Hardened Site Concept

The concept of hardening missile launch sites as a means of insuring missile survivability is not valid, particularly if the enemy attacking weapons are of high yield and low CEP. This point may be illustrated by considering a few examples of the probability of survival.

If the enemy should deliver weapons similar to the U. S. TITAN II (yield 10 megatons, CEP 0.75 nm), the following figures would apply:

(1) A 200 psi launch site would have a 38 per cent probability of surviving a single enemy weapon delivery; it would have a 14 per cent chance of surviving two enemy weapon deliveries; and a 5% chance of surviving more than two.

(2) If the site hardness were increased to 300 psi the probability of surviving a single weapon delivery would become 49 per cent; the probability of surviving two weapon deliveries would become 24 per cent; and the probability of surviving three deliveries would be 12 per cent.

If the enemy should develop a 40 megaton weapon and the ability to deliver it with a CEP of 0.5 nm, the following figures would apply:

(1) A 100 psi launch site would have a probability approaching zero of surviving a single enemy weapon delivery.

(2) A 300 psi launch site would have a 2 per cent probability of surviving a single weapon delivery; it would have a probability approaching zero of surviving two weapon deliveries.

These figures show that hardening missiles sites -- even to 300 psi -- will not assure survival against enemy weapons of high yield and accuracy. Furthermore, it is not at all certain that missile sites really can be hardened to withstand 300 psi and still fire in retaliation. On the contrary, it is quite uncertain. Since little testing has been done on underground structures with nuclear weapons, many problems are yet to be solved. Great gaps exist in our knowledge of ground shock, ground-shock loading on structures and the response of these structures to air-blast overloading. Since underground missile sites would have to withstand ground-induced shock as well as the air-blast pressure wave that also induces ground shock, there is considerable uncertainty as to how these sites would respond. The fact that the Air Force is conducting a multi-million dollar research and development program in protective construction, mostly aimed at problems in the lower overpressure range, indicates that the Air Force is acutely aware of the lack of knowledge in this area.

The accuracy with which ground-induced pressures can be predicted is low compared with the accuracy of prediction of air-blast loadings on surface construction. Such factors as soil conditions and ground water level affect the ground loadings. Experimentation has shown that there is much greater variation in amplitude and frequency in ground-transmitted shock than there is in air-induced shock.

Appreciable amounts of ground displacement can be expected within two crater radii. In view of these factors several important casualties that could prevent retaliation appear to require further investigation. Some of these are:

1. Misalignment due to differential motion between the top and bottom of the silo, i.e., permanent displacement of earth in which the silo is set.

2. Misalignment due to displacement of the missile or silo in the rotational mode.

3. Unpredictable difficulties arising from the movement of complex communications systems, piping and cabling systems, electronic systems, and computers.

4. Failure of shock mounting of critical items of equipment or inadequate flexibility at structural discontinuities.

5. Damage to sealed silo doors from extreme thermal and blast levels resulting in alteration of critical mating surfaces and affecting door openings.

6. Throw out of earth from near misses thus covering silo doors and resulting in difficulties in opening silo doors.

The foregoing illustrates that there are many problems and a great deal of uncertainty connected with ground shock. The magnitudes and acceleration rates found with nuclear weapons have never been experienced before. When conventional design criteria are used as a basis, large allowances and extrapolations have to be made. There are many opportunities for both over-design and under-design and, indeed, for gross omission or miscalculation. It is inescapable that unquestioned reliance on the validity of the concept of hardening missile sites to withstand 300 psi may be fraught with peril.

A number of basic questions need to be answered satisfactorily before it can be confidently assumed that missiles in hardened sites will be able to withstand 300 psi and still fire. Among these are:

1. How much credence can be placed in "best guesses" of consultants for predicting ground shock loading on structures and ground motions resulting from a large yield nuclear explosion? Factual knowledge in these areas is extremely meager and consists of measurements made during a few full scale nuclear explosions at the Nevada Test Site, and Eniwetok Proving Ground. Thi information has been extrapolated by means of theory and semi-empirical means.

2. How much faith can be placed in theoretical solutions to ground shock problems? The only available solutions are based on simplified mathematical models which are generally limited to homogenous isotropic media.

3. How much faith can be placed in semi-empirical extrapolations which ignore the plastic behavior of the soil under load and make gross assumptions

as to the effects of weapon size?

4. Are the assumed shock response spectra of the structures which are used for designing the shock mountings realistic?

5. Is it reasonable to assume that shock testing of various components of equipment will guarantee against failure of the assembled piece of equipment or system which is subjected to blast loading at the design level?

6. What is the probability that a complex system such as a Minuteman missile just off the drawing board will give acceptable full performance following a rigid test which subjects the system to full design loading conditions?

Unanswered Questions Relating to Minuteman Development Progress

The preceding discussions comparing Polaris and Minuteman have been predicated upon the assumption that the design performance characteristics of the Minuteman missile will be attained. However, they have not yet been attained, and there are good reasons for questioning whether they will be attained on schedule. Satisfaction on this point is mandatory in any comprehensive consideration of Minuteman, particularly if decisions are to be made on force levels. As a bare minimum, the following questions should be answered:

1. In order to meet the operational dates of Minuteman, it appears that design freeze on most items would have to take place by June 1961 at the latest. Only 5 flight tests (3 flat pad and 2 silo launches) are scheduled before that date. Is this considered to be an adequate flight test program upon which to base production?

2. What is the cause of the failure to meet the 1 December 1960 date for the first flight test firing? How much will this <u>actually</u> set back the initial operational date?

3. The Minuteman Development Plan states that the first wing will be deployed with missiles having a range capability of 4600 to 5000 nm vice the design range of 5500 nm. This decrease in range capability will reduce the target value covered to 55-85 per cent of that expected with design range. If a range of only 4000 nm is attained--a possibility that has been suggested--the target value covered would be about 10 per cent of that expected with design range. In view of this important consideration, is large-scale production justified prior to test results which assure attainment of design range?

4. When will the design specific impulse of 245 for the second stage be achieved?

5. How will the expected payload and missile inert parts weights be altered to permit reaching design performance goals? This question is particularly pertinent since the expected range of the first Minuteman flight test is less than 4000 NM and the re-entry body for this test is to weigh only 311 pounds (approximately one-third of planned full weight).

6. In view of the low range expected on Minuteman research and development flight tests, how many Atlas missiles will be required to flight test the Minuteman re-entry body at full range?

7. In view of the fact that the anti-missile may become highly effective against a ballistic missile with a single warhead and no accompanying decoys, are there any plans to incorporate multiple warheads or sophisticated penetration aids into the Minuteman missile? If so, how will this affect the already serious weight problems in reaching design range?

8. Will targeting plans for Minuteman be based on a 500 KT yield or on an untested yield of 900 KT?

9. At present the firing procedure specified for each Minuteman squadron calls for salvo or predetermined ripple fire of all 50 missiles. Are there any plans for removing this lack of flexibility?

10. Are there any plans to reduce the excessive time required for a change in target when the new target azimuth is significantly different from the previous one?

APPENDIX A

Detailed Polaris and Hardened and Dispersed Minuteman Weapon Systems Costs

Missile Costs

The cost of the first 800 missiles was chosen as the basis for deriving an average unit missile cost. This number of missiles is large enough to take account of the production learning process and was used for both weapons systems. For Polaris the average unit cost was estimated to be 1.121 million dollars ($1.121 M). See Tab I.

A comparable average unit cost for Minuteman was difficult to derive because of the paucity of cost information available. No actual costs exist since the missile is not yet developed. Detailed descriptions of the missile and its production costs are unavailable. Various fragments of information are available. These include the following:

1. Reported by the Air Force in a letter of 7 June, 1960 from Secretary Douglas to Senator Engle.

First full scale R&D missile	$3.6 M
First prototype production model, combat missile	2.5
1st missile	2.2
10th missile	1.71

50th missile	1.25
60th missile	1.21
70th missile	1.19
80th missile	1.15
90th missile	1.12
100th missile	1.10

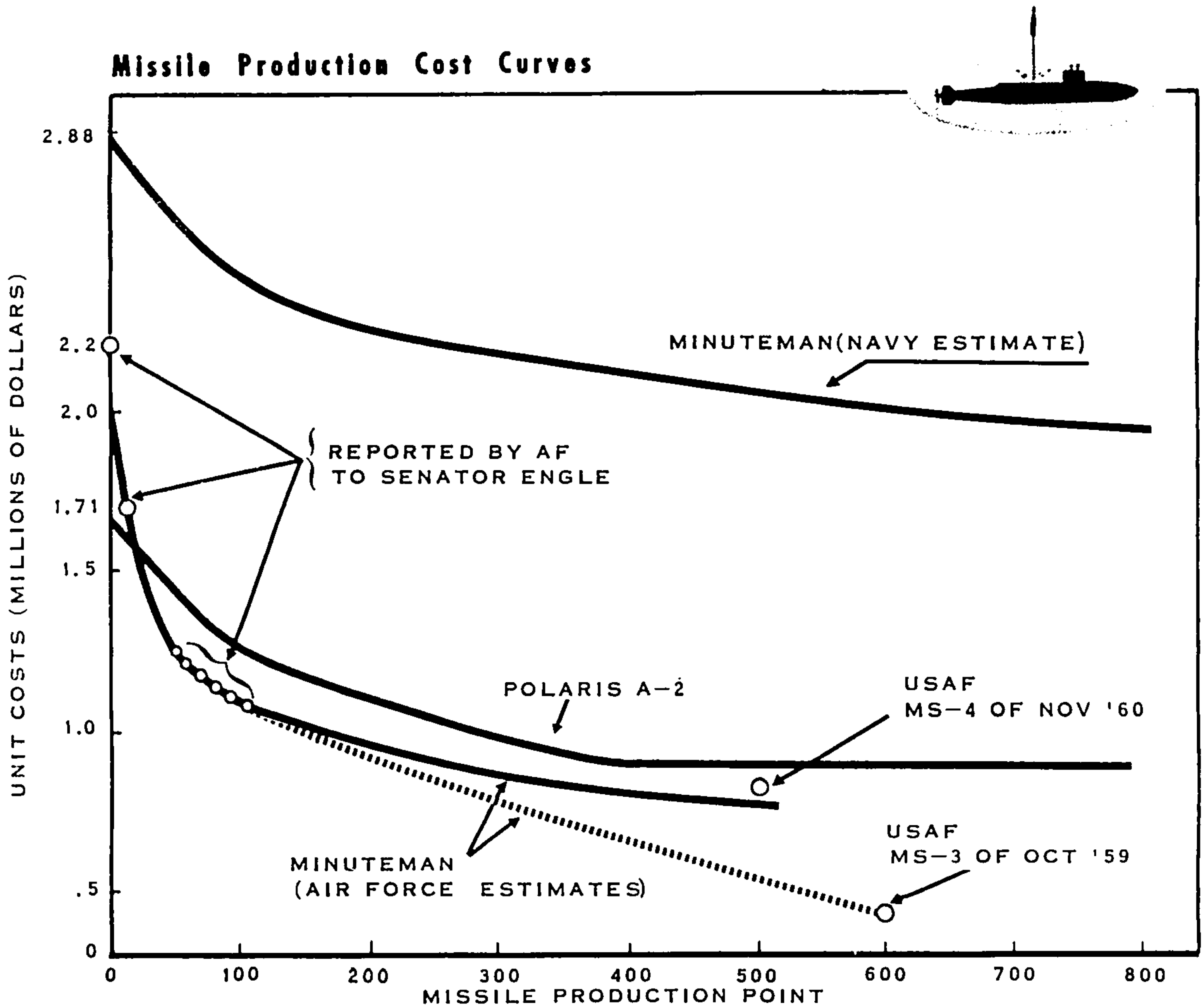
2. Reported on the Air Force MS-4 form of 15 November 1960:

500th missile ($.738 M + $.074 M spares)	$0.812 M

3. Reported on the Air Force MS-3 form of 1 October 1959:

600th missile	$0.422 M

These reported figures are plotted in Figure 5. The curve of Air Force estimates begins at $2.2 M for the first production item. This is a drop of $1.4 M, or 39 per cent, from the cost of the first R and D missile. Since this transition has not yet been made, it appears that a more realistic estimate of the degree of improvement would be smaller. Experience with the Polaris missile - a system in which the transition has been made and is a matter of record - indicates a drop in cost of 20 per cent is appropriate from the first R & D unit to the first production item. If this experience factor is used in place of the Air Force estimate, a unit cost of $2.88 M is obtained for the first production item.


Missile Production Cost Curves
UNIT COSTS (MILLIONS OF DOLLARS)
2.88
2.2
2.0
1.71
1.5
1.0
.5
0
MINUTEMAN(NAVY ESTIMATE)
REPORTED BY AF TO SENATOR ENGLE
POLARIS A-2
USAF MS-4 OF NOV '60
USAF MS-3 OF OCT '59
MINUTEMAN (AIR FORCE ESTIMATES)
0
100
200
300
400
500
600
700
800
MISSILE PRODUCTION POINT
FIGURE 5

A similar situation exists with respect to the shape of the production learning curve. The Air Force estimates predict extremely sharp decreases which have not been borne out by experience. Comparison of the shapes of the Air Force estimated curve and the Polaris experience curve, shown in Figure 5, clearly indicate this.

Starting with $3.6 M for the first R and D missile, which, it is assumed, is based on actual data, and applying actual Polaris R and D experience leads to the selection of $2.88 M as the cost of the first production unit. When this starting point is used and the Polaris experience-based learning rate is applied, the Minuteman curve takes on the same shape as the Polaris curve, but it is positioned somewhat above the Polaris curve. That is, the large, solid propellant missile costs more than the small solid propellant missile; and the unit cost of each decreases at a comparable rate as production experience is gained.

This is an entirely reasonable prediction. Both missiles are solid propellant ballistic missiles, inertially guided and based on the same technology. Minuteman is approximately twice as big as Polaris. This size adds to the required propellant. The Minuteman missile has three stages; the Polaris missile has two stages. The 5500 mile design range of the Minuteman missile demands more costly guidance equipment. The Minuteman motor cases, employing vacuum melted forged ring section and integrally machined heads, are known to be very expensive. For these reasons, unsubstantiated estimates that the Minuteman missile will cost less than the Polaris missile are contrary to experience, logic and intuitive judgement.

Reading values from the Navy-estimated Minuteman cost curve, the average unit cost of the first 800 Minuteman missiles is estimated as follows:

Missile Numbers	Avg. Unit Cost		Extended Cost
1-100	$2.65 M		$265.0 M
101-250	2.32 M		348.0
251-800	2.09 M		1149.5
		TOTAL	1762.5

Average Unit Cost = $\frac{\$1762.5\ M}{800} = \$2.203$

This figure is assumed to cover the missiles, spare parts and components, and static firing of one motor set out of every six sets produced for quality assurance. It is applied to operational, spare and training missiles.

Other Polaris Costs

The average unit cost of Polaris submarines, derived from the cost of the first 14 submarines exclusive of lead ships of each class (omitted to eliminate R and D costs), is 106.521 million dollars.

The average unit cost of Polaris submarine tenders is taken to be 61.241 million dollars--the estimated cost of a new construction tender.

The cost of personnel transitional training, as reported in the MS-3 and MS-4 forms, is 0.3 million dollars per submarine crew.

The annual operating cost of the Polaris submarine, as estimated in TAB II, is $3.211 M per submarine.

Minuteman Launch Complex

The Bureau of Yards and Docks has completed a cost evaluation study based upon the final technical criteria for design of Minuteman operational launch facilities in order to provide a careful, independent estimate of the cost of a land-based missile facility for three squadrons (150 missiles plus 15 control centers). The result of this study is tabulated below:

Description	Estimated Cost (Dollars)
1. 150 Launch Centers (silo, support building, paving, fencing, etc) @ 475,000	71,250,000
2. 15 Launcher Control Centers (Control Center support bldg, paving fencing, etc.) @ 1,214,000	18,210,000
3. Roadway paving, including one bridge	5,148,000
4. Electrical work (substations, transformer stations, pole transmission line, direct burial cable installation, batteries to maintain efficiency in cases of loss of power.)	59,001,000
TOTAL	153,609,000

When the first three items of this listing are summed and deductions are made to remove the contingency and contract administration allowances that were included, a figure of $80,870,000 results. This figure is of interest because it may be compared with the following actual bids, covering the first three items above, received for the construction of the three squadron missile facility at Malmstrom Air Force Base.

$78,907,000 (low bid)
83,000,000
98,000,000

These figures show the high degree of accuracy of the estimates made by the Bureau of Yards and Docks.

The estimates of the Bureau of Yards and Docks have been used as a base to estimate the cost per missile of the launch complex less land:

$$\text{Unit Cost (less land)} = \frac{\$153.609 \text{ M}}{150} = \$1.024 \text{ M}$$

This base cost must be increased to account for a number of important items not yet accounted for. These include:

1. Real estate (land)

2. Civil engineering (site clearing)

3. Wells (for sanitation)

4. Any allowance for strengthening the public and government-owned primary and secondary roads that must be used to approach the additional roadways constructed for the complexes.

5. Strategic Missile Support Area (SMSA)

6. Ground support equipment such as:

   a. Fire control equipment not in the missile
   b. Test and checkout equipment
   c. Transporter erector
   d. Maintenance vans
   e. Fire apparatus
   f. Snow removal equipment
   g. Personnel and security vehicles
   h. Water storage facility at site
   i. Security equipment and systems (TV, alarms, cabling, etc.)

Allowances for Ground Support Equipment and SMSA (items 5 and 6) are made elsewhere (see next section), but no allowance has yet been made for items 1, 2, 3, and 4. Nor will any allowance be made for items 2, 3, and 4, since no data is available and the cost of these items would not be major. However, item 1 is too significant to be omitted, and an estimate must be included. Since no two missiles are to be closer than 5 nautical miles, land for each silo must encompass at least the area of a circle of radius 2.5 nautical miles, or about 20 square miles. This is the equivalent of about 14,500 acres which, evaluated at $10 per acre, amounts to some $145,000 per missile. When this latter figure is combined with the base cost, a final cost per missile is obtained:

Unit Cost = $1.024 + .145 = $1.169 M

Other Minuteman Costs

The cost of personnel transitional training has been taken to be $.082 M per missile as reported in the Air Force MS-3 and MS-4 forms.

The Minuteman annual operating cost has been taken to be $0.505 M per missile as reported in the MS-4 form.

The cost of Ground Support Equipment has been taken to be the same as that reported to Congressman Holifield and Senator Engle for the first two squadrons:

Item	1st squadron	2nd squadron
Ground support equipment	$52.3 M	42.5
Ground support equipment spares	7.8	6.4
Total	60.1	48.9

Ground support equipment has been assigned a ten year life. Hence, the cost per missile for ground support equipment for 15 years has been estimated to be:

$$\text{Cost per missile} = \frac{(60.1 + 48.9)\ 1.5}{100} = \$1.635\ \text{M}$$

This figure is in very close agreement with the figure ($1 M per missile for 10 years) estimated by the Army's Operations Research Office in their report ORO-SP-143, Costs and Vulnerability of Hardened and Mobile ICBM Systems, June 1960, SECRET.

Base facilities refers to the Strategic Missile Support Area (SMSA). The Minuteman Development Plan shows the facility to cost $2 M at Malmstrom Air Force Base, where three squadrons (150 missiles) are to be based. The unit cost of the SMSA is thus:

$$\text{Unit Cost} = \frac{2.0}{150} = \$.013\ \text{M}$$

TAB I

Polaris Missile Costs

1. The actual cost of the first 400 Polaris missiles, from the latest budgetary submission, is as follows:

FY	No. Shipfill Missiles	Cost
60 & prior	129	$162.561 M
61	115	153.646
62	156	210.655
	400	$526.862 M

These 400 missiles were comprised of 150 A-1 missiles and 250 A-2 missiles. The costs included the missiles (air frame, motor set, re-entry body and guidance package), spare parts and components, and static firing one motor set for quality assurance purposes out of every six sets produced.

2. The A-2 missile production curve has been estimated as follows:

Block	Average Cost (thousands of dollars)
35-79	1358
80-124	1223
125-215	1100
216-396	990
397 and after	890

Using this curve, which is plotted in Figure 5 preceding, the cost of the second lot of 400 Polaris missiles has been estimated to be 370.400 millions of dollars.

3. The average unit cost of the first 800 Polaris is computed as follows:

Cost of first 400 missiles	$526.862 M
Cost of next 400 missiles	370.400 M
Cost of first 800 missiles	897.262 M

$$\text{Average Unit Cost} = \frac{\$897.262}{800} = \$1.121 \text{ M}$$

TAB II

Polaris Annual Operating Cost

Ref : (a) "Cost Estimates of Operating Ships, Air Craft and Task Forces," Office of the Comptroller, Department of the Navy, 31 December 1959.

1. Military pay for two crews:

24 officers @	$10,000 =	240,000
200 enlisted @	5,000 =	1,000,000
		$1,240,000

2. Medical costs (costs of technical medical and dental supplies and equipment used aboard ship):

$1000	per year per crew (from reference (a))
x 2	crews
$2000	per year

3. Extra transportation for crews from tender to continental U. S. and return:

$400	per round trip
448	trips (2 per man per year in each crew)
$179,200	per year

4. Fuel:

Labor to renew core	$ 350,000
Cost of replacement core	2,500,000
	$2,850,000

Replacements occur at end of 6 and 15 years. Since the initial investment cost of the submarine is amortized over a 15 year period, the annual fuel cost is based on one re-coring during the first 15 years of operating.

$$\text{Fuel cost per year} = \frac{(2{,}850{,}000)}{15} = \$190{,}000$$

5. Overhaul Cost (to provide the labor and material required to accomplish regularly scheduled overhauls):

Reference (a) gives the annual overhaul cost of several types of submarines as follows:

SS	$390,000
SSG	369,000
SSK	444,000
SSR	435,000

These figures are increased by a factor of three to account for the greater complexity of the SSB(N) and used to derive an estimated overhaul cost of $1,200,000, which is applied annually.

6. Supplies and equipage (including Naval Stock Account items used in day-to-day submarine operations and used by tenders to accomplish repairs):

Reference (a) shows $98,000 for SS, SSG SSK and SSR. Applying a factor of 2 for complexity and a factor of 2 for the extreme reliability required provides an estimated annual cost for the SSB(N) of $400,000.

7. Tabulation of Polaris annual operating and maintenance costs:

Military pay	$1,240,000
Medical costs	2,000
Extra transportation	179,200
Fuel (nuclear)	190,000
Overhaul Cost	1,200,000
Supplies and Equipage	400,000
	$3,211,200

Annual Operating and Maintenance Cost = $3.211 M (per submarine)