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Volume I
PILOT ANALYSIS

SUBMARINE WEAPON SYSTEM EMPLOYING GUIDED MISSILES FOR 1960-70

MAY 1958

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11665

A STUDY CONDUCTED FOR
THE OFFICE OF NAVAL RESEARCH
BY THE
GENERAL DYNAMICS CORPORATION
ELECTRIC BOAT DIVISION ★ CONVAIR - POMONA

Volume I
PILOT ANALYSIS

SUBMARINE WEAPON SYSTEM EMPLOYING GUIDED MISSILES FOR 1960-70



66AA 11665

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FOREWORD

This report applies to the first six months phase of an Operations Research study required by Contract Nonr 1667 (00). Under the sponsorship of the Undersea Warfare Branch of the Office of Naval Research, this contract was issued to the General Dynamics Corporation with the Electric Boat Division acting as the prime contractor, and Convair (Pomona Division) as the subcontractor.

As specified by the contracting agency, strike submarine weapon systems consisting of various types of submarines and various types of missiles to attack coastal targets in the time period of 1960-1970 will be subjected to operations analysis. A measure of effectiveness will be formulated to compare the various submarine-missile systems generated in order to obtain the optimum system.

It is not the purpose of the completed study to determine the absolute effectiveness of such a weapon system in future wars. Rather, given the general requirements for this type of weapon system, the study's purpose is to determine an optimum system through decision charts involving weapon cost, campaign duration, operational availability and mission characteristics.

The Naval planners should consider many other weapon systems to carry out the same missions. Among these might be submarines carrying aircraft, aircraft carriers carrying aircraft and guided missiles, seaplanes carrying guided missiles, etc.

The present contract does not stipulate the characteristics of the weapon system or the missions it should accomplish. For this reason the contractor considered as complete a list of missions as possible. This was done in an attempt to permit viewing weapon system selection on as broad a base as possible of the unpredictable missions of the future.

Similarly, it was desired to make this weapon system as insensitive as possible to variations in the national policy, in the field of "all out war" vs "limited war". To this end, the weapon system was predicted on a technological basis with flexibility for either event, leaving the final decision to the weapon system planner.

The first phase of this study is termed a Pilot Study. Where a weapon system study involves consideration of many parameters, it is important to gain a quick view over the entire spectrum, rather than indulge in lengthy unprofitable component studies. Only thus can proper direction be maintained. Its purpose is to restrict the area of choice. At the same time it should define those parameters or considerations towards which solutions appear to be most sensitive. Should any of these parameters or considerations in the sensitive areas be in fields of inadequate development of the state of the art or those in which statistics are noticeably absent, it would be so indicated.

As in any study on future weapon systems, extrapolations in the state of the art have been made. These will introduce differences of opinion. However, it is anticipated that the broader implications of this study will be useful to the weapon system planner.

For convenience, this report is published in two volumes. Volume I contains the text of the study, while Volume II contains the appendixes of supporting matter.

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SUMMARY

THE PROBLEM

The study is concerned with the aspects of selecting a submarine-missile strike system for the time period of 1960-70. The strike system is assumed to be directed against coastal targets of the Eurasian landmass. Target complexes for several typical missions are chosen. Two levels of enemy defense are assumed since antisubmarine and antimissile defenses cannot be accurately estimated. Only nuclear warheads are considered and one warhead per target is assumed. The weapon system is taken to consist of submarines, submarine-launched missiles and supporting system functions. A foundation is developed for the selection of the optimum weapon system. Sensitive areas are defined which point to additional study efforts in the second phase of this study.

METHOD OF SOLUTION

The problem was considered as typical of those faced by the military weapon system planner. An analytical approach was taken to arrive at the solution. Significant steps in the approach are as follows:

1. The weapon system is defined as a family of possible combinations of various submarine-missile and supporting system configurations. The variables of the components are treated parametrically.
2. An operational task representing one concept of the type of warfare in which the weapon system would be employed is defined.
3. A measure of effectiveness is established which considers, together with operational availability, campaign duration and other factors of equal importance, the cost to the U.S. to obtain, maintain, and operate the weapon system in the type of warfare represented by the operational task.

The final result of the above steps is a series of decision charts involving variables related to the weapon system and the operational task with boundaries set by operational availability date, budgetary limitations, and campaign durations, Figure S-1. These decision charts allow the weapon system planner to select an optimum weapon system within the limitations of the assumptions contained in the development of the report. An example of weapon system selection is given to aid the weapon system planner in using the decision charts.

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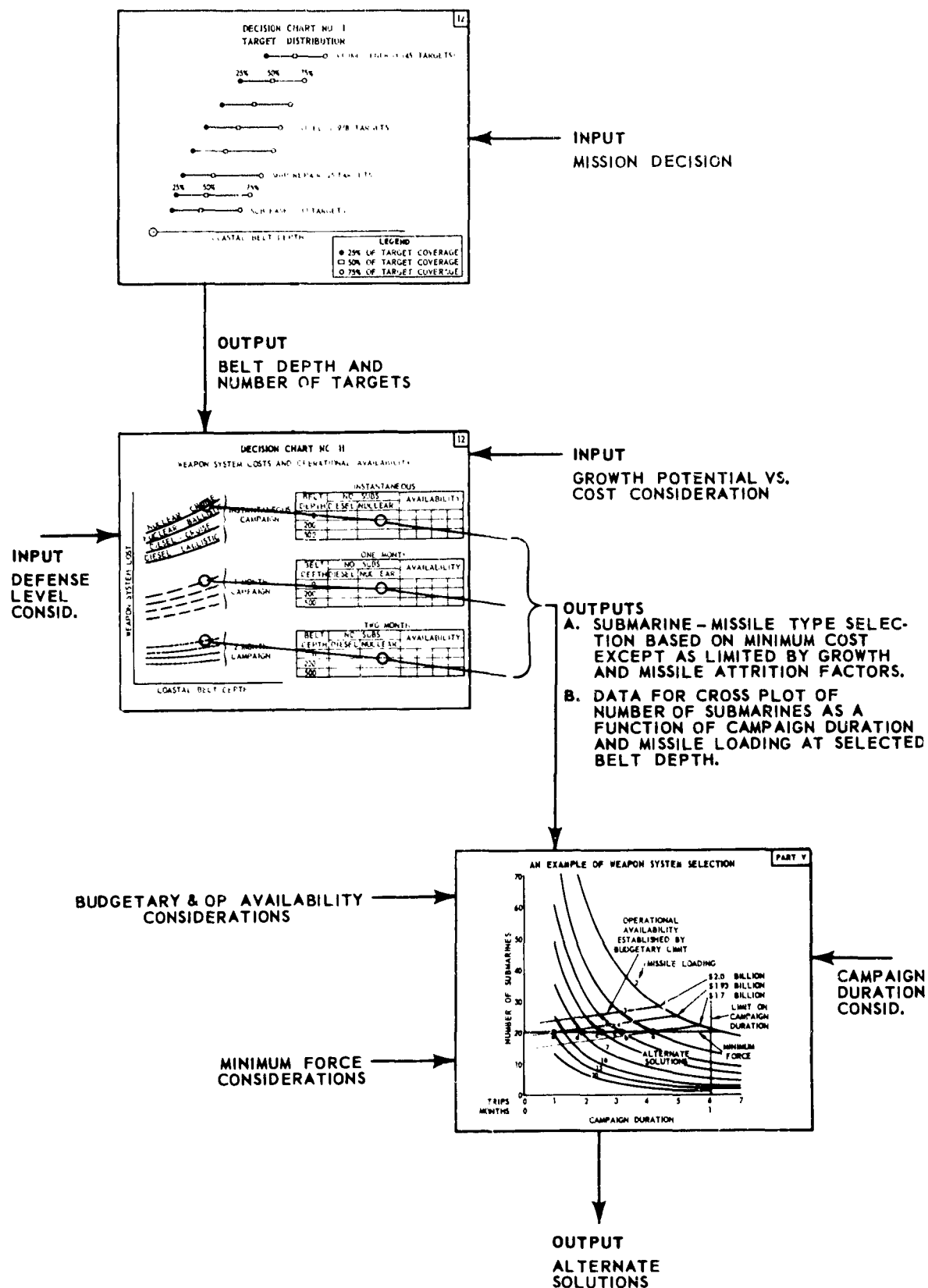


Figure S-1. Decision Charts Related to Weapon System Selection.

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THE WEAPON SYSTEM

The weapon system is defined which consists of a combination of the elements shown in Figure S-2 and the supporting system described by Figure S-3. These elements are:

- The Missile

 - The Warhead

 - The Guidance System

- The Submarine

 - The Navigation System

Three families of missiles are developed:

 - Solid propellant ballistic missiles 0-300 miles

 - Liquid propellant ballistic missiles 0-1000 miles

 - Ramjet cruise missiles 0-1000 miles

Warhead weights from 500 to 3,000 pounds are considered in the study. However, only the 1500-pound warhead is carried through in detail. Estimates of system cost variations affected by using other warhead weights can be obtained by considering an equivalent range point on the 1500-pound curves.

Probable fuzing methods are discussed briefly. Missile guidance is examined. The field is narrowed to inertial and single-station radio plus inertial systems for the ballistic missiles. Radar map-matching is added as a feasible system for the cruise missiles. Accuracies expected for missile guidance alone range from 1000 ft. CEP for the map-matching system to 6000 ft. CEP at 1000 nautical miles for the cruise missile inertial system.

Three families of submarines are developed which accommodate from 2 through 20 of the generalized missiles:

- New Diesel-Electric Submarines

- New Nuclear Submarines

- Fleet Conversions

Fleet conversions were found to be restricted to accommodating short-range ballistic missiles or one or two long-range ballistic or cruise missiles.

Possible methods of navigating the submarine are examined. Two methods which appear most suitable from a passive defense standpoint are selected — long-range radio system (radux) and submarine inertial navigation system (SINS). Both are expected to be operational by 1965 with accuracies of 1 mile and $\frac{1}{2}$ mile respectively.

An assumption of target location error of 3000 ft. is made. Total delivery error is then computed to be between 1 and 2 nautical miles, at ranges to 1000 nautical miles, except when the map-matching system is used. For this case, total error would be 1000 ft. CEP for all ranges.

The supporting system is essentially the same as that of existing submarine support systems. The changes that would be required in specific areas such as facilities, personnel, and logistics are only examined briefly.

THE OPERATIONAL TASK

The operational task is developed in terms of a mission, an operating cycle of the weapon system used in performing the mission, and the enemy efforts to prevent the accomplishment of the mission.

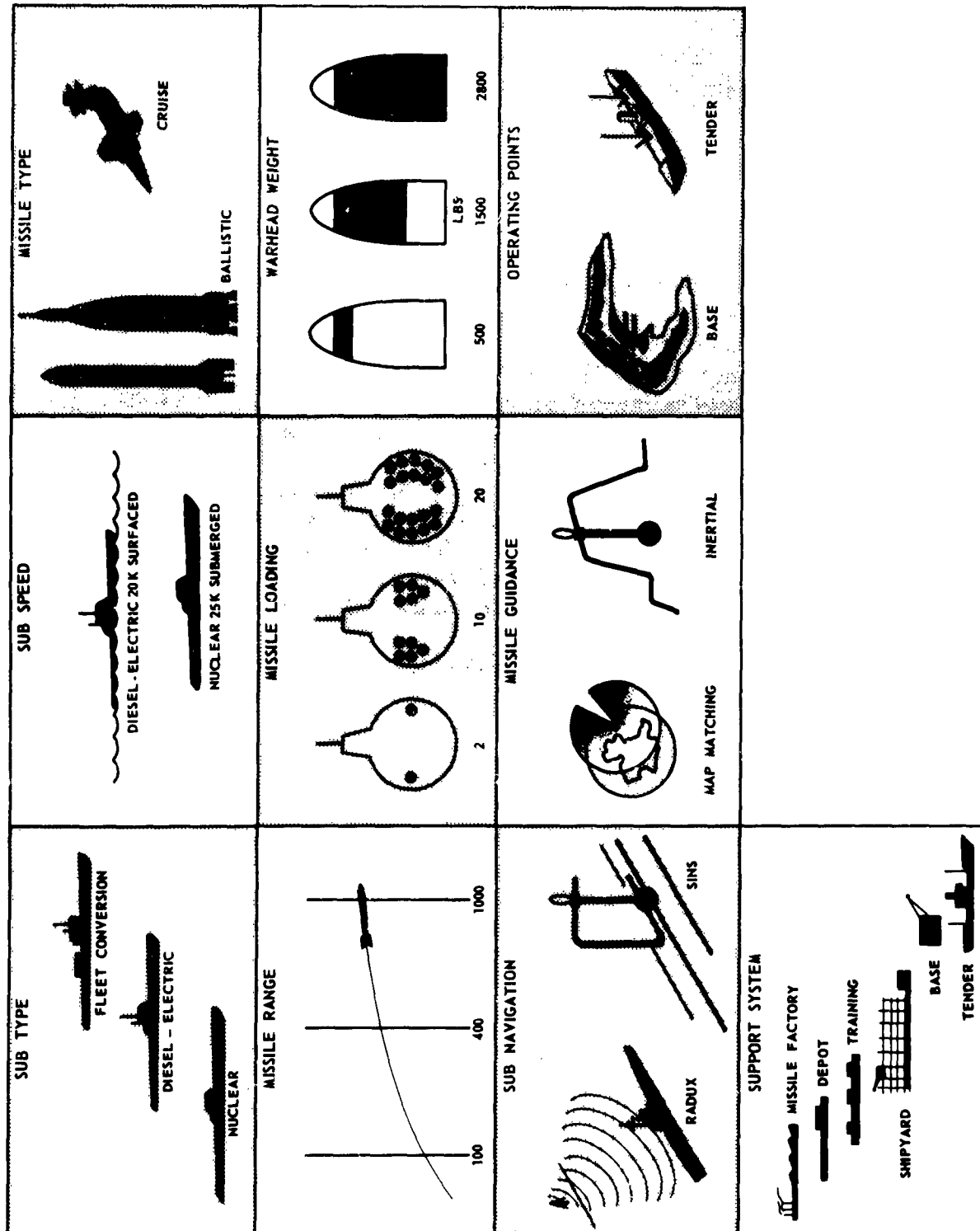


Figure S-2. Total Systems Parameters.

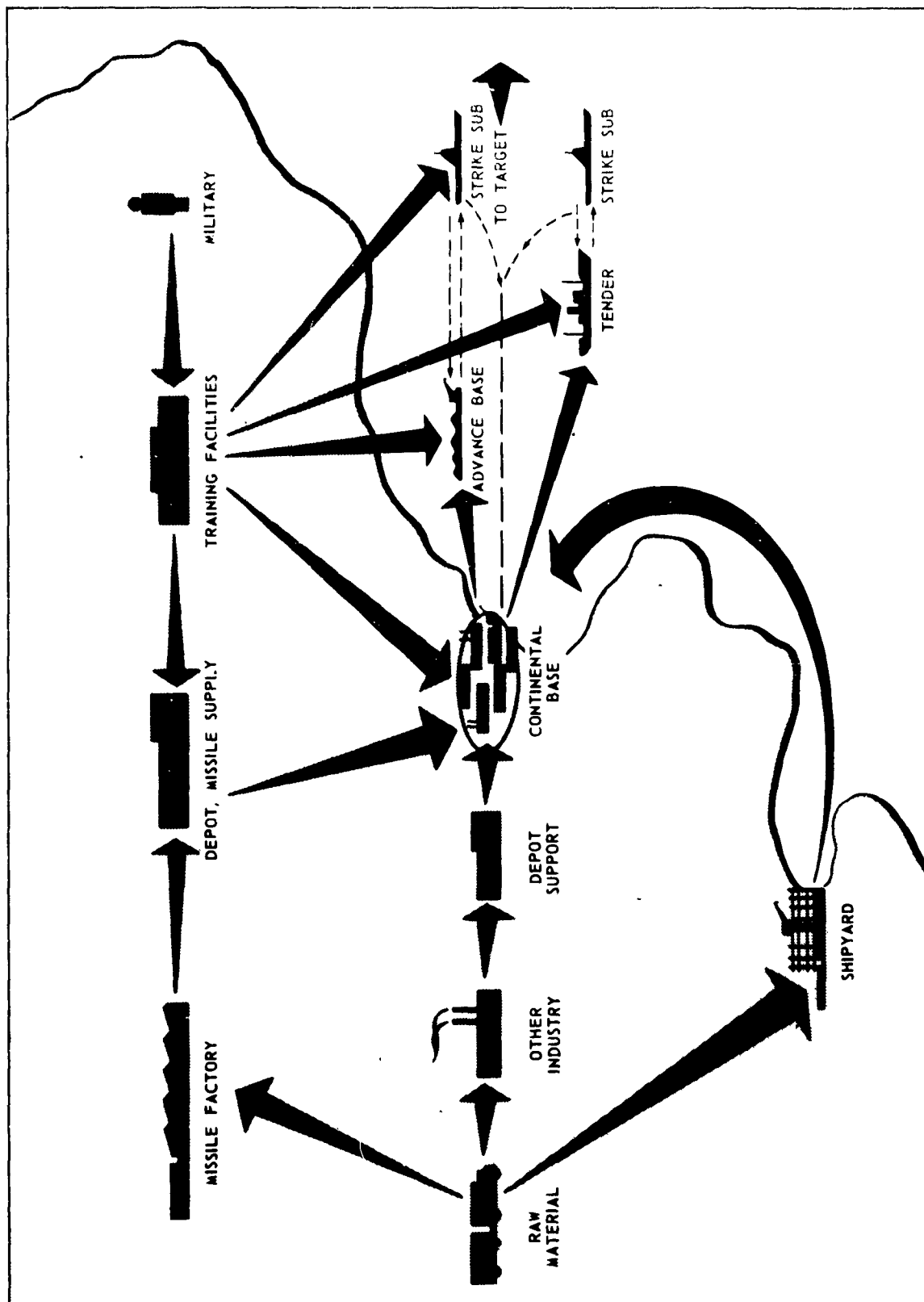


Figure S-3. Supporting Systems.

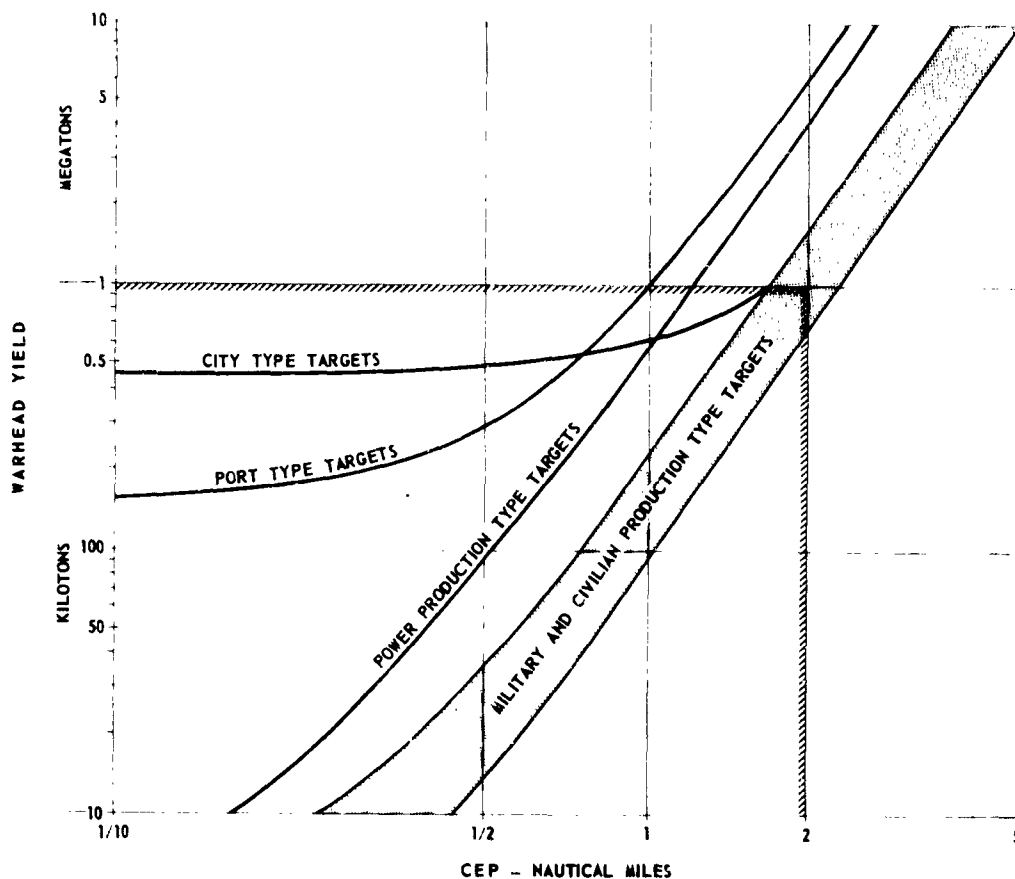


Figure S-4. Relation Between CEP and Yield Required for 50% Destruction of Type Targets.

A study of possible missions is conducted. Target size and hardness are used to establish warhead yield and weapon delivery accuracy requirements associated with each mission. The resulting Figure S-4 is of interest. Target distribution is studied to correlate inland distance to targets with missions. Since mission decision is left to the weapon system planner, inland distance or belt depth is left as a basic parameter.

An operating cycle is postulated. Figure S-5 shows the cycle of the weapon system chosen. It should be noted that only one operating cycle, of many possible, has been used in the pilot study. As a consequence conclusions should be viewed against this possible limitation. Further effort is needed to demonstrate the effect of using other operating cycles. The variables of the cycle, such as submarine speed, trip distance and fraction of submarine force which can be utilized in the task, factors which can be controlled by the U.S., are fixed within reasonable limits. The enemy defense efforts are expressed in terms of probable submarine attrition incurred while performing the operating cycle. A defense model is developed using two levels of forces and technologies, both based on U.S. capability in the ASW field. A low level of enemy defense is assumed as equivalent to present U.S. capability; a high level is assumed as representative of predicted U.S. capability by the time period 1965. Although these assumed levels may

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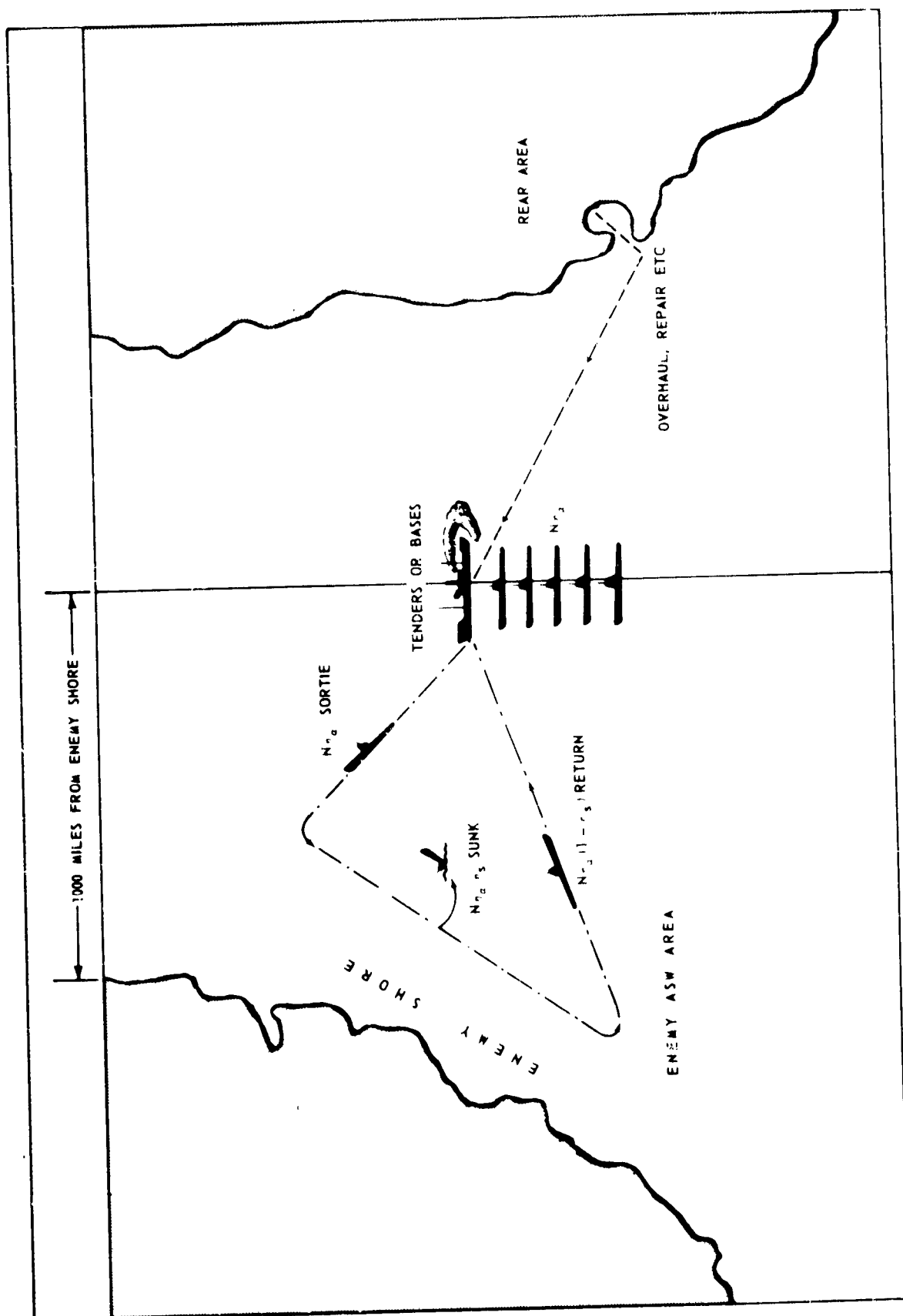


Figure S-5a. Operations Cycle - Submarine.

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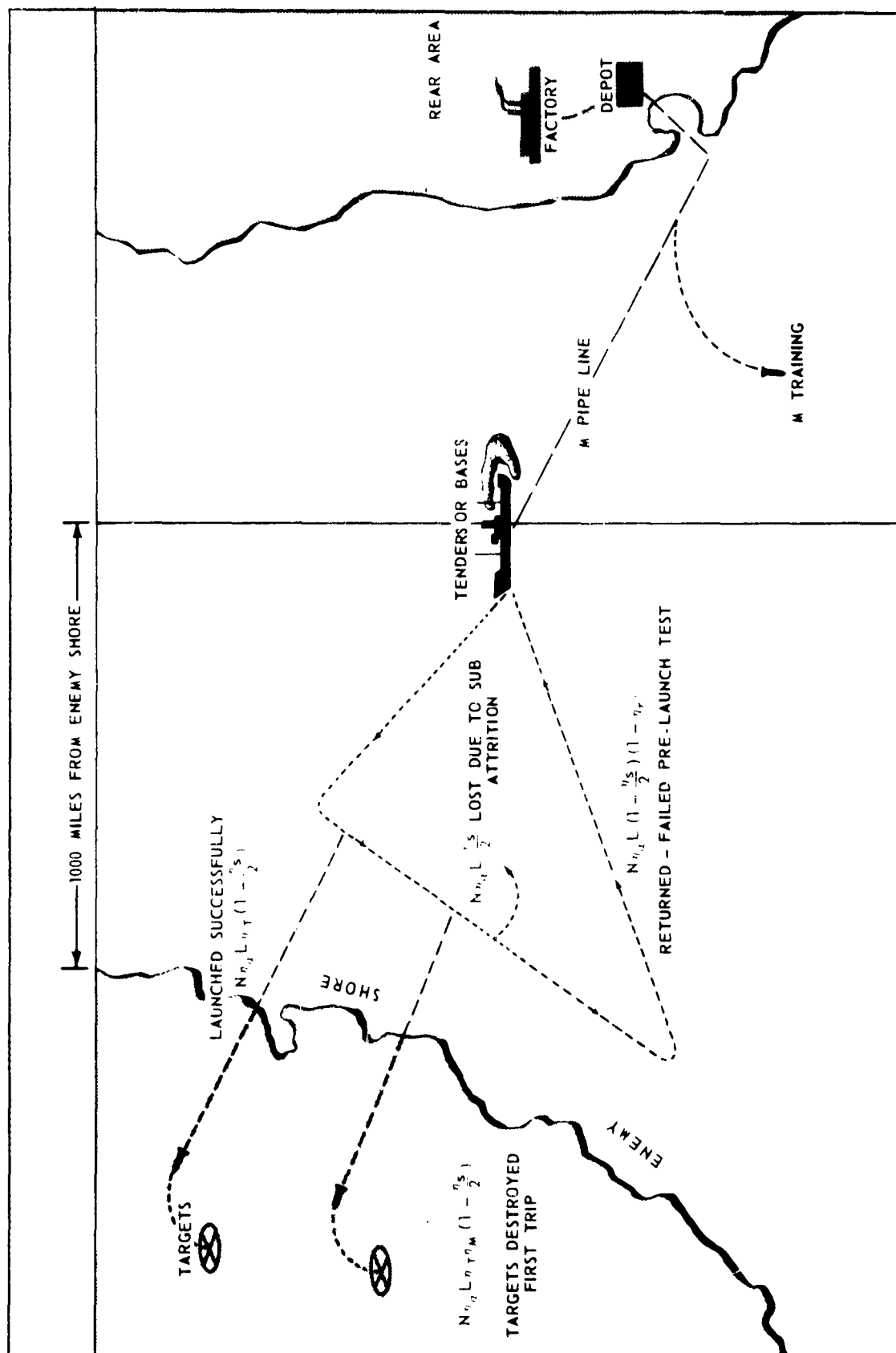


Figure S-5b. Operations Cycle - Missile.

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be open to criticism, a realistic enemy defense model was not available to the study due to TOP SECRET classification of intelligence of Russian defense effort. Nevertheless, the effect of varying degrees of defense effort against the weapon system is shown and the variations reflected in total weapon system effectiveness for the two assumed levels of defense.

THE RESULTS

The principle accomplishments of the pilot study are:

1. An organized method of study for the submarine-strike weapon system.
2. The development of a measure of effectiveness in the form of decision charts for use in quantitative evaluation and comparison of submarine-missile strike weapon systems.
3. Presentation of an example of the procedure the weapon system planner may use to assist in making his decisions.
4. Delineation of sensitive areas in weapon system selection.

The pilot study makes no attempt to evaluate the effectiveness of the submarine-missile strike as a method of warfare. However, within the limitations of the study, conclusions may be drawn. It is possible that some of these conclusions, even in their rough-cut form, may aid the weapon systems planner who may desire to make comparisons with other weapon systems.

CONCLUSIONS

Important conclusions that are forecast by this study are:

1. Against a reasonable level on enemy radar equipped ships, aircraft and blimps, risk of detection with time is multiplied by a large factor if the submarine surfaces to launch. The development of submerged launching techniques would be worthwhile.
2. Approximately 50% of the total number of targets and all of the Naval targets, such as ports, harbors, shipbuilding facilities, etc., are within a coastal belt of 500 miles. The total number of targets increases to 85% for a coastal belt of 1,000 miles.
3. The expected total delivery accuracies, on the order of 1 to 2 nautical miles, will dictate a one megaton warhead to insure 50% destruction of most types of targets. Reduction of this error to $\frac{1}{2}$ mile or less would be necessary to put the yield requirements in the kiloton class.
4. A combination of long-range missiles and high missile loading gives payoff in:
 - a. Increasing maximum delivery rate.
 - b. Reducing total weapon system cost.
 - c. Increasing target coverage capability.
 - d. Reducing submarine attrition.
5. Campaign duration cannot be picked on military considerations alone. There are many interrelated factors, which were examined in the study, limiting the choice of campaign duration.
6. From the standpoint of growth potential, the combination of nuclear submarine and ballistic missile appears to be most promising.

7. Fiscal budgetary limitations are as important as technological development in determining the operational availability of the weapon system.
8. Supporting systems need not differ radically from existing submarine support systems.
9. A feasible weapon system containing as few as 20 submarines could conceivably destroy as many as 100 targets in a campaign period of approximately one week. This must not be viewed as the final "optimum solution". The cost to obtain, maintain and operate this weapon system for a period of 5 years would be on the order of 1.8 billion dollars. The system could be available by 1967. The above conclusion must be viewed within the framework of assumptions contained in the study. Care must be exercised in using this example in view of the many assumptions contained in its determination. Detailed statistics of this example follow:

Campaign Duration	- 10 days
Number of Trips	- 2
Number of Submarines	- 20
Submarine Type	- Nuclear
Submarine Navigation System	- SINS and auto sextant
Submarine Tonnage	- 4020 tons
Missile Loading	- 7
Missile Type	- Rocket ball'stic
Missile Guidance	- Inertial
Missile Weight	- 57,500 pounds
Warhead Weight	- 1500 pounds
Missile Range	- 1000 miles
Total Missile Delivery Error	- 1 mile
Belt Depth Coverage	- 500 miles
Number of Targets Hit	- 100
Offshore Launching Distance	- 360 miles
Weapon System Cost	- 1.82 billions
Operational Availability	- 1967

SENSITIVE AREAS

During the course of the study, areas were uncovered that are of considerable importance to the study of this particular weapon system. Best available information in these areas has been included in the pilot study. However, it is believed that further study and refinement in these areas would benefit greatly in insuring the selection of the best submarine strike weapon system. These areas are:

1. Navigation and guidance systems.
2. Antisubmarine warfare and submarine counter warfare using nuclear weapons.
3. Future ASW detection systems.
4. Antimissile defense.
5. Missile handling and launching.
6. Guided missile-submarine strike tactics.
7. Warhead technology.
8. Preliminary design of submarines and missiles as a mated weapon system.
9. Budgetary considerations applicable to the weapon system in the framework of the total defense effort.

THE PROBLEM

PART A

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Chapter 1 STATEMENT OF PROBLEM

This study deals with the aspects of selecting a submarine-missile strike system for the time period of 1960-70. The strike system is assumed to be directed against coastal targets of the Eurasian landmass. The weapon system is taken to consist of submarines, submarine-launched missiles, and supporting system functions. This chapter introduces the concept and objectives of a pilot study. This approach is used for the present phase of the study. The physical elements of the problem are described. The basic assumptions underlying the study are stated. This forms the basis for determining a method of solution which is treated in the following chapter.

PILOT STUDY CONCEPT AND OBJECTIVES

The number of parameters entering in the study of a submarine strike system is large. A pilot study concept was used for the initial (6 months) phase of this study. It represents a first cut treatment of the entire spectrum of parameters. These parameters pertain to the physical elements and the operation of the submarine strike system. The following objectives were formulated for the pilot study:

1. Determination of the important factors in the selection of the best submarine missile strike system for attacking targets in the Eurasian coastal belt during the time period 1960-1970.
2. Correlation of these factors by means of a measure of effectiveness to form the basis for weapon system selection. Development of a method of solution that relates all the steps leading to the application of the measure of effectiveness.
3. Determination of values for the basic design parameters of the weapon system configuration that could be operational during the 1960-70 time period. This is to be done within the framework of stated assumptions.
4. Delineation of those sensitive areas where:
 - a. State of the art cannot be accurately extrapolated.
 - b. Effort was restricted by time limitations of the study.

A comprehensive critique of the pilot study was omitted. Limitations of the study time places this effort into a later study phase.

PHYSICAL ELEMENTS OF THE PROBLEM

The following major components form the physical elements of the problem. To implement the objectives of the pilot study, most components were allowed to vary.

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1. The Submarine
 - Type Propulsion — variable
 - Nuclear -- new
 - Diesel Electric — new
 - Diesel Electric — conversion
 - Power and Speed — variable
 - Navigation System — variable
 - Missile Loading
 - (Number of missiles carried per submarine) — variable
 - Loading and Launching Methods — variable
2. The Missile
 - Range — variable (0 to 1000 miles)
 - Propulsion — variable
 - Rocket — Ballistic
 - Airbreathing — Cruise
 - Warhead
 - Weight — variable
 - Yield
 - Megaton
 - Kiloton
 - Interchangeability — assumed
 - Fuzing
3. Supporting Systems
 - Tenders
 - Advanced Bases
 - Training Facilities
 - Manufacturing Facilities
 - Logistics
4. Eurasian Coastal Belt and Related Targets
 - The coastal belt of the Eurasian landmass was assumed to contain the targets forming the objective of the strike system. This introduces the following elements:
 - Coastal Belt
 - Depth — variable (0 — 1000 miles)
 - Location — variable
 - Asia
 - USSR
 - European Satellites
 - Targets
 - Location — variable
 - Asia
 - USSR
 - European Satellites
 - Type (Mission) — variable
 - Number — variable
 - Distribution — variable
 - Size — variable
 - Hardness — variable
 - Worth — variable

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5. Enemy Defense Elements

In operating against the Eurasian landmass the strike system is exposed to the enemy defense system. The defense involves both antisubmarine warfare and antimissile defense systems. The difficulty in estimating such capabilities is accentuated by the fact that estimates must be made for a time period 5 to 15 years in the future.

The one reasonable approach that can be made is to project U. S. capabilities into the future. Using this as a basis a high and low level of defense is established to bracket possible levels.

a. Antisubmarine Warfare

Surface Craft

Sonar

Submarines

Sonar

Aircraft

Radar

Sonobuoys

Passive Long-Range Listening

Active Long-Range Listening

Blimps

Towed Sonar

Helicopter

Dunked Sonar

b. Antimissile Defense

Antimissile defense components are in the conceptual stage. Best estimates would indicate zero capability by 1965 against the type missiles presented in this study.

ASSUMPTIONS

Assumptions were made in this study which form an integral part of the Problem Statement. These assumptions are listed below. There are additional assumptions made throughout the report. Most of these additional assumptions relate to the numerical values of constants only partly documented.

1. Only nuclear warheads will be considered. There is uncertainty on warhead technology for the time period under study. Therefore, the missile designs shall be based on the following alternate warheads.^{1 2}

Diameter — in.	30	25	20	15
Length — in.	70	70	55	40
Weight — lbs.	2800	1500	1000	500
Yield — MT	3.0	1.0	1.0	1.0

Some of the above numbers have been modified, acceptable for purposes of this study, to keep the security level down to SECRET.

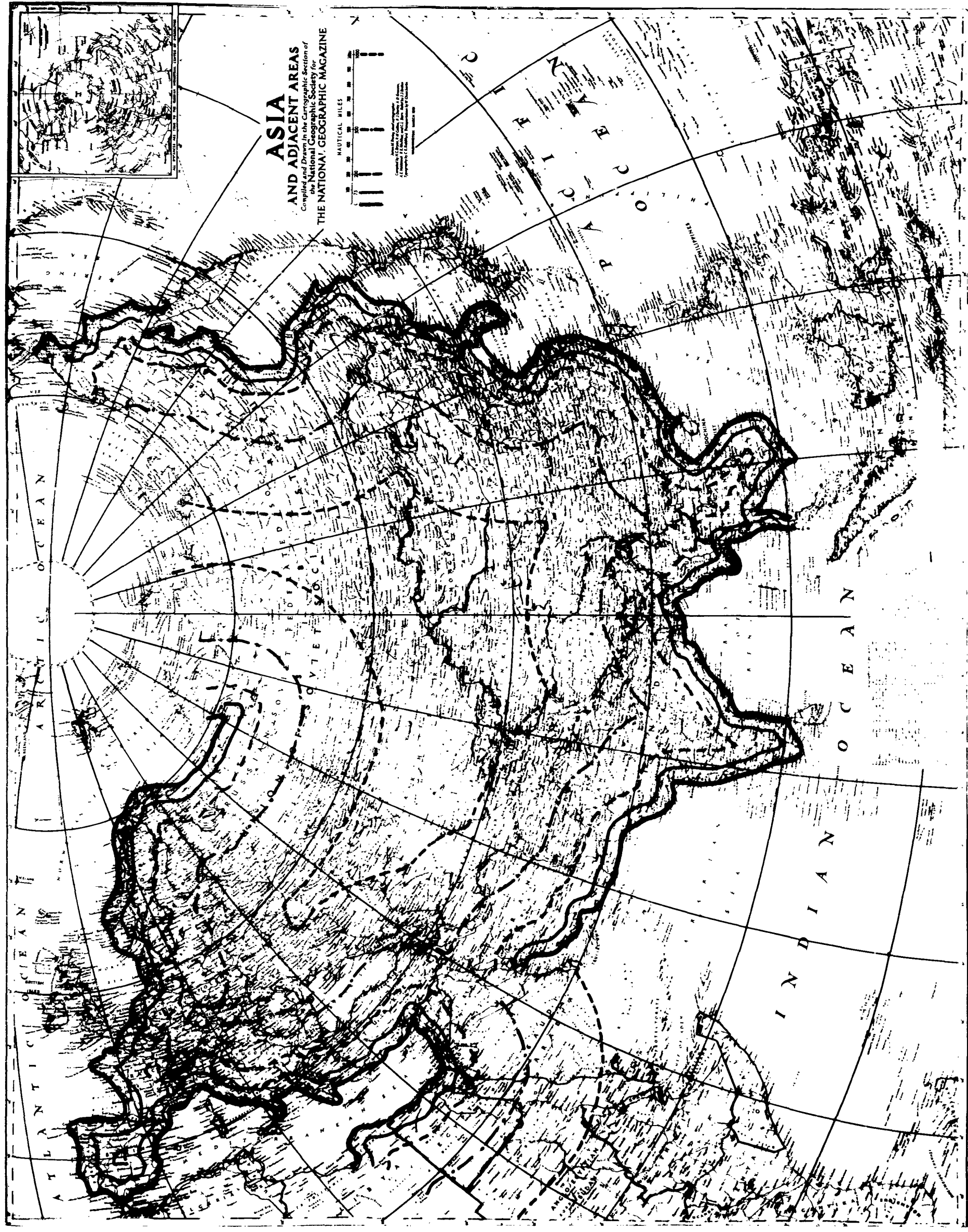
Notes: ¹ CNO SECRET Letter Serial 00253 P 36 of 30 June 1955.

² Unpublished notes, BuAer-Field Command AFSWP Conference, Sandia, 18-21 July 1955.

Kiloton warheads that might be employed alternately would in all cases be smaller and weigh less than the selected megaton weapon.

2. One warhead per target is assumed. This is justifiable on the following basis: The weight spread of warheads with relatively large yield differences is becoming small as warhead technology improves. Similarly it has been shown³ that fissionable material is more efficiently employed in a single warhead rather than in two or three. This was shown to be true on the basis of minimum amount of fissionable material for a given amount of damage.
3. The missile has flexibility for using either megaton or kiloton warheads.
4. Improvements in the ability to achieve reductions in the total missile delivery accuracy (submarine position, missile guidance, and target location) will determine at what point:
 - a. Only megaton weapons can be used consistent with the then existing national policy.
 - b. Either megaton or kiloton weapons can be used, consistent with the then existing national policy.
5. The weapon system is assumed to be directed against coastal belts of China, USSR and European Satellites during the 1960-70 time era.
6. An effective coastline is assumed, Figure 1-1, eliminating areas of limited accessibility.
7. Target complexes for several typical missions will be chosen. This improves the capability of handling unforeseen missions. Development of a limited single purpose weapon system is avoided.
8. Antisubmarine warfare and antimissile defenses cannot be accurately estimated. Therefore, two levels of enemy capability will be assumed to test the sensitivity of the problem solution to it.

Note: ³ Operational analysis working paper No. 54. "A Method for Determining the Most Economical Yield for a Given Target as a Function of Weapon Cost and Delivery Cost" by Irvin Feister, June 1954.
Asst. for Operations Analysis, Deputy Chief of Staff, Hq. U. S. A. F.



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Chapter 2 METHOD OF SOLUTION

Chapter 1 presented the Problem Statement of the study and some of the important underlying assumptions. This chapter presents the method of solution employed. First a general breakdown of the study is presented. Then the method of solution is developed. The method of solution is designed to fulfill the objectives of the pilot study as stated in Chapter 1. This involves primarily a method for weapon system selection. This leads to two steps: First, the development of a measure of effectiveness. This provides the basic means for weapon system selection. The second step involves the application of the measure of effectiveness. This consists of assembling all analytical steps necessary to provide the data for use in the measure of effectiveness.

GENERAL BREAKDOWN OF STUDY

The submarine strike weapon system study is presented in two volumes. Volume I contains the text of the study, while Volume II contains the supporting data. Volume I in turn is functionally divided into five (5) parts.

Part A — The Problem (Chapters 1 and 2)

Here the problem underlying the present study is defined. The basic assumptions used throughout the study are shown. The measure of effectiveness is defined which is ultimately used for weapon system decision.

Part B — The Weapon System (Chapters 3, 4, 5, and 6)

The physical elements of the system are discussed. The submarine, the missile and the various supporting systems are generated. Finally, the various possible combinations of weapon systems are formed into a family or matrix of weapon systems.

Part C — The Operational Task (Chapters 7, 8, and 9)

Here various missions and associated target complexes are studied. Their destruction is defined. The total error in missile delivery is derived from the various sources of error. Enemy defense levels, capabilities, and associated attrition models are determined. Environmental factors are studied. Finally, force requirements are established as a function of significant depending variables.

Part D — Application of the Measure of Effectiveness (Chapters 10, 11, and 12)

Here the systems of the matrix are costed. Their operational availability and mission characteristics are combined into the measure of effectiveness in the form of decision charts. This then forms the basis for weapon systems selection.

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Part E -- Results

The outcome of the study is presented. Sensitive areas requiring further efforts are indicated.

METHOD FOR WEAPON SYSTEM SELECTION

The elements of the study described above are geared to the selection of a submarine missile strike system. This involves determination of a suitable measure of effectiveness and its application. The application of the measure of effectiveness consists of defining all steps that provide the data for use in the measure of effectiveness.

1. The Measure of Effectiveness

A focal point in any operations research study is the definition of the measure of effectiveness. For the submarine strike system the measure of effectiveness should yield the following:

Selection of an "optimum" submarine missile strike weapon system.

Selection of an associated "optimum" coastal belt depth penetration capability.

The term "optimum" is defined by the particular measure of effectiveness.

a. Economic Factors

Economic factors form an important part in measures of effectiveness. In this study they may be viewed in the following alternate ways:

(1) Comparison of the Drain on the Economy of the U. S. with the Draining on the Economy of the Enemy

This factor has obvious merits. However, the major disadvantage in its use is the low order of accuracy that could be expected in determining the cost to the enemy in obtaining, maintaining and operating a defense system plus damage sustained. The drain on the economy to the U. S. of obtaining, maintaining and operating the weapon system could be determined with a much higher degree of accuracy. The accuracy of estimating the enemy's outlay may be expected to differ appreciably from that of the U. S. Thus, the ratio of such values would have little meaning.

(2) Drain on U. S. Economy Only

This factor represents the cost to the U. S. to obtain and maintain a strike system, capable of destroying a fixed number of targets at a given campaign duration. It provides a possible basis for comparison between different configurations of the strike system. It also provides a possible basis for comparison with other weapon systems, and allows introduction of budgetary limitation factors.

b. The Need for Decision Charts

Total cost of procurement, maintenance and operation can be determined for each combination within the weapon system matrix. However, cost is but one factor that enters in weapon system selection. There are others of equal importance. They may be listed as:

Campaign Duration
System Operational Availability
Mission Characteristics
Budgetary Limitations
System Growth Potential

These factors are not readily combined into a single expression. However, they can be correlated through the use of decision charts. These charts are described as follows and shown in Figure 2-1.

Decision Chart I gives cumulative number of targets in various categories as a function of target belt depth. After selecting a mission for the weapon system and associating the target categories with the mission selected, the weapon system planner can determine the number of targets and the target belt depth requirements from this chart.

Decision Chart II gives weapon system minimum cost as a function of coastal belt depth of targets for selected numbers of missiles carried per submarine. Parameters of the system such as submarine type, missile type, missile range and defense level are reflected in this chart. Tables of force requirements and operational availability, associated with the belt depth and submarine type, are included as inserts. These tables are computed for selected campaign durations; specifically for an instantaneous 1-month and 2-month campaign. This chart permits the weapon system planner to quickly determine the effect of large variations in fundamental parameter of weapon system selection.

c. Use of Decision Charts

Figure 2-1 shows how the decision charts are related to factors of campaign duration, defense level, budgetary and operational availability limitations, system growth potential and minimum force level. These factors should be viewed as inputs to the decision charts, controlled by the weapon system planner, which set boundaries or determine cutoffs. Optimum weapon system selection is then made from the narrowed field of systems.

General procedure in using these charts is:

- (1) Select a mission and obtain from Decision Chart I the number and coastal belt depth of targets.
- (2) Establish qualifying considerations as to:
 - (a) Campaign duration.
 - (b) Budgetary and operational availability.
 - (c) Minimum force level desired.
 - (d) Defense level expected.
 - (e) Growth potential versus relative weapon system cost.
- (3) Derive possible solutions from Decision Chart II using inputs of step 1 and 2 above.
- (4) Select one solution from those possible appearing as optimum within the framework of the considerations.

Detailed steps of this procedure will be given in Chapter 12.

d. Deviations from the "Optimum" System

It is important to be able to determine penalties associated with deviations from the "optimum" system as defined by the measure of effectiveness. This is of particular interest to the weapon system operator. For instance, a reduction in attrition level may penalize the "optimum" system slightly. However, the operator would wish for the attrition level to approach zero. Thus, at the discretion of the weapon system planner, departure from the "optimum" system to favor the weapon system operator's viewpoint may be made.

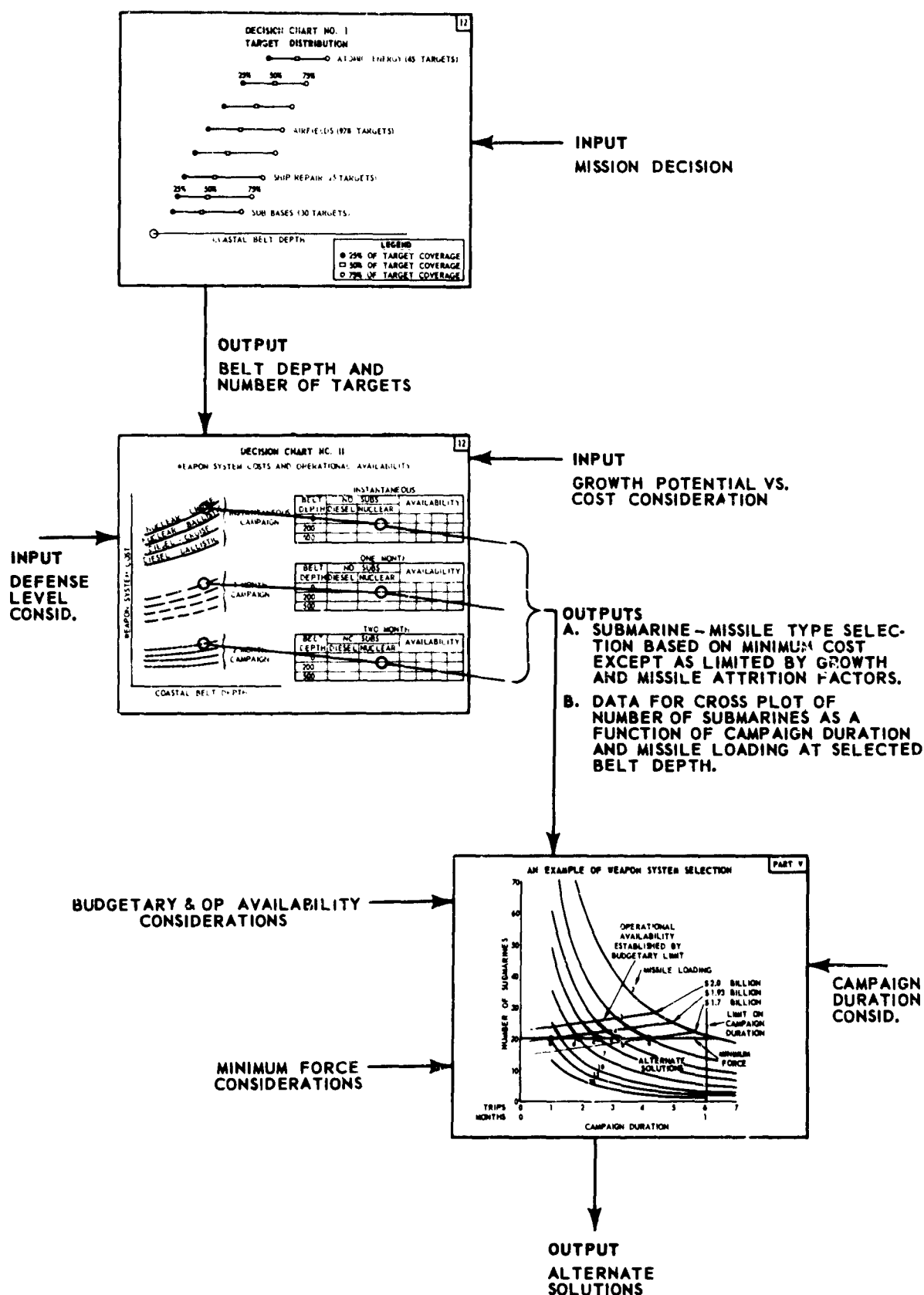


Figure 2-1. Decision Charts Related to Weapon System Selection.

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2. The Application of the Measure of Effectiveness

This part of the method of solution consists of assembling all analytical steps necessary to provide the data for use in the measure of effectiveness. Figure 2-2 was prepared to more clearly present the relationship between the many factors which lead to the final decision charts. The blocks shown in Figure 2-2 represent in most cases the end product of major steps contained in the various chapters.

The individual blocks may be more clearly understood by reference to the appropriate chapter.

Figure 2-2 may be viewed as an analogue computer where the various blocks may be fed with varying storage information.

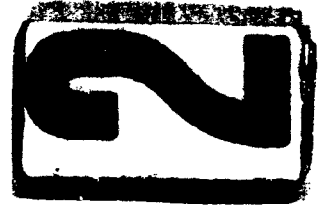
Typically it was beyond the objective of Phase I to go comprehensively into the problem of logistics. With the multiplicity of pipelines and close tie-in between logistic and strategic planning peculiar to modern wars, further study in arriving at an optimum comprehensive logistic plan for such a weapon system is indicated.

Such a logistic study would feed new information into various blocks such as the pipeline factor, war readiness reserve factor costing blocks and others.

Similarly one might wish to study the effect of the use of primary battery submarines (not covered in the present study) and other system changes. With the new information fed into all pertinent blocks, the "computer" can be run through.

An effort was made to bracket or use upper or lower limit values for most significant parameters in order to cover the entire spectrum of possible weapon system versions.

Chapter 12 presents the numerical solution to the purely schematic array shown in Figure 2-2.



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THE WEAPON SYSTEM

THE PART B

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Chapter 3 THE MISSILE

A major component of the weapons system is the missile. Two types of missiles are considered for use with submarines. They are:

1. Ballistic missiles with rocket engines.
2. Cruise missiles with airbreathing engines.

This chapter presents general design characteristics of selected configurations of each missile. It also includes a discussion of warheads, fuzing, guidance, and operational reliability. The data are used to determine some of the design requirements of the submarines in Chapter 4 and to make up total weapon systems in Chapter 6. The data are also used in costing missiles in Chapter 10. Supporting missile data are included in detail in Volume II, Part B.

BALLISTIC MISSILES

Two types of ballistic missiles are shown:

1. Solid propellant missiles.
2. Liquid propellant missiles.

Typical configurations for each of these missiles are shown in Figure 3-1a and 3-1b respectively.

The solid propellant missiles are single stage vehicles; the liquid propellant missiles are divided into single stage and one and one-half stage vehicles, (one powered stage with a separating nose cone). The gross weight and gross volume versus range of the generalized missiles are shown in Figure 3-2.

For the liquid rocket power plants, the assumed configuration consists of a regeneratively-cooled rocket motor, turbopump feed system, gas generator for turbine drive, valves, plumbing, controls and gimbal system. Motor gimbaling is provided for pitch and yaw control during powered flight and tangential turbine exhausts provide roll control. For the solid fuel rocket engines, jet vanes are used to control the missile during the power-on phase of flight.

The shape of the nose can affect re-entry heating and dispersion. However, nose cone design is a problem beyond the scope of this study. For purposes of this study a reasonable nose cone shape, a 15 degree half-angle cone, was assumed. Allowances were made for an attitude control system to minimize angle of attack upon re-entry and for cooling system weights. Volume II, Part B covers these items in more detail.

It is assumed that the solid propellant missiles use an end burning solid and that the liquid propellant missiles use liquid oxygen plus hydrazine or liquid oxygen plus gasoline. The curves of Figure 3-2 are based on these fuels.

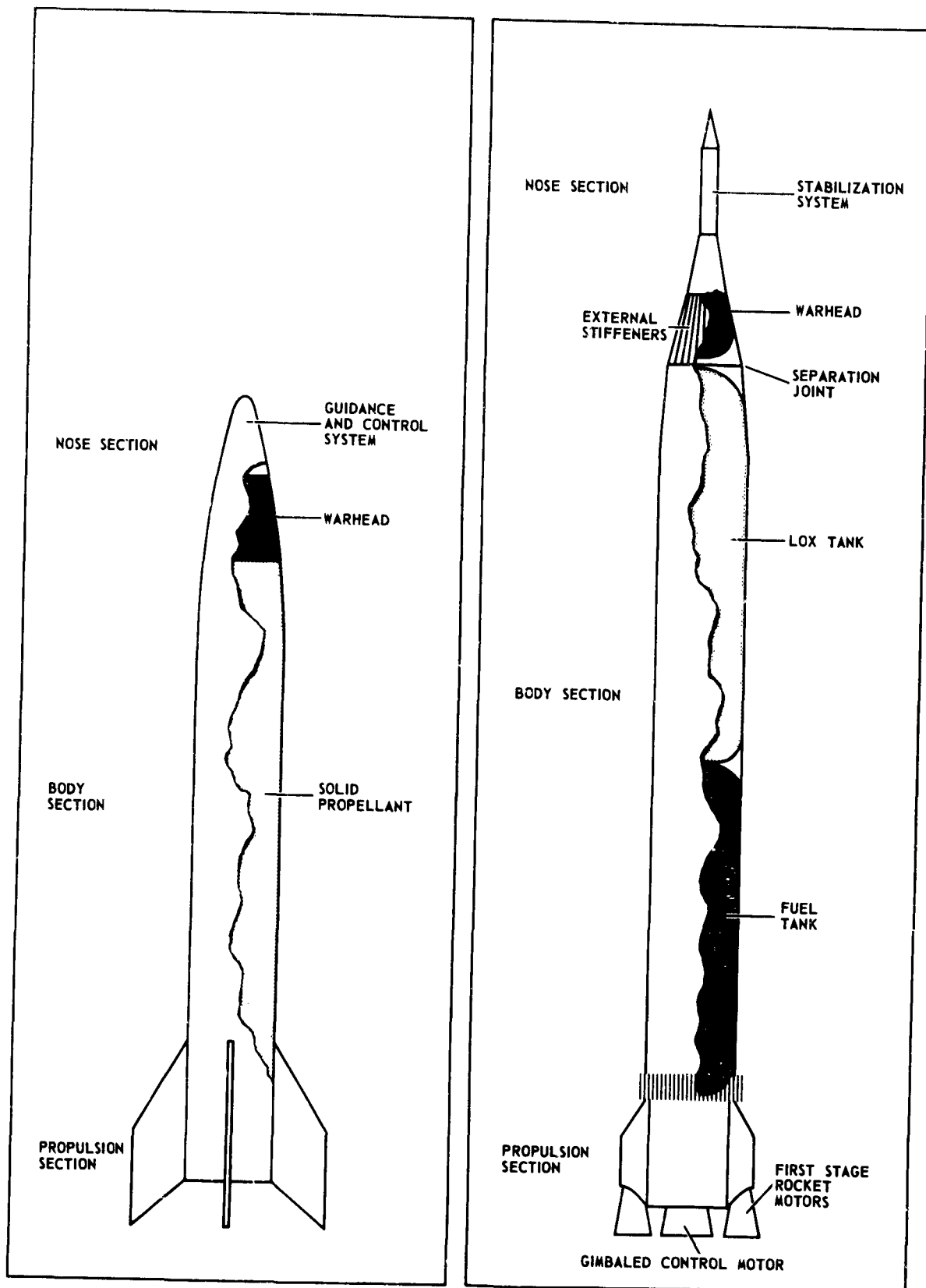


Figure 3-1. Ballistic Missile - (a) Solid Propellant; (b) Liquid Propellant.

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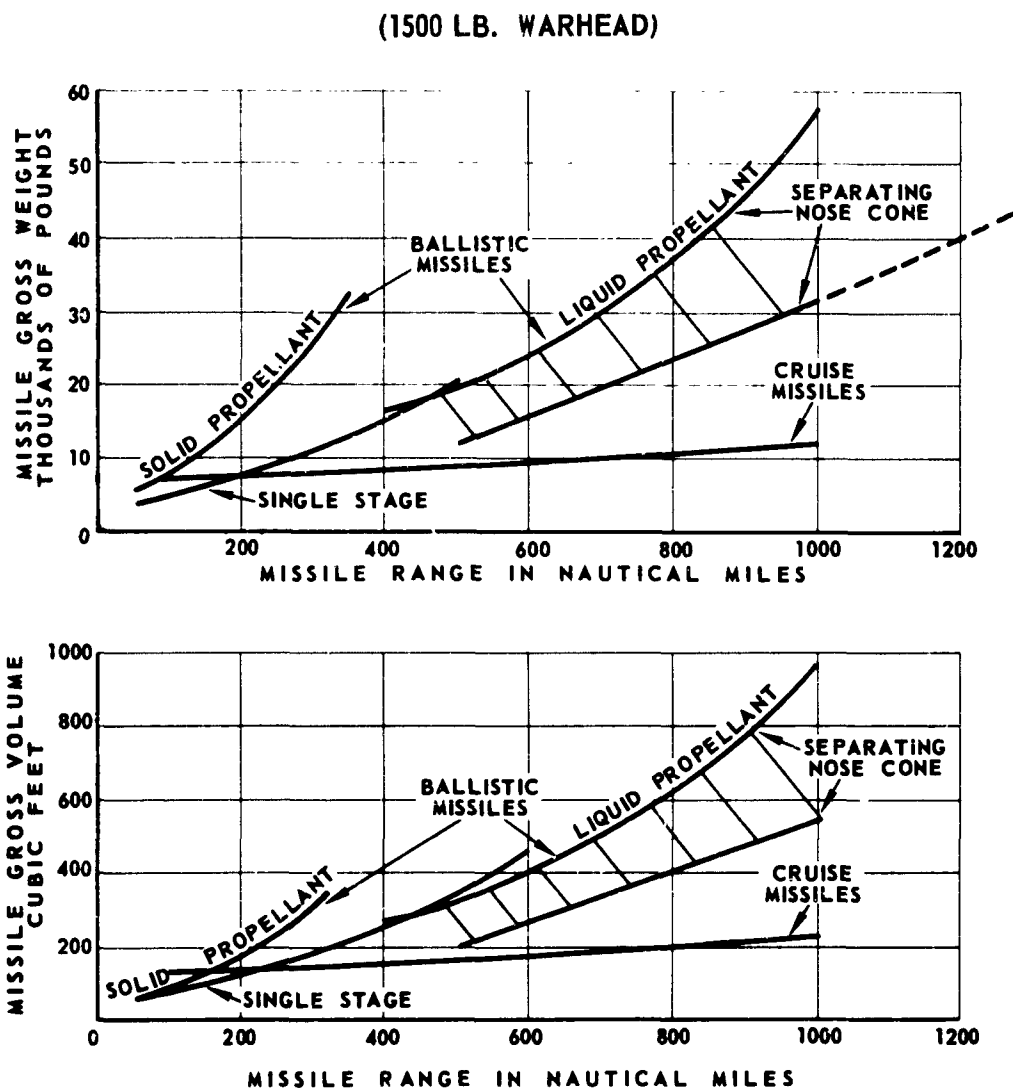


Figure 3-2. Gross Weight and Gross Volume of Generalized Missiles vs Range (1500 lb. Warhead).

The gross weights shown in Figure 3-2 are the result of a first estimate. The missiles are assumed to carry a 1500-pound warhead and to be operationally available in the period 1965-68. The spread in gross weight indicated for the liquid propellant ballistic missiles is indicative of the effect of design criteria. The lower curve is based on a blunt nose cone and thin-gauge, pressurized tank construction similar to that used in the Atlas Model-7 design. The upper curve is based on a sharp nose cone and conventional construction methods. The more conservative missiles represented by the upper curve are the ones referred to in the rest of this study. Any refinements to this choice must await actual preliminary design work.

The solid propellant missiles are attractive from a handling standpoint but are surpassed in efficiency by liquid propellant missiles at relatively short ranges — less than 100 nautical miles. The former missiles are further handicapped by the difficulties associated with controlling the missile velocity at motor burnout. Liquid propellant missiles, on the other hand, may pose handling problems with certain fuels. Liquid

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oxygen plus hydrazine are a high performance combination, however motor cooling and storage of the liquid oxygen constitute problems which must be solved. A final choice of fuel would be a compromise of performance, handling, storage, and other factors. A more detailed discussion of fuels is included in Volume II, Part B.

Two-stage vehicles are not considered. There is a crossover between 700 and 1000 nautical miles, but the added complexity of two-stage operation does not appear to justify the saving in gross weight. It is also assumed in the study that only liquid propellant missiles will be used at ranges exceeding 100 nautical miles. This assumption should be reviewed in detail in subsequent phases of the study. Recent information¹ indicates that large solid propellant rockets are feasible which would compare favorably performance-wise with liquid propellant rockets.

CRUISE MISSILES

The cruise missiles are generalized in the same manner as the ballistic missiles. Gross weight and gross volume versus range for cruise missiles are also shown in Figure 3-2.

The possible airframe configurations of cruise missiles are numerous. For the purposes of this study an airframe similar to that of Triton is assumed. A sketch of this configuration is shown in Figure 3-3. A change in configuration would primarily affect stowage aboard the submarine.

The cruise missiles are assumed to carry the same warhead as the ballistic missiles — 1500 pounds. The powerplant is a ramjet engine using kerosene as a fuel. Cruise speed is Mach 3.5. Takeoff thrust is assumed to be provided by a liquid fuel booster. For the purposes of this study such powerplants as turbojets, air-turbo rockets, accelerating ramjets, etc. are not considered.

Again the gross takeoff weights presented are only a first estimate. Shipboard requirements, different boost conditions, maneuverability requirements, etc., may result in changes in gross takeoff weights. These refinements must also await actual preliminary design work.

WARHEADS

As stated in Chapter 1, only nuclear warheads are considered in this study. There is also uncertainty on warhead technology for the time period under study. Therefore, the missile designs in this chapter and in Volume II, Part B, are based on the following alternate warheads.^{2 3}

Diameter — in.	30	25	20	15
Length — in.	70	70	55	40
Weight — lbs.	2800	1500	1000	500
Yield — MT	3.0	1.0	1.0	1.0

Notes:¹ Special Report No. 993, "Preliminary Evaluation of the Feasibility of Solid Propellant Rockets with Total Impulse From One to Twenty Million Lb. -Sec."

² Aerojet General Corporation, July 1955.

³ Chief of Naval Operations SECRET ltr Serial 00253 p 36 of 30 June 1955.

³ Unpublished notes, BuAer-Field Command AFSWP Conference, Sandia, 18-21 July 1955.

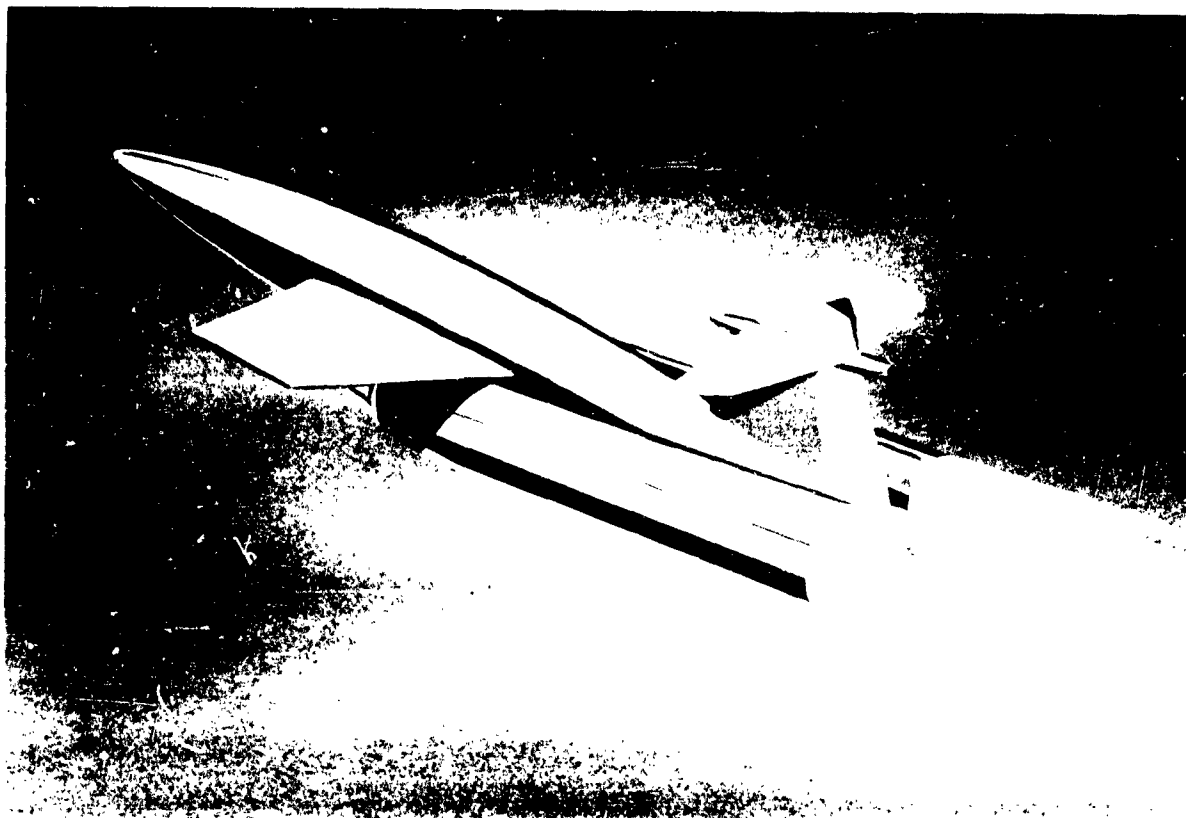


Figure 3-3. Cruise Configuration.

Some of the above numbers have been modified in a way acceptable for this study in order to keep the security level down to SECRET.

The missile designs are based on warheads with megaton capabilities. Kiloton warheads would be smaller and weigh less than a selected megaton warhead. Consequently, the missiles presented in this study have the capability of delivering either megaton or kiloton warheads.

For purposes of optimizing the weapon system, only the 1500-pound warhead case is carried through. To a first approximation, missile cost and thus weapon system cost is dependent only on missile gross weight, all other parameters being fixed. Consequently, the effect of variations in warhead weights on weapon system cost can be indicated roughly by determining an equivalent range point on the 1500-pound curve. This can be illustrated by Figure 3-4. This figure indicates the following:

<u>Warhead</u>	<u>Range</u>	<u>Weight</u>	<u>W. S. Cost</u>
1500 lb.	R ₁	W ₁	1500 lb. at R ₁
1500 lb.	R ₂	W ₂	1500 lb. at R ₂
2800 lb.	R ₁	W ₂	1500 lb. at R ₂

FUZING

Several types of fuzes are available for nuclear warheads:

1. Altimeter-radar or barometric
2. Timed
3. Contact

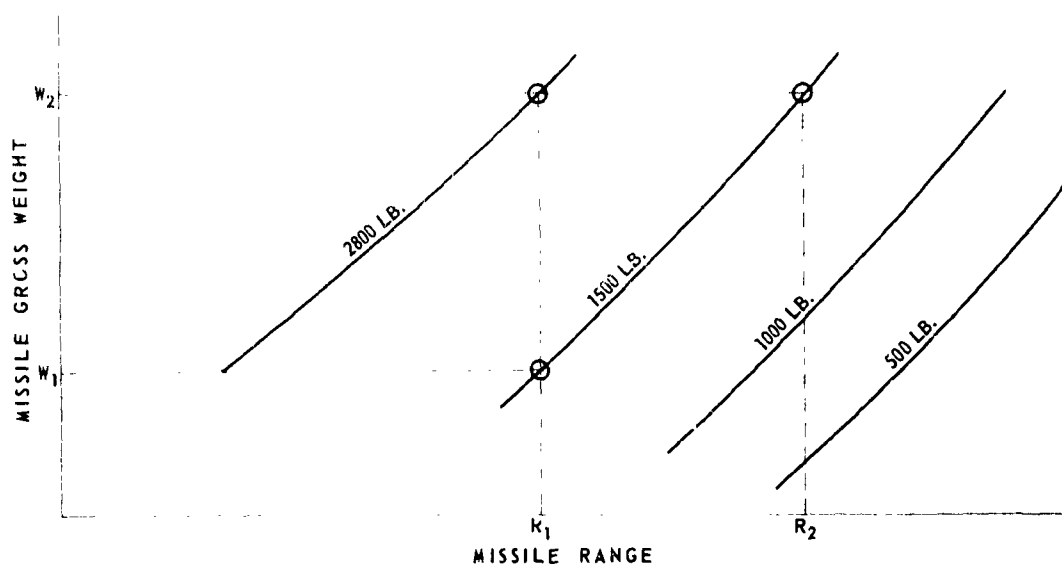


Figure 3-4. Trade-Off Between Range and Warhead.

Depending on the nature of the mission an air burst or a ground burst might be called for. This would dictate the type of primary fuze which would most likely be used in parallel with a secondary fuze to assure detonation.

MISSILE GUIDANCE

Missile guidance problems are treated separately in Chapter 5 which deals with the Total Error in Missile Delivery. Guidance equipment weight is the only factor that affects performance as treated in this chapter. For cruise missiles, the guidance equipment weight was assumed constant at 400 pounds; for the ballistic missiles the guidance equipment weight was varied as a function of range as follows:

Range	Equipment Weight
0-150 nautical miles	50 pounds
150-500 nautical miles	150 pounds
500-1000 nautical miles	300 pounds

MISSILE OPERATIONAL RELIABILITY

Missile operational reliability, for the purposes of this study, is considered to be the major contributor to missile attrition. Attrition due to enemy action is discussed in Chapter 8 which deals with Enemy Defense Levels and Capabilities.

Theoretically, design reliability of a missile is 100%, however, operational reliability will be less than 100%. This decrease in reliability is caused by such factors as fabrication techniques, production tooling and test equipment, packaging, handling, logistics, maintenance, improper usage, and lack of personal training. A detailed treatment of operational reliability is beyond the scope of this study. However, in order to give some recognition to operational reliability the following assumptions are made.

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1. There will be some simple checkout of the missile on board the submarine. Ninety percent of the missiles subjected to this checkout will be launched. The remainder will be brought back for repair.
2. Of the missiles launched, 80% will successfully detonate a warhead in the vicinity of the target.

These reliability figures are used as a factor in the determination of force requirements, Chapter 9.

Chapter 4 THE SUBMARINE

The missile carrier in this weapon system is the submarine. This chapter presents generalized submarine design data for the following combinations:

<u>Type</u>	<u>Power-Plant</u>	<u>Missile</u>
Fleet Conversion	Diesel-Electric	Ballistic
New Construction	Nuclear	Cruise

These data are based on existing submarine designs and preliminary submarine designs extrapolated to cover the ranges of displacement of interest in this study.

A relationship between missile range and submarine displacement is established. This provides basic data for Force Requirements, Chapter 9 and System Costing, Chapter 10. The chapter also introduces the problems of handling and launching the different missiles that might be carried aboard a submarine.

Supporting data for the submarine parameters are included in Volume II, Part A.

FLEET CONVERSION (Diesel-Electric)

The fleet conversions are restricted to the Guppy type submarine. It is also assumed that there will be no major hull alterations. On this basis, missile stowage will be within either existing torpedo stowage spaces or an added external hangar.

The torpedo stowage spaces will accommodate only small ballistic missiles. Twenty-four missiles having a range of approximately 100 nautical miles can be carried in these spaces if the launching tubes are also used for stowage.

External hangar installations would be similar to existing Regulus conversions. Such installations could accommodate 2 ballistic missiles with a 500-mile range or 10 ballistic missiles with a 200-mile range. Alternately one or two cruise missiles with a configuration similar to Triton and a range of 1000 miles could be carried.

It is evident that for the longer range missiles the capacity of a converted submarine is limited to one or two. However, operational availability, Chapter 11, and system cost, Chapter 10, may make these units a desirable choice.

NEW CONSTRUCTION

Both diesel-electric and nuclear boats are considered in the new construction. A geometric family of vessels was generated for each type. The details of this process, including the design assumptions, are given in Volume II, Part A.

1. Missile Loading

Missile loading, or the number of missiles per submarine, was handled in the same way for both the diesel-electric and the nuclear boats. Missile stowage

is assumed to be internal. Space allowances are made for missile service equipment, handling and loading, packing factor, framing, compensation tankage, and compartment service equipment. Loading is presented as armament volume in equivalent tons of sea water. (See Figure 4-1.)

2. Submarine Speed Selection

The speed selection for both diesel-electric and nuclear boats is made on the basis of existing design practice. Trade-off between submarine speed and missile loading or other factors was not studied in this first analysis. A detailed study of the relationship between submarine speed and missile loading should be included in a second phase of this study.

3. Diesel-Electric Submarines

The diesel-electric boats presented in this chapter are assumed to operate on a snorkel cycle of two charges per day. Maximum surfaced speed is 20 knots. The diesel-electric submarines are rated on the basis of surfaced speed which represents their greater speed capability.

Figure 4-1 presents the relationship between the selected family of diesel-electric boats and missile loading.

4. Nuclear Submarines

The nuclear submarines are rated on the basis of submerged speed. Maximum submerged speed is 25 knots. The family of submarines is based on a series of preliminary power plant designs considered to be representative of the likely operational plants for 1960 through 1965.

Figure 4-1 also shows the relationship between the selected family of nuclear boats and missile loading.

MISSILE HANDLING AND LAUNCHING

In generating the submarine parameters, no details of handling and launching the missile have been included. This is an area requiring considerable study and preliminary design effort. This is especially true for the longer range missiles.

From a passive defense standpoint it appears desirable to launch missiles from a submerged position. It appears equally feasible to accomplish this type of launching with both ballistic and cruise missiles, but probably not before 1965 on an operational basis (see Chapter 11 for additional discussion).

One possible method of submerged launch for a ballistic missile is to make the missile free floating, release it from the submarine and fire it after it reaches the surface.¹ Venting problems, structural problems, and acoustic problems which might be introduced aboard the submarine by lighting off the missile power plant in a tube or on the deck are avoided by this launching scheme.

This procedure for launching missiles is assumed in Chapter 8, Enemy Defense Levels and Capabilities.

Handling of the missiles is a problem. It appears likely that large ballistic missiles would be put aboard in an empty condition. Once on board the missiles would be fueled and from then on subjected to a minimum of handling. This may not be possible

Note: ¹ Report No. R-0329, NADC Johnsville, Pa., 25 May 1951.

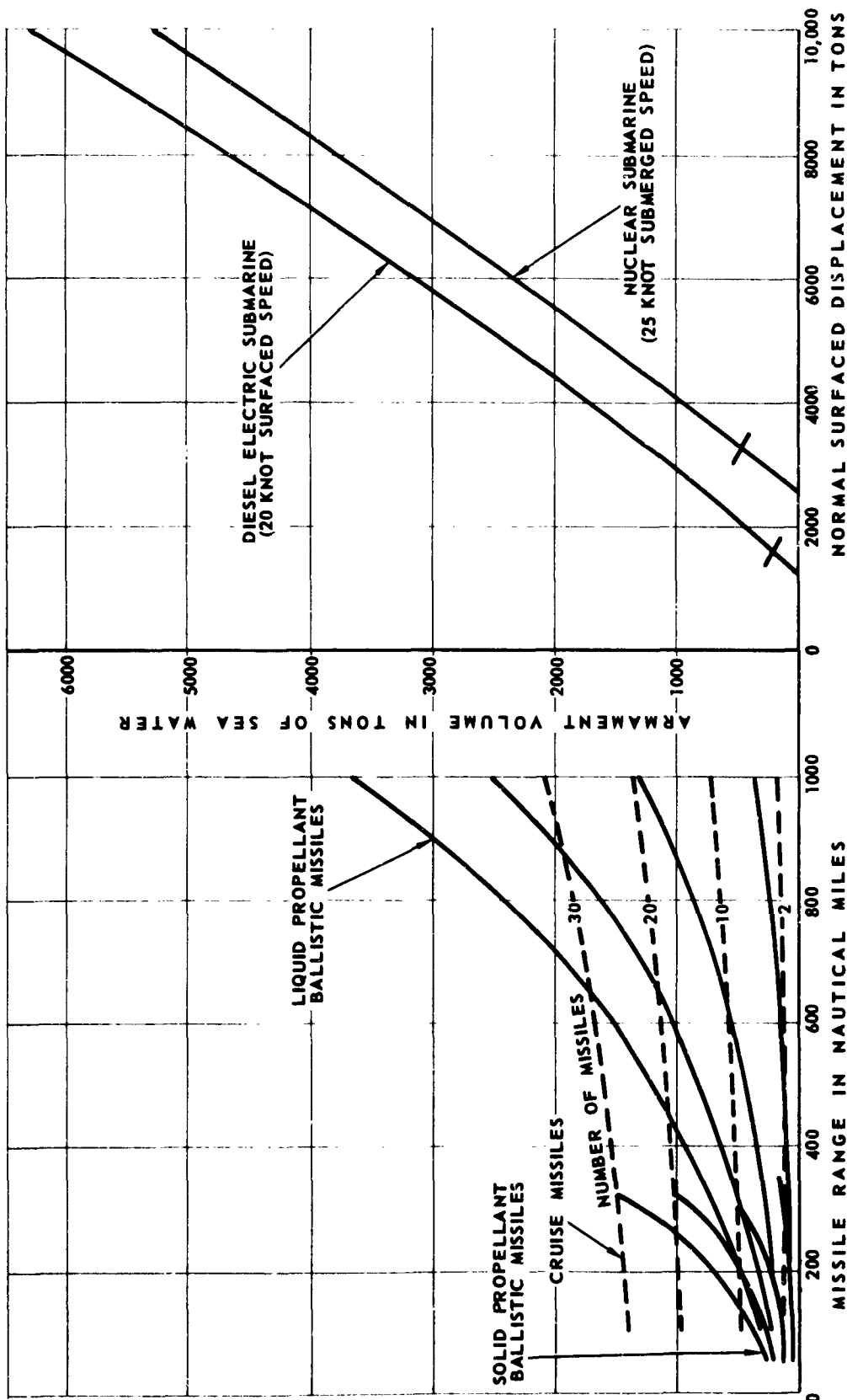


Figure 4-1. Relationship Between Missile Loading and Submarine Displacement.

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with certain fuels and would be consideration in the choice of fuels as mentioned in Chapter 3. Cruise missiles, at least through 1965, will probably be handled and launched in the same manner as currently planned for Regulus II. More detailed study of handling, including feasibility studies of specific schemes, is indicated for future work.

The importance of the problems mentioned in this section in affecting operational procedures and submarine attrition indicates that considerable effort should be expended in these areas in subsequent phases of the study.

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Chapter 5 THE TOTAL ERROR IN MISSILE DELIVERY

The accuracy of missile delivery will influence decisions to use megaton or kiloton warheads. This point was introduced in Chapter 1. The total error in missile delivery is combined with vulnerability requirements in Chapter 7. This gives the relationship between missile range and yield requirements.

The total error in missile delivery is a combination of three errors which for this study are assumed to be mutually independent. These errors are submarine position error, missile guidance error, and target location error. The individual errors are presented for the methods and equipments which can be used for navigation, guidance, and location. Combination of the errors for use in Chapter 7 completes the chapter.

The results should only be considered as a best preliminary estimate of the accuracies attainable by 1965. Failure of a development program or operational degradation of a system would effect revisions of these estimates. The fields of navigation and guidance are rapidly changing ones and therefore require further study.

SUBMARINE POSITION ERRORS

There are and will be available a number of methods of navigating and positioning a submarine. When and where a particular method can be used will depend on such factors as tactics, weather, and security. The following is a list of some of these methods:

1. Long-range radio (RADUX)
2. Celestial (SEXTANT)
3. Radar
4. Sonar
5. Optical
6. Inertial (Submarine Inertial Navigational System)
7. Dead-reckoning

Methods 1, 2, and 6 are considered most likely to be used on the basis of both accuracy and security. Methods 3, 4, and 5 come under the general classification of piloting. However, accuracies and qualifying comments are presented in Figure 5-1 for each of the methods.

Method Classification	System and Availability	Accuracy Standard Deviation	Remarks
1.	Radux - 1960	1 mile at 2000 miles	Present accuracy is 5 miles at 2000 miles. Improvement is expected within 5 years. Signals can be received with the antenna 5 feet below the surface. Transmitters are susceptible to enemy homing missiles.
2.	Hand Sextant - Current	1 - 2 miles	Fair weather system. Estimates of accuracies attainable range from $\frac{1}{2}$ mile to 2.5 miles.
	Automatic Sextant - 1960	0.8 mile	Fair weather system. Some estimates place ultimate accuracy of automatic sextant at 1000 feet.
3.	Radar - Current	900 feet	Requires accurately charted reference landmarks. Submarine limited to 3-5 miles away. Disclose submarine position.
4.	Active Sonar plus sea mount - not known	No data	Requires the presence of a suitable sea mount, previously mapped. Increases the submarine's susceptibility to detection.
	Planted Sonar Transponder Beacon - not known	Essentially that of planting the beacon	Beacons could be located by the enemy and replaced with homing devices. Beacons must be planted in the first place. Reliability may be a problem.
5.	Periscope - Current	300 feet	Obtained under ideal conditions. Requires accurately charted reference landmarks. Submarine limited to 3-5 miles off shore.
6.	SINS - 1965	$\frac{1}{2}$ mile in 10 hours	Stated accuracy is expected by 1965. System can also be used as highly accurate gyrocompass and as an artificial horizon for an automatic sextant. Present accuracy is 5 miles max. error, 1-1.5 miles RMS error.
7.	Dead Reckoning - Current	No data	Depends on gyrocompass error and estimates of winds and currents.

Figure 5-1. Accuracies of Various Navigational Systems.

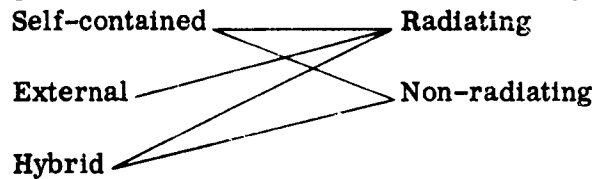
The system accuracies quoted in Figure 5-1 should be operationally available by 1965. Accuracies for positioning by hand-sextant, radar, and periscope are currently attainable. In all cases accuracy of the charts being used introduces uncertainties in the determination of position.

On the basis of the assumptions of Chapter 8, Enemy Defense Level and Capabilities, it appears that a "best" navigation system for the submarine would be either Radux or a combination of an automatic sextant and SINS.

MISSILE GUIDANCE ERROR

Missile guidance error is dependent in part on the choice of guidance system and attainable accuracy of the instruments used to implement this system.

Generally speaking, most guidance systems are covered by the following matrix:



Typical guidance systems within this array are:

Inertial
Star Tracker
Doppler Navigator
Magnetic
Command
Homing

Possible combinations of these systems are shown in Figure 5-2.

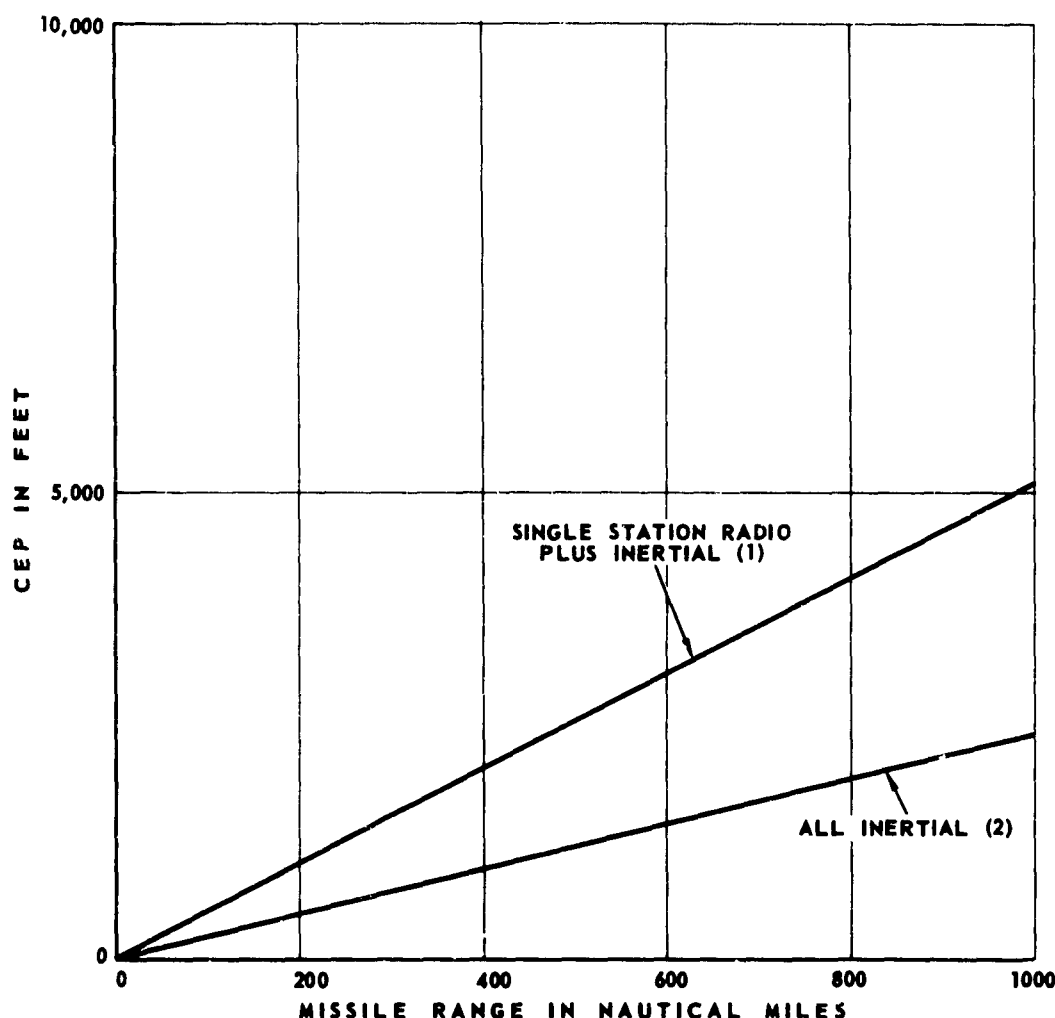
System	Inertial	Star Tracker	Magnetic	Doppler Navigator	Command	Homing
Inertial	X			X	X	X
Star Tracker		X				X
Magnetic			X			X
Doppler Navigator	X			X		X
Command	X				X	X
Homing	X	X	X	X	X	X

Figure 5-2. Possible Combinations of Typical Guidance Systems.

In this study, guidance systems for ballistic missiles are restricted to inertial and command plus inertial. Other systems and combinations are not considered practical for this type of vehicle. Terminal guidance corrections are not included in the accuracy estimates for the systems. Terminal guidance corrections are feasible but the pay-off of the added system complexity must be ascertained.

Cruise vehicles on the other hand can conceivably be equipped with any of the guidance combinations indicated in Figure 5-2. This is due primarily to the nature of the flight path — lower speed and essentially constant altitude. Figure 5-3 shows CEP versus range for two guidance systems which could be used in ballistic missiles. The single station radio plus inertial is less accurate than the all inertial system, but it is assumed to be instrumented with much poorer inertial components. The main reason for considering such a system is that it might be available at an earlier date than the all inertial system with comparable accuracy.

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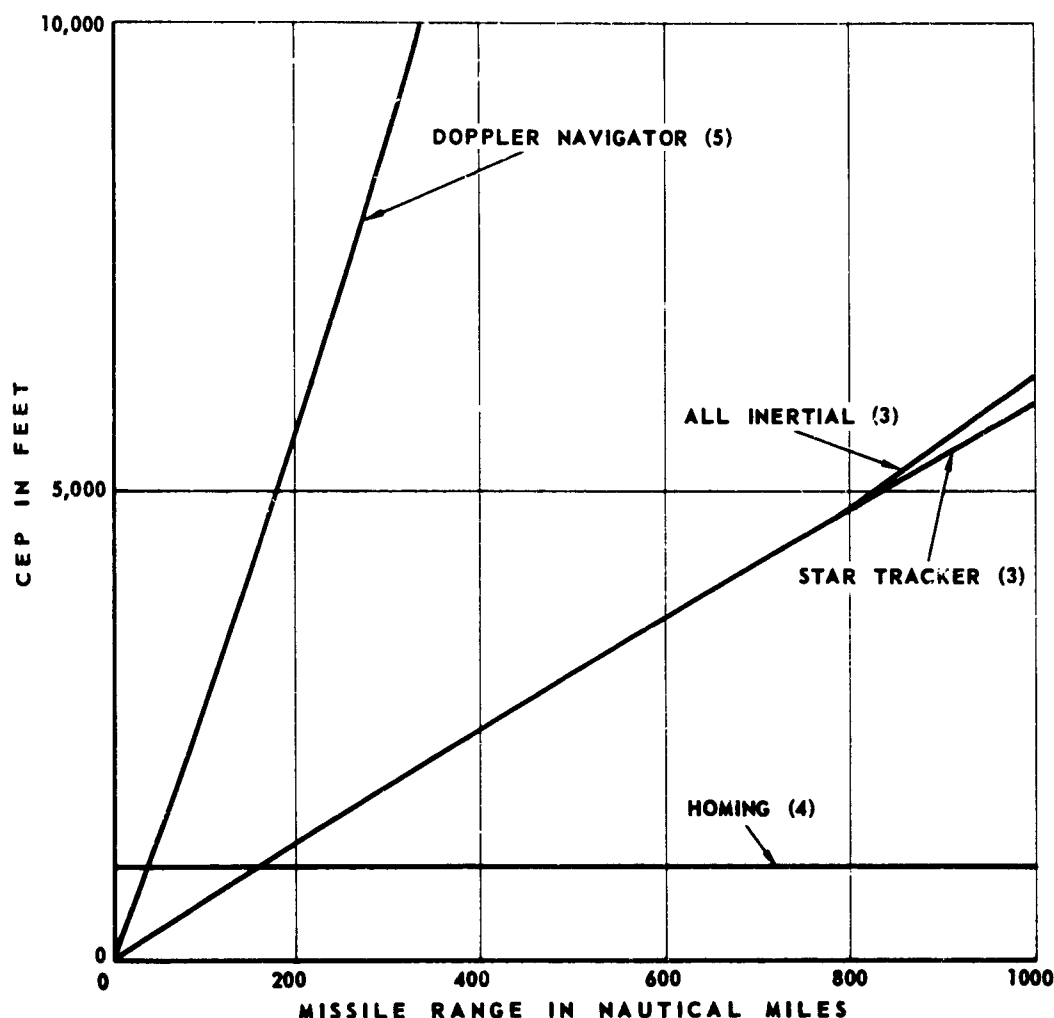


- (1) RAND REPORT, RM-1397, "SINGLE STATION RADIO GUIDANCE FOR BALLISTIC MISSILES" W.E. FRYE, (TO BE PUBLISHED)
- (2) RAND REPORT, RM-1322, "THE GUIDANCE OF LONG RANGE BALLISTIC MISSILES BY ACCELEROMETER SYSTEMS", W.E. FRYE, 18 AUGUST 1954

Figure 5-3. Guidance Accuracy for Ballistic Missiles CEP vs Range.

Figure 5-4 shows CEP versus range for several guidance systems which could be used in cruise missiles. The homing system is radar map-matching. Its usability depends on the availability of radar reconnaissance or the ability to synthesize radar maps. Goodyear Aircraft Corp. does not consider electronic countermeasures to be effective against this type of system. Satisfactory performance with 50% degradation of the information is claimed. Trounce which is now in use with Regulus I has poorer accuracy than the Doppler navigation system. In addition, the system requires a picket submarine which would be vulnerable to enemy action. Magnetic guidance is considered unsatisfactory because of the difficulties in extrapolating magnetic data and in predicting magnetic storms.

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- (3) RAND REPORT, RM-666, "ERRORS IN TYPICAL LONG RANGE SURFACE-TO-SURFACE UNDAMPED INERTIAL GUIDANCE SYSTEMS" E.V. STEARNS, 7 AUGUST 1951
- (4) CONVAIR REPORT, TM 339-23-84, "TRIP REPORT, GOODYEAR AIRCRAFT CORP.", R.G. DICKEY, 25 AUGUST 1955
- (5) U.C.L.A. AND RESEARCH AND DEVELOPMENT BOARD, "SYMPOSIUM ON SELF-CONTAINED NAVIGATION SYSTEMS", 9-10 FEBRUARY 1953

Figure 5-4. Guidance Accuracy for Cruise Missiles CEP vs Range.

In subsequent phases of the study, missile guidance should be analyzed in detail. Countermeasures, reliability, and operational problems are some of the factors which should be considered. One or more of them could outweigh the accuracy of a system in making a choice. The accuracies shown in Figures 5-3 and 5-4 should be attained by 1962 except for the homing system. Operational availability is discussed in more detail in Chapter 11.

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TARGET LOCATION ERROR

The uncertainty in target position is difficult to evaluate at present. Geodetic information on many of the areas of interest is either nonexistent or not available to the U.S.¹ This is a problem that besets all long-range missile systems. The situation is not likely to improve rapidly either and as a matter of fact, it may degrade with the construction of new cities and bases. Consequently, for purposes of this study it is assumed that the standard deviation of target location is $\frac{1}{2}$ nautical mile.

TOTAL ERROR

The total error or effective CEP is the combination of the individual errors which have been discussed in this chapter. As a first approximation the individual error distributions are assumed to be nearly circular and mutually independent. The errors can then be combined as the square root of the sum of squares. This does not apply to the homing system of guidance shown in Figure 5-4. The total error for combinations using this system is the error of the system itself.

The total error of the best combinations is shown in Figure 5-5. In Chapter 7 these results are combined with target information to determine the yield requirements for particular missions. The effect of increasing total error on yield requirements is also shown in Chapter 7.

Note: ¹ Army Map Service, CONFIDENTIAL ltr F4-061.2(910) (1 Sept. 1955) re Chart Information; request for

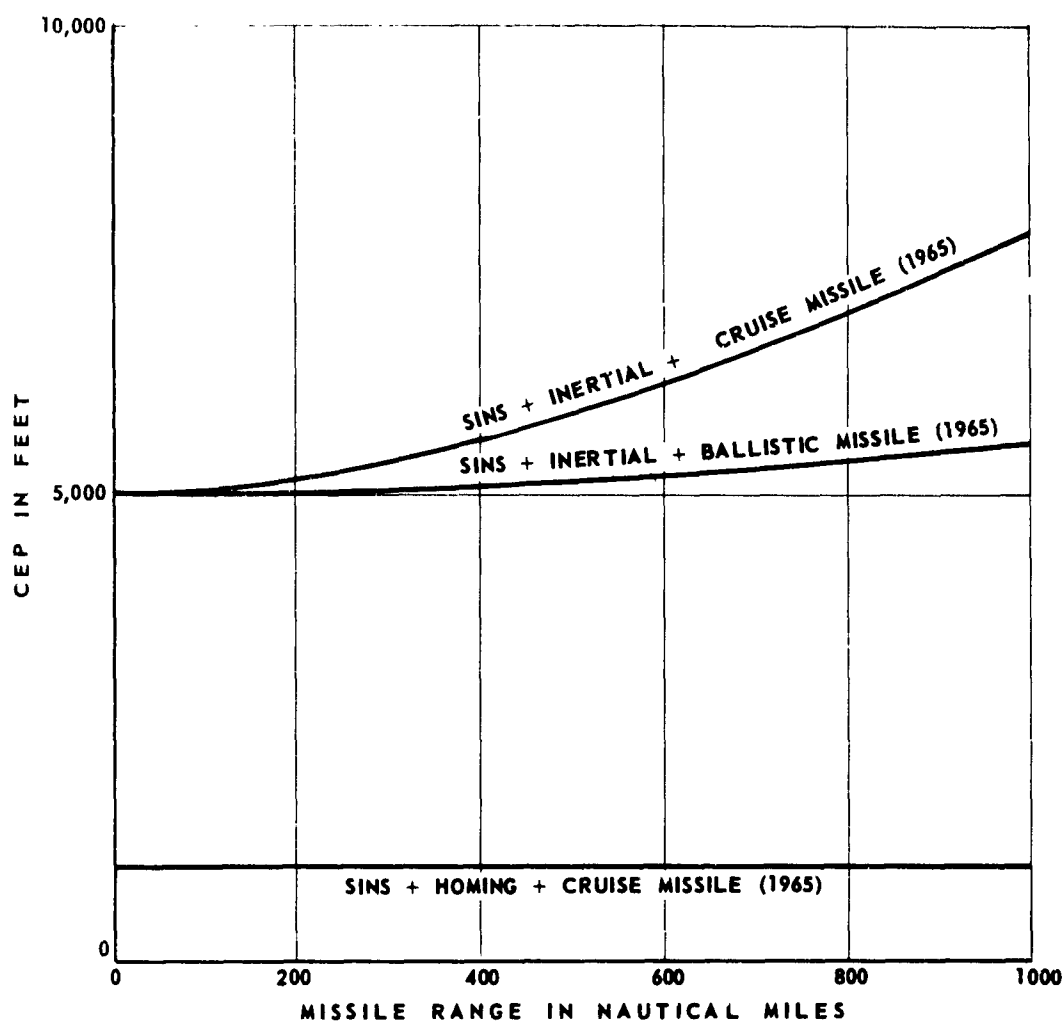


Figure 5-5. Total Error vs Missile Range for "Best" Systems.

Chapter 6
TOTAL WEAPON SYSTEMS

Missiles, submarines, guidance systems, and navigation systems are to be combined with a supporting system to form total weapon systems. This chapter effects the combination and presents the family of possible total systems, which form the basis for this study.

SYSTEM COMPONENTS AND VARIABLES

1. Submarines

The submarines to be included in the total system are discussed in detail in Chapter 4. The variations include:

- Conversions
- New Construction
- Type of Propulsion
- Missile Loading
- Speed
- Navigation System

Navigation systems for the submarine are discussed in Chapter 5.

2. Missiles

The missiles to be included in the total system are discussed in detail in Chapter 3. The variations include:

- Missile Type
- Propellant
- Missile Range
- Warhead Weight
- Guidance System

Guidance systems for the missiles are discussed in Chapter 5.

3. Supporting Systems

The components and interconnections of the supporting systems are shown in Figure 6-1. Most of the system is similar to existing submarine support systems. Differences are due to the introduction of nuclear powerplants and missiles with atomic warheads. These additions do not affect the basic structure of the system but they do require amplification and modification of several of the components. Three major areas of the system which must be considered are:

- a. Logistics
- b. Facilities
- c. Personnel

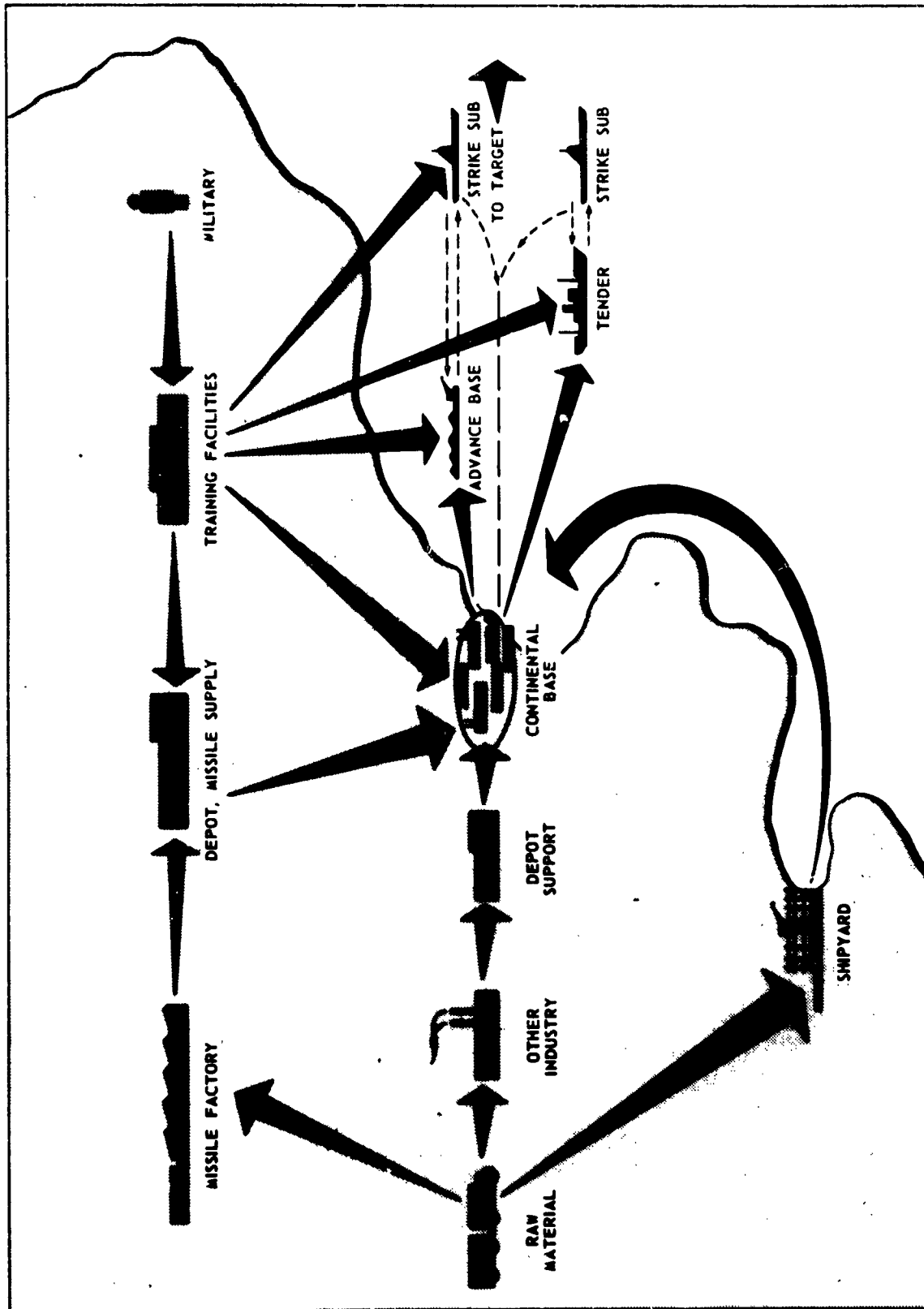


Figure 6-1. Supporting Systems.

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These areas comprise the support of the total systems and are considered fixed items in the study.

a. Logistics

Logistics, in the present Navy organization, relates to the following functions:

- (1) Supply
- (2) Maintenance, Repair and Salvage
- (3) Medical Services
- (4) Personnel Services
- (5) Transportation
- (6) Construction

Supply would be augmented by missiles and those items peculiar to a nuclear submarine.

Maintenance, Repair and Salvage would require major additions in order to service and repair nuclear powerplants and guided missiles.

Medical Services would have to add a health physics unit for preventing and caring for radiation injuries.

Personnel Services would remain unchanged in nature. However, rotation and replacement may have to be stepped up.

Transportation would have to cope with the problems of shipping large missiles and atomic warheads to their various destinations.

Construction would be charged with providing the new repair and maintenance facilities and the new storage facilities for nuclear powerplants, missiles and atomic warheads.

The area of Logistics is one that requires additional study in subsequent phases.

b. Facilities

Facilities, for the purpose of this study, include only:

- (1) Depots
- (2) Continental Bases
- (3) Advanced Bases
- (4) Tenders

Missile factories and shipyards are also part of the total system but are not costed in Chapter 10. No immediate increase over present facilities is considered.

Missile Depots would have to be increased to handle the new missiles.

Continental Bases would be provided with repair facilities for handling nuclear submarines. They would also require storage facilities for missile fuels, decontamination units, etc. No new bases are contemplated.

Advanced bases would also be equipped with facilities for handling nuclear submarines and for servicing and handling guided missiles. Again, only existing bases are considered.

Tenders would have to be modified to service and handle guided missiles and atomic warheads. They would also include missile fuel storage or even fuel generating facilities.

The tender is an important system component in this study. It is assumed in Chapter 9, Force Requirements, that the submarine operates from tenders or advanced bases which are within 1000 miles of the selected missile launch point.

c. Personnel

As the complexity of weapon systems increases, the personnel requirements become more stringent. In addition to the technical proficiencies currently required of submarine crews, two new specialties are required by this weapon system. They are missilemen and nuclear propulsion engineers. Existing facilities for training these specialists are considered adequate. However, technical personnel problems can become very serious and extensive effort should be directed at minimizing the degree of specialization required to successfully operate the system.

FAMILY OF TOTAL WEAPON SYSTEMS

The individual component variations which have been presented in the study thus far are compiled in Figure 6-2. The combination of one of each the parameters included constitute a total weapon system. The total of the possible combinations of the parameters constitute the family of total weapon systems.

1. Force Requirements

The number of submarines and the number of missiles included in any particular total system are determined by the force requirements (see Chapter 9).

2. Feasible Combinations

Of the possible combinations represented by Figure 6-2, not all are considered feasible. Typically, a combination of a fleet conversion boat carrying twenty (20) 1000 mile range ballistic missiles is not feasible. Forty-one feasible total systems are costed in Chapter 10 to provide basic data for the decision charts of Chapter 2.

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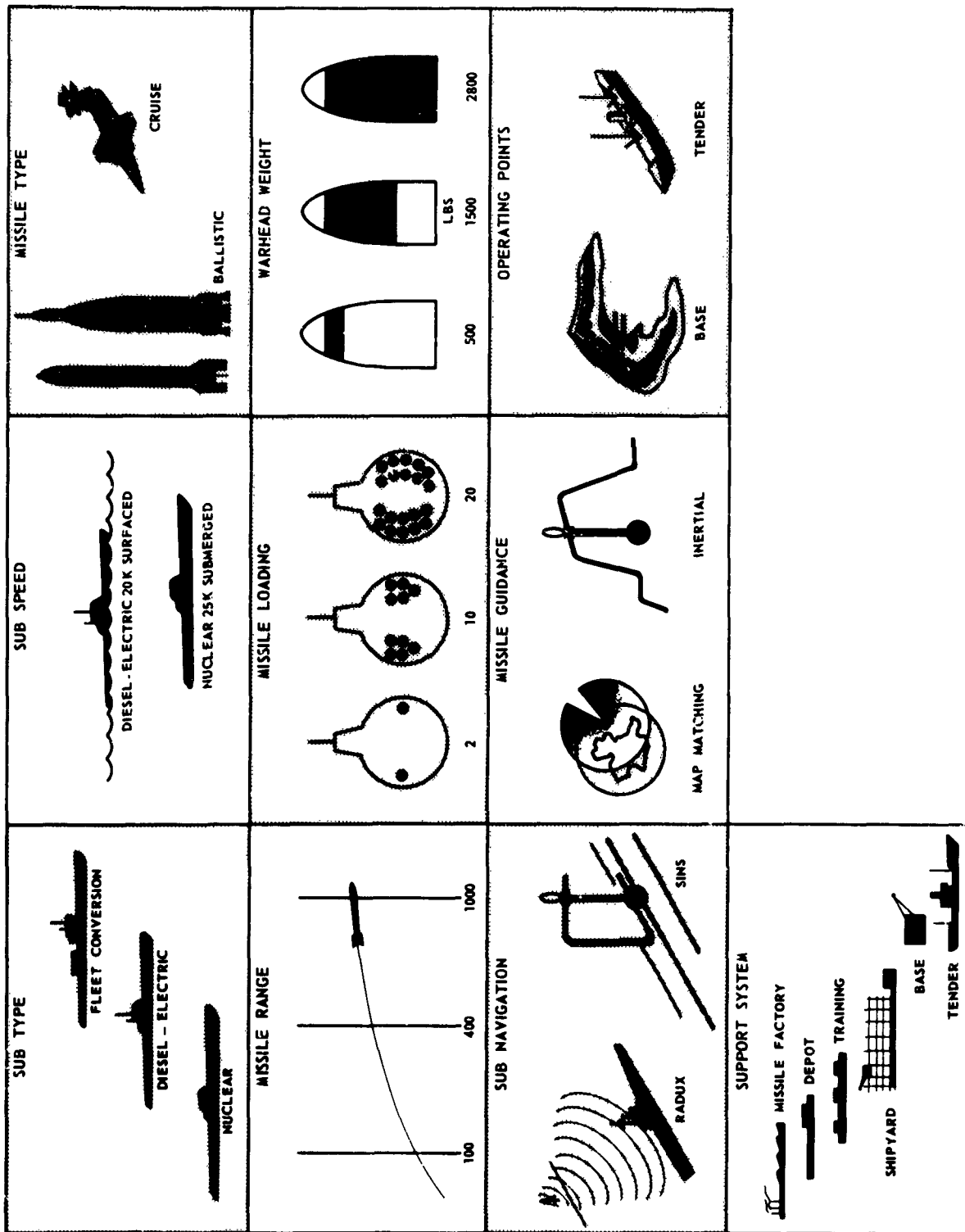


Figure 6-2. Total Systems Parameters.

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THE OPERATIONAL TASK

PART C

Chapter 7
THE TARGET COMPLEX AND ITS DESTRUCTION

In order to provide the weapon system planner with an estimate of the mission utility of the submarine guided missile weapon system, a preliminary analysis has been made of possible missions which might be assigned to this weapon system. The analysis shows that classes of present day targets become available as coastal belt depth increases, how many targets are in each class, and what the warhead yield requirements would be as a function of missile range to destroy or neutralize these targets. The analysis is based on data furnished by the Office of Naval Intelligence for the target areas and belt depths described with respect to the reference "accessible coastline" illustrated in Figure 7-1. Figure 7-2 shows the locations of the coastal belt regions measured from this accessible coastline. These data are described in detail in Part C of Volume II of this report.

In addition, a generalized target model is developed to enable estimation of submarine and missile attrition costs in later chapters.

TARGET CLASS DISTRIBUTIONS AS A FUNCTION OF BELT DEPTH

Figure 7-3 summarizes target distribution data furnished by the Office of Naval Intelligence for the entire Sino-Soviet-Satellite bloc, and Figure 7-4 shows how the target distributions vary for the three bloc components. From this information, targets in 75-, 200-, 500- and 1000-mile coastal belt depths are:

- | | |
|----------------|---|
| 75-mile belt | - Most of the Asiatic naval targets and some of the European (i. e. - ports, bases, shipbuilding and repair). |
| 200-mile belt | - About half of the naval targets (almost all of the naval targets in China and about half of the remaining Chinese targets). |
| 500-mile belt | - Almost all of the Chinese and Satellite targets. About 2/3 of the Russian naval targets and about 1/4 of the Russian quantity targets (airfields, power plants). |
| 1000-mile belt | - Almost all Communist bloc targets except for about 1/3 of an internal target group (aircraft and missile, liquid fuel, atomic energy), almost entirely in Russia. |

NUMBER OF TARGETS AS A FUNCTION OF BELT DEPTH

Figure 7-5 summarizes the numerical data used for Figure 7-3. The numbers of targets may be seen to increase rapidly with belt depth. Figure 7-5 indicates that approximately 100 and 300 targets are reasonably frequent target class and group totals at all belt depths. These two numbers were accordingly chosen as comparison totals for this study. The use of two target numbers also provides a means for intrapolation by the weapon system planner.

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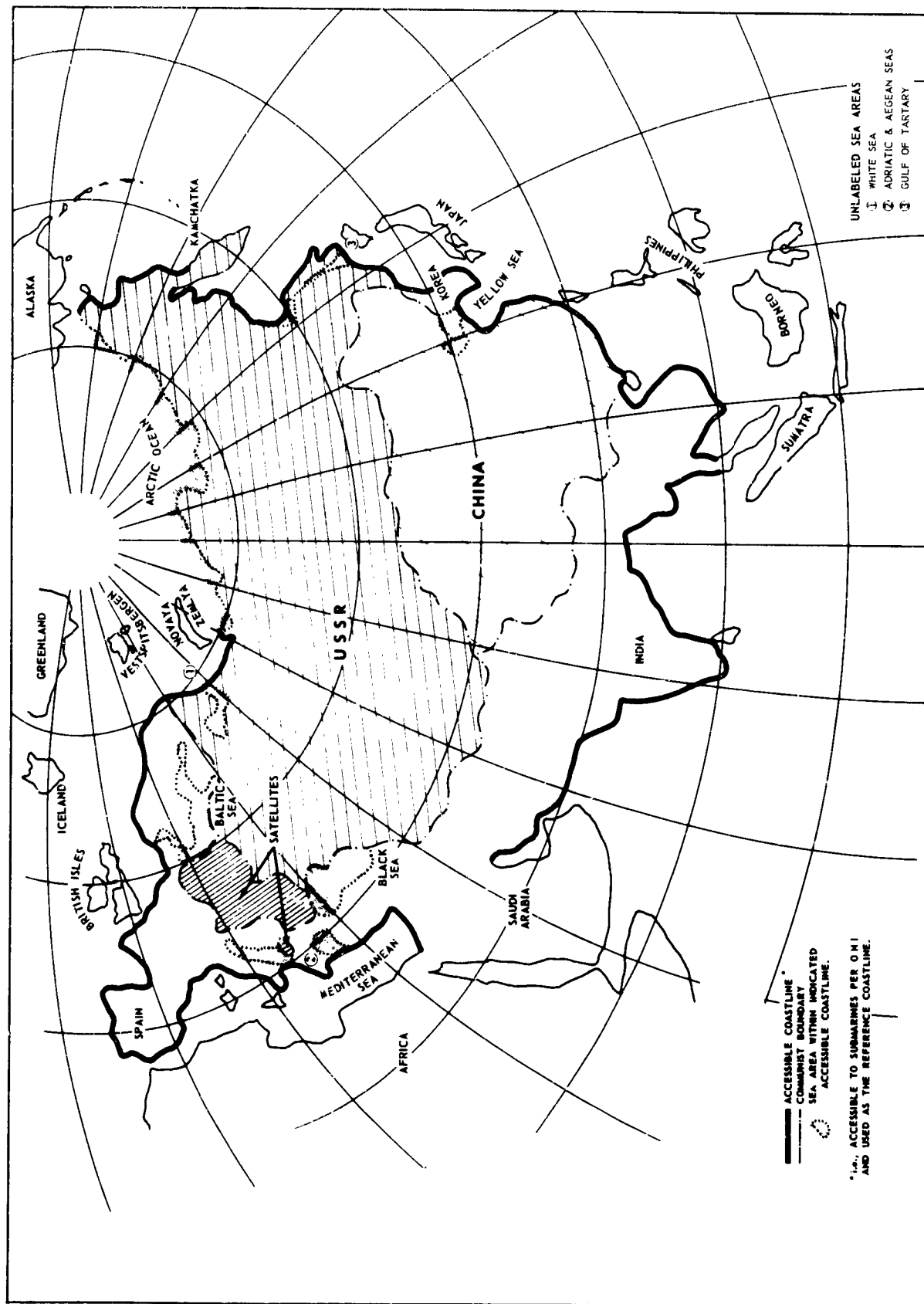


Figure 7-1. Location of Accessible Coastline Around Sino-Soviet-Satellite Bloc.

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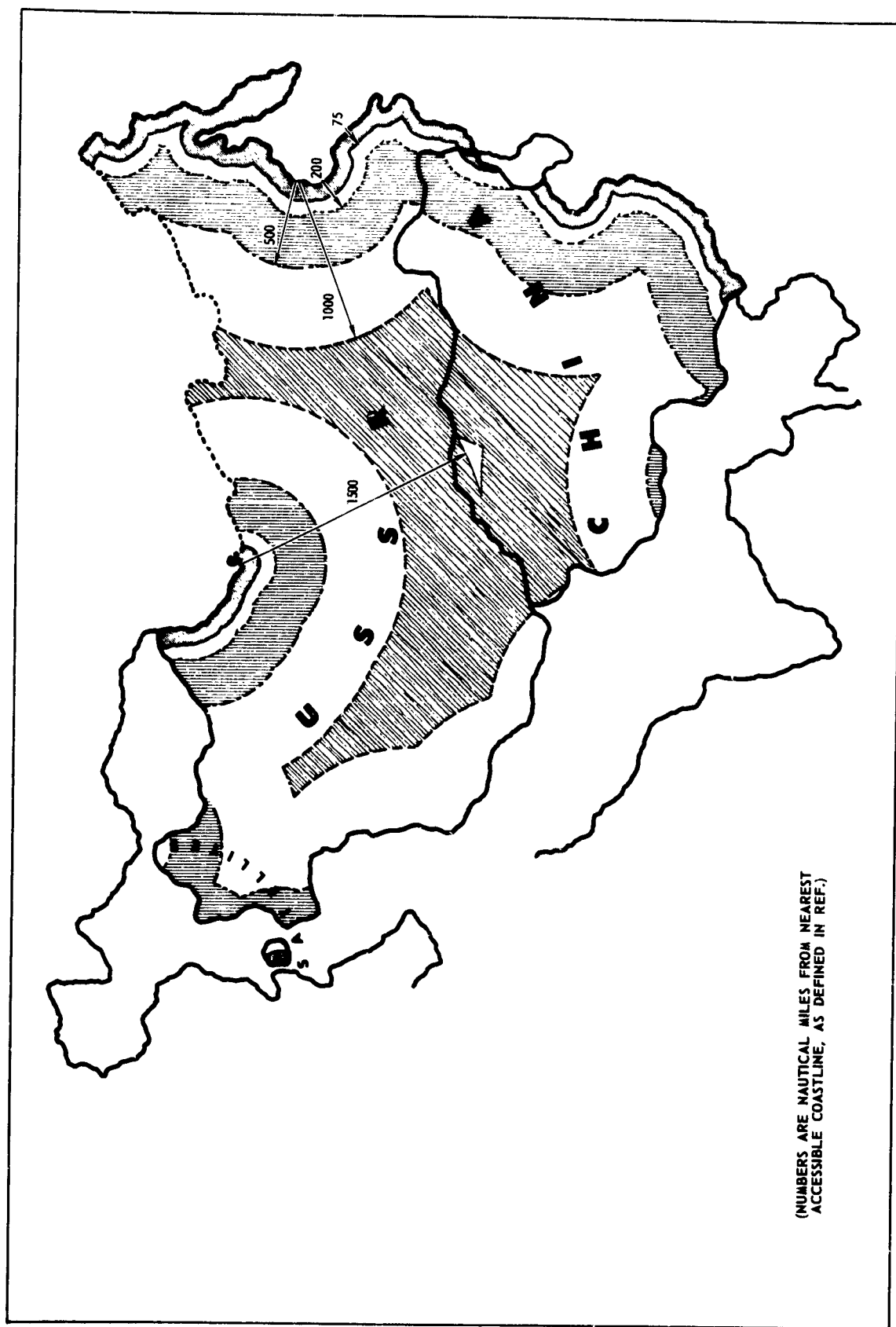


Figure 7-2. Location of Coastal Belt Regions in USSR, China and European Satellites.

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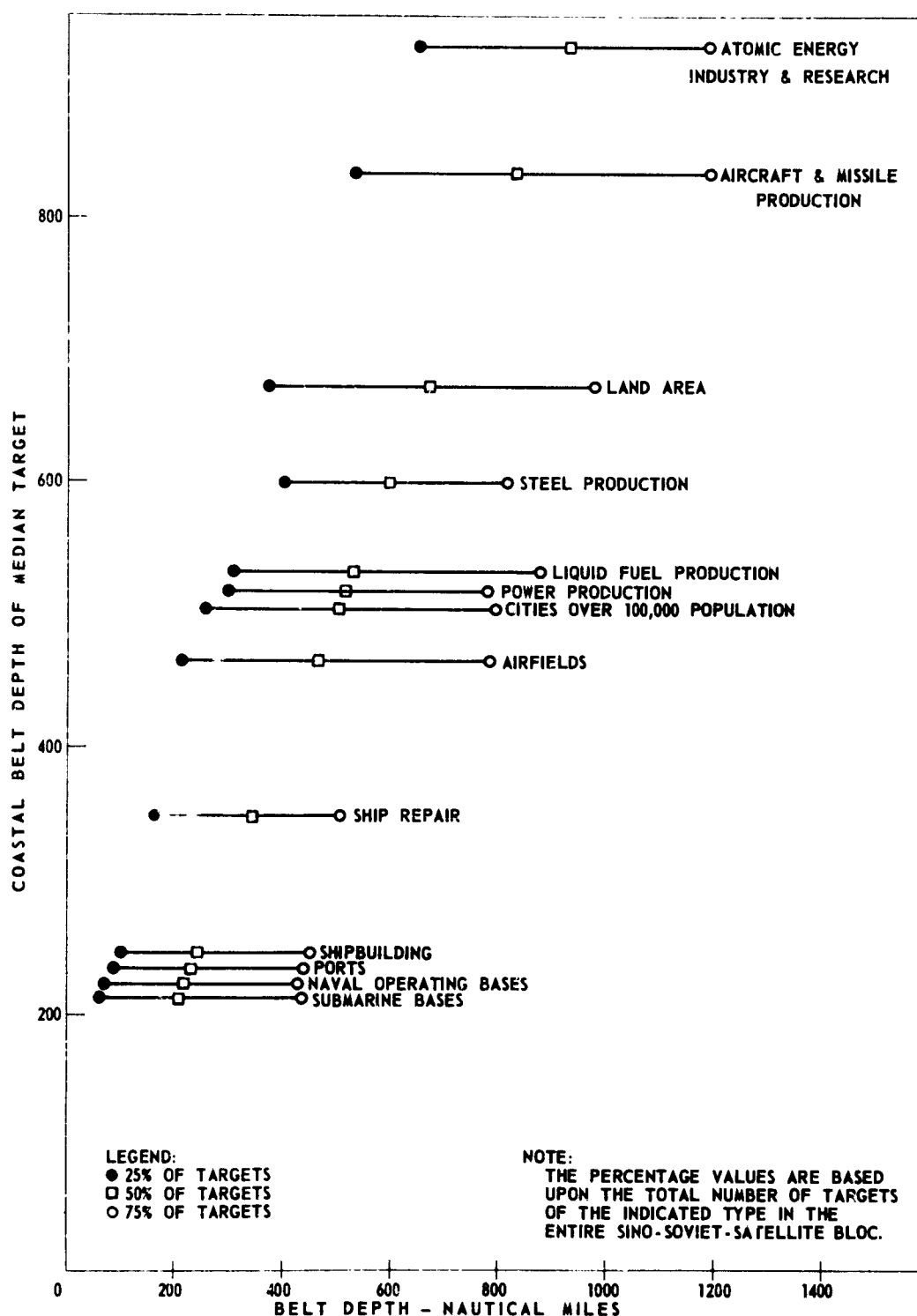


Figure 7-3. Distribution of Several Classes of Targets in Eurasian Coastal Belts.

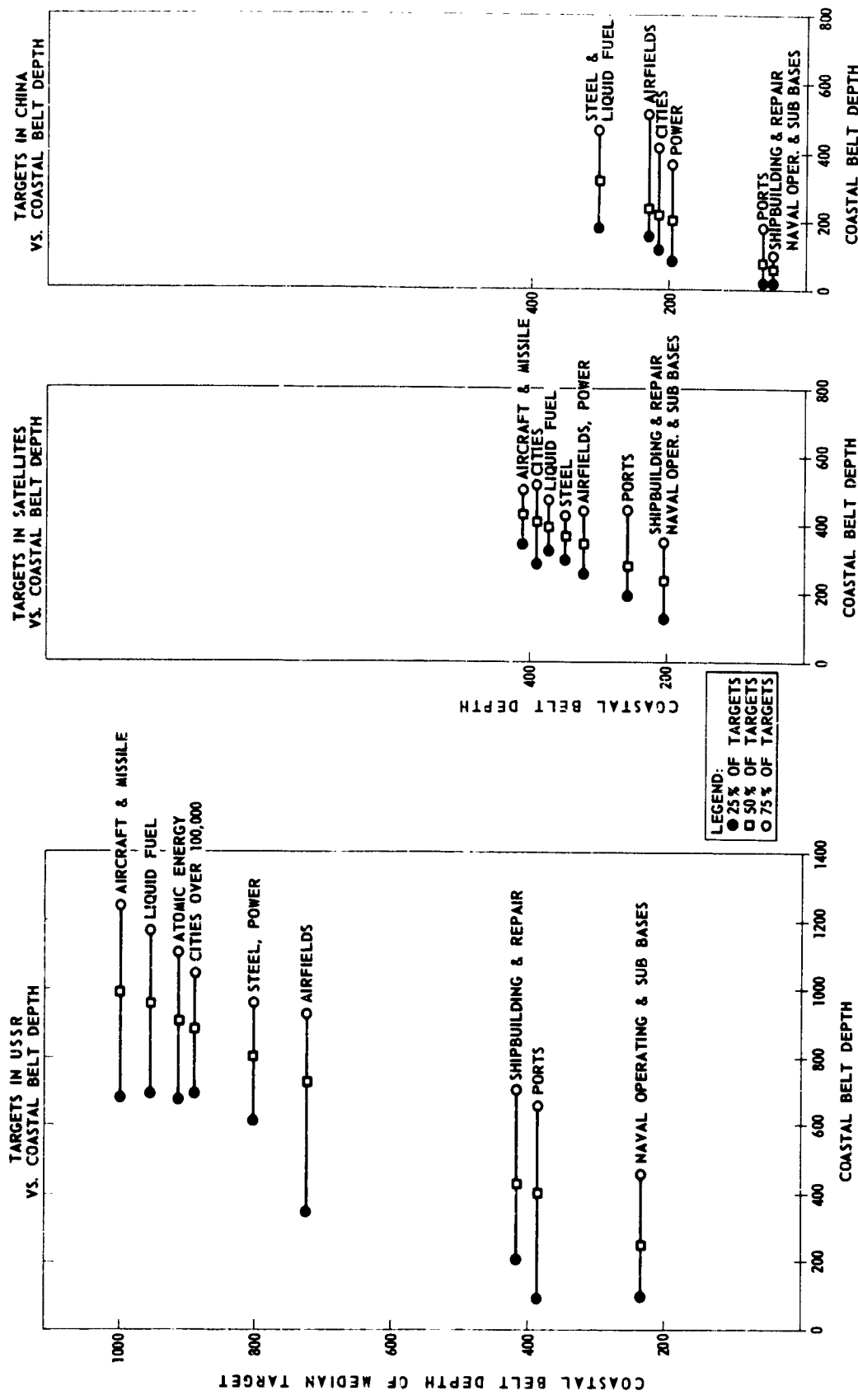


Figure 7-4. Comparison of Target Distributions for USSR, Satellites and China Separately.

COASTAL BELT DEPTH	75	200	500	1000	1600
<u>Naval Target Group</u>					
Naval Operating Bases	7	9	16	20	21
Submarine Bases	13	14	23	29	31
Ship Building	14	20	41	50	53
Ship Repair	3	8	16	24	25
Ports	58	87	130	169	178
Total Outer Group	95	138	226	292	308
<u>Middle Target Group</u>					
Liquid Fuel Product	4	5	57	98	194
Steel Production	4	11	76	170	194
Cities Over 10 ⁵ Pop.	15	42	93	173	200
Total Middle Group	23	58	226	441	520
<u>Inner Target Group</u>					
Aircraft & Missile Prod.	1	1	19	55	89
Atomic Energy Ind. & Rea	0	1	5	28	45
Total Inner Group	1	2	24	83	134
<u>Quantity Target Group</u>					
Airfields	126	199	523	856	978
Power Production	33	82	413	715	817
Total Quantity Group	159	281	936	1571	1795
<u>Total of All Groups</u>					
China Alone	105	195	343	370	410
Satellites Alone	9	83	660	743	743
USSR Alone	164	201	409	1274	1604
Total Communist Bloc	278	479	1412	2387	2757

Figure 7-5. Summary of Target Distributions - Entire Communist Bloc.

WARHEAD YIELD REQUIREMENTS

1. Yield - Target size and Vulnerability - Delivery Error

The major factors involved in determination of the warhead yield requirements are discussed in detail in Volume II, Parts C and D. Figure 7-6 was prepared to illustrate these factors. It may be seen in this figure that large targets (ports, cities) require large yields, even for low delivery errors, and that a one megaton yield will provide a 50% or better destruction probability for all targets, providing the delivery CEP is less than about 6000 feet (the range is from about 50% probability for ports to about 90% for shipbuilding, etc.).

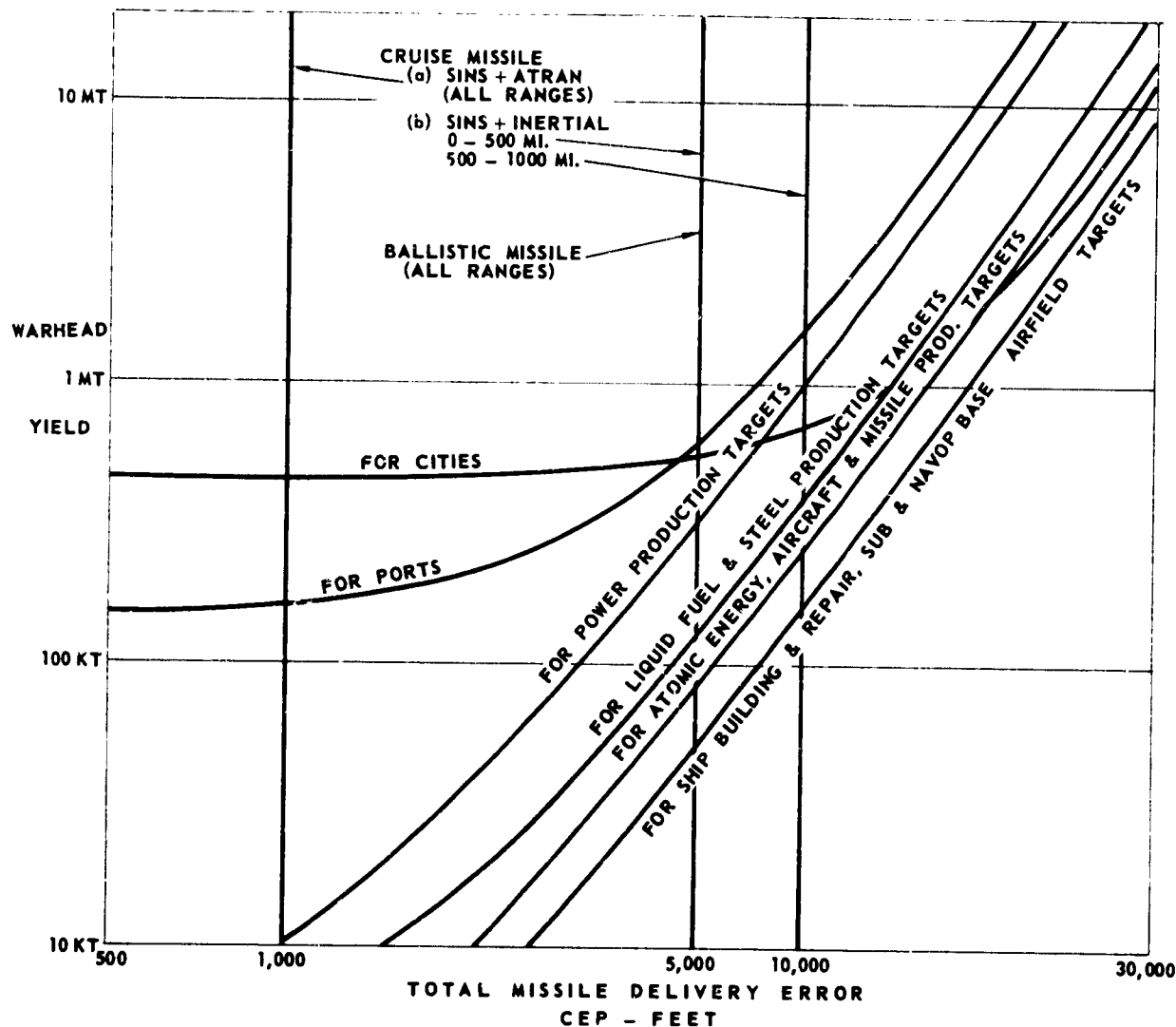


Figure 7-6. Effect of Total Missile Error on Warhead Yield Requirements.

It may also be seen that a 10 kiloton weapon would provide a 50% or higher destruction probability for the smaller targets if the CEP were about 1000 feet. The yield requirements rise so rapidly with increase in CEP, however, that a one-megaton weapon would provide less than 50% destruction probability for any of these targets if the CEP were 3 miles or greater.

2. Yield Requirement as a Function of Missile Range

From Figure 5-5, Chapter 5, the following approximate total missile delivery accuracies are indicated (in terms of circular error probable):

	Missile Range	
	0-500 Mi.	1000 Mi.
Ballistic Missile (SINS + inertial)	5000 ft.	5000 ft.
Cruise Missiles (SINS + inertial)	5000 ft.	7500 ft.
Cruise Missile (SINS + Atran)	1000 ft.	1000 ft.

Figure 7-6 shows these values superimposed on the warhead yield - delivery error curves. Within the accuracy of these calculations, a one-megaton weapon would provide about 50% destruction probability for all targets at both 5000 and 7500 ft. CEP.

The lower three curves of Figure 7-6 describe about half the Communist bloc targets. At 5000 ft. CEP, a 100 kiloton weapon could be considered adequate, while the yield would increase to about 300 kilotons for similar destruction at 7500 ft. CEP.

With the lower error, cruise missile yield requirement is independent of missile range. In this case, however, the maximum required yield applies only to about 10% of the targets, while the remainder can be handled by warheads of 10 kilotons or lower yield. In general, warhead yield requirements are not primarily as dependent upon missile range as they are upon the type of missile guidance.

THE TARGET MODEL

In order to simplify the analysis, each submarine is assumed to operate against a separate group of coastal targets on each trip. This group of targets is arranged within a target area whose depth is the coastal belt depth under discussion and whose length is an arbitrary 1000 miles. The task of the submarine is to approach the coast and then move parallel to it along a path that will permit full coverage of the target rectangle. Figure 7-7 illustrates this simplification.

The possible availability of any target outside the rectangular target area is ignored, as is any scatter of targets within the target area that would permit missile launching further offshore than the indicated possible launching region. Additional submarines are not allowed to cooperate to shorten the path length along the shoreline. It is believed that this model represents a reasonably realistic extreme case that will enable comparison of missiles and submarines for this preliminary study. Volume II, Part C, discusses some alternative target models that might have greater utility for the more detailed Phase II analysis.

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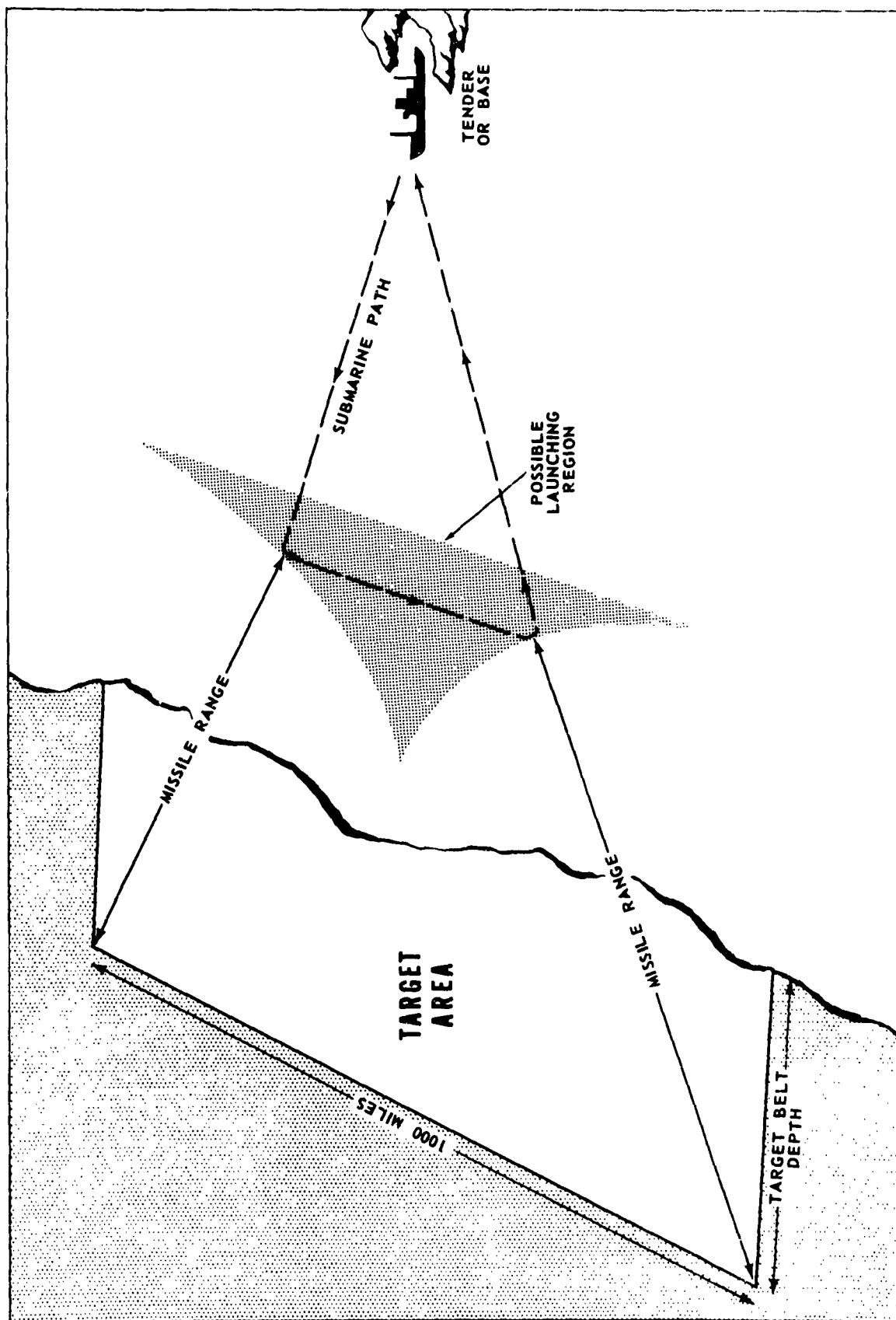


Figure 7-7. The Target Model.

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Chapter 8 ENEMY DEFENSE LEVELS AND CAPABILITIES

There are obvious difficulties in trying to project an enemy's defenses several years into the future in order to estimate his capabilities in defeating a weapon system. However, what an enemy's war philosophy will be, what form his defense will take, and what his defense expenditure will be are questions having bearing on the study. Because of time limitations and TOP SECRET classification of data regarding Russian defense efforts, direct answers to these questions have not been attempted. The pilot study has taken upper and lower defense levels for the enemy based on U.S. effort and technology. Enemy defense capability in missile defense and ASW defense are treated separately. The effect of method of launch is discussed in general terms only.

MISSILE DEFENSE

Time available for detection, tracking and transfer of information would be on the order of minutes for short-range missiles to less than one-half hour in the case of the 1000-mile missiles. This makes automatic defense systems mandatory. Studies are being conducted in this field, but systems of this sort are known to be only in the development stage in the U.S. at this time. During the 1960-70 period it is possible that systems capable of coping with this problem may become available. However, this introduces the measure versus countermeasure problem, a study that will not be undertaken in the pilot study. For purposes of this preliminary study it is assumed that missile attrition due to enemy action is zero.

ENEMY ASW DEFENSE

In defending his shores against a strike by submarines the enemy must keep a large off shore area under constant surveillance and have an antisubmarine attack force in constant readiness. These requirements indicate that any effective defense will be of quite high level. In the present pilot study two levels of defense are postulated and used only to test the sensitivity of the complete strike system to an enemy defense. The low level is about that which the U.S. could muster today with surface ships; and the high level is based upon predictions for U.S. capabilities in 10 years. No claim is made for accuracy of this procedure in predicting the future USSR capabilities. Study was made principally on the detection phase of the defense system, while the localization and kill phases were summarily assumed to have an over-all success probability of 50% pending further study.

Submarines can be detected with underwater sound either by passive listening or by active echo ranging. In either case the submarine has good opportunities for evading detection, for he can run quietly at deep levels, and he can hear active echo ranging

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signals long before the active sound system recognizes an echo from him. Based upon these factors the submarine has at present developed considerable skill in evading detection by sound.

Both passive and active sound systems can either be carried by vehicles for a systematic search operation or installed permanently for a barrier type operation. The ranges of systems vary from a few miles to about a hundred miles. The active sonars during World War II had average ranges of about 1 mile, but have since been increased through new developments up to about 10 miles. Passive listening by submarines is now capable of detecting snorkeling or cavitating submarines up to distances of about 200 miles. Low frequency high power echo ranging from submarines is being developed to operate at ranges up to 100 miles. A complete submarine detection system could comprise aircraft radar and sonar, surface ship radar and sonar, submarine radar and sonar, and permanently installed sonar barriers. The principal payoff of radar search would be in detecting the submarine if he surfaces and in aiding swift attack by aircraft.

The two defense levels postulated for the pilot study are as follows:

LOW LEVEL

Number of Surface Sonar Search Craft	50
Sonar Sweep Width	7 miles
Speed	15 knots
Fixed Sonar Installations	Adequate to prevent submarine from snorkeling longer than 15 minutes.
Radar Search	Adequate to prevent submarine from surfacing or running on the surface.

Added to the low level force are 15 blimps and 25 helicopters with the following capabilities:

HIGH LEVEL

	<u>Blimps</u>	<u>Helicopters</u>
Number of Blimps	15	25
Sonar Sweep Width	13.5 miles	40 miles (all 25 craft)
Speed	50 knots	10 knots

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The defense area is postulated to be variable. Three specific defense zones are chosen as follows to illustrate the method of calculating submarine attrition probabilities:

<u>Length of Coast Miles</u>	<u>Off Shore Extension of Surveillance Area</u>	<u>Total Area Square Miles</u>
1000	100	10^5
1000	200	2×10^5
1000	400	4×10^5

No force levels are assumed for fixed sound surveillance systems and aircraft radar patrols except that they will be adequate to limit snorkeling, and fast running, and to deny the submarine the use of the surface for launching. The skill factor f arises from the submarine's capability of avoiding the detection or kill or both which is thought to be fairly good. If the submarine can avoid q percent possible contacts on himself, then the number of detections of him is $1-q=f$. Here q is assumed to be 97.5% which gives 2.5% for f . This number is not presented as a most probable average based upon the analysis of operational data, but is chosen as a likely average.

Since World War II, ranges of search sonars have increased somewhat because of the use of lower frequencies. OpDevFor¹ reports an average range for the new SQS-5 (XN-1) operating off Key West of 14 kiloyards, which is about twice that of the SQS-4 and about six times that of old QHB. It seems reasonable to assume that such a sonar would give a sweep width of 6 miles average over the oceans, and around 2 miles for poorer than average conditions.

Accurate estimates of Russian Naval forces in 1960 are not forthcoming at this time due to TOP SECRET classification, however, from estimates attributed to Adm. R. B. Carney² the following ASW force could be assembled:

Destroyers	150
Submarines	500
Destroyer Escorts	60
Patrol Vessels	<u>1000</u>
Total	1710 ASW Vessels

The length of coast lines now under control of Russia is about 7000 miles. Added to this by land conquest could be about 5000 more miles, bringing the total possible miles of coast line up to 12,000. Assuming that 1200 of these vessels could be used for ASW purposes, Russia could muster 100 vessels to guard 1000 miles of coast line. Such an even distribution would not be likely, though, and concentration of vessels around certain areas of coast line would probably be made. Fewer than 1200 vessels could in this way be as effective over the entire coast line of 12,000 miles as 1200 would be without concentration.

Based on unconfirmed and unclassified data the assumption of 50 ships on station per 1000 mile coast line does not seem unreasonable.

Notes: ¹ OpDevFor Op S/329/S67 - 1st Interim Report - June 1955
² U. S. News and World Report for September 30, 1955

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SUBMARINE TACTICS

The submarine has potentialities that can enable him to abort all enemy search efforts save those using active sonar, but to do this he will be forced to run at deep levels continuously. This tactic will require him to remain in enemy waters for long periods of time (up to 200 hours) and while deeply submerged he will be cut off from radio and celestial navigation. On the average, a diesel-electric boat will have to rise to periscope levels to recharge about $\frac{1}{2}$ hour every 30 miles, which would put him under threat of surface vessel sonars, and long-range fixed listening installations. He could elude the latter by snorkeling short periods of time (15 minutes or less)³, but he could not avoid increasing his time of exposure to active sonar while running close to the surface. A nuclear or primary battery boat would likely have to rise occasionally for navigational observations and perhaps for changing air in the boat. All in all, it seems that to carry out his mission he would have to degrade his optimum capabilities in a way that would give the enemy some time to find him. In the defense model treatment given below, this would appear in the skill factor, or in the time spent in the area. It is assumed here that the submarine avoids 97.5% of the possible contacts through skillful use of his potentialities such as his ability to hear active sonar signals before the sonar recognizes an echo from him, to disappear below the thermal layer, etc. Indeed, as will be shown later, the individual skill of the submarine in penetrating a high level enemy defense must be high, and will be an important factor for his survival. The importance of this factor suggests that further analysis of operational data which would statistically assess the potentialities of the submarine would be a valuable contribution.

CALCULATIONS OF SUBMARINE DETECTION PROBABILITIES

It is assumed that the enemy forces search the area off the coastal belt in a random manner and that the submarine is equally likely to be anywhere in the area. The probability of being detected at least once under these assumptions is

$$P = 1 - e^{-E}$$

where E is the expected number of contacts. In this model where the submarine must stay for awhile in the enemy surveillance area, his chances of being detected as a function of time are of interest. The expected number of contacts in a time T by N searching ships each having a sweep width Sw and traveling at a speed v is

$$E = A \frac{S_w v}{4} T$$

where A is the area under surveillance. It is within the power of the submarine to avoid some of these contacts because of his ability to hear the pinging sonar at a range greater than the sonar operator hears his echo. If he avoids a fraction q percent of the contacts, the expected number of contacts is reduced by $(1-q) = f$, so that E becomes

$$E = \frac{A S_w v}{4} T f$$

Note: ³ OpDevFor Op/J59/A16-3 Series

The probability of being detected at least once is thus

$$P = 1 - e^{-\frac{NS_w v T f}{A}}$$

This function, showing how the chance of the submarine being detected increases with time, is illustrated in Figure 8-1. Six curves calculated by substituting in the above equation the numbers picked as examples as indicated under Enemy ASW Defense of this chapter. They show that the probability of a submarine being detected can vary through wide limits, depending principally upon the area density of the searching forces, and the duration of the time the boat remains in enemy waters. These curves are used in calculating the launching positions that will give the minimum attrition rates when the missile ranges, target belt depths, and kill probabilities are known or assumed. It must be pointed out that the employments here of the submarine and of the ASW forces are different from employments of the past when the strike targets of the submarine were limited to surface shipping. Historically, the submarine's principal problem was to penetrate a screen which took little time, while the present operation requires the submarine to play hide and seek with ASW forces in a large area over perhaps several hundred hours of time. Further, the sonar ranges will be much longer, and the kill probabilities using nuclear depth bombs will be much higher.

DETECTION DUE TO LAUNCH

Launching of the missile by the submarine is assumed to be done in a manner devised to allow him to keep his secrecy of submergence, and to confuse the enemy's counter action of localizing him. This could be done by launching with a detachable missile carrier which could rise to the surface, or by launching the missile underwater⁴. These techniques have not been developed, nor have they been analyzed in this study. However, the gain for the submarine seems great enough for serious consideration of such techniques. Calculations based on data of detection by air patrol and sonar search and by the sonar detection probabilities given above indicate that with comparable densities of air and surface craft if the submarine surfaces for 10 minutes, his chances of being detected from the air are about equal to those of his being detected by sonar while running submerged for 150 hours. These calculations show that:

Search Craft Density Per square mile	Prob. of Detection	Aircraft Radar Search Time on Surfaced Submarine	Ship Sonar Search Time on Submerged Submarine
		Minutes	Hours
12 x 10 ⁻⁵	.25	10	150
24 x 10 ⁻⁵	.43	10	150

Based on these data, it is assumed that the submarine weapon system of 1960-1970 will not surface to launch.

Note: ⁴ University Michigan Aero. Research Center — Project Wizard Report
No. UMM-46

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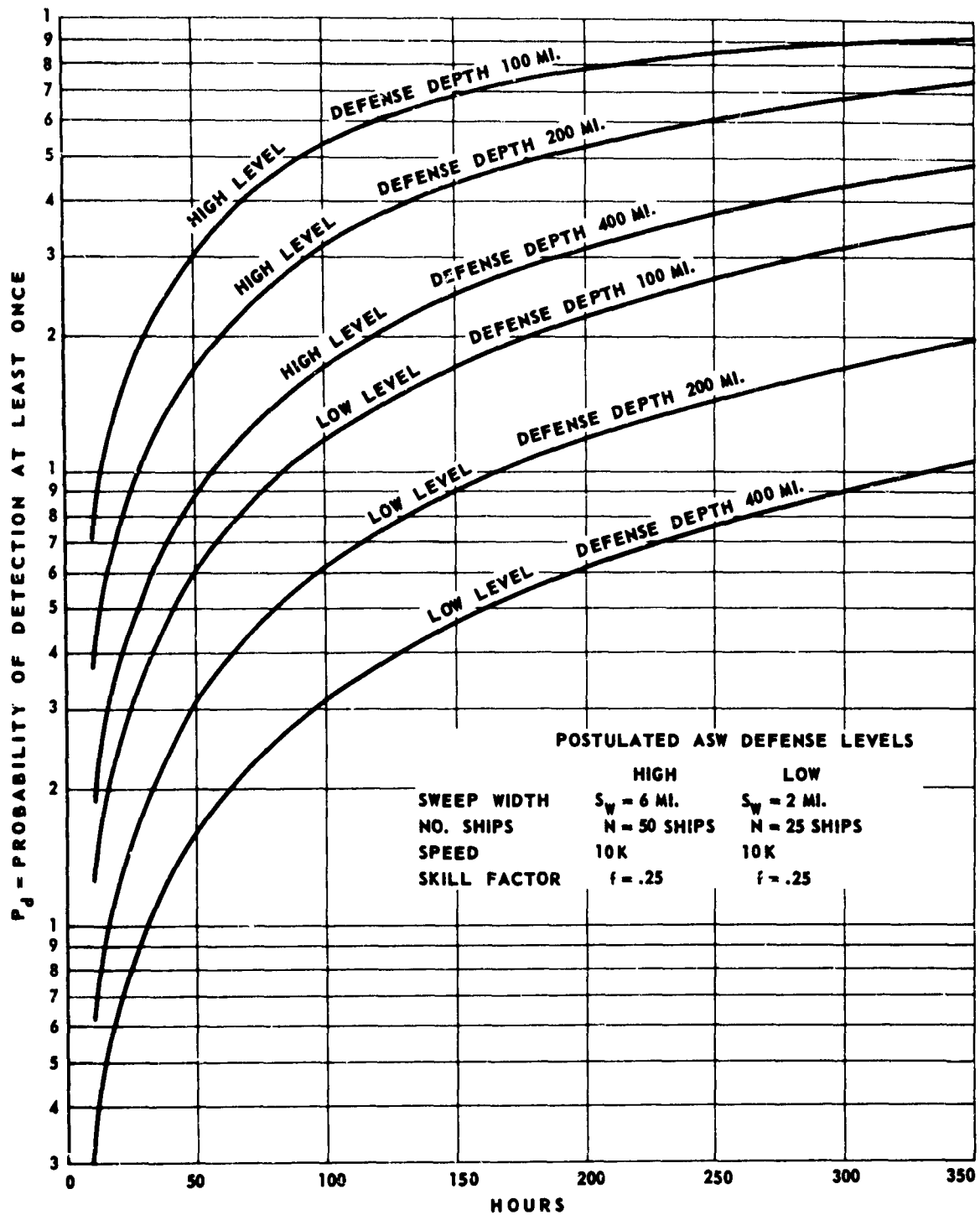


Figure 8-1. Probability of Detection vs Various ASW Defense Levels

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CRITIQUE OF THE POSTULATED ENEMY DEFENSE

The detection model used here postulates a random search by surface vessels for a submarine equally likely to be at any point within the searched area. In addition the submarine is allowed to play a game at avoiding detection based upon three things that he can use to his advantage: One, the ranges of present day sonars are very short compared to the distances between random searching ships; two, the submarine can detect the searchers long before he is detected by the searchers; and three, his speed of movement can be about the same as that of his adversaries. Thus, he has many areas where he can hide, he is amply warned of the threat, and he has the ability to move into safe areas before he is detected. Operational data on his chances of winning at this game are not available, though it is felt that they are very high. With the assumed high defense level employing 90 vehicles searching an area 1000 by 400 miles only about 4000 square miles are covered at any one time which leaves 396,000 square miles for hiding. He can even increase this area by using depth below the thermal layer. However, if he is to carry out a mission under enemy threat, he cannot spend all of his time playing the game of avoidance but must expose himself to detection sometimes. If, for example, the boat is powered by nuclear engines, or primary batteries, he will probably have to rise to shallow levels to take bearings and to launch. If it is diesel powered he must in addition travel at periscope depth some 10% to 15% of his time, which at 6 knots would put him up for $\frac{1}{2}$ hour for every 30 miles. Continuous deep running would probably degrade his navigational accuracy to such an extent that making his entire transit at the lower levels would not be feasible. Fast running, which he must do at every encounter with a surface ship to get out of the way, increases his chances of being picked up by passive sonar. It appears therefore, that an analysis of this game would give the submarine a very high probability of avoiding his enemy, but not 100%. The assumed value of 97.5% satisfies in magnitude this estimate, and still gives the searching forces some chance of finding him.

ANTISUBMARINE GROWTH POTENTIAL

As the submarine's great potentialities for stealth depend in a large part upon the huge areas he has available for hiding, ASW efforts aimed at taking from him these areas would strike directly at his skill. To do this with present sonar ranges, densities of searching vehicles would be beyond the capabilities of any country to support. Ranges must be appreciably increased. Progress toward this end is being made with active sonar developments in the 700 cycle region and with passive in the very low frequency region 20 to 500 cycles. The LORAD system mounted on a submarine is reporting echos from submarines at ranges of 30 miles in deep water and the prospects for increasing the range to 90 miles are reported good. It is conceivable that a screen of five LORAD equipped submarines spaced 100 miles apart and running abreast parallel to the coastline could sweep out a 500 mile strip fast enough to catch any submarine that had ventured 50 miles or so within the defense zone. For shallow water a huge transducer 40 by 100 feet that will handle a million watts of power is being developed which may get submarine echos at ranges up to 150 miles. Thirty such systems could keep an area of 750,000 square miles under continuous surveillance. The cost of the system would be high, about 100 million dollars, which still isn't completely unfeasible.

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Passive listening is being developed to detect noises that the submarine cannot silence such as shaft squeaks, hull vibration, hull cavitations, gear noises, etc. The complete silencing of a piece of machinery as large as a submarine is extremely difficult. It is possible that large arrays of passive hydrophones can be laid on the bottom which the submarine can never avoid either by going around or by achieving a noise level too low for them to detect.

Listed below are systems now under active development which in 10 years could be available for an ASW defense system:

1. Long-range low frequency active sonar (700 cps)
 - Fixed Installations
 - Submarine Platforms
 - Surface Ship Platforms
2. Long-range low frequency listening (100 to 1000 cps)
 - Fixed Installations
 - Submarine Platforms
 - Surface Ship Platforms
3. Medium-range towed sonar (10 kc)
 - Blimp Towed
 - Helicopter Towed
 - Surface Ship Towed
4. Helicopter Sweep Search

In Figure 8-2 are listed estimated performance parameters of these systems. In all cases the numbers are believed to be reasonable. The search rates vary between 48 and 5600 square miles per hour, this latter figure being predicated on the theoretical feasibility of an 800 kiloyard blimp-towed sonar.

Vehicle	Sonar	Av. Lateral Range K. Y.	Sweep Width (Est.) Miles	Speed Knots	Search Rate Sq. Mi. Per. Hr.	References and Remarks
DD's	SQS-5	15	10	15	150	OpDevFor OP/S329/867- Fairly reliable operational data.
Submarines	SQS-5	15	10	15	150	Assuming SQS-5 is put on submarine.
	BQR-4	40 Deep Water	40	3	120	Passive-Detects Snorkel only. Submarine must run slow to keep down self-noise.
		16 Shallow Water	16	3	48	
	LORAD	60	120	5	1100	Sweep width degraded due to low estimated probability of detection.
Helicopters	AQS-4	24	12	9	108	10 helicopters or 12 mi. front moving at 9 knots OEG Study 486.
Blimps	AQS-3	2.0	2	25	50	Low search rate due to short range reported. Ref. O. R. L. Penn State Serial 7958-227.
Theoretical Optimum Blimp-Sonar Performance		80	80	70	5600	Extremely optimistic Ref. Goodyear GER 4844.
Conservative Guess above		40	40	50	2000	Due to high speed and long range. May be realized in deep water.
Fixed Installations	LORAD					Range 100 Mi. in deep water.
Project Collusus						Range 100 Mi. in shallow water.

Figure 8-2. Area Search Rates for DD's, Submarines, Helicopters and Blimps.

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Chapter 9 FORCE REQUIREMENTS

The weapon system is defined in Chapter 6. Its limitations and capabilities in terms of total error are described in Chapter 5. The target and defense models are defined by Chapters 7 and 8 respectively. Force requirements can now be estimated which, in conjunction with total system cost, Chapter 10, will form the basis for Decision Charts II as will be shown in Chapter 12. Specifically, this chapter will estimate how many submarines and missiles of each paired combination of submarine and missile are required in the weapon system to give it the capability of destroying a selected number of targets in a given time. Steps in the determination of force requirements are shown in Figure 9-1. A fuller development of these steps is given in this chapter. End results are also included, but detailed calculations and additional intermediate steps are contained in Volume II, Part E.

FORCE REQUIREMENT EQUATIONS

Figure 9-2 is a functional sketch of the submarine and missile operations cycle. Numbers of submarines and missiles associated with the first trip are indicated, where

N = Initial number of submarines in the weapon system

η_s = Probability of submarine attrition per trip

η_a = Submarine utilization factor, fraction of submarines in weapon system available in forward area

η_T = Probability of successful missile prelaunch test

η_m = Probability of successful missile delivery after successful prelaunch test

t = Number of trips

T_t = Cumulative number of targets destroyed after t trips

M_t = Total number of missiles in weapon system

M = Number of missiles expended during t trips

M_{Fired} = Missiles fired during t trips

M_{Lost} = Missiles lost due to attrited submarine during t trips

L = Number of missiles carried per submarine per trip

A general relationship between N - number of submarines in the weapon system; T_t - targets hit; and M - missiles fired in t trip, has been derived, Volume II, Part E, on the assumption that only one missile is fired on each target, Chapter 1. It is also assumed that it is equally likely that submarine attrition occurs at any time during the trip (or that on the average the attrited submarine fires half of its missiles before being attrited). The resulting equations are:

$$N = \frac{T_t}{\eta_a \eta_m \eta_T L (1 - \frac{\eta_s}{2})} \quad (9-1)$$

where $\phi = [1 + (1 - \eta_s \eta_a) + (1 - \eta_s \eta_a)^2 + \dots + (1 - \eta_s \eta_a)^{t-1}]$

$$\text{and } M = \frac{T_t \left[\eta_T \left(1 - \frac{\eta_s}{2} \right) + \frac{\eta_s}{2} \right]}{\eta_m \eta_T \left(1 - \frac{\eta_s}{2} \right)} \quad (9-2)$$

Values for the submarine utilization factor η_a , and the missile reliability factors, η_T and η_m , will be estimated. Parametric values of T_t targets hit, and L missile loading will be chosen. However, values for η_s , the probability of submarine attrition per trip depend on submarine tactics and missile range. A trip model will be developed reflecting submarine tactics. Based on this trip model, η_s will be expressed in terms of missile range R_M for use in evaluating equation (9-1).

1. Submarine Utilization Factor

The fraction of submarines available in the forward area, η_a , has been estimated^{1 2} as having possible values from .3 to as high as .9. This factor is a function of the amount of advance notice of impending action, the length of the operation, and may vary with submarine type. If it were assumed that a portion of the force would be required continuously on station it could be expected that about 1/3 of the N submarines in the system would be available for the mission at any time. However, with the opening of hostilities this factor might be expected to be increased through curtailment of routine training, maintenance and overhaul. If, on the other hand, sufficient advance notice could be had as to when to ready the task force for hostilities, the initial availability might be as high as .9. This value would fall off as mechanical or other limitations occur and replacement submarines were not available. For the present study it is assumed that a constant value of .6 represents a reasonable value that could be attained with some alert and one that could be maintained for any type of submarine for a period of approximately six months.

2. Missile Reliability

Missile reliability factors, η_T and η_m , are chosen as in Chapter 3 to have values of .9 and .8 respectively.

3. Number of Targets

Number of targets, T_t , will be carried parametrically to show the requirements for destroying 100 or 300 targets respectively.

4. Missile Loading

Missile loading, L , will be carried parametrically as 2 and 20 missiles per boat.

THE TRIP MODEL

The target model of Chapter 7 is used to set the requirement of total coverage capability for belt depths of 0, 200 and 500 miles, and a belt length of 1000 miles per submarine. Operating off this target model on a track giving total coverage capability

Notes: ¹ ComSubRon 5
² ComSubPac Planning Officer

METHOD USED IN DETERMINATION OF FORCE REQUIREMENTS

FIG. 9-1

STEPS	RESULTS	STEPS	RESULTS
1	Express force requirements to hit a selected number of targets as a function of submarine attrition and number of trips, missile loading, submarine availability, and missile reliability.	5	Using the results of Steps 1 and 4 express force requirements as a function of missile range for the various belt depths and selected numbers of trips. Missile loading, submarine availability and missile reliability are held constant.
2	Set up a trip model describing possible submarine tracks within the defense zone for attacking targets in various belt depths and using different missile range capabilities.	6	Select the missile range on the basis of minimum weapon system cost for two cases: a. Hitting all targets in one trip. (instantaneous campaign) b. Hitting all targets in a given time. (campaign duration 1 or 2 months)
3	Select track for each missile range and belt depth giving minimum time in the defense zone. Express minimum time in the defense zone as a function of missile range and target belt depth.	7	Having selected the missile range in Step 6 for a given campaign duration and using these ranges in combination with the results of Step 5, express force requirements as a function of belt depth for the instantaneous (1 trip), 1 month and 2 months campaign.
4	Using the attrition curves of Chapter 8, convert time in the defense zone to attrition probability per trip as a function of missile range and belt depth.		NOTES Steps 3 through 7 are repeated for all combinations of submarine and missile and high and low defense levels. Several intermediate steps have been omitted for clarity. These steps are included in text.

Figure 9-1. Method Used in Determination of Force Requirements.

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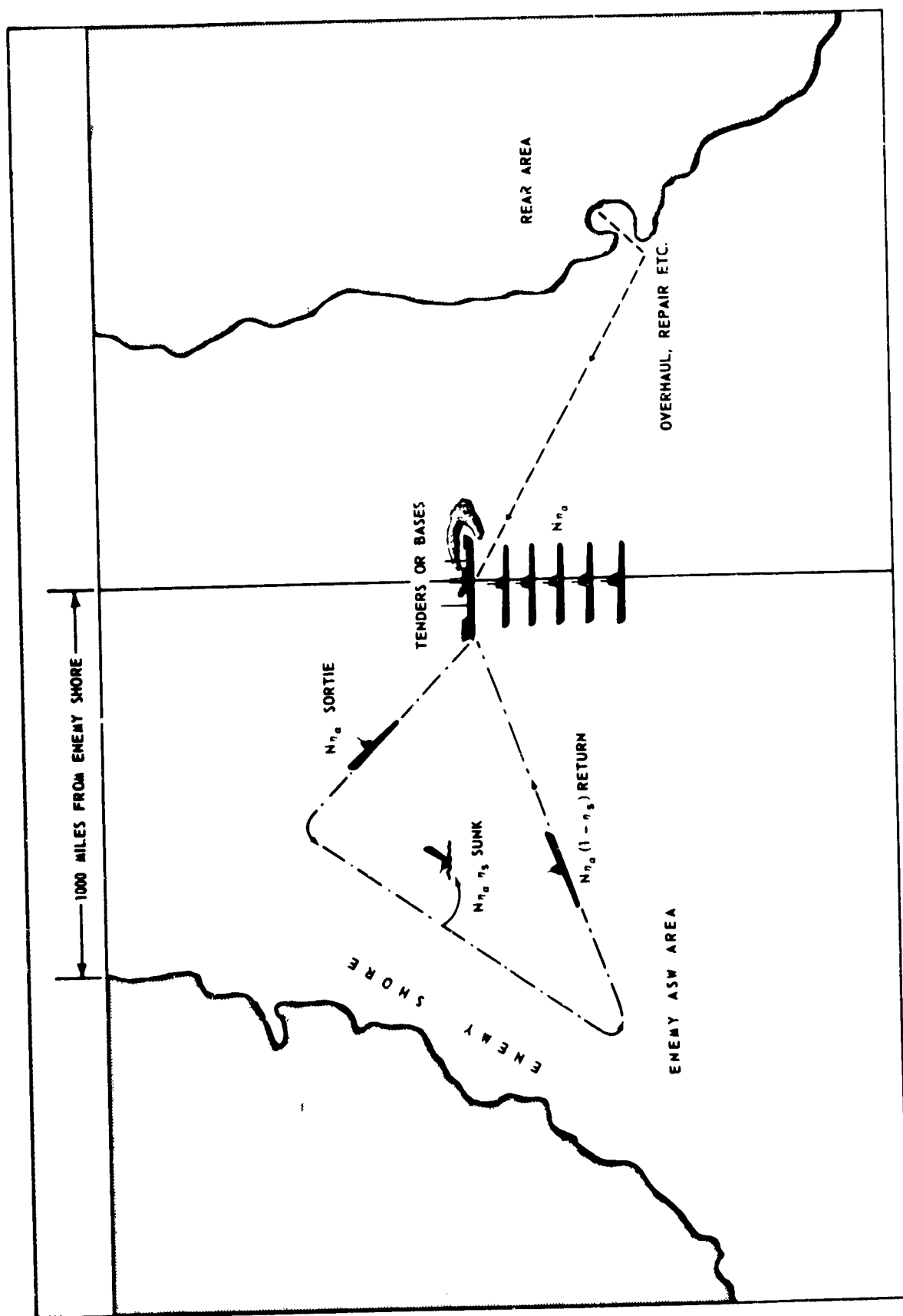


Figure 9-2a. Operations Cycle - Submarine.

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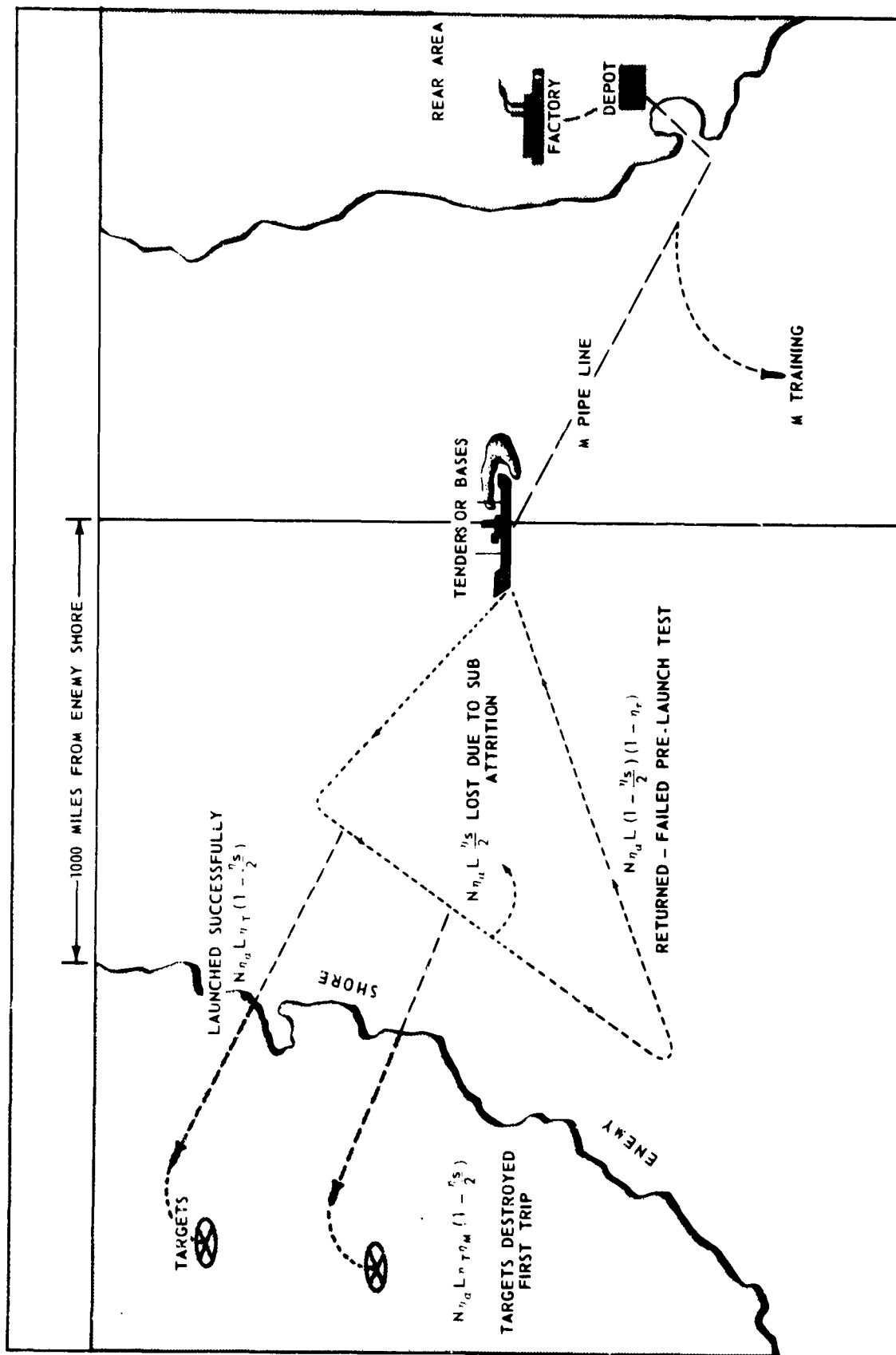


Figure 9-2b. Operations Cycle - Missile.

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of the target area places the submarine in the defended area for varying lengths of time depending on submarine speed, length of the delivery line, and depth of penetration of enemy defenses. Possible tracks of the submarine operations off the target and between the target area and the tender or base are shown in Figure 9-3. The location of the tender 1000 miles from the enemy coast should not be viewed as the optimum location. This distance was only chosen as a reasonable first trial location. Other trip models should be tested to indicate sensitivity of weapon system to trip model.

MINIMIZING TIME IN THE DEFENSE ZONE

Referring to Figure 9-2, it is assumed that the submarine will choose a track that will permit him to remain for the shortest time in the defended area. The average speed the submarine could use would be determined by its own speed capability and the enemy environment. Figure 9-4 shows the assumed speeds:

Submarine Type	Average Speed in Active ASW Areas	Average Speed in Passive ASW Area	Maximum Sustained Speed
Diesel-Electric	5 knots	(see Note)	20 knots
Nuclear	15 knots	5 knots	20 knots

Figure 9-4. Submarine Speeds in Active and Passive ASW Areas.

Note

With a fixed long-range frequency passive ASW installation, it is expected that the detection probability of the snorkeling submarine would be quite high. Hence, the diesel-electric submarine is assumed to remain outside of this defense area.

Time in the area is minimized considering both length of track and speed along track. The various possible tracks have been plotted and the times computed for each track, Volume II, Part E. The resulting minimum time tracks are assumed to be the ones the submarine would use. These minimum times are then plotted against their associated missile ranges for each belt depth. Figure 9-5 is an example of these plots.

SUBMARINE ATTRITION AS A FUNCTION OF MISSILE RANGE

Having determined the time in the defense zone as a function of missile range, attrition probability, η_g , for each type of submarine is then computed by cross plotting Figure 9-5 and Figure 8-1 from Chapter 8. An example of the resulting plots of submarine attrition probability as a function of target belt depth and missile range is shown in Figure 9-6.

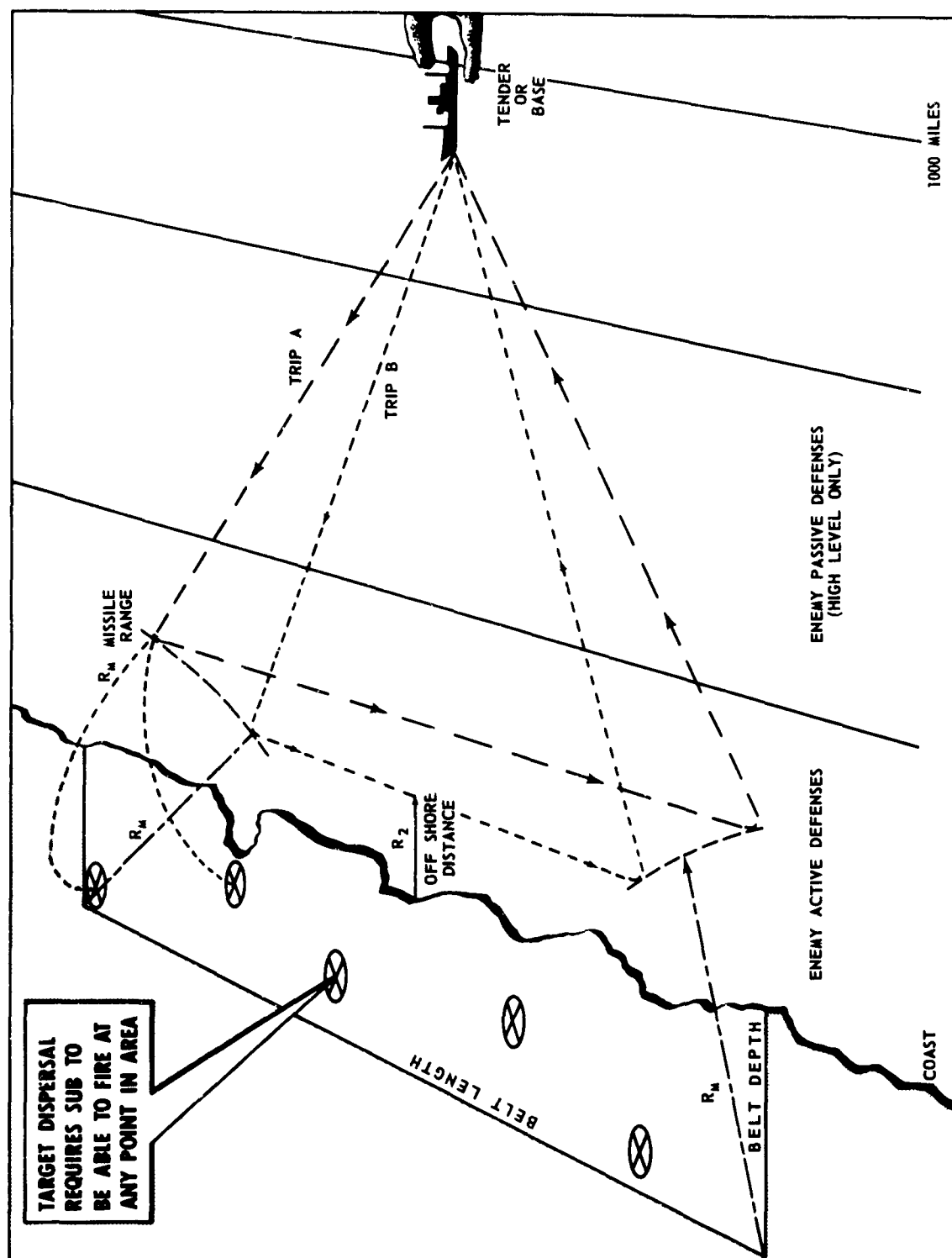


Figure 9-3. Trip Model.

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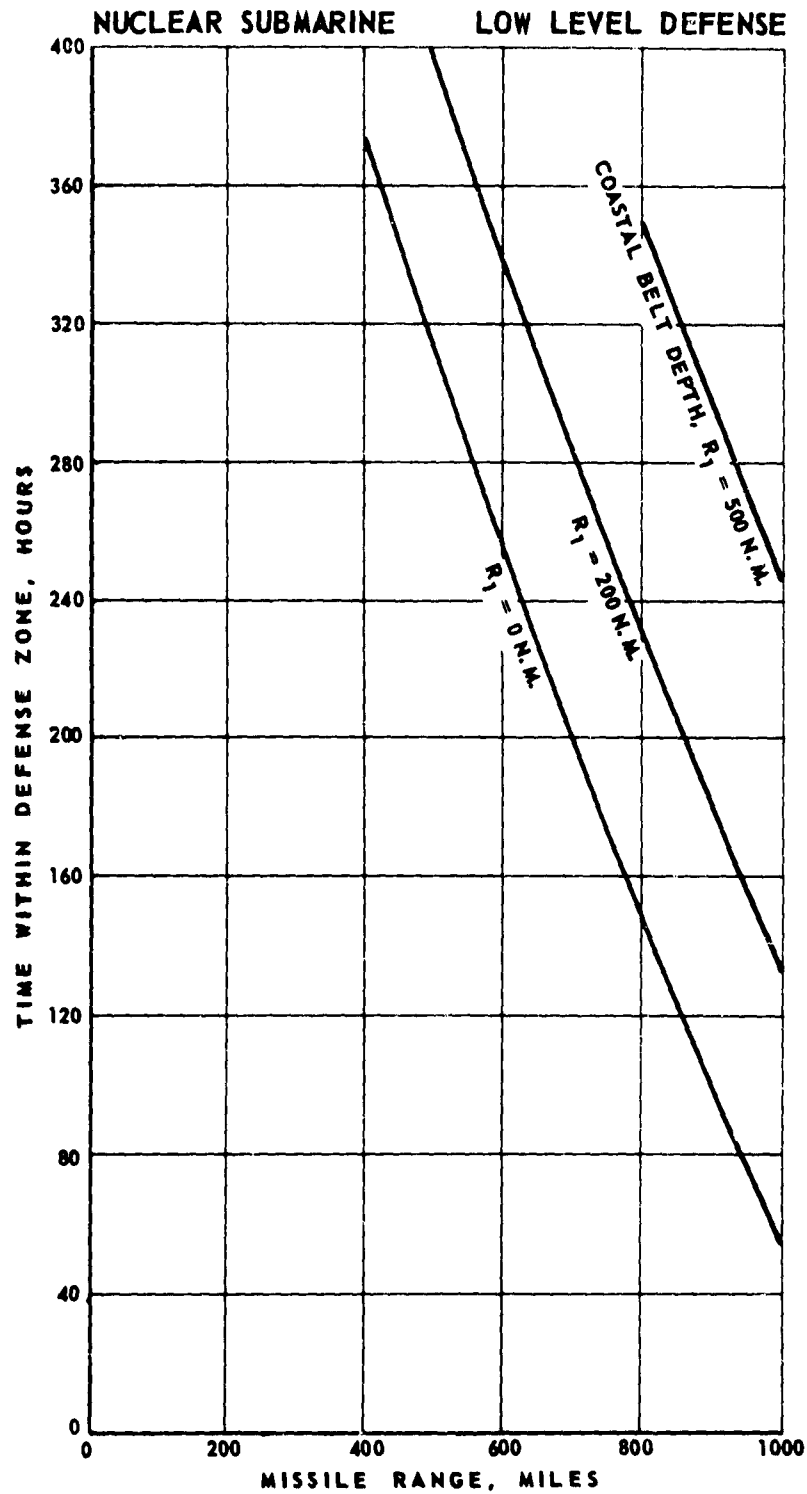


Figure 9-5. Time Within Defense Zone vs Missile Range.

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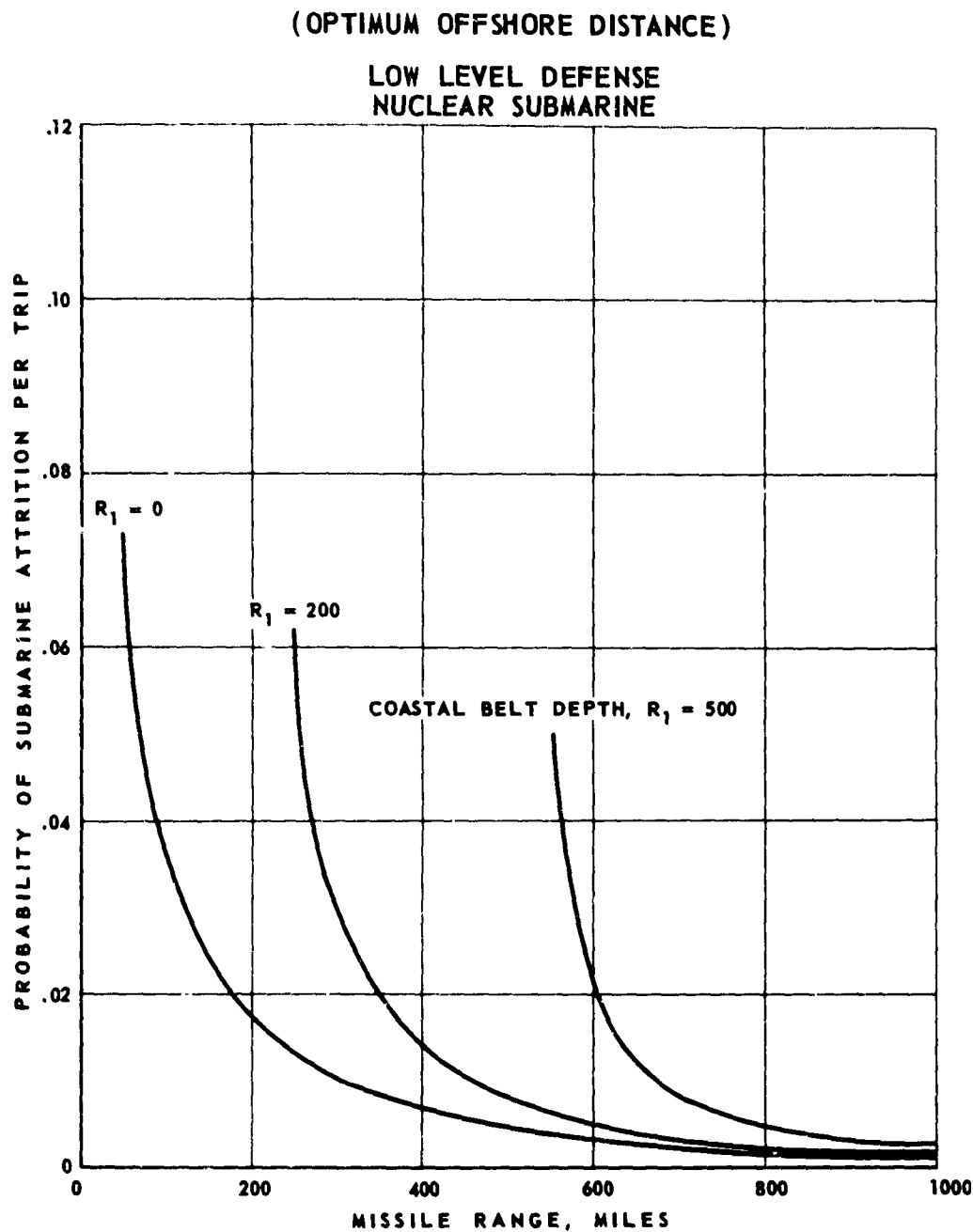


Figure 9-6. Probability of Submarine Attrition Per Trip vs Missile Range.

FORCE REQUIREMENTS AS A FUNCTION OF MISSILE RANGE

Using the estimated values of the other factors of equation (9-1), submarine force requirements per target hit are first plotted as a function of submarine attrition for 1, 5, and 10 trips. Figure 9-7 shows examples of these plots. Combining Figures 9-6 and 9-7 gives submarine force requirements per target as a function of missile range. A typical case is shown in Figure 9-8. Force requirements for the selected number of targets are obtained by multiplying submarine requirements per target by the number of targets it is desired to hit.

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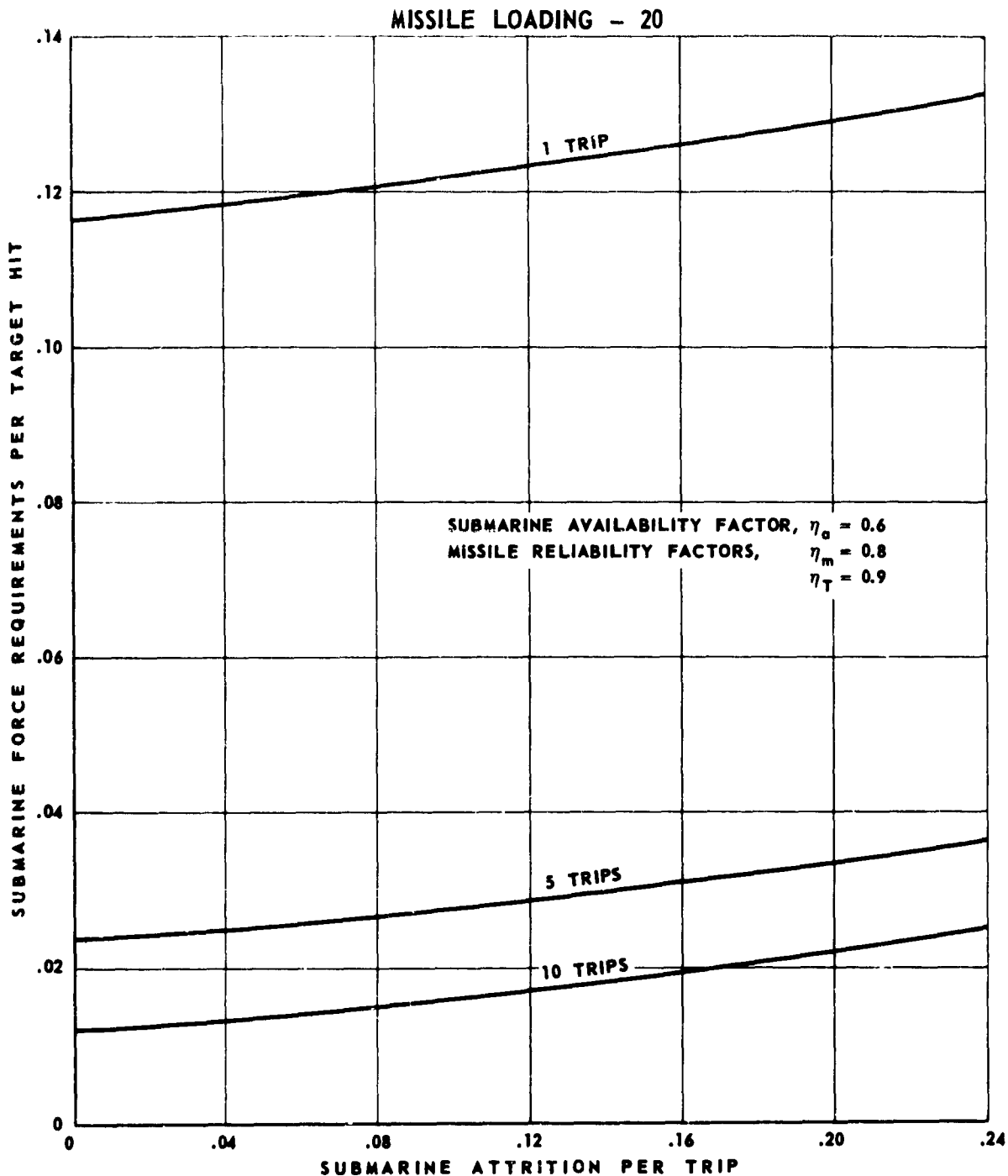


Figure 9-7. Submarine Force Requirements Per Target Hit vs Submarine Attrition Per Trip.

SELECTING THE MISSILE RANGE

The desired length of the campaign is left to the decision of weapon system planners. Force requirements to hit a selected number of targets will be shown for a one (1) trip campaign (essentially instantaneous) and for one (1) and two (2) month campaign. For

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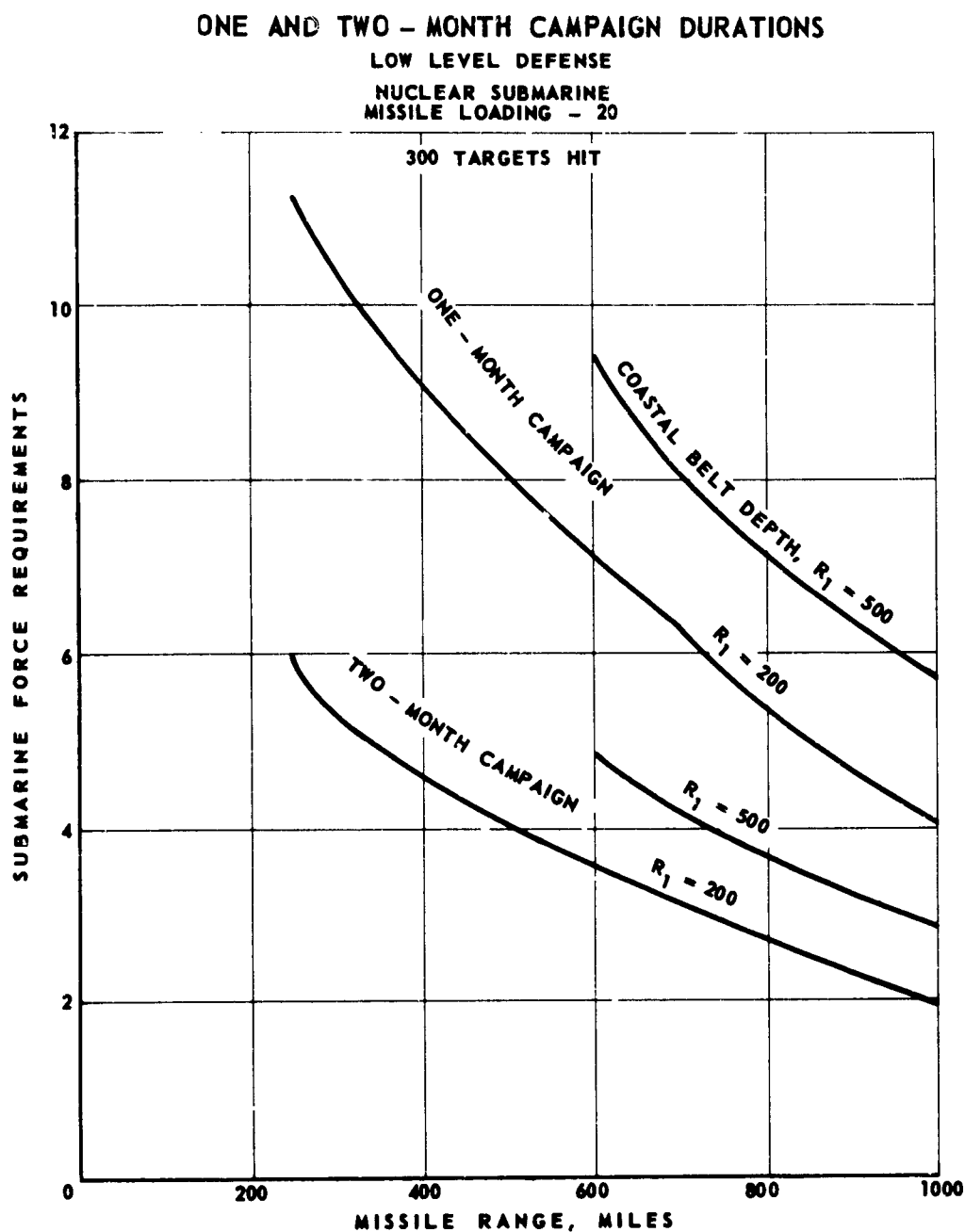


Figure 9-8. Submarine Force Requirements Per Target Hit vs Missile Range.

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the one trip case time difference of trips by different submarines is neglected. For the longer campaign, force requirements are placed on a per month basis.

1. Single Trip Case (Instantaneous Campaign)

As shown in Figure 9-8 increasing the missile range decreases the forces required to hit a given number of targets in a fixed number of trips. This is the result of lowered attrition with increasing missile range. Chapter 10 shows unit cost of the weapon system, determined as a function of missile range, increasing as missile range increases. However, with force requirements decreasing as a function of missile range, optimum missile ranges for the single trip case are determined as the minimum cost point on the plot of weapon system force costs as a function of missile range. Figure 9-9 illustrates this selection of missile range. In this manner an optimum missile range is selected for the single trip (instantaneous campaign) for each submarine-missile combination and belt depth.

2. Multiple Trip Case

For the multiple trip case, another approach is taken. Trip times become quite important. The number of missiles that can be fired per month varies significantly with missile range and also with submarine speed capability within the defense environment. For weapon system comparison it is of interest to put force requirements on a time scale. In other words, force requirements to hit a selected number of targets per unit time (chosen as per month) will be determined. The trip times for each type submarine and belt depth have been computed as a function of missile range. Adding a 48-hour turn around time per trip, the number of trips per month is plotted as a function of missile range. Figure 9-10 is an example. Cross plotting Figure 9-10 with Figure 9-8 gives force requirements to hit a selected number of targets in a given time as a function of missile range, Figure 9-11. Again plotting cost data of Chapter 10, as in Figure 9-9, and cross plotting data from Figure 9-10, gives Figure 9-12, weapon system cost to hit a selected number of targets in a given time as a function of missile range. From Figure 9-12, it is seen that the weapon system cost continues to decrease with increasing missile range. This is due to the rapid drop in force requirements with decreased trip time as missile range is increased, while unit weapon system cost is increasing relatively slowly with missile range. This would indicate that for a specified campaign duration, on the order of a month or two, that the longest range missile available in the time period should be selected in order to minimize the weapon system cost. From Chapter 11, it is seen that missile ranges on the order of 1000 miles should become available in the time period of 1960-1970. For this reason, a 1000-mile missile is assumed as the optimum available for the 1-and 2-month campaign durations.

FORCE REQUIREMENTS IN TERMS OF BELT DEPTH

With the missile range selection having been made for the instantaneous campaign (1 trip case) as in Figure 9-9 and for the 1-and 2-month campaign as 1000 miles, the weapon system force requirements for each belt depth are now selected from the plots of force requirements versus missile range. Final graphs of force requirements versus belt depth for the instantaneous, 1-month, and 2-month campaigns for each defense level and for each submarine type are now made. Figure 9-13 and 9-14 show these results.

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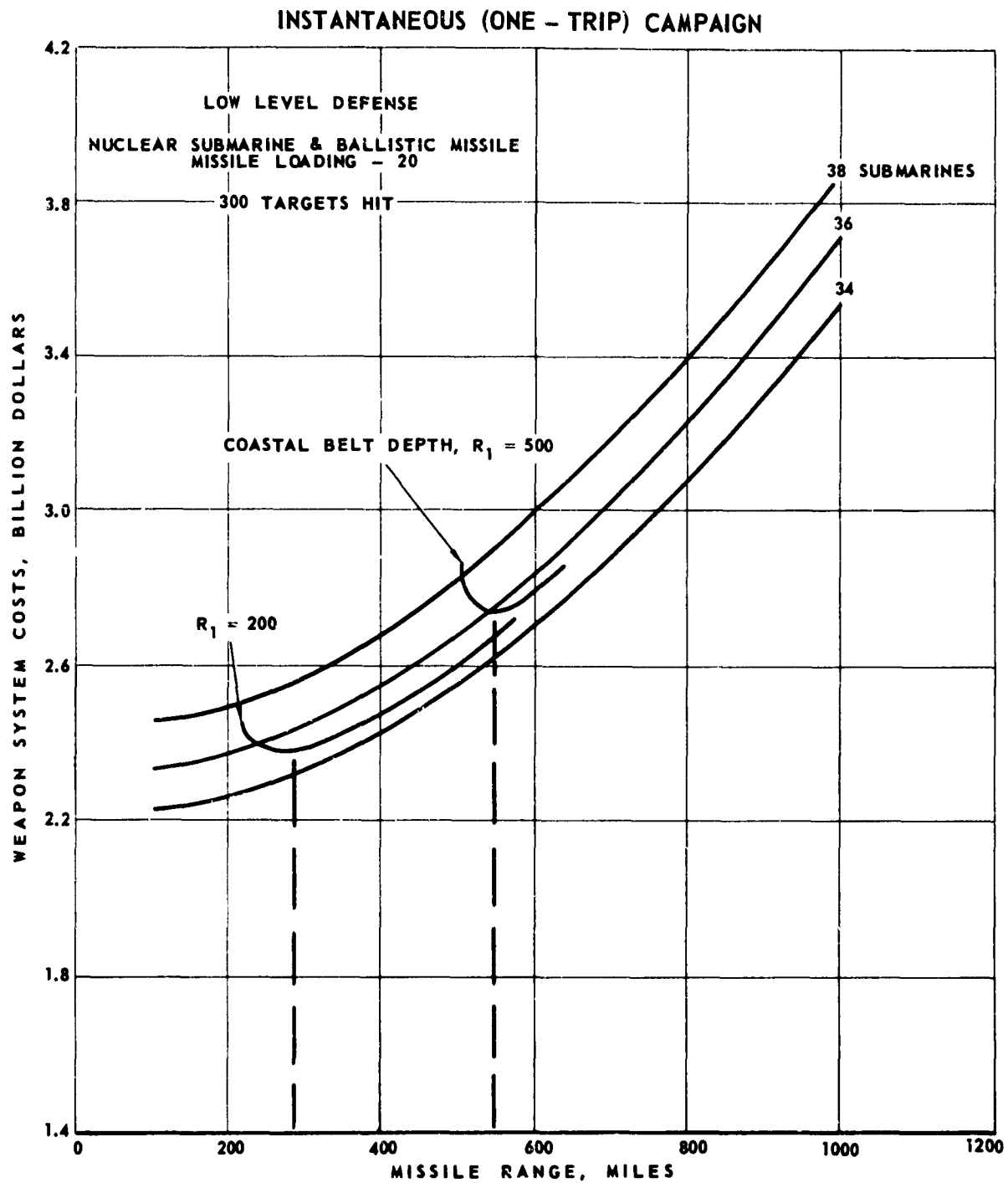


Figure 9-9. Minimum Weapon System Costs vs Missile Range.

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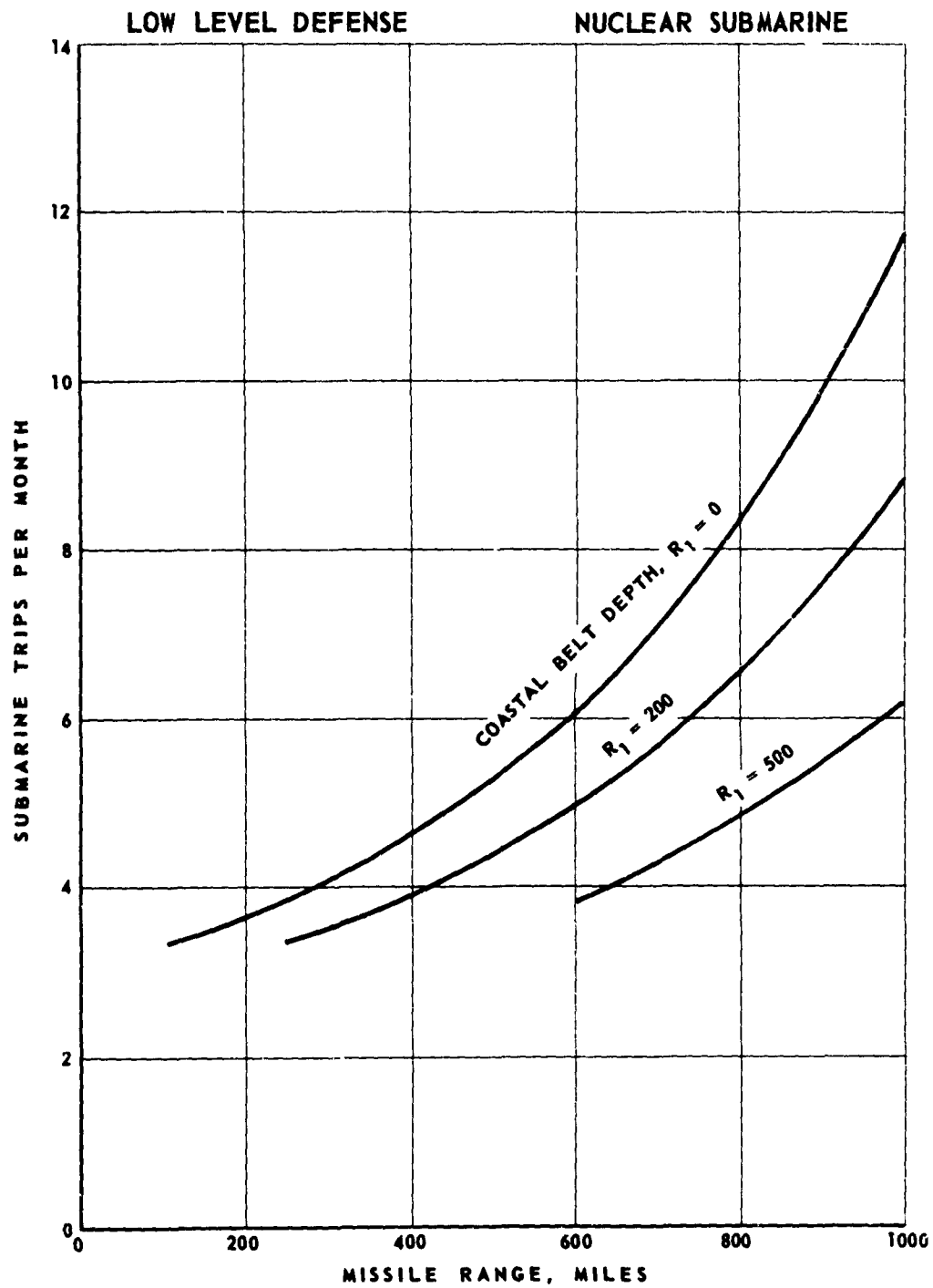


Figure 9-10. Submarine Trips Per Month vs Missile Range.

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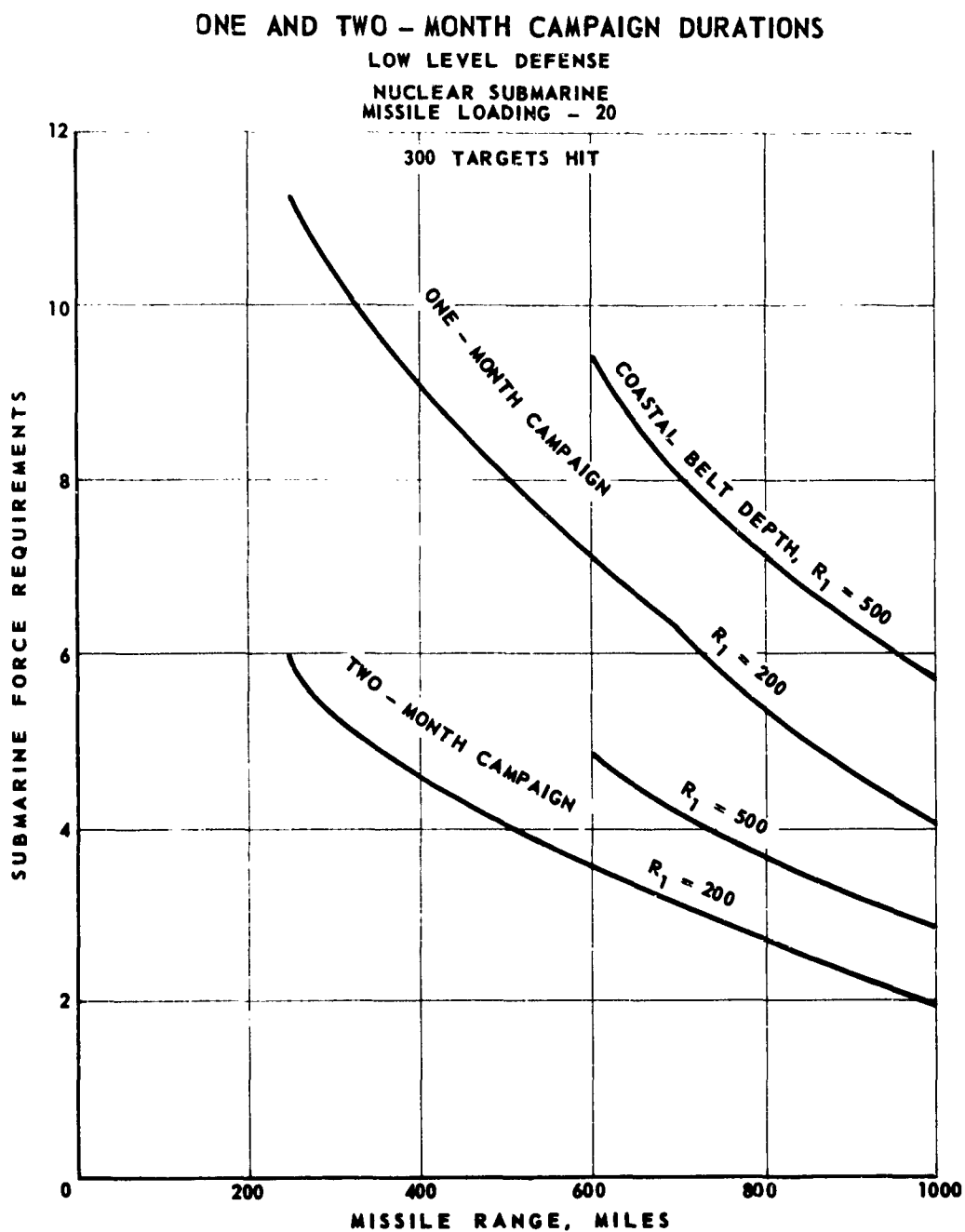


Figure 9-11. Submarine Force Requirements vs Missile Range.

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ONE AND TWO - MONTH CAMPAIGN DURATIONS

LOW LEVEL DEFENSE

NUCLEAR SUBMARINE - BALLISTIC MISSILE
MISSILE LOADING - 20

300 TARGETS HIT

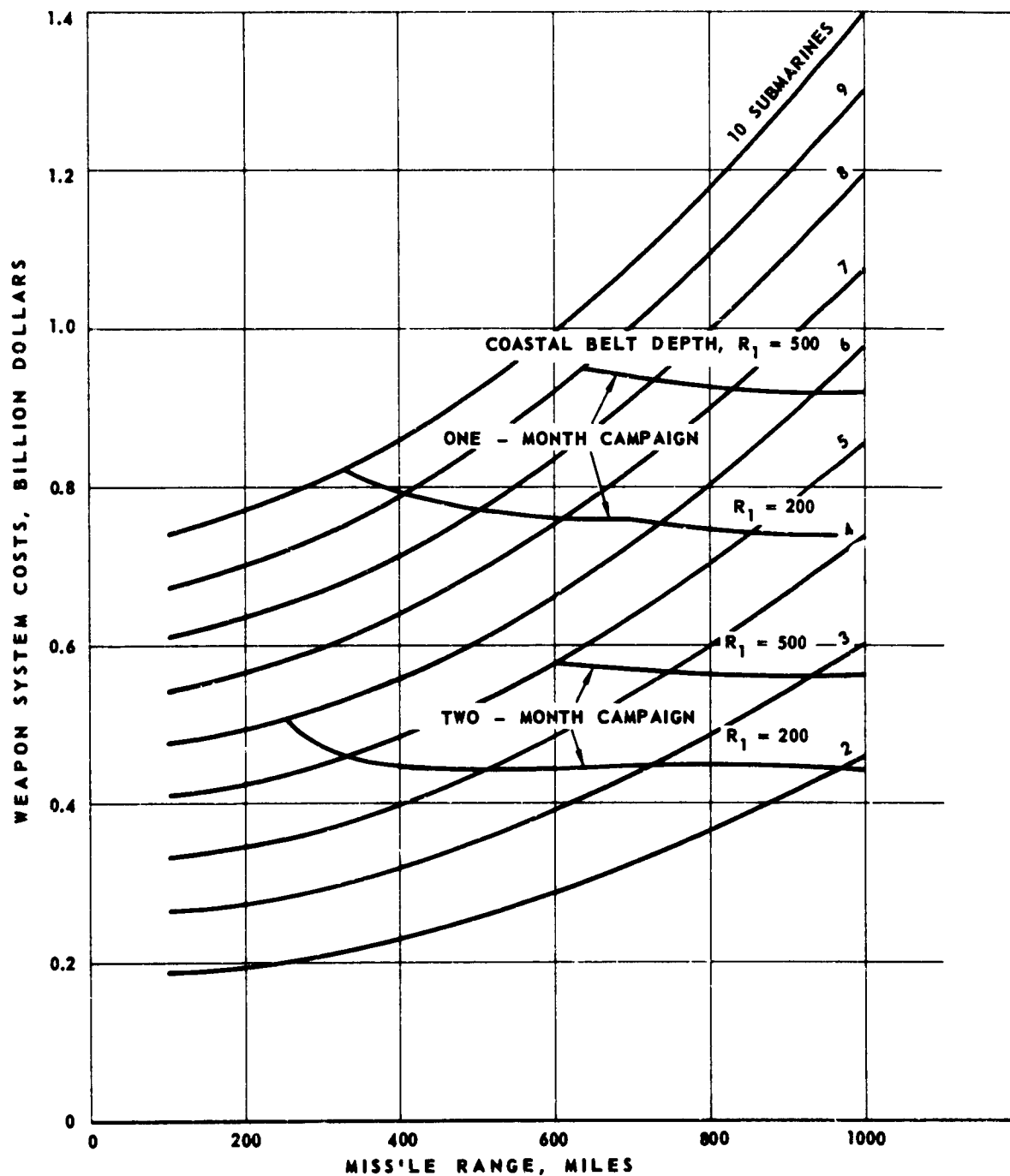


Figure 9-12. Weapon System Costs vs Missile Range.

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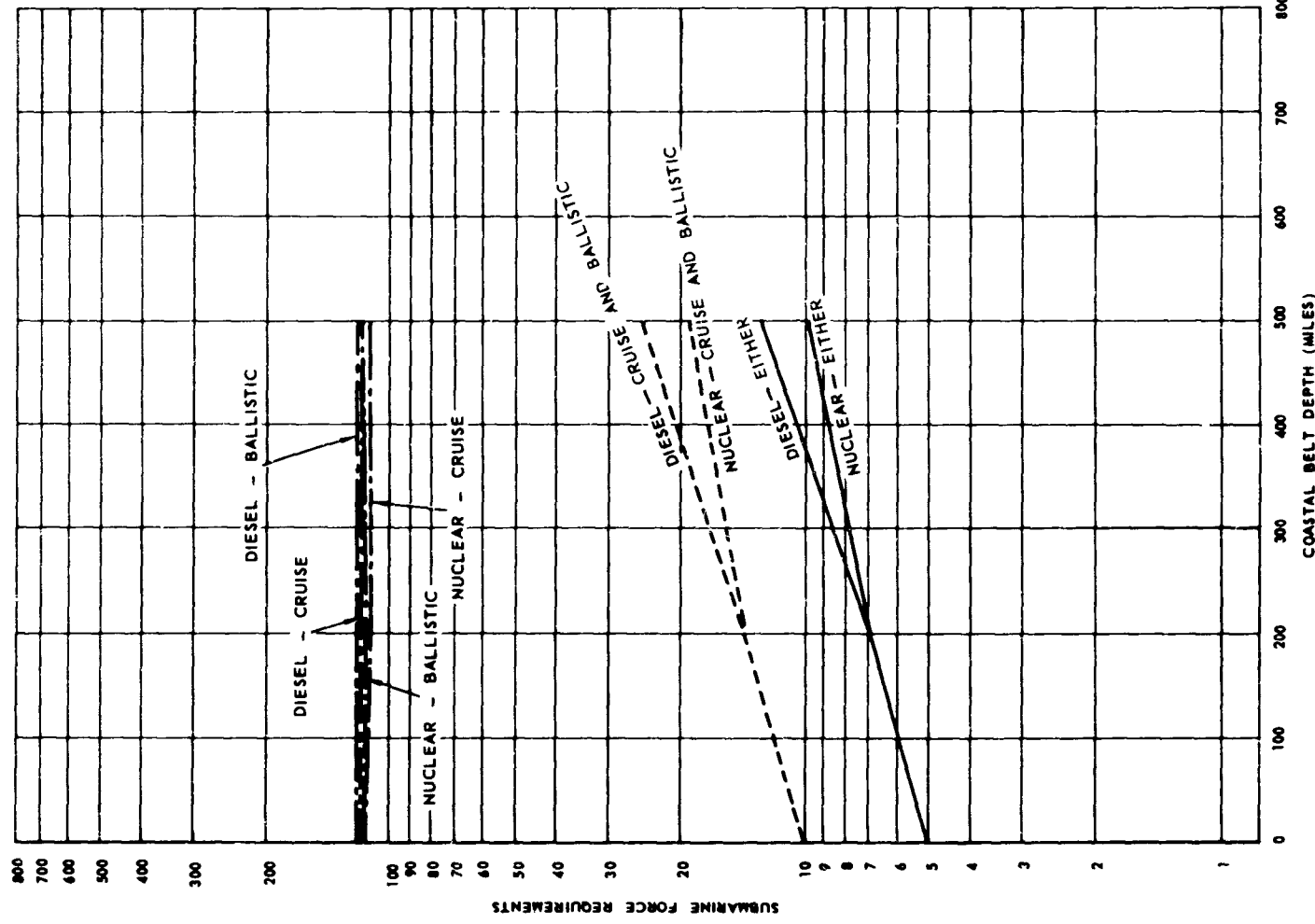
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SUBMARINE FORCE REQUIREMENTS VS COASTAL BELT DEPTH

100 TARGETS HIT
LOW LEVEL DEFENSE

----- INSTANTANEOUS (ONE TRIP) CAMPAIGN
----- ONE MONTH CAMPAIGN
----- TWO MONTH CAMPAIGN

MISSILE LOADING - 2



MISSILE LOADING - 20

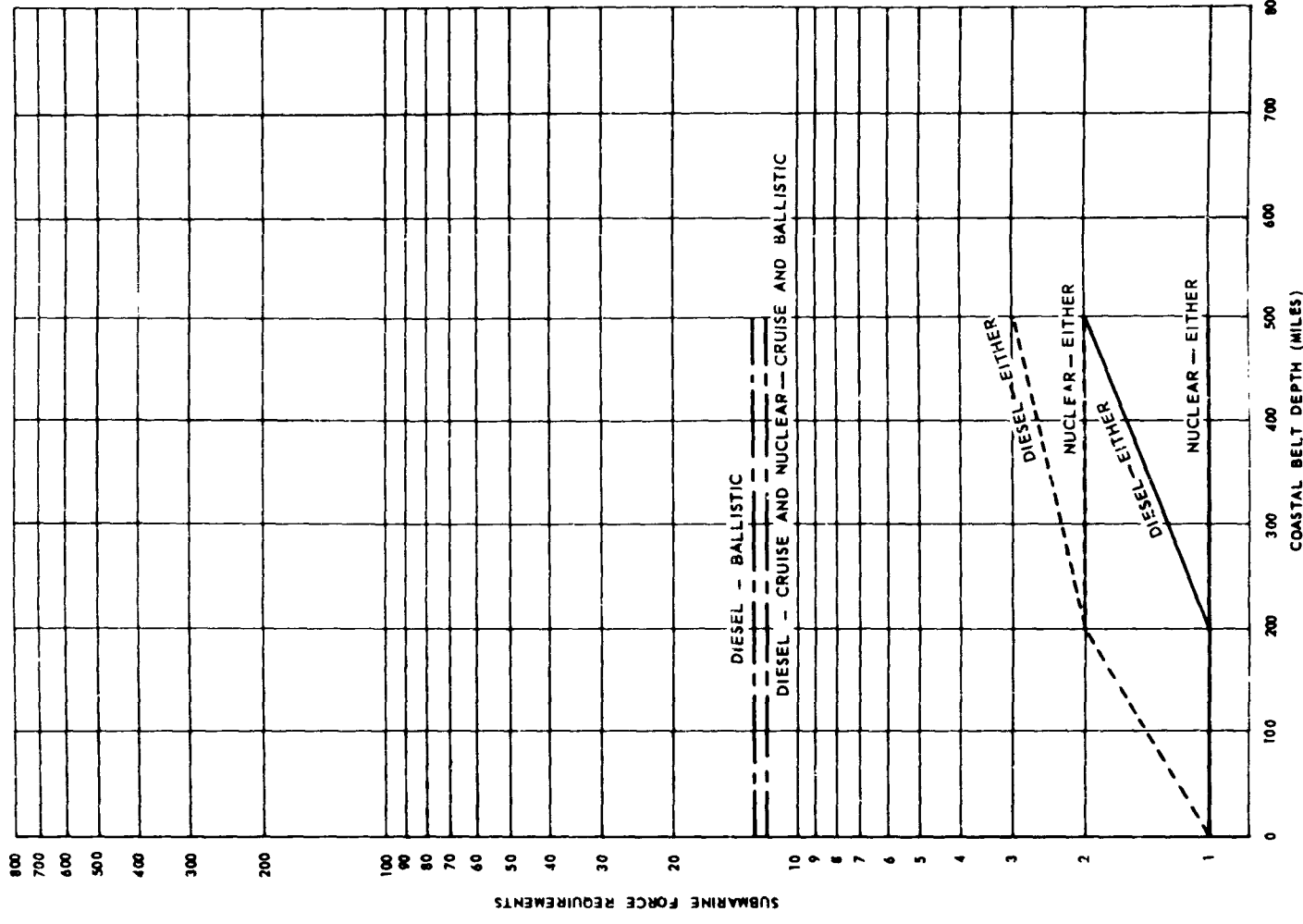


Figure 9-13. Submarine Force Requirements vs Coastal Belt Depth. Sheet 1 of 2

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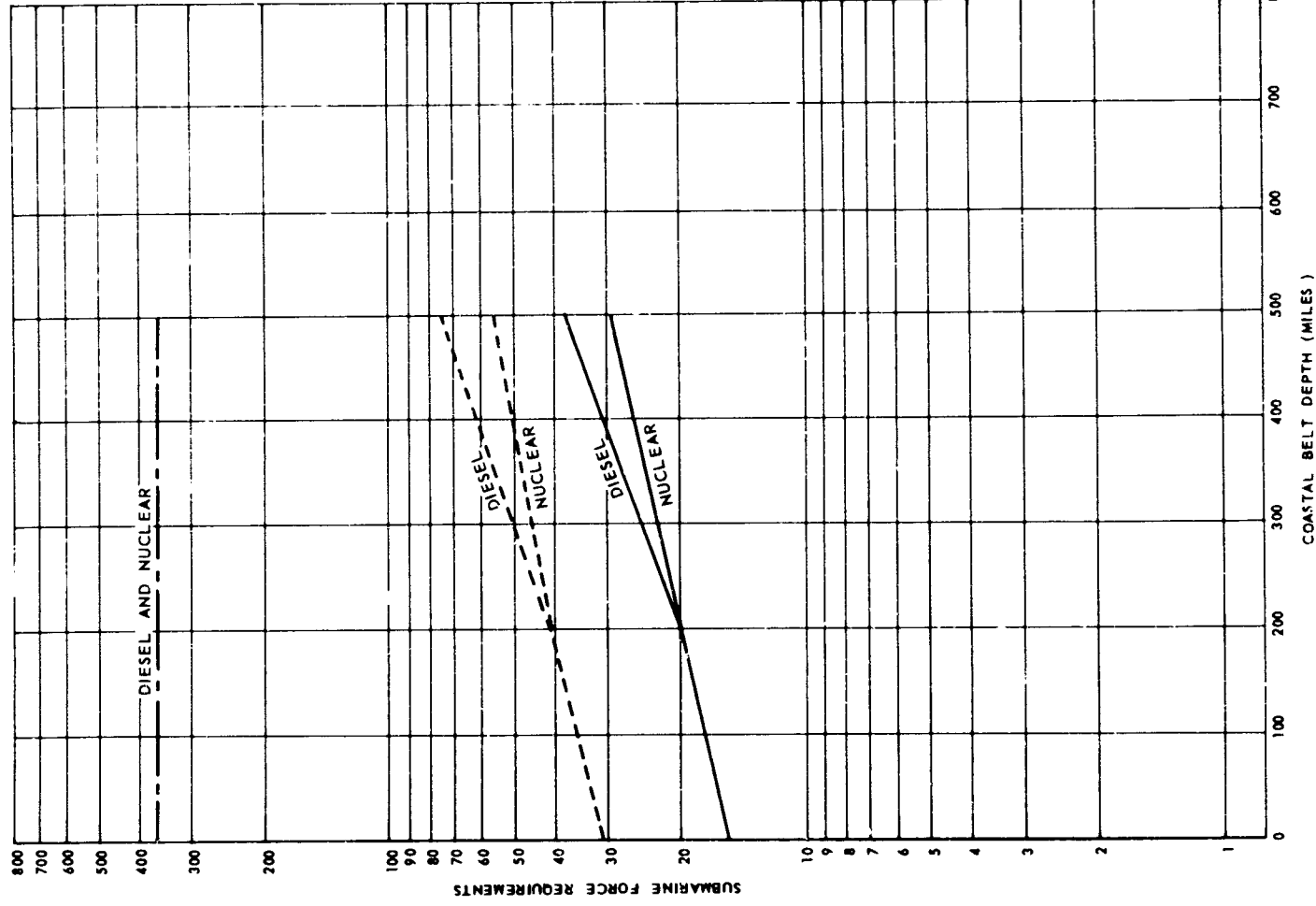
SUBMARINE FORCE REQUIREMENTS VS COASTAL BELT DEPTH

300 TARGETS HIT

LOW LEVEL DEFENSE

— INSTANTANEOUS (ONE TRIP) CAMPAIGN
- - - ONE MONTH CAMPAIGN
- - - TWO MONTH CAMPAIGN

MISSILE LOADING - 2



MISSILE LOADING - 20

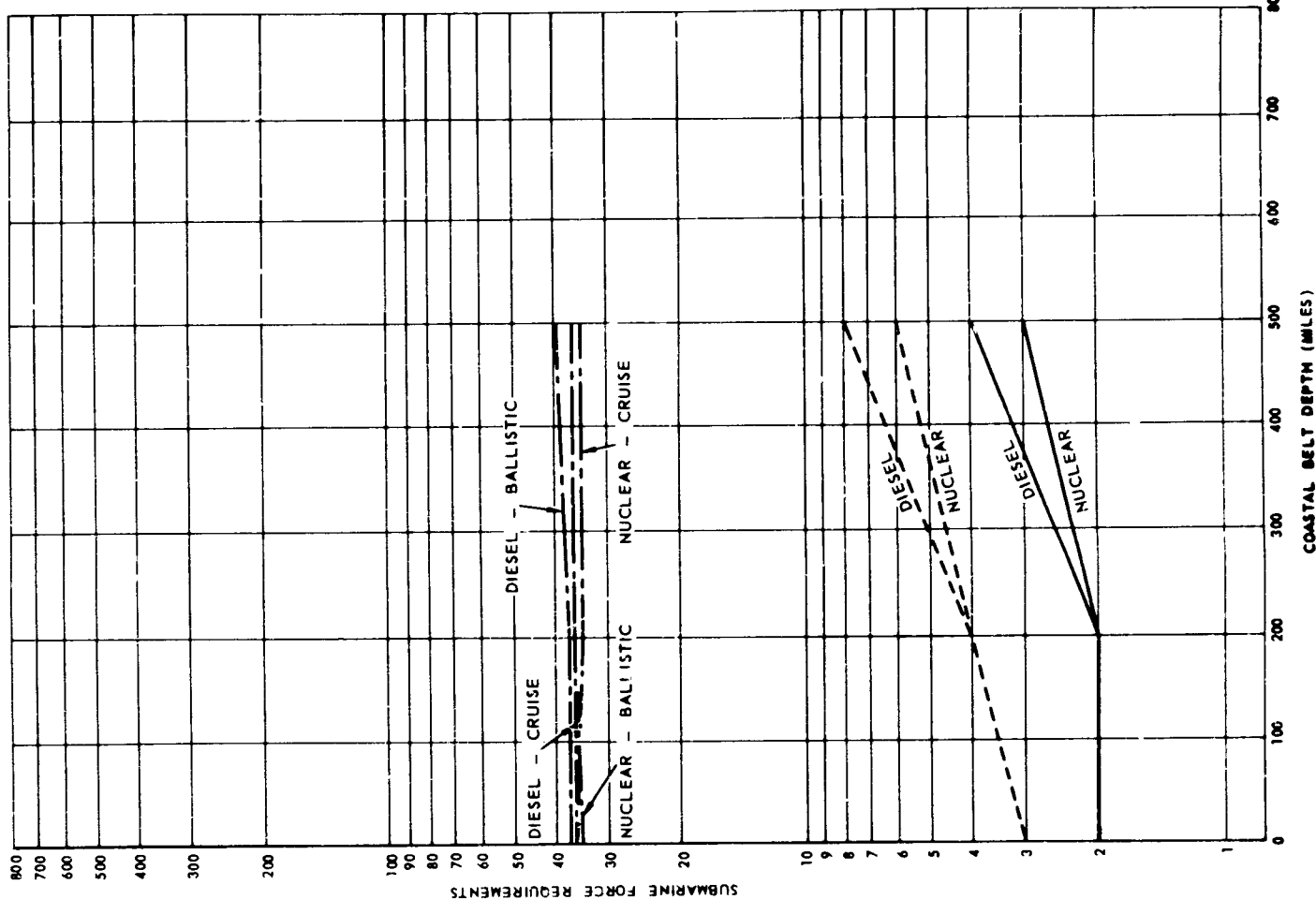


Figure 9-14. Submarine Force Requirements vs Coastal Belt Depth (300 Targets Hit). Sheet 1 of 2

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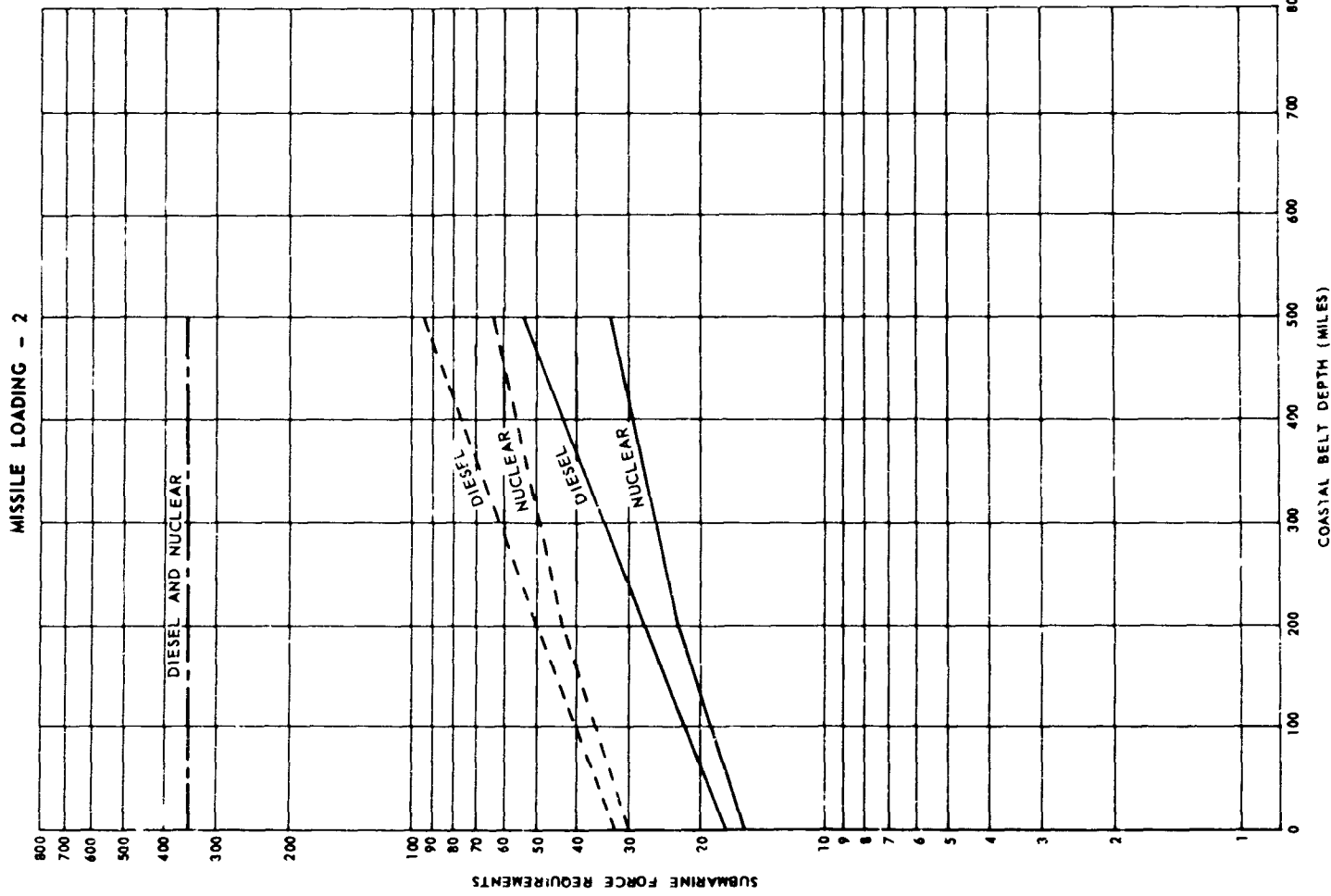
SUBMARINE FORCE REQUIREMENTS VS COASTAL BELT DEPTH

300 TARGETS HIT

HIGH LEVEL DEFENSE

----- INSTANTANEOUS (ONE TRIP) CAMPAIGN
----- ONE MONTH CAMPAIGN
----- TWO MONTH CAMPAIGN

MISSILE LOADING - 2



MISSILE LOADING - 20

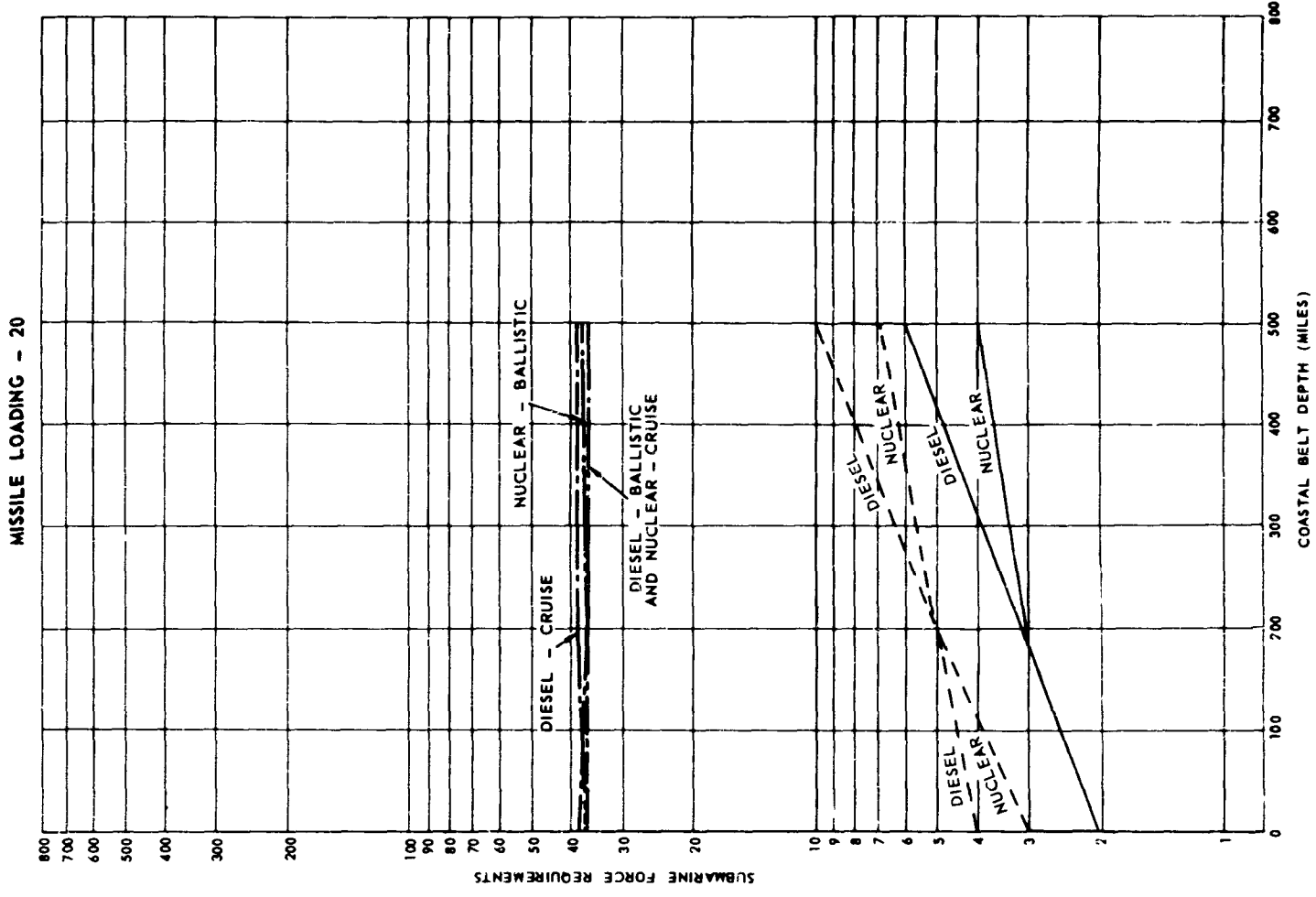
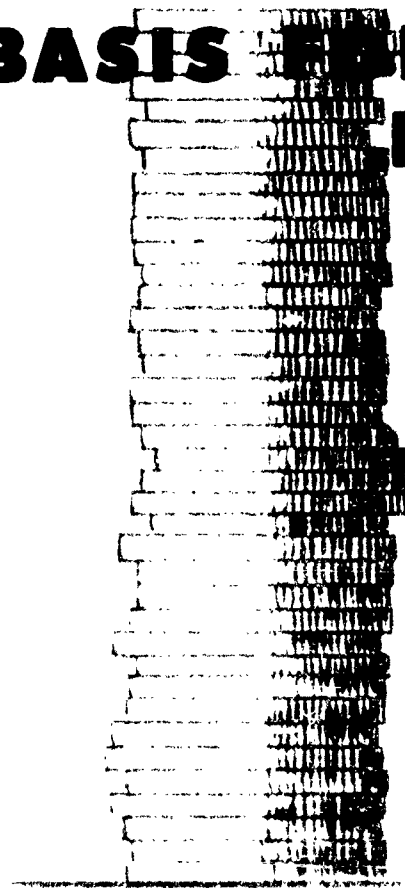


Figure 9-14. Submarine Force Requirements vs Coastal Belt Depth (300 Targets Hit). Sheet 2 of 2

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BASIS FOR MAKING DECISIONS



PART D

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Chapter 10 SYSTEM COST

Note

The cost data presented is for use in this study only. It is not intended by General Dynamics that the cost data contained herein be used for any other purpose, contractual or otherwise.

The pilot study costing has been directed toward providing cost data for two hundred forty-six (246) submarine strike weapon systems. The weapons system costs are an important part of the measure of effectiveness, by which weapons system selection is made. All system costs include an initial procurement and five (5) year readiness (operational) period. The costs derived are based on design parameters established in Chapters 3, 4, 5, 6 and 9. This chapter presents costing definitions, basic costing assumptions and total system cost presentation. System cost structure breakdown is presented in Volume II.

WEAPONS SYSTEM COSTING DEFINITIONS

The weapon systems costed are composed of missiles, submarines and their associated supporting elements. The costing effort has been directed by the system design parameters established in Chapters 3, 4, 5, 6 and 9. A weapons system for purposes of this study is identified by:

- | | | |
|---------------------|---|---|
| Force Requirements | — | Number of submarines
10 — 50 — 100 |
| Types of Submarines | — | Fleet boat conversion
New construction diesel-electric
New construction nuclear |
| Types of Missiles | — | Ballistic
Cruise (Airbreathers) |

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Missile Loading	— On board loadings of 2 — 10 — 20
Missile Ranges	— Nautical miles from launch point 100 — 400 — 1000
Target Complex	— Missiles adequate to destroy 100 — 300 targets

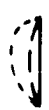
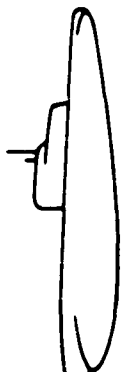
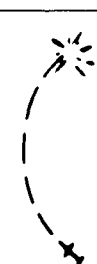
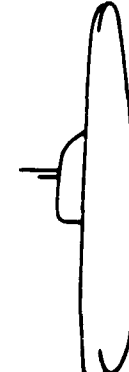
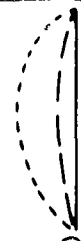
Further design parameters are discussed in their respective chapters. Based on the above system identifications the maximum potential systems are shown in Figure 10-1. Two hundred forty-six (246) submarine strike weapon systems have been costed. Eliminations were made in the fleet boat conversion type, since it was considered impractical to convert for some types of longer range missiles for the 10-and 20-missile loading category.

BASIC COSTING ASSUMPTIONS

The voluminous costing task requires extensive use of basic cost assumptions for the pilot study phase. The following basic costing assumptions apply to all systems unless specifically noted otherwise.

1. Basic Costing Assumptions — General
 - a. All costs are based on the 1955 dollar value.
 - b. Transportation costs are based on a 2% factor of the expendable items.
 - c. All system costs reflect a fully operational system for a five (5) year period. No incremental costing has been included.
 - d. Study and development costs have not been included directly or prorated, except in the submarine cost data.
 - e. The depreciable items are assumed to be written off 100% during the five (5) year operations period with no residual value.
 - f. Sequential costing benefits, those received from previous programs or potential transmitted to other future programs, have not been considered.
2. Basic Costing Assumptions — Submarine
 - a. Conventional submarine base equipment will be adequate for all systems assuming a transition from SS's to SSG's (conventional power plants).
 - b. Guidance submarines (picket-intermediate guidance control) have not been costed in the study. It is assumed that the guidance system used will not require picket submarines.
 - c. Only defense armament is included in the submarine costs, no provision is made for conventional torpedo attack operations.
 - d. Submarine base requirements relative to submarine force requirements are bases to subs: (1:10 — 3:50 — 5:100).
 - e. Tenders will not carry nuclear fuel.
 - f. For costing purposes maximum speeds of 25 knots submerged and 20 knots surfaced for nuclear and diesel-electric submarines respectively have been assumed.

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FORCE REQUIREMENTS NO. OF SUBMARINES	TYPES OF SUBMARINES	TYPES OF MISSILES	MISSILE LOADINGS (ACTUAL)	MISSILE RANGES (NAUTICAL MILES)
(10)	(A) CONVERTED DIESEL-ELECTRIC 	(X) BALLISTIC 	(2) 	(100) 
(50)	(B) NEW CONSTRUCTION DIESEL-ELECTRIC 	(Y) CRUISE (AIRBREATHERS) 	(10)  (20) 	(400) 
(100)	(C) NEW CONSTRUCTION NUCLEAR 		                               	(1000) 
FACTOR (3)	X	X	X	X
(3)	(3)	(2)	(3)	(3)
				= 162

REPEAT FOR 100 AND 300 TARGETS $2 \times 162 = 324$ CONFIGURATIONS

Figure 10-1. Weapon System - Submarine - Missile Combinations.

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3. Basic Costing Assumptions — Missile
 - a. Second user benefits (other system potential) has not been considered in computing the missile production costs.
 - b. Missile power plant costs reflect the lower cost in each category (solid rocket vs liquid rocket). Ramjet and turbojet missile costs are considered the same for the pilot study comparisons.
 - c. Nuclear warhead costs have not been included. It is assumed that a nuclear warhead would cost relatively the same regardless of the delivery system used.
 - d. Combined torpedo-missile training will be given to submarine crews.
 - e. Training missiles are non-recoverable.
 - f. Missile depot installations will be located on or adjacent to the submarine base.
4. Basic Costing Assumptions — Support
 - a. Costs for the following items have not been included in the pilot study:
 - (1) Support command at the various levels, major, intermediate and immediate.
 - (2) Reconnaissance operations.
 - (3) Production facilities, submarine or missile.
 - (4) Campaign cost per day other than the cost of the missile required for a specific target complex.
 - b. A fixed construction rate has been used for all installations. Overseas construction rates will be applied in Phase II costing.
 - c. The shipyard requirements related to submarine force requirements are submarines to shipyard (10:1 — 50:2 — 100:3).

DEFINITION OF WEAPONS SYSTEM COST STRUCTURE

1. General

A basic cost structure applicable to all systems contains: Installations, Equipment, Stocks, Personnel, Expendables and Maintenance Items. Costs for these items are divided between Initial Procurement and Annual Operations. This cost structure is patterned after Rand costing methodology. Definitions for these cost items are given in the costing section of Volume II. Throughout the costing compilation maximum consideration has been given to adaptation of existing conventional submarine facilities to the proposed system. Figures 10-2 and 3 reflect the conventional facilities at a typical submarine base and dry-dock, and the additional facilities required for nuclear-powered submarine operations and missile installations. The cost items are analyzed under the two major system categories, the missile system and the submarine system.
2. The Missile System
 - a. Lamentation

The guided missile industry in the United States is ten (10) years young. Missile system cost data is as "green" as the missile industry, to date there has been little opportunity to compare estimates vs actuals and few production programs to judge by. Pilot study costing has not been allocated sufficient time to prepare detailed missile cost estimates. However, it is felt that the missile cost data is sufficiently accurate for pilot study purposes.

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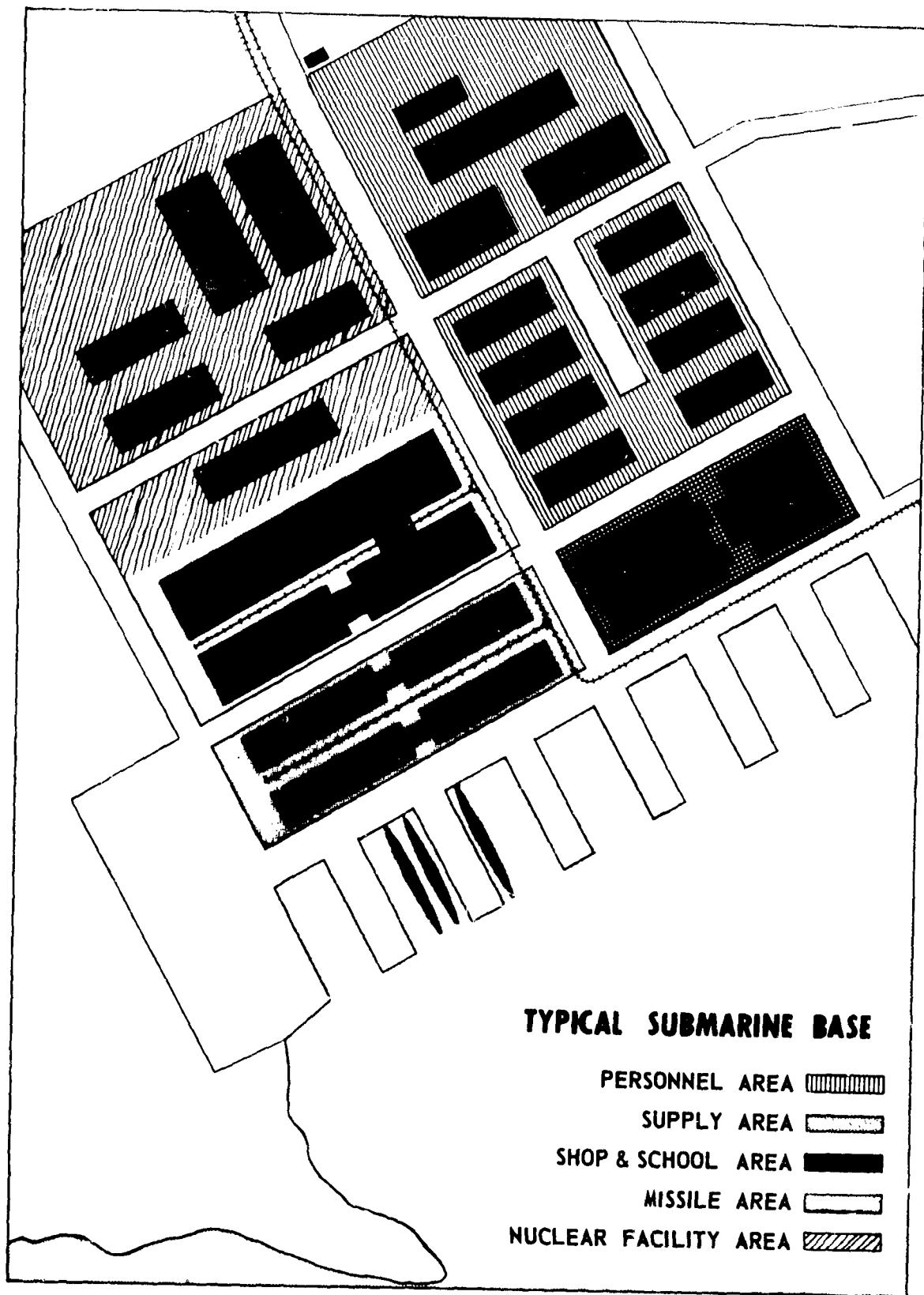


Figure 10-2. Typical Submarine Base.

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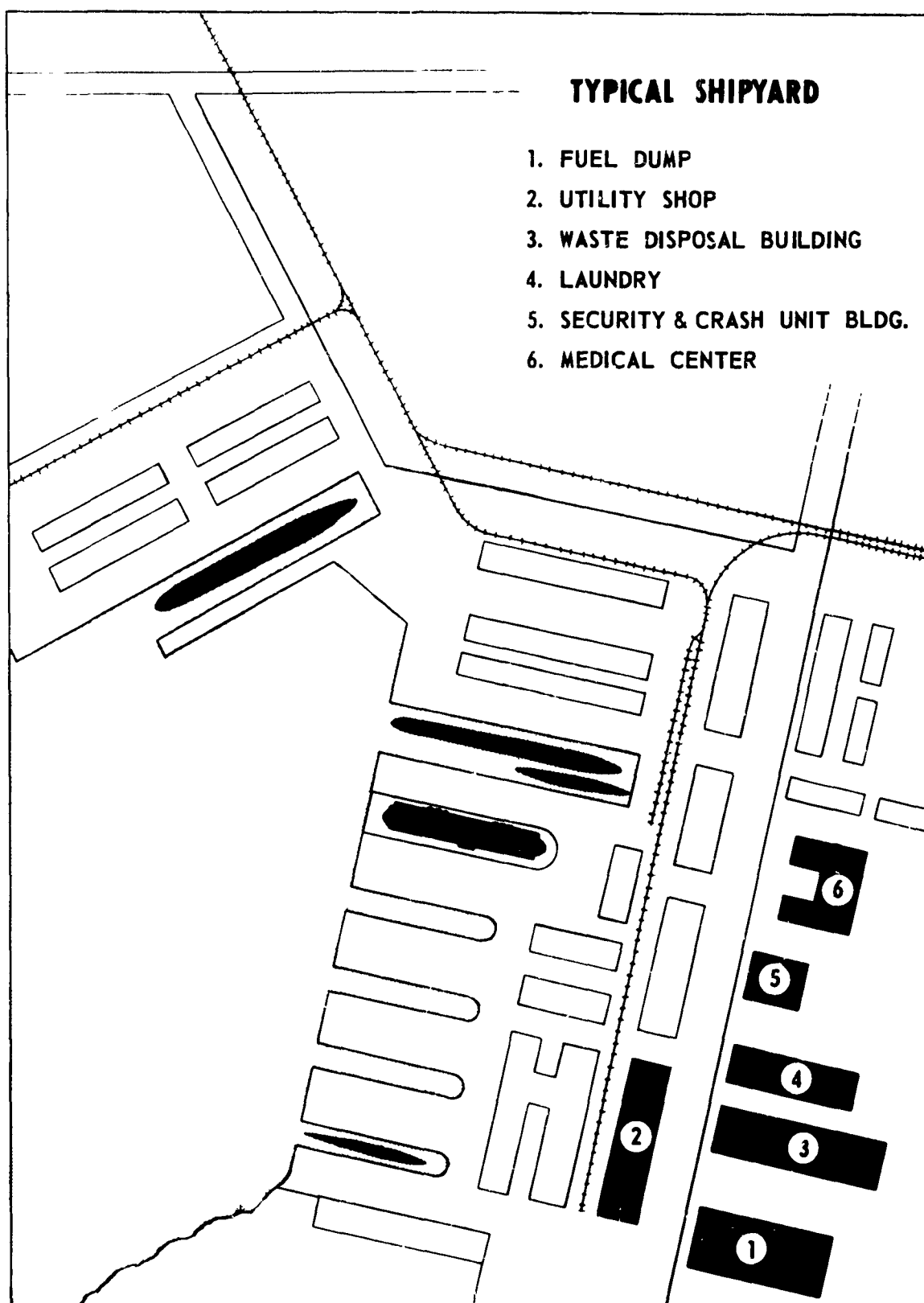


Figure 10-3. Typical Shipyard.

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b. Missile Data Source

Missile cost data has been obtained from magazines¹, Convair accounting records, U. S. Navy Bureaus², and missile cost studies^{3 4 5}. Missile component cost data, principally solid and liquid power plant costs, have been obtained from power plant contractors^{6 7 8}.

c. Cost Compilation

- (1) Since detailed missile cost data is highly proprietary, it was not possible to analyze the various complete missile costs obtained. The missile cost data curves shown in Figure 10-4 were prepared as follows:
 - (a) Costs of presently planned production missiles were obtained where possible. Missile costs obtained were by and large for an entirely assembled missile, thus missile costing has been done in terms of missile gross weight and range. Quantities of missiles on which costs were obtained varied from large production lots to a few pilot line missiles.
 - (b) The average unit cost of the missiles under consideration was determined. Using a 90% learning curve, unit costs were obtained, in all cases, for the 60th unit. Points were thus obtained and plotted on an average unit cost versus gross weight graph. Using the points thus established, two curves were then drawn, one for ballistic and one for cruise missiles (Figure 10-4).
- (2) The number of missiles required for a particular system was determined by the following factors:
 - (a) The initial shakedown allowance for each submarine.
 - (b) The numbers of submarine crews to be maintained over a five (5) year operational period.
 - (c) The size of the target complex.
 - (d) The predetermined missile reliability values.

Notes: ¹ Aviation Week, 14 March 1955, page 233.

² Bureau of Ordnance and Bureau of Aeronautics.

³ H. J. Knippenberg, C. F. Riley, J. C. Shay and H. P. Griggs "A Production Cost Estimate of the XSSM-A-14 Redstone Guided-Missile System." Booz, Allen & Hamilton and Operations Research Office, Johns Hopkins University ORD-T-257 11 December 1953 (SECRET).

⁴ W. B. White and R. W. Krueger "Defense of the Continental United States by Various Missile and Gun Systems for the Period 1953 to 1959" The Rand Corp. RM-626 1 October 1951 (SECRET).

⁵ E. W. Srull, W. K. Brehm and J. T. Montgomery, "A Comparison of Three Atlas Vehicle Configurations" Convair, San Diego ZO-7-004 May 1954 (SECRET).

⁶ E. P. Gebhard and K. D. Miller, Jr. "Preliminary Propulsion Studies for Convair-Submarine-Launched Missiles" M. W. Kellogg Co. TM No. PED 552 18 August 1955 (CONFIDENTIAL).

⁷ W. P. Turner "Cost Estimating Data for Propulsion System of SWSS Missile Study" Reaction Motors, Inc. Ltr. Turner to Foreman dated 19 August 1955 (CONFIDENTIAL).

⁸ Aerojet Corporation and Marquart Corporation verbal discussion August 1955.

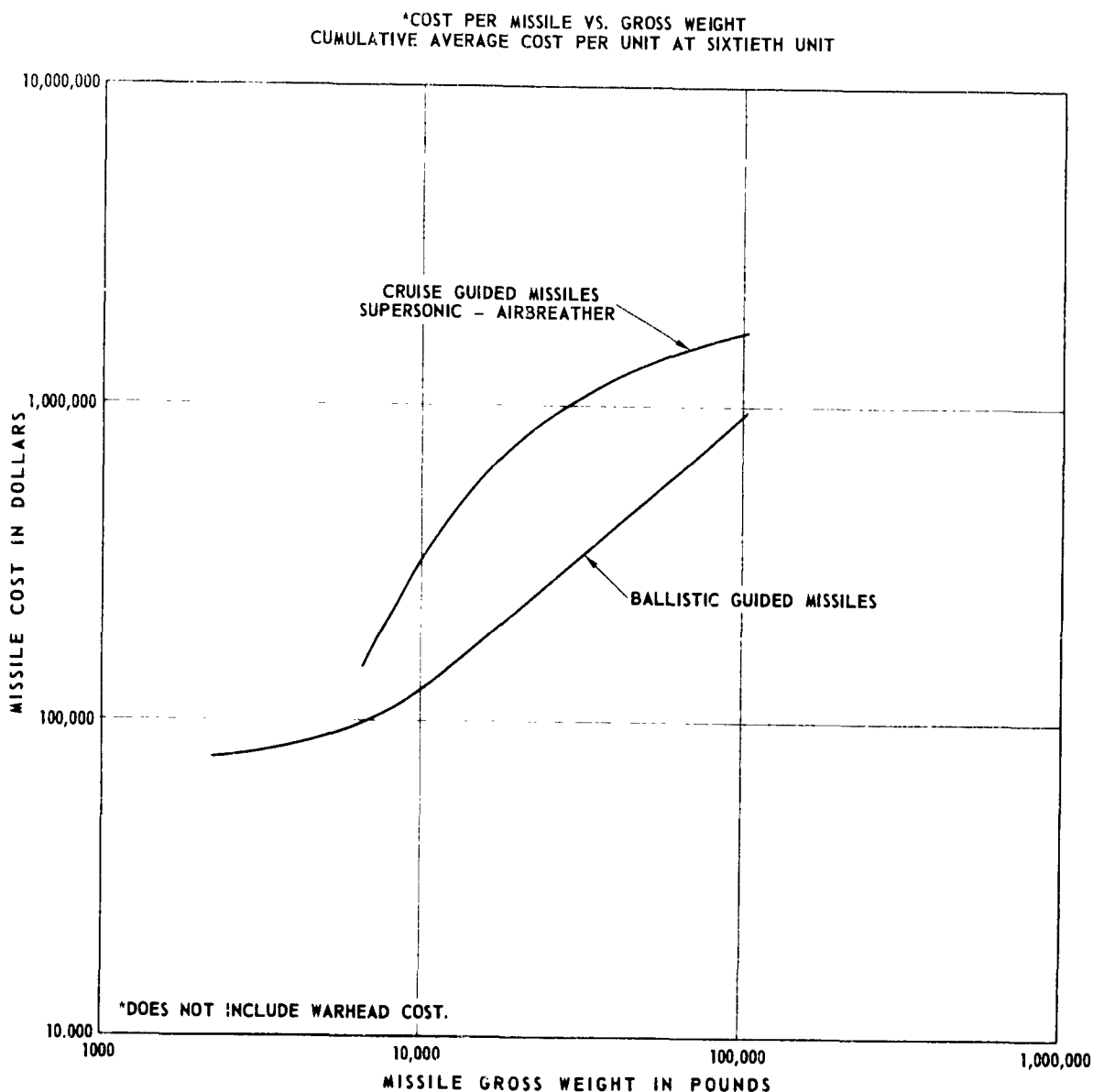


Figure 10-4. Typical Guided Missile Cost Curves.

Costs for these missiles were determined as follows:

- (a) Based on the missile design requirements for a particular submarine strike missile the missile gross weight was determined.
- (b) The costs for a given missile were obtained by use of a 90% missile production learning curve. A forty (40) missiles per month production rate has been assumed.

d. Installations

Costs have been provided for missile depot checkout and storage facilities. All depot checkout buildings are designed for six (6) checkout bays

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and storage space for two hundred (200) missiles. Additional storage space has been costed for systems requiring storage in excess of the depot building capacity. The number of schools and depots are based on the size of the submarine force and the two (2) ocean Navy concept.

<u>Submarine Force</u>	<u>Depots</u>	<u>G/M Schools</u>
10	1	1
50	3	2
100	5	2

e. Equipment

The equipment requirements to outfit the missile system installations consists of depot checkout and handling gear. In addition, the transport gear required to move missiles from storage sheds to checkout depots to submarine and/or tender loading docks is costed for each system. The transport equipment costs were influenced by a production study made for a surface-to-surface missile⁹.

- f. Costs have been provided to staff the additional facilities and operate the equipment. The base support costs have not been included for pilot study pricing. Depot checkout personnel are assumed to be predominately civilian. The ratio of 3 to 1, civilians to service personnel has been used. The missile school personnel costs have been included in the missile training cost per man.

g. Maintenance

A 1:1 ratio has been used for electronic equipment maintenance over the life of the equipment in the study. The maintenance costs for other equipments and installations is based on usage and climatic conditions.

3. Submarine System

Submarine system cost data has been based on a new mission concept for the submarine service. The prime submarine mission to date has been to neutralize enemy ocean shipping. The new mission utilizes the submarine as a mobile launching base for surface-to-surface guided missiles. The cost analysis must identify the submarine conventional operations which are carried over to the new system, those operations which are modified, and new operations which must be costed into the system.

In the pilot study costing, fleet conversions, new diesel-electric and nuclear-powered submarines are considered. The missile volume and number carried (missile loading) are the prime submarine size controlling factors.

Note: ⁹ H. J. Knippenberg, C. F. Riley, J. C. Shay and H. P. Griggs "A Production Cost Estimate of the XSSM-A-14 Redstone Guided-Missile System". Booz, Allen and Hamilton and the Operations Research Office. Johns Hopkins University ORO-T-257 11 December 1953 (SECRET)

a. Installations

For conventional submarine power plant operations the base and drydock facilities are considered adequate. Costs have been provided for additional or modified installations required for nuclear-powered submarines. There are presently two (2) nuclear submarines in operation, both are prototype units. A cost estimate was made of the nuclear submarine base and shipyard installations requirements.

b. Equipment

Submarine construction estimates were prepared by the Electric Boat Division. These estimates were used in preparing submarine cost data used in the study. Figure 10-5 is an example of typical submarine cost curves. These curves were prepared by plotting unit submarine cost versus shaft horsepower. Cross plots were made in terms of unit submarine cost versus surface displacement in tons to give the wide range of costs and tonnage required to price the submarine in all systems considered in the study.

Costs relative to converted fleet boats (SSG's) were obtained from Navy offices, based on conversion costs for the U. S. S. TUNNY and U. S. S. CARBONERO. Submarine design requirements are given in Chapter 6. Areas, requiring specific cost consideration are:

Tonnage:	Surface displacement adequate to carry the number of missiles required for a given system, missile volume (range) being the controlling factor for a specific missile configuration. The surface displacement tonnage ranges from 1325 to 6400.
Power Plant:	Power plant sizes were selected for required speeds.
Armament:	Conventional torpedo installations are not provided. Submarines for this system will carry defensive armament only.
Missile Installation:	The costs for the most expensive type installation have been used. The magnitude of the costing task precludes detail variance of costs for the various proposed launching schemes, missile checkout arrangements, missile fuel storage, and loading, storage and transfer mechanisms. A detailed cost study would reveal the cost variance between the possible missile installation designs. By staying on the "high side" for each major missile installation component, it is felt the costs are adequate for pilot study use.

In addition to submarine construction costs, other major equipment items are submarine tenders and submarine base and shipyard equipment.

It is assumed that the present submarine tenders would be adequate after modification for missile operations. The tender modification would provide the submarine force with a mobile missile depot. Other tender functions would be conventional, except that a nuclear-powered submarine would not be refueled with fissionable material from the tender.

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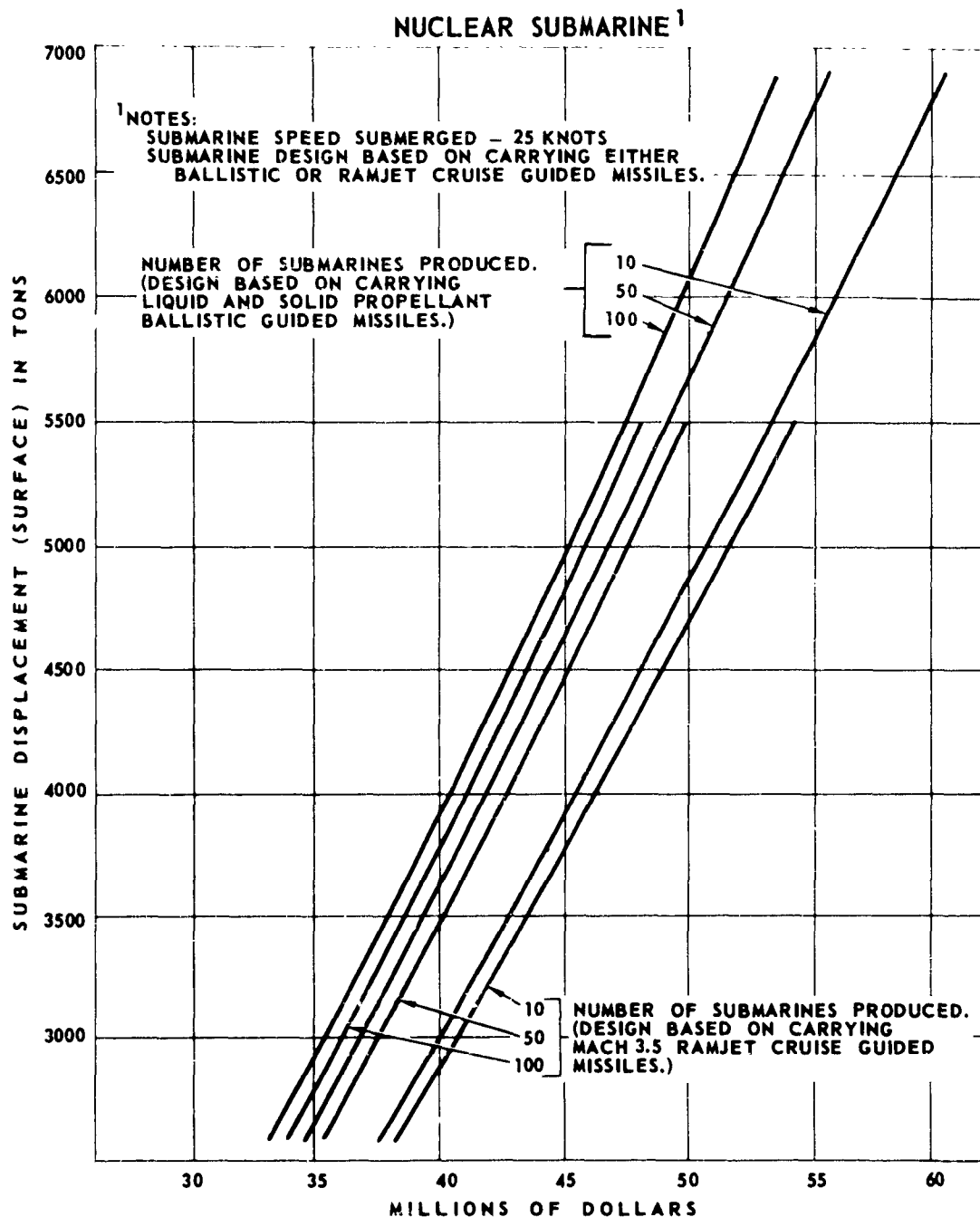


Figure 10-5. Typical Submarine Cost Curves.

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The equipment requirements for the submarine bases and shipyard cover the needs for nuclear-powered submarine operations. Cost data in this area is similar to cost data in 3a above.

Ratios for submarine force to bases drydocks and tender requirements are:

<u>Submarine</u> <u>Force</u>	<u>Bases</u>	<u>Shipyard</u>	<u>Tenders</u>
10	1	1	1
50	3	2	4
100	5	3	8

c. Personnel

Personnel (manning) requirements are based on conventional submarine operations. The size of the crew will vary slightly with increased submarine size. Crew size relative to submarine surface displacement used in the study is:

<u>Submarine Surface</u> <u>Displacement Tonnage</u>	<u>Submarine</u> <u>Crew Size</u>
2000	90
4000	90
6000	100
8000	110
10,000	120

The tender crew (1,000 men) does not vary with submarine size. A twenty percent (20%) factor has been used to maintain one hundred percent (100%) operational crews. Thus, twelve crews have been costed for a ten boat force.

The pay and allowances have been based on 1955 rates. Training costs are covered in two areas: submarine training and missile training. For pilot study purposes, it is assumed that no initial mass training will be required for missile or submarine operations. It is assumed that the initial missile training would be acquired thru cadre operations during the research and development phase. There would be an adequate supply of submariners available to man the SSG's. The training costs included cover refresher and replacement requirements during the operational period. This principle applies both to submarine crews and tender crews.

d. Maintenance

Maintenance costs for conventional submarines, tenders, base facilities and equipment are based on current data supplied by the Navy¹⁰. Maintenance costs for the submarine missile system installations and equipment are based on BuAer supplied data. Cost of maintaining a nuclear

Note: ¹⁰ U. S. Navy, Office of Assistant Comptroller, Director of Budgets and Reports

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powered submarine fleet is similar to converted boats except for power plant maintenance. The power plant portion of the maintenance costs are based on an "on board" reactor overhaul with components only removed for shore rework. Throughout the various systems the submarine maintenance costs have increased as a function of submarine tonnage.

TOTAL WEAPON SYSTEM COSTS

It is not practical to present cost schedules for the complete spectrum of systems costed. A sample set of system cost schedules is presented in Figure 10-6. Detail evaluation of system costs is covered in Volume II, Part F. The costs have been prepared along lines of the Rand methodology which will facilitate comparison with other weapon systems.

The basic cost charts for total weapons system costs are shown in Figures 10-7 and 10-8. These cost curves when used in conjunction with force requirements (Chapter 9) result in the decision charts presented in Chapter 12.

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100 TARGET COMPLEX (\$000,000)

COST AREA	10 NUCLEAR SUBMARINES - MISSILE LOAD OF 10 EACH									
	100 MILE CRUISE			400 MILE CRUISE			1000 MILE CRUISE			% OF TOTAL SYSTEM
	INITIAL PROCURE- MENT	5 YEARS OPER- ATION	% OF TOTAL SYSTEM	INITIAL PROCURE- MENT	5 YEARS OPER- ATION	% OF TOTAL SYSTEM	INITIAL PROCURE- MENT	5 YEARS OPER- ATION	% OF TOTAL SYSTEM	
	(\$000,000)									
INSTALLATIONS	14.516		14.516	1.90		15.142	1.87		16.510	1.87
EQUIPMENT	449.769	2.099	451.868	58.40		456.965	2.725	459.690	473.527	3.837
PERSONNEL		54.111	54.111	7.00			55.611	55.611		57.111
TRANSPORTATION		.826	.826	.01			.986	.986		1.429
STOCKS	84.825		84.825	11.00		100.785		100.785	141.638	
EXPENDABLES		41.365	41.365	5.35			49.365	49.365		71.485
MAINTENANCE		126.240	126.240	16.34			127.249	127.249		127.499
TOTAL SYSTEM COST	549.110	224.641	773.751			572.892	235.936	808.828	631.675	261.361
% OF TOTAL	71.0	29.0	100.0			70.8	29.2	100.0	70.7	29.3
										100.0

Figure 10-6. Submarine Strike Weapons System Sample Cost Schedule.

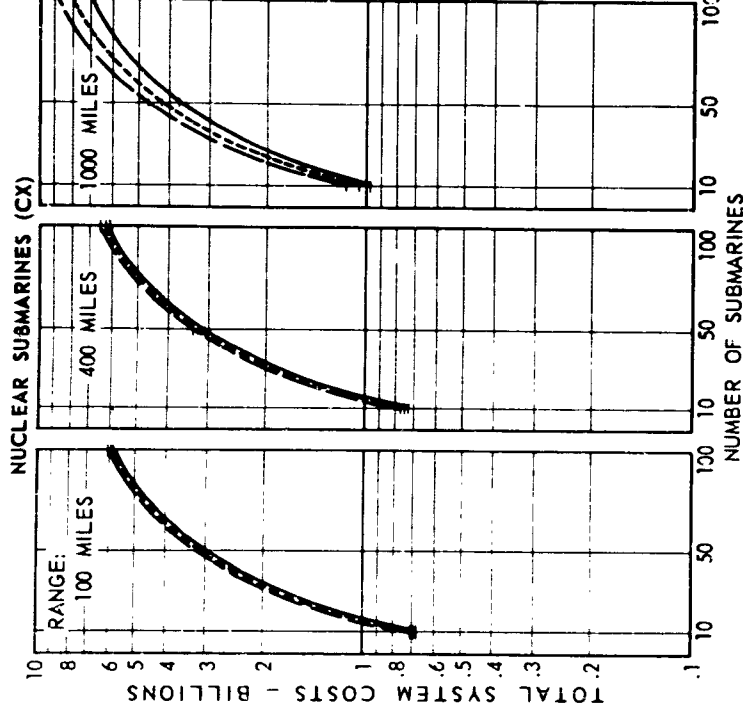
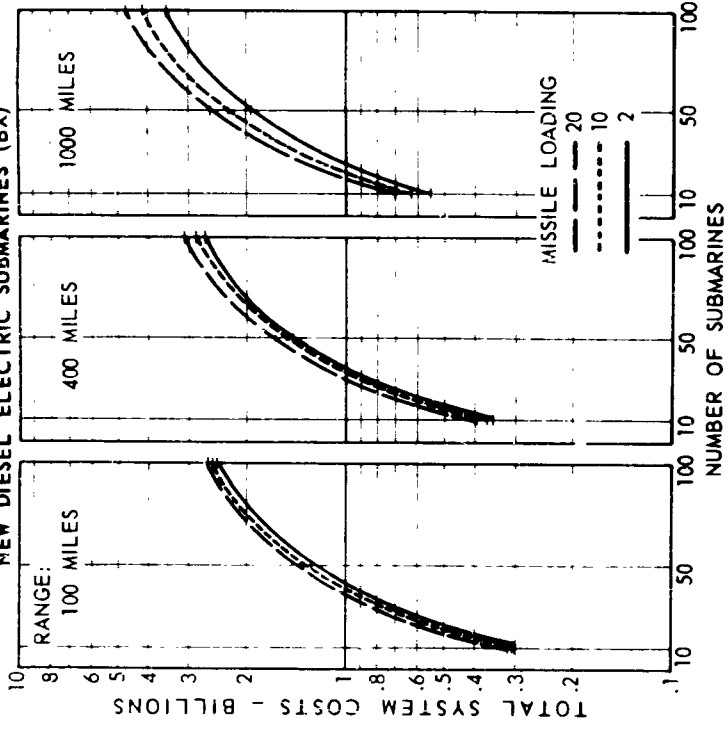
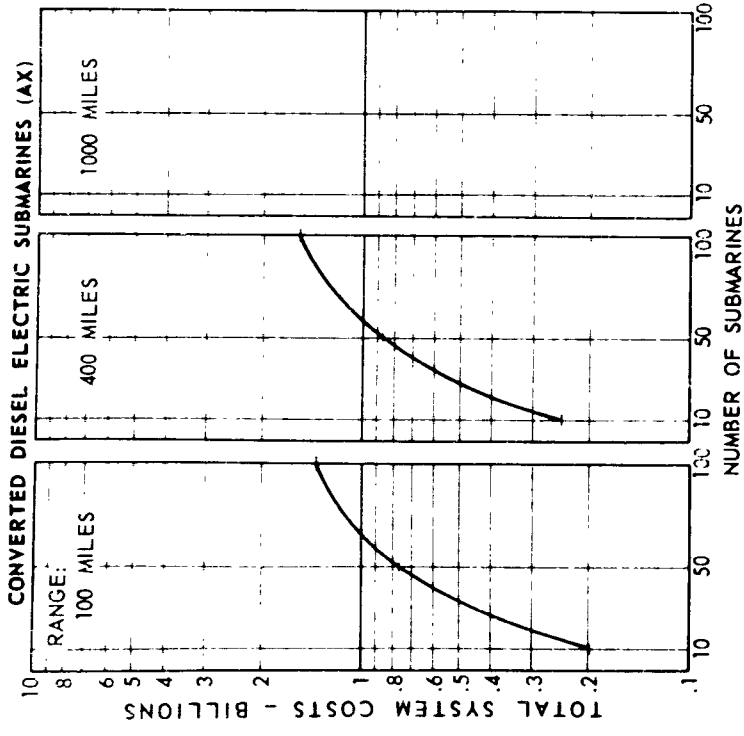
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SUBMARINE STRIKE WEAPONS SYSTEM - BASIC COST CHARTS

BALLISTIC MISSILES - 100 TARGETS



Submarine Weapon System

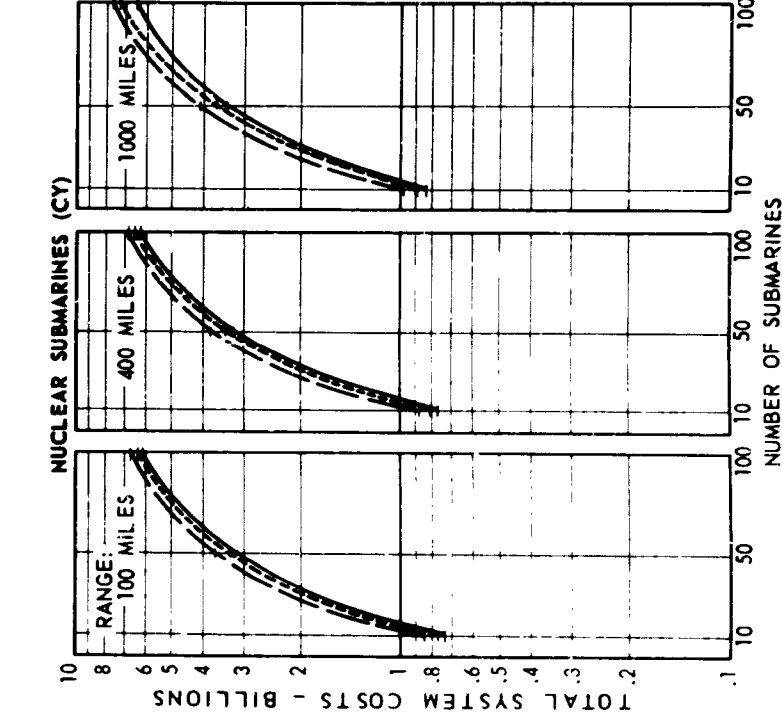
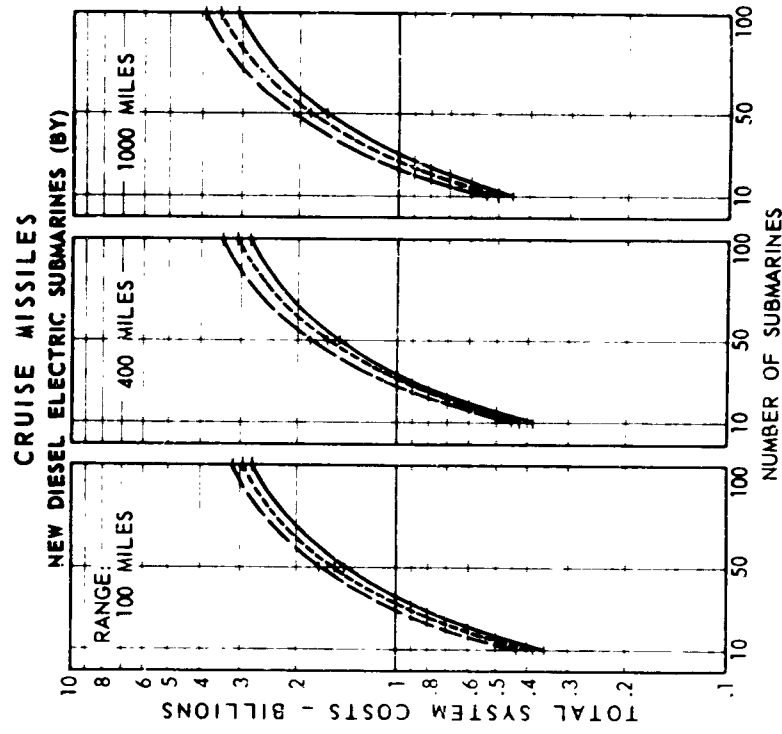
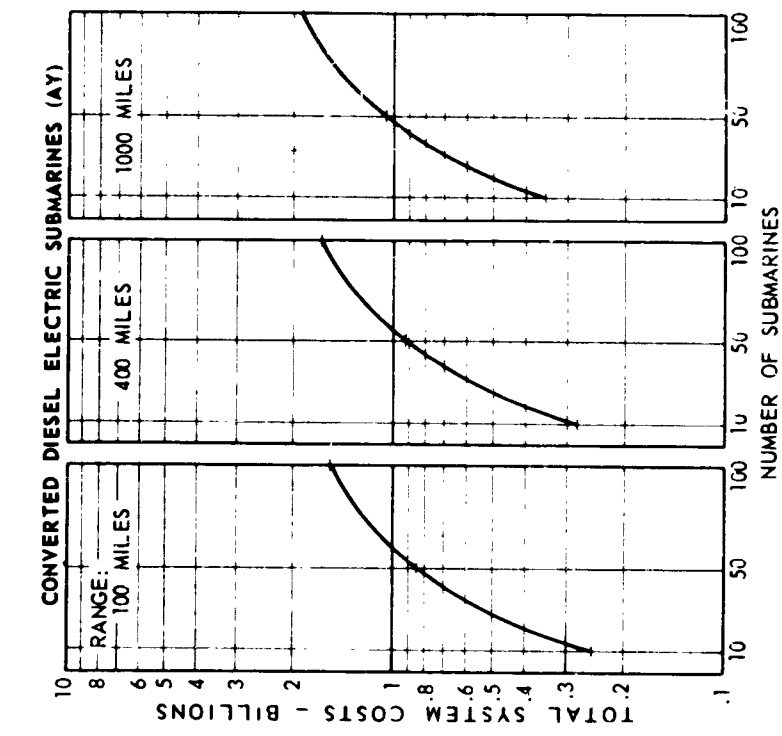


Figure 10-7. Submarine Strike Weapons System - Basic Cost Charts (Ballistic Missiles - 100 Targets).

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SUBMARINE STRIKE WEAPONS SYSTEM - BASIC COST CHARTS

FIG. 10-8

BALLISTIC MISSILES - 300 TARGETS

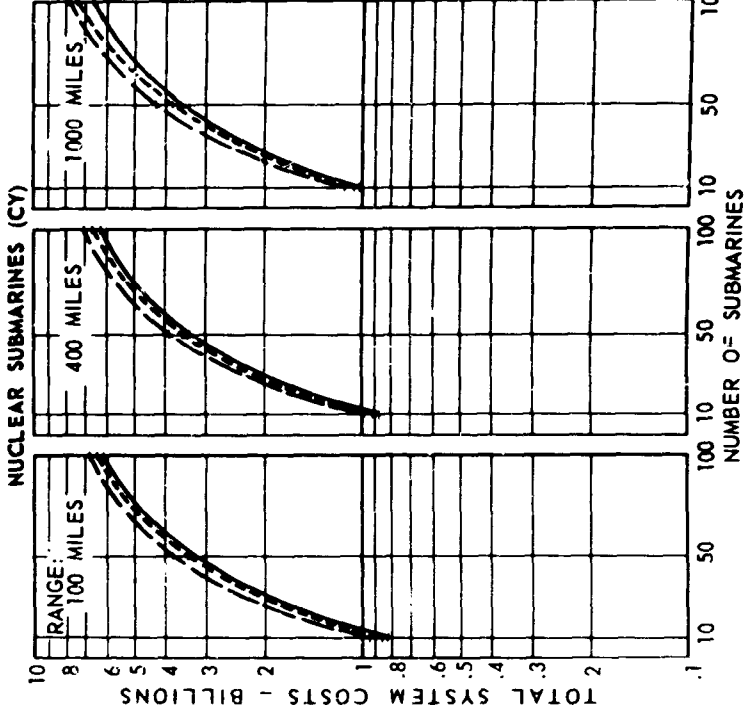
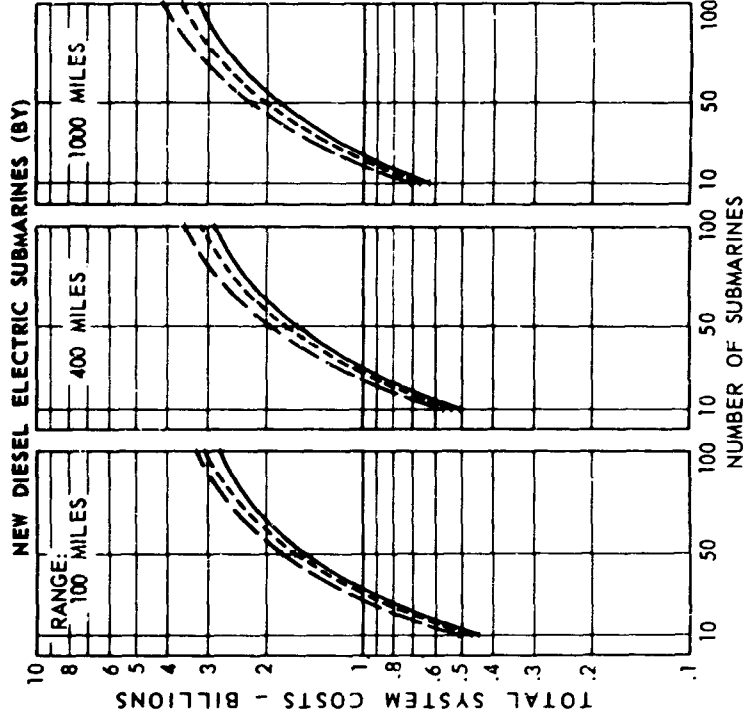
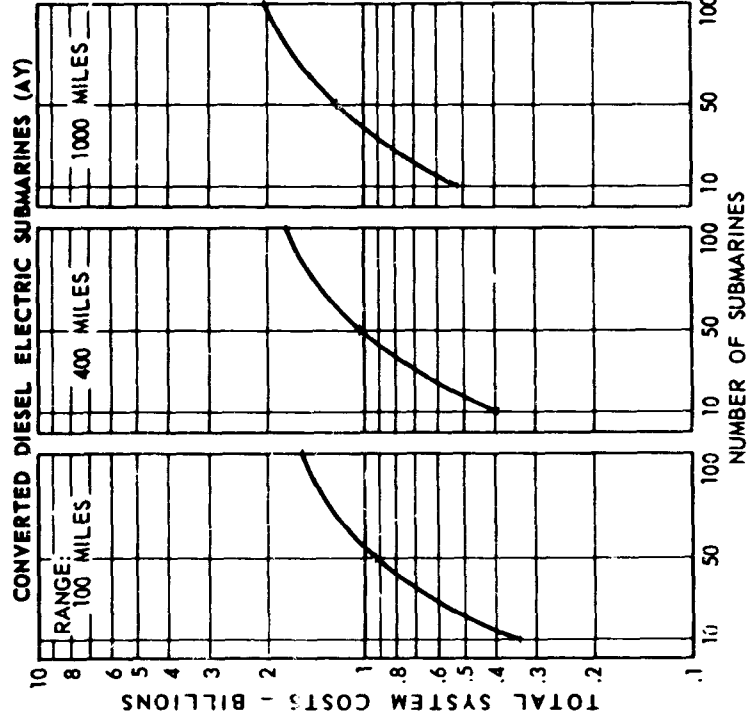
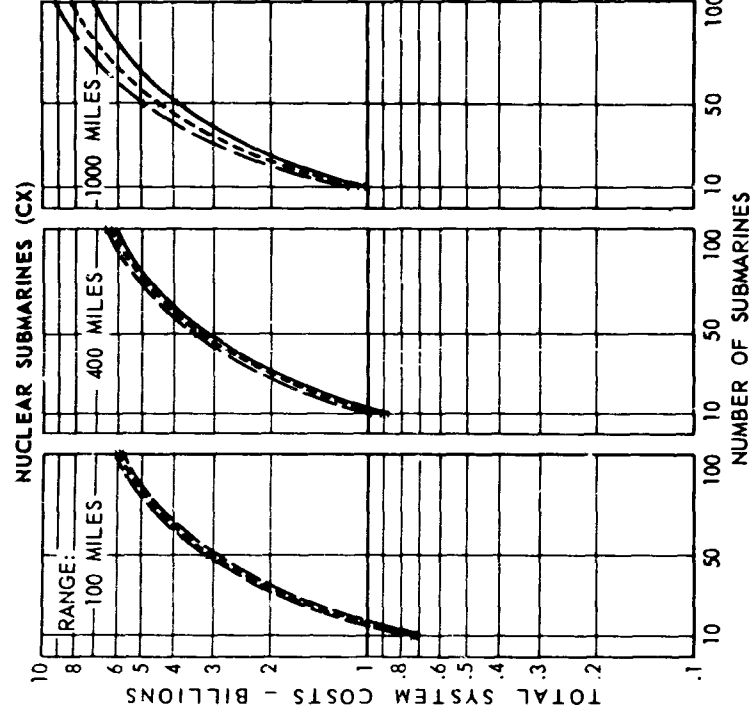
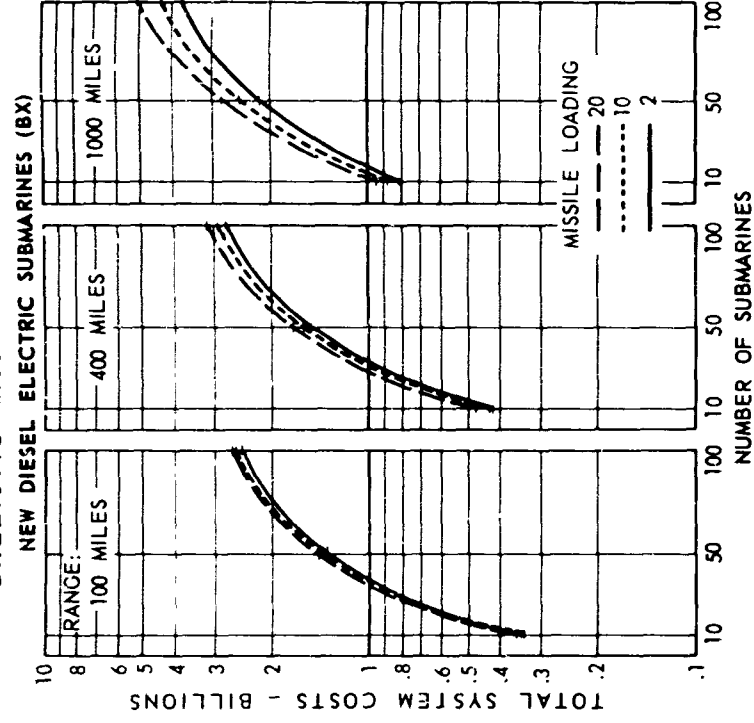
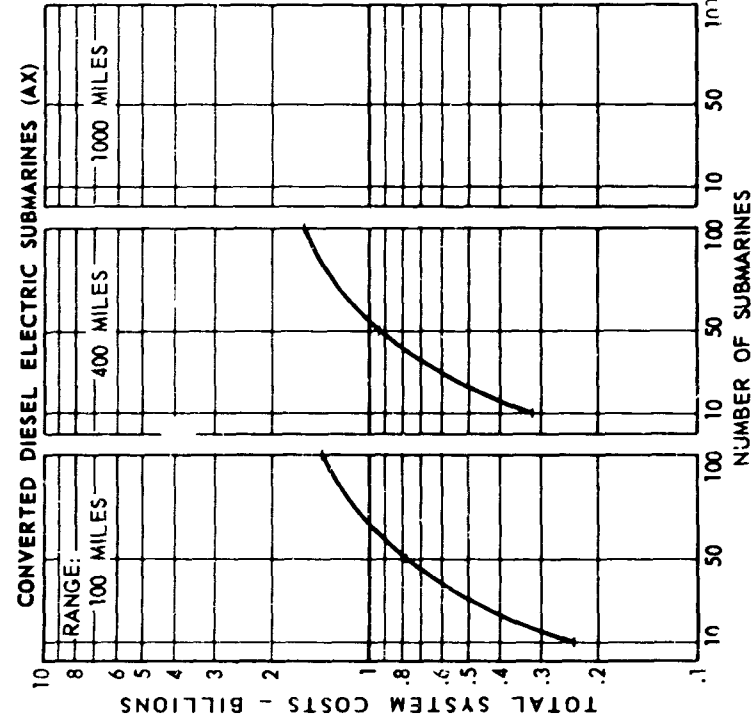


Figure 10-8. Submarine Strike Weapons System - Basic Cost Charts (Ballistic Missiles - 300 Targets).

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Chapter 11 OPERATIONAL AVAILABILITY AND SYSTEM GROWTH

In the evaluation of the various configurations of the strike-submarine weapon system, the factors of operational availability and system growth potential of each configuration need to be considered. One that would become available in 1968 would be of less value to this period of 1960-1970 as compared to one available in 1961. Similarly, a configuration possessing the possibility of future growth would be more desirable than one of equal effectiveness and the same availability date but possessing little or no growth potential.

Consistent with the assumptions made in Chapter 1, the various configurations of the weapon system described in Chapter 6, and an assumed go-ahead date of January 1957, for initiating work on the weapon system, the operational availability of the weapon system is presented. The basis for and the method of determining the operational availability of the weapon system is presented in Volume II, Part G.

The data presented are based on the assumption that the future rate of expenditure of effort on the United States military program will be approximately the same during the next 15 years as it has been during the past few years. The expenditures for the military program of the United States are discussed in Volume II, Part G.

DEFINITIONS

The definitions of weapon system operational availability and system growth, as the terms are employed in this study, are as follows:

1. Weapon system operational availability means:
 - a. The weapon system satisfies operational requirements.
 - b. Adequate quantities of the system's components have been delivered so that tactical employment may be initiated.
 - c. Production of the system's components is at a level sufficient to sustain tactical employment of the weapon system.
 - d. Supporting services, such as logistics and personnel, to the system are adequate and functioning.
2. Weapon system growth means the system's increase in performance with the passage of time. This increase in performance may result from modifications to the system and/or advancements in basic technology affecting the system, such as the introduction of new fuels.

OPERATIONAL AVAILABILITY

The operational availability and growth potential of each system configuration has to be determined in the evaluation of the weapon system. This necessitates that each

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component of a configuration be considered to determine its effect on the whole. A configuration of the strike-submarine weapon system consists of the following major components: submarine, guided missile, logistics, and personnel. The availability of the missile and/or the submarine will determine the availability of the system, since the training of personnel and the modification of the logistic system occur during the design, production, and test phases of the missile and/or the submarine.

Part G of Volume II establishes budgetary limitations which may be expected to apply to the strike-submarine weapon system. These limitations are \$50,000,000, minimum annual rate; and \$275,000,000, maximum annual rate, for submarine construction based on an analysis of recent Navy budgets. For the purpose of determining the availability of the submarine component of the weapon system, an annual rate of expenditure of \$200,000,000 per year was assumed. On the basis of recent Navy budgets for aircraft and related procurement and the missile cost data in Chapter 10, the operational availability of the missile component of the system should not be influenced by budgetary considerations.

1. Operational Availability — New Missile Designs

Figure 11-1, which is based on the time requirements of the various United States guided missile programs, presents the time required for a new guided missile design to become operationally available. The analysis of the missile programs reveals that a design based essentially on the same knowledge employed in a preceding missile design will become available in about 80% of the time of the preceding missile, as shown in Figure 11-1. Data on missile characteristics are presented in Chapter 3.

Figure 11-2 is a schedule of a typical guided missile program. It will be noted that there is sufficient time while the production model is undergoing operational suitability testing for the rate of production and the stockpile of missiles to reach levels which permit missile operational availability.

2. Operational Availability — New Submarine Designs

The time required for the first unit or units of a new submarine design to become available is presented in Figure 11-3. The availability of the submarine component of the weapon system, as shown in Figures 11-5 and 11-6, is dependent on the following variables: submarine size, number of submarines, annual rate of expenditure for submarines, and the type of submarine. Data on submarine characteristics are presented in Chapter 4.

3. Operational Availability — Existing Missile and Submarine Designs

Figure 11-4 presents the data on the availability of missiles either currently available or in the process of design and production. The dates shown do not include any allowance for the time that would be required should it be necessary to modify a missile in order to be able to launch it from a submarine.

There are three types of submarines either currently available or in the process of design and construction that could be employed in the weapon system. Two of these, the new guided missile-submarine currently in design and the nuclear powered NAUTILUS type, essentially constitute new submarine designs and their availability would be determined from the data presented in Figure 11-3. The availability of the diesel-electric fleet-type submarine of World War II would be dependent on the extent of the conversion required to enable the submarine to carry and launch missiles, which is dependent on the missile to be employed. The availability of the converted fleet-type submarine is presented in Figures 11-5 and 11-6.

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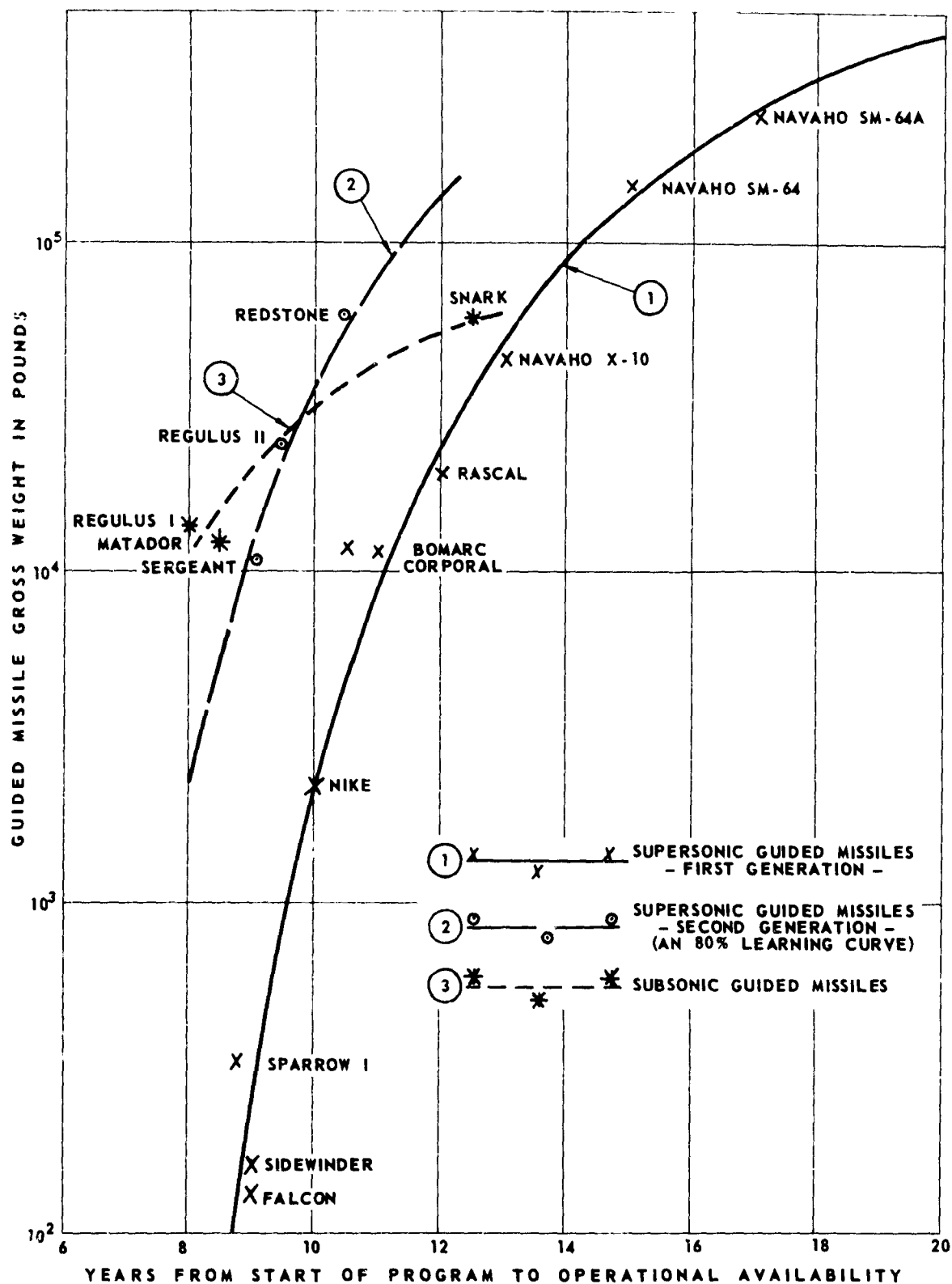


Figure 11-1. Guided Missile Development.

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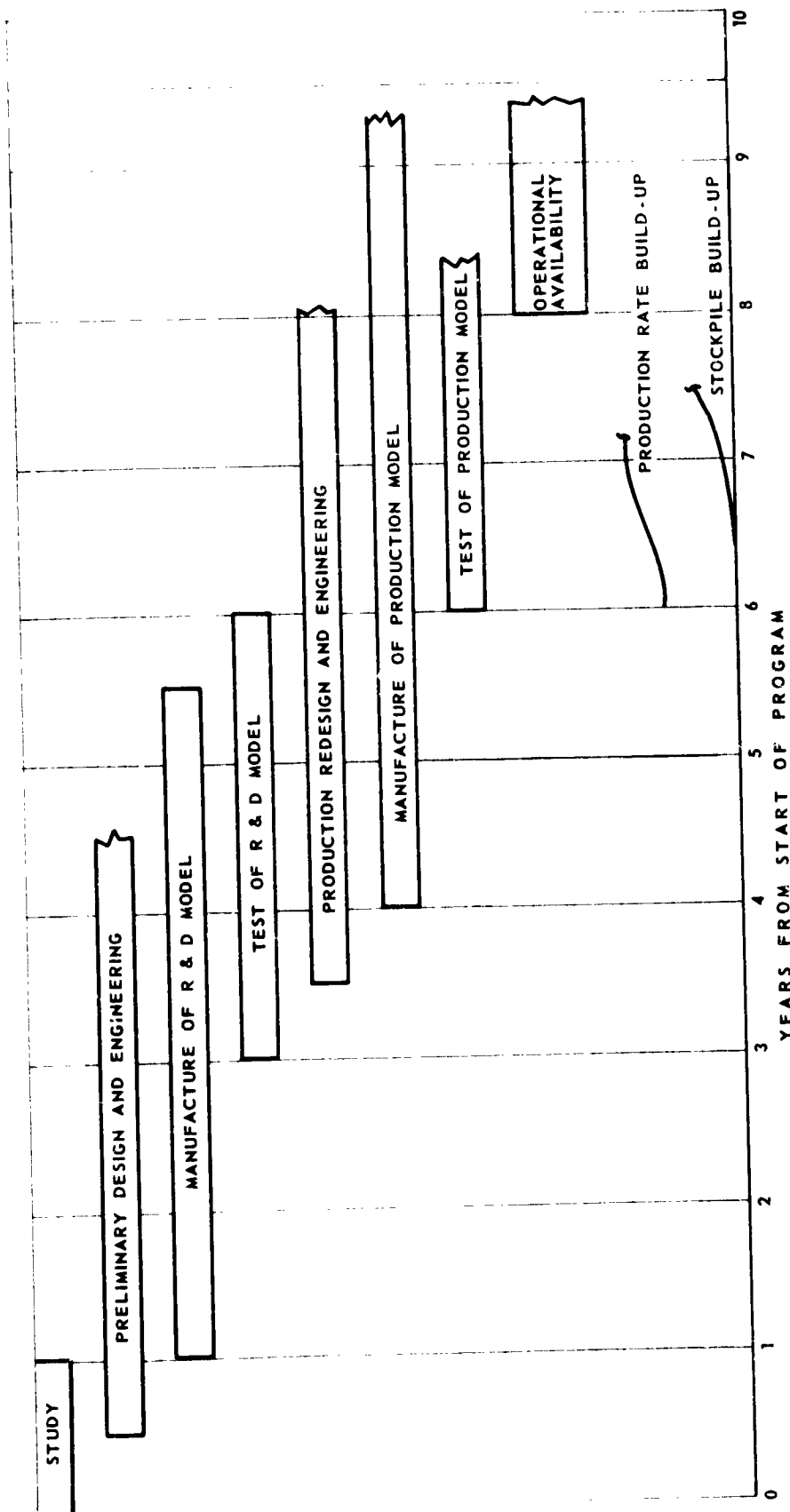


Figure 11-2. Typical Guided Missile Program Schedule.

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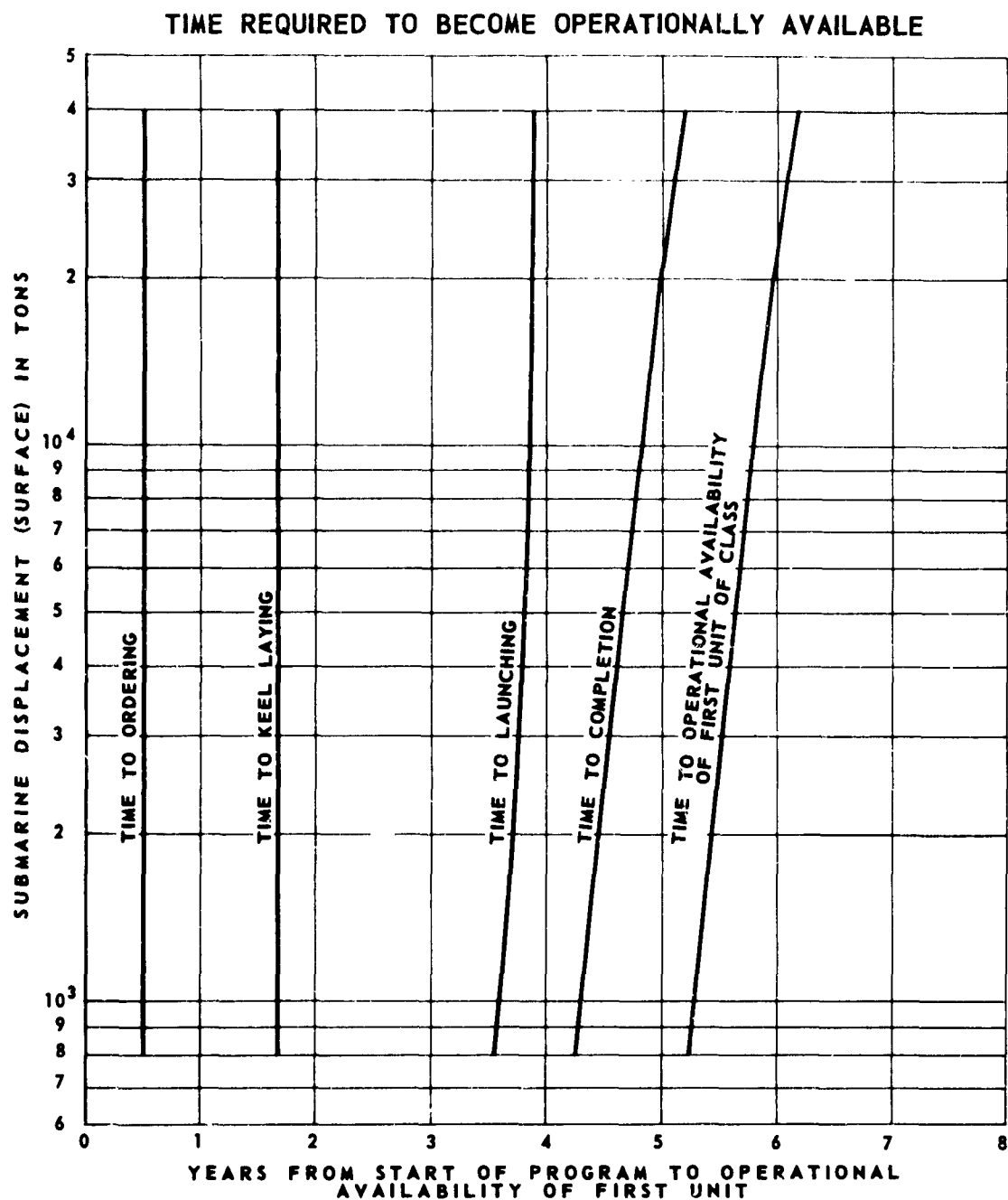


Figure 11-3. Submarine Development.

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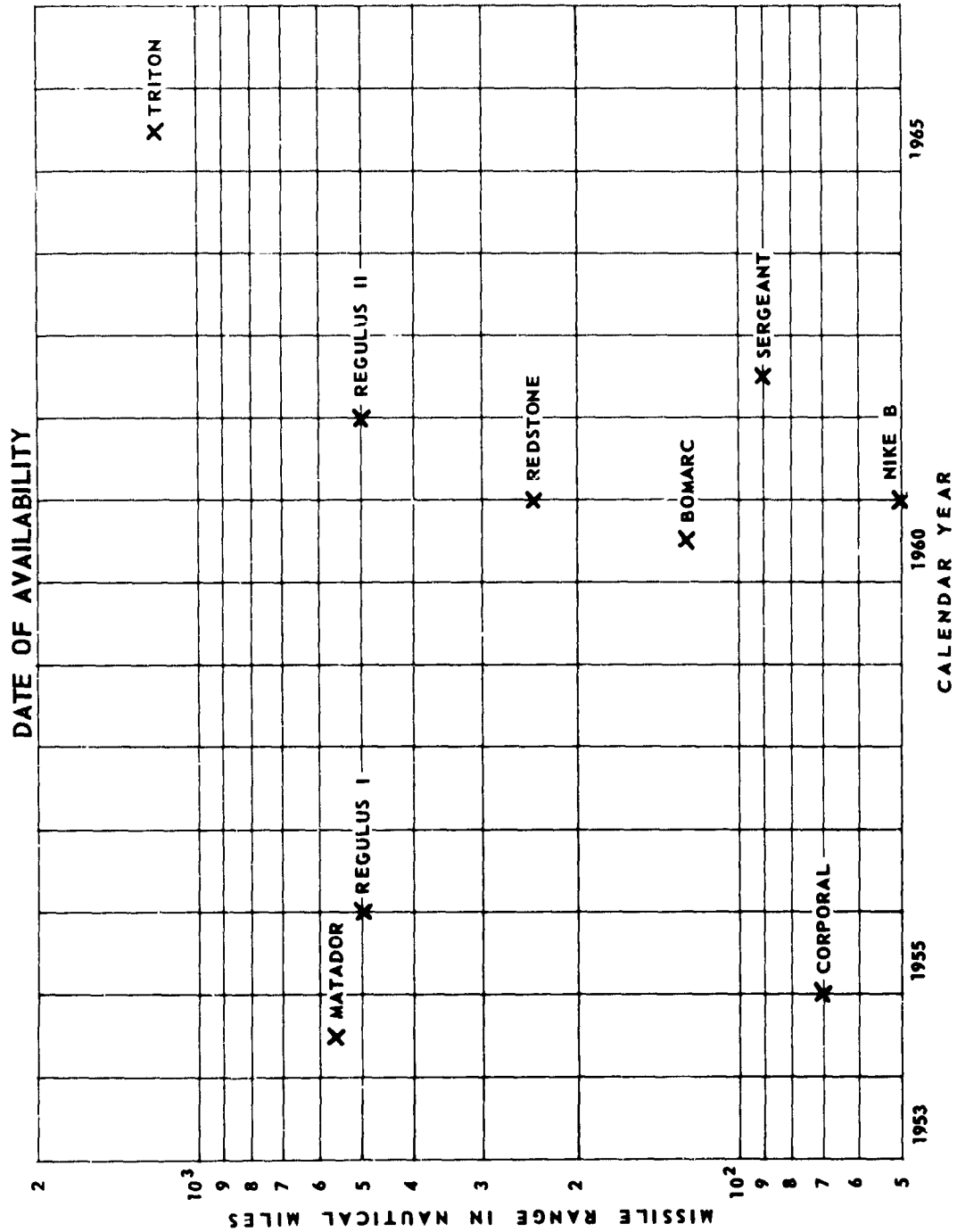
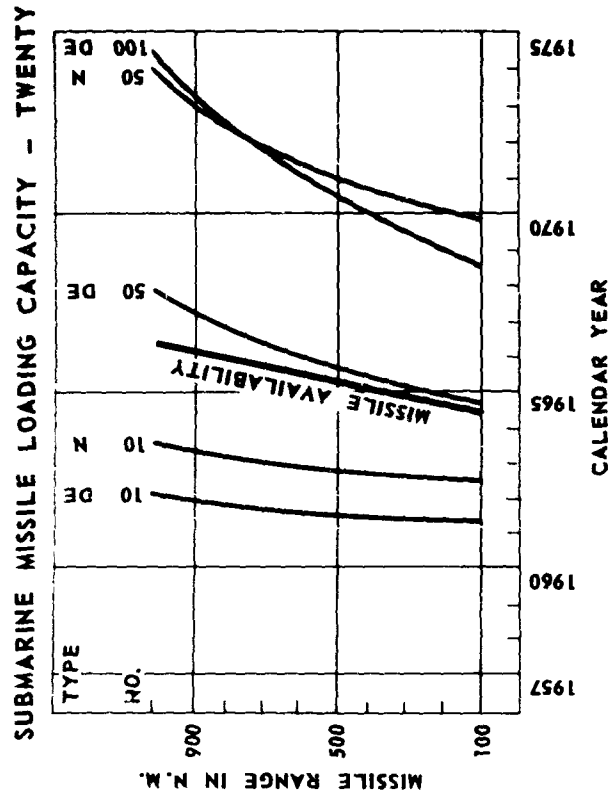
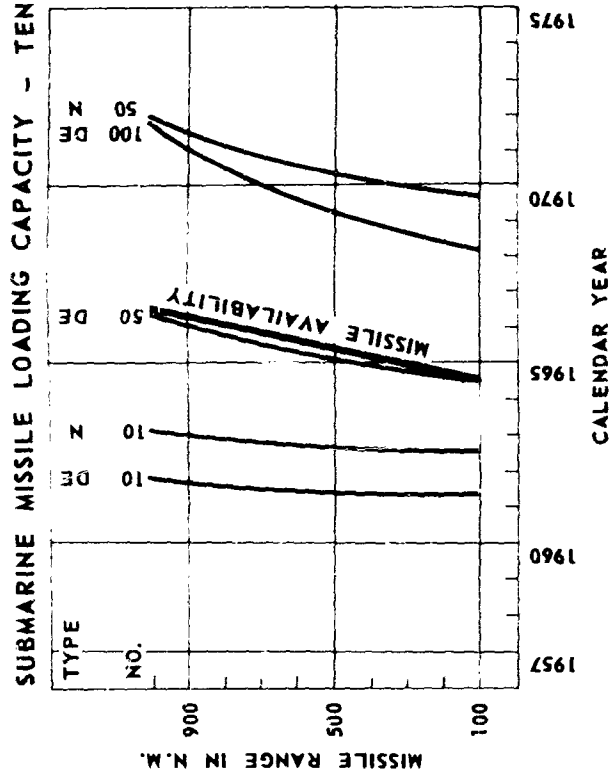
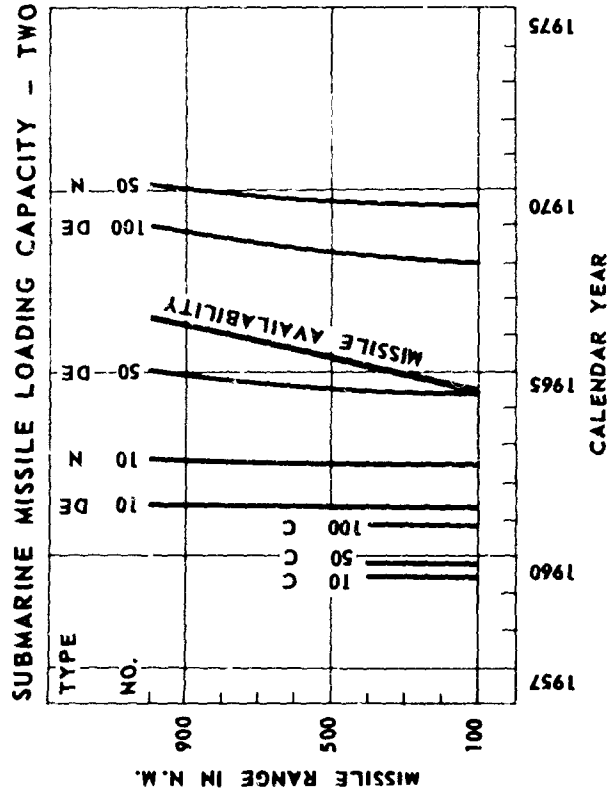


Figure 11-4. Operational Availability of Existing Guided Missile Programs.

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LIQUID PROPELLANT BALLISTIC GUIDED MISSILE
GO-AHEAD DATE - JANUARY, 1957



DETERMINATION OF WEAPON SYSTEM OPERATIONAL AVAILABILITY

NO WEAPON SYSTEM CAN BE AVAILABLE PRIOR TO THE DATE OF MISSILE AVAILABILITY. THE SUBMARINE AVAILABILITY CURVES TO THE LEFT OF THE MISSILE AVAILABILITY CURVE ARE SHOWN FOR INFORMATION PURPOSES ONLY AND DO NOT DETERMINE SYSTEM OPERATIONAL AVAILABILITY.

TO ILLUSTRATE THE EMPLOYMENT OF THE THREE CHARTS ABOVE IN THE DETERMINATION OF THE OPERATIONAL AVAILABILITY OF THE STRIKE-SUBMARINE WEAPON SYSTEM, TWO EXAMPLES ARE PRESENTED BELOW:

1. FIRST, A WEAPON SYSTEM CONSISTING OF TEN NUCLEAR SUBMARINES (SUBMARINE MISSILE LOADING CAPACITY OF TWO) AND FIVE HUNDRED NAUTICAL MILE RANGE MISSILES WOULD BECOME AVAILABLE THE MIDDLE OF 1966. THE AVAILABILITY OF THE SYSTEM BEING LIMITED BY MISSILE AVAILABILITY.
2. SECOND, A WEAPON SYSTEM CONSISTING OF ONE HUNDRED DIESEL-ELECTRIC SUBMARINES (SUBMARINE MISSILE LOADING CAPACITY OF TWENTY) AND NINE HUNDRED NAUTICAL MILE RANGE MISSILES WOULD BECOME AVAILABLE ABOUT THE MIDDLE OF 1974. THE AVAILABILITY OF THE SYSTEM WOULD IN THIS CASE BE LIMITED BY SUBMARINE AVAILABILITY.

NOTES:

MISSILE WARHEAD - 1500 LB.

NUCLEAR SUBMARINE SPEED SUBMERGED - 25 KNOTS

DIESEL-ELECTRIC SUBMARINE SPEED SURFACED - 20 KNOTS

LIQUID PROPELLANT - LIQUID OXYGEN AND HYDRAZINE

ANNUAL RATE OF EXPENDITURE FOR SUBMARINES -

TWO HUNDRED MILLION DOLLARS

TYPE OF SUBMARINES - (DE) NEW DIESEL-ELECTRIC SUBMARINE

(N) NEW NUCLEAR SUBMARINE

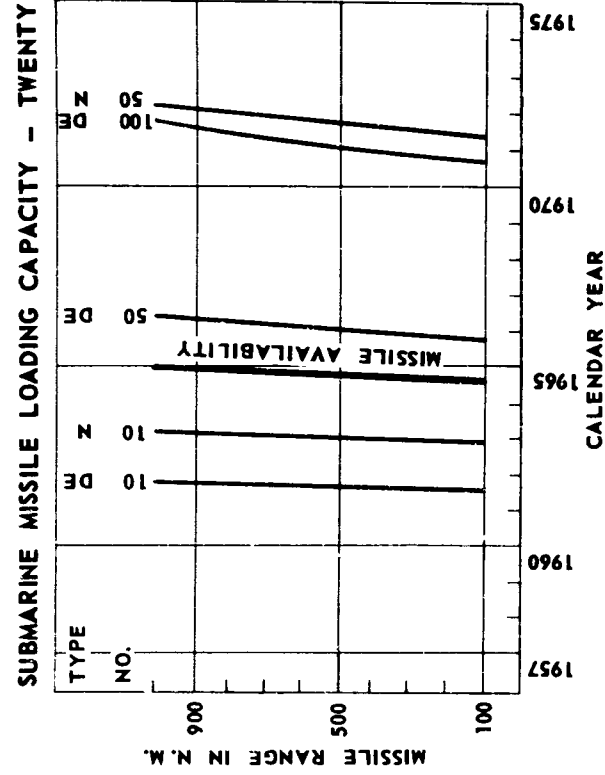
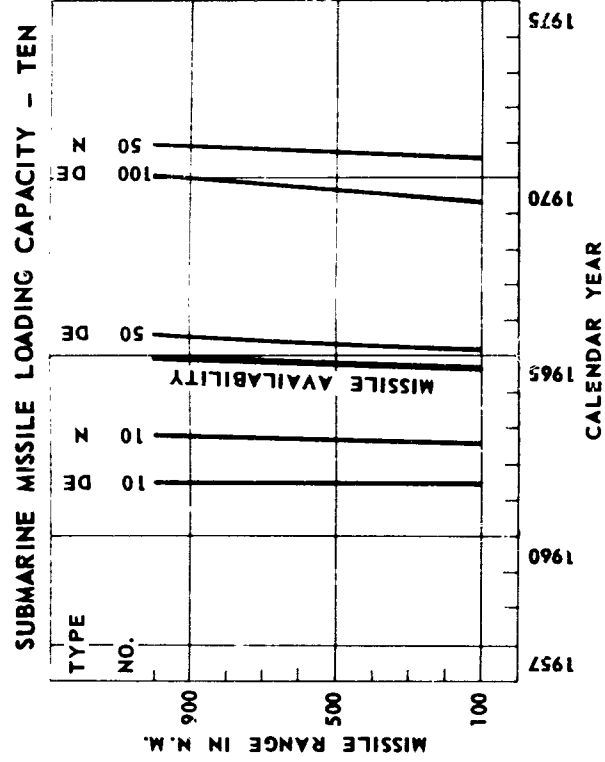
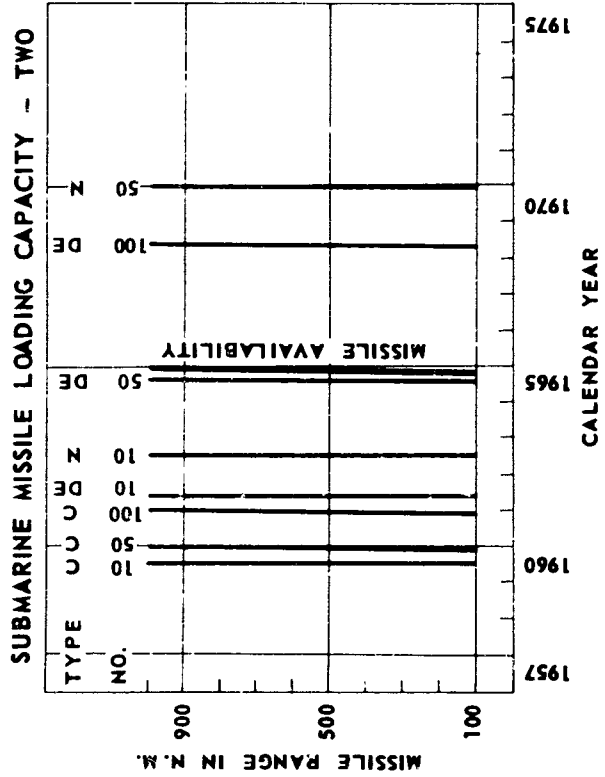
(C) CONVERTED DIESEL-ELECTRIC WORLD WAR II

FLEET TYPE SUBMARINE

Figure 11-5. Strike - Submarine Weapon System Operational Availability (Liquid Propellant Ballistic Guided Missile).

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MACH 3.5 RAMJET CRUISE GUIDED MISSILE
GO-AHEAD DATE - JANUARY, 1957



DETERMINATION OF WEAPON SYSTEM OPERATIONAL AVAILABILITY

NO WEAPON SYSTEM CAN BE AVAILABLE PRIOR TO THE DATE OF MISSILE AVAILABILITY. THE SUBMARINE AVAILABILITY CURVES TO THE LEFT OF THE MISSILE AVAILABILITY CURVE ARE SHOWN FOR INFORMATION PURPOSES ONLY AND DO NOT DETERMINE SYSTEM OPERATIONAL AVAILABILITY.

TO ILLUSTRATE THE EMPLOYMENT OF THE THREE CHARTS ABOVE IN THE DETERMINATION OF THE OPERATIONAL AVAILABILITY OF THE STRIKE-SUBMARINE WEAPON SYSTEM, TWO EXAMPLES ARE PRESENTED BELOW:

1. FIRST, A WEAPON SYSTEM CONSISTING OF TEN NUCLEAR SUBMARINES (SUBMARINE MISSILE LOADING CAPACITY OF TWO) AND FIVE HUNDRED NAUTICAL MILE RANGE MISSILES WOULD BECOME AVAILABLE THE LATTER PART OF 1965. THE AVAILABILITY OF THE SYSTEM BEING LIMITED BY MISSILE AVAILABILITY.
2. SECOND, A WEAPON SYSTEM CONSISTING OF ONE HUNDRED DIESEL-ELECTRIC SUBMARINES (SUBMARINE MISSILE LOADING CAPACITY OF TWENTY) AND NINE HUNDRED NAUTICAL MILE RANGE MISSILES WOULD BECOME AVAILABLE THE MIDDLE OF 1972. THE AVAILABILITY OF THE SYSTEM WOULD IN THIS CASE BE LIMITED BY SUBMARINE AVAILABILITY.

NOTES:

- MISSILE WARHEAD - 1500 LB.
- NUCLEAR SUBMARINE SPEED SUBMERGED - 25 KNOTS
- DIESEL-ELECTRIC SUBMARINE SPEED SURFACED - 20 KNOTS
- ANNUAL RATE OF EXPENDITURE FOR SUBMARINES - TWO HUNDRED MILLION DOLLARS
- TYPE OF SUBMARINES - (DE) NEW DIESEL-ELECTRIC SUBMARINE
- (N) NEW NUCLEAR SUBMARINE
- (C) CONVERTED DIESEL-ELECTRIC WORLD WAR II FLEET TYPE SUBMARINE

Figure 11-6. Strike - Submarine Weapon System Operational Availability (Mach. 3.5 Ramjet Cruise Guided Missile).

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4. Operational Availability — Other Weapon System Components

While personnel and logistics are major components of the weapon system, they do not determine weapon system availability. Each of these components require less time than either the missile or the submarine to become available. Where the schedule of one of the above two components has to be integrated into either the missile or the submarine schedule, as the training or personnel does, this may be accomplished without affecting the availability of the system, as illustrated by World War II experience. Also, it is assumed that all warheads to be used in this study will be available by 1960 to 1962.

5. Charts Reflecting Operational Availability of a Weapon System

Figures 11-5 and 11-6 present the operational availability of the various configurations of the strike-submarine weapon system described in Chapter 6. It may be seen that in most cases the availability of the weapon system is limited by the missile availability. Where the submarine becomes the limiting factor, it does so only because of budgetary limitations. The data contained in these two figures are used in the development of the strike-submarine weapon system operational availability decision charts presented in Chapter 12.

SYSTEM GROWTH

As was stated above, system growth means the system's increase in performance with the passage of time. It is through possessing the capability of growth that the system is capable of accomplishing future missions and thereby extending its operational life. Growth of the weapon system may result from growth in the missile and/or the submarine, and that growth may result from modification to the component and/or advancements in the state of the art. The growth potential of the missile lies in such areas as: increased range, increased speed, reduced missile circular probable error, and more efficient warhead. Submarine growth potential may be realized in areas such as: reduced attrition rate, reduced navigational error, and increased missile loading capacity.

1. System Growth — Missile

The missile should be capable of growth with the passage of time. This could be accomplished through the capability of being able to accommodate future powerplants, guidance systems, and warheads. There are several advancements expected to occur prior to the end of the 1960-1970 period being considered in this study. These advancements could be in the fields of guidance and propulsion, as well as in other fields.

a. Propulsion

Pentaborane, with approximately 50% higher energy than present day fuels, will become available for airbreathing cruise missiles in about 1960-1961 (Project Zip). This will result in an increase of missile range of 75% to 90%.

The availability of liquid propellant fuels is as follows: liquid oxygen - JP-5 in 1960; liquid oxygen - hydrazine by 1965 (which is based on present know-how); and liquid fluorine - hydrazine or pentaborane by 1967-1968 (which will require advancements in the state of the art). The last will provide an increase in missile range of approximately 75% greater than the range obtained when employing the first fuel.

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Chapter 12 WEAPON SYSTEM SELECTION

Chapter 2 presented an outline of the measure of effectiveness employed as a basis for weapon system selection. This led to a series of decision charts (Figure 2-1) involving the following decision factors:

- Weapon System Cost
- System Operational Availability
- Mission Characteristics
- Budgetary Limitations
- System Growth Potential

Chapter 2 (Figure 2-3) also showed the relationship of the various steps preceding the assembly of the decision charts. These steps were quantitatively developed in Chapters 3 through 11.

This chapter presents the decision charts. These in turn provide the quantitative means by which weapon system selection can be effected. An example of selection of an optimum weapon system is given.

DECISION CHART INVOLVING TARGET CHARACTERISTICS

Chapter 7 provides the basis for Decision Chart I, Figure 12-3 or Figure 7-3, involving number of targets and target belt depth requirement for use with Figure 12-4.

DECISION CHARTS INVOLVING WEAPON SYSTEM COST AND OPERATIONAL AVAILABILITY

Figures 12-1 and 12-2 present the numerical solution of submarine force requirements, Chapter 9, associated total weapon system cost, Chapter 10, and year of operational availability, Chapter 11. Major weapon system characteristics are also listed. These data form the basis for Decision Chart II, Figure 12-4 and 12-5.

Figure 12-4 represents the decision chart involving weapon system cost and operational availability. Weapon system cost is plotted against coastal belt depth. Number of submarines and operational availability date is also noted.

Thus, weapon systems may be selected from Figure 12-4 at the belt depth defined by Decision Chart I from the point of view of cost, number of submarines required and operational availability dated. Any point selected from Figure 12-4 may be correlated with Figures 12-1 and 12-2 to obtain detail characteristics such as submarine displacement, missile gross weight, etc.

Many assumptions are underlying this study. It was not desired to omit from the decision chart those weapon systems which are costlier than the "least expensive one". This allows a possible critique on the assumptions. It also permits inclusion of qualifying considerations into the decision making.

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The availability of solid propellant fuels on the basis of impulse to weight ratios is as follows: a ratio in the order of 200 by 1965 (as compared to a ratio of about 168 for the Sergeant missile), and ratios in excess of 200 to 210 by 1967-1968 at the earliest (which will require advancements in the state of the art).

b. Guidance

With respect to cruise guided missiles, an all-inertial guidance system designed to a 1 mile circular probable error at the end of 3 hours of flight will be available in 1962, and an Atran (Automatic Terrain Recognition and Navigation) monitored all-inertial guidance system could be available for supersonic cruise missiles by 1965.

All-inertial guidance systems will be available for ballistic missiles by 1960. An inertial-radio command combination system will be available by about 1960. The problems associated with the re-entry of ballistic missiles into the atmosphere should be solved in sufficient time to permit the employment of the solution in missiles that would be available in 1965 or 1966. Data on missile guidance are presented in Chapter 5.

2. System Growth

The submarine would have growth potential by being capable of: being modified to accommodate different types of missiles and different sizes of missiles; being modified to accommodate new propulsion units; launching various types and sizes of missiles; accommodating future navigation systems. By 1960, it will be possible to navigate to within a maximum error of 1 mile whenever it is possible to employ celestial navigation. By 1965, a submarine inertial navigation system should be operationally available, which should enable the submarine to navigate to within a maximum error of 3 or 4 miles at all times. When the inertial system is combined with the celestial navigation, it should be possible to hold to within a circular probable error of one-half mile for a period of 10 hours, at least. Data on submarine navigation are presented in Chapter 5.

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Chapter 12 WEAPON SYSTEM SELECTION

Chapter 2 presented an outline of the measure of effectiveness employed as a basis for weapon system selection. This led to a series of decision charts (Figure 2-1) involving the following decision factors:

- Weapon System Cost
- System Operational Availability
- Mission Characteristics
- Budgetary Limitations
- System Growth Potential

Chapter 2 (Figure 2-3) also showed the relationship of the various steps preceding the assembly of the decision charts. These steps were quantitatively developed in Chapters 3 through 11.

This chapter presents the decision charts. These in turn provide the quantitative means by which weapon system selection can be effected. An example of selection of an optimum weapon system is given.

DECISION CHART INVOLVING TARGET CHARACTERISTICS

Chapter 7 provides the basis for Decision Chart I, Figure 12-3 or Figure 7-3, involving number of targets and target belt depth requirement for use with Figure 12-4.

DECISION CHARTS INVOLVING WEAPON SYSTEM COST AND OPERATIONAL AVAILABILITY

Figures 12-1 and 12-2 present the numerical solution of submarine force requirements, Chapter 9, associated total weapon system cost, Chapter 10, and year of operational availability, Chapter 11. Major weapon system characteristics are also listed. These data form the basis for Decision Chart II, Figure 12-4 and 12-5.

Figure 12-4 represents the decision chart involving weapon system cost and operational availability. Weapon system cost is plotted against coastal belt depth. Number of submarines and operational availability date is also noted.

Thus, weapon systems may be selected from Figure 12-4 at the belt depth defined by Decision Chart I from the point of view of cost, number of submarines required and operational availability dated. Any point selected from Figure 12-4 may be correlated with Figures 12-1 and 12-2 to obtain detail characteristics such as submarine displacement, missile gross weight, etc.

Many assumptions are underlying this study. It was not desired to omit from the decision chart those weapon systems which are costlier than the "least expensive one". This allows a possible critique on the assumptions. It also permits inclusion of qualifying considerations into the decision making.

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WEAPON SYSTEM DATA SUMMARY
100 TARGETS HIT

LOW LEVEL DEFENSE														HIGH LEVEL DEFENSE																									
Sub-Missile	Missile Loading (No.)	Coastal Belt Depth R ₁ (Miles)	Number of Submarines (No.)	Submarine Tonnage (Tons)	Optimum Missile Range R _m (Miles)	Unit Missile Gross Weight (Lbs)	Off-Shore Distance R ₂ (Miles)	Weapon System Cost (Billion Dollars)	Operational Availability (Year)	Sub-Missile	Missile Loading (No.)	Coastal Belt Depth R ₁ (Miles)	Number of Submarines (No.)	Submarine Tonnage (Tons)	Optimum Missile Range R _m (Miles)	Unit Missile Gross Weight (Lbs)	Off-Shore Distance R ₂ (Miles)	Weapon System Cost (Billion Dollars)	Operational Availability (Year)	Sub-Missile	Missile Loading (No.)	Coastal Belt Depth R ₁ (Miles)	Number of Submarines (No.)	Submarine Tonnage (Tons)	Optimum Missile Range R _m (Miles)	Unit Missile Gross Weight (Lbs)	Off-Shore Distance R ₂ (Miles)	Weapon System Cost (Billion Dollars)	Operational Availability (Year)										
CAMPAIGN DURATION: INSTANTANEOUS (ONE TRIP)														CAMPAIGN DURATION: INSTANTANEOUS (ONE TRIP)																									
Diesel Conversion - Ballistic (AX)	2	0	120	1525	150	6500	110	1.64	1965	Diesel Conversion - Ballistic (AX)	2	0	123	1525	420	15500	400	1.89	1966	Diesel Conversion - Ballistic (AX)	2	0	126	1525	600	24500	400	2.07	1966	Diesel Conversion - Ballistic (AX)	2	0	129	1525	810	27000	400	2.34	1966
New Diesel - Ballistic (BX)	20	0	120	1525	330	24000	30	1.75	1966	New Diesel - Ballistic (BX)	20	0	126	1525	900	46500	400	2.53	1967	New Diesel - Ballistic (BX)	20	0	129	1525	1170	53000	400	2.82	1967	New Diesel - Ballistic (BX)	20	0	132	1525	1560	69000	400	3.19	1967
Nuclear - Ballistic (CX)	20	0	120	1525	600	24000	0	2.00	1966	Nuclear - Ballistic (CX)	20	0	129	1525	1620	72000	400	2.29	1967	Nuclear - Ballistic (CX)	20	0	132	1525	2160	93000	400	2.58	1967	Nuclear - Ballistic (CX)	20	0	135	1525	2880	122000	400	3.44	1967
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS																									
Diesel Conversion - Ballistic (AX)	2	0	5	1525	1000	57500	860	0.35	1967	Diesel Conversion - Ballistic (AX)	2	0	6	1525	1000	57500	860	0.38	1967	Diesel Conversion - Ballistic (AX)	2	0	7	1525	1000	57500	860	0.41	1967	Diesel Conversion - Ballistic (AX)	2	0	8	1525	1000	57500	860	0.44	1967
New Diesel - Ballistic (BX)	20	0	5	1525	1000	57500	360	0.44	1967	New Diesel - Ballistic (BX)	20	0	6	1525	1000	57500	360	0.47	1967	New Diesel - Ballistic (BX)	20	0	7	1525	1000	57500	670	0.50	1967	New Diesel - Ballistic (BX)	20	0	8	1525	1000	57500	670	0.53	1967
Nuclear - Ballistic (CX)	20	0	5	1525	1000	57500	360	0.64	1967	Nuclear - Ballistic (CX)	20	0	6	1525	1000	57500	360	0.67	1967	Nuclear - Ballistic (CX)	20	0	7	1525	1000	57500	670	0.70	1967	Nuclear - Ballistic (CX)	20	0	8	1525	1000	57500	670	0.73	1967
CAMPAIGN DURATION: ONE MONTH														CAMPAIGN DURATION: ONE MONTH																									
Diesel Conversion - Ballistic (AX)	2	0	10	1525	1000	57500	860	0.35	1967	Diesel Conversion - Ballistic (AX)	2	0	11	1525	1000	57500	860	0.37	1967	Diesel Conversion - Ballistic (AX)	2	0	12	1525	1000	57500	860	0.39	1967	Diesel Conversion - Ballistic (AX)	2	0	13	1525	1000	57500	860	0.41	1967
New Diesel - Ballistic (BX)	20	0	10	1525	1000	57500	360	0.44	1967	New Diesel - Ballistic (BX)	20	0	11	1525	1000	57500	360	0.47	1967	New Diesel - Ballistic (BX)	20	0	12	1525	1000	57500	670	0.50	1967	New Diesel - Ballistic (BX)	20	0	13	1525	1000	57500	670	0.52	1967
Nuclear - Ballistic (CX)	20	0	10	1525	1000	57500	360	0.64	1967	Nuclear - Ballistic (CX)	20	0	11	1525	1000	57500	360	0.67	1967	Nuclear - Ballistic (CX)	20	0	12	1525	1000	57500	670	0.70	1967	Nuclear - Ballistic (CX)	20	0	13	1525	1000	57500	670	0.72	1967
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS																									
Diesel Conversion - Ballistic (AX)	2	0	5	1525	1000	57500	860	0.35	1967	Diesel Conversion - Ballistic (AX)	2	0	6	1525	1000	57500	860	0.38	1967	Diesel Conversion - Ballistic (AX)	2	0	7	1525	1000	57500	860	0.41	1967	Diesel Conversion - Ballistic (AX)	2	0	8	1525	1000	57500	860	0.44	1967
New Diesel - Ballistic (BX)	20	0	5	1525	1000	57500	360	0.44	1967	New Diesel - Ballistic (BX)	20	0	6	1525	1000	57500	360	0.47	1967	New Diesel - Ballistic (BX)	20	0	7	1525	1000	57500	670	0.50	1967	New Diesel - Ballistic (BX)	20	0	8	1525	1000	57500	670	0.52	1967
Nuclear - Ballistic (CX)	20	0	5	1525	1000	57500	360	0.64	1967	Nuclear - Ballistic (CX)	20	0	6	1525	1000	57500	360	0.67	1967	Nuclear - Ballistic (CX)	20	0	7	1525	1000	57500	670	0.70	1967	Nuclear - Ballistic (CX)	20	0	8	1525	1000	57500	670	0.72	1967

Figure 12-1. Weapon System Data Summary - 100 Targets Hit.

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WEAPON SYSTEM DATA SUMMARY
300 TARGETS HIT

LOW LEVEL DEFENSE												HIGH LEVEL DEFENSE															
Sub-Missile	Coastal Belt Loading Depth R ₁ (Miles)	Off-Shore Distance R ₂ (Miles)	Weapon System Cost (Billion Dollars)	Operational Availability (Year)	Sub-Missile	Coastal Belt Loading Depth R ₁ (Miles)	Off-Shore Distance R ₂ (Miles)	Weapon System Cost (Billion Dollars)	Operational Availability (Year)	Sub-Missile	Coastal Belt Loading Depth R ₁ (Miles)	Off-Shore Distance R ₂ (Miles)	Weapon System Cost (Billion Dollars)	Operational Availability (Year)													
CAMPAIGN DURATION: INSTANTANEOUS (ONE TRIP)														CAMPAIGN DURATION: ONE MONTH													
Diesel Conversion - Ballistic (AX)	2	0	110	4.20	1525	360	1525	210	8000	150	0	400	4.68	(Available On Two Trip Basis)	Diesel Conversion - Ballistic (AX)	2	0	110	4.68	(Available On Two Trip Basis)	Diesel Conversion - Ballistic (AX)	2	0	110	4.68	(Available On Two Trip Basis)	
New Diesel - Ballistic (BX)	20	0	110	7.26	1525	360	1525	210	8000	150	0	400	8.70	1989	New Diesel - Ballistic (BX)	20	0	110	8.70	1989	New Diesel - Ballistic (BX)	20	0	110	8.70	1989	
Nuclear - Ballistic (CX)	20	0	110	21.20	1525	360	1525	210	8000	150	0	400	21.10	2024	Nuclear - Ballistic (CX)	20	0	110	21.10	2024	Nuclear - Ballistic (CX)	20	0	110	21.10	2024	
CAMPAIGN DURATION: ONE MONTH														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.90	1525	360	1525	210	8000	150	0	400	0.96	1967	Diesel Conversion - Ballistic (AX)	2	0	110	0.96	1967	Diesel Conversion - Ballistic (AX)	2	0	110	0.96	1967	
New Diesel - Ballistic (BX)	20	0	110	1.07	1525	360	1525	210	8000	150	0	400	1.20	1967	New Diesel - Ballistic (BX)	20	0	110	1.20	1967	New Diesel - Ballistic (BX)	20	0	110	1.20	1967	
Nuclear - Ballistic (CX)	20	0	110	1.60	1525	360	1525	210	8000	150	0	400	1.92	1967	Nuclear - Ballistic (CX)	20	0	110	1.92	1967	Nuclear - Ballistic (CX)	20	0	110	1.92	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.63	1525	360	1525	210	8000	150	0	400	0.67	1967	Diesel Conversion - Ballistic (AX)	2	0	110	0.67	1967	Diesel Conversion - Ballistic (AX)	2	0	110	0.67	1967	
New Diesel - Ballistic (BX)	20	0	110	0.73	1525	360	1525	210	8000	150	0	400	0.84	1967	New Diesel - Ballistic (BX)	20	0	110	0.84	1967	New Diesel - Ballistic (BX)	20	0	110	0.84	1967	
Nuclear - Ballistic (CX)	20	0	110	1.02	1525	360	1525	210	8000	150	0	400	1.29	1967	Nuclear - Ballistic (CX)	20	0	110	1.29	1967	Nuclear - Ballistic (CX)	20	0	110	1.29	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.88	1525	360	1525	210	8000	150	0	400	0.88	1966	Diesel Conversion - Ballistic (AX)	2	0	110	0.88	1966	Diesel Conversion - Ballistic (AX)	2	0	110	0.88	1966	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.98	1525	360	1525	210	8000	150	0	400	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.98	1525	360	1525	210	8000	150	0	400	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.98	1525	360	1525	210	8000	150	0	400	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.98	1525	360	1525	210	8000	150	0	400	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.98	1525	360	1525	210	8000	150	0	400	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.98	1525	360	1525	210	8000	150	0	400	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.98	1525	360	1525	210	8000	150	0	400	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
Diesel Conversion - Ballistic (AX)	2	0	110	0.98	1525	360	1525	210	8000	150	0	400	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
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New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
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New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
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New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
CAMPAIGN DURATION: TWO MONTHS														CAMPAIGN DURATION: TWO MONTHS													
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New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.32	1525	360	1525	210	8000	150	0	400	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	Nuclear - Ballistic (CX)	20	0	110	2.80	1967	
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Diesel Conversion - Ballistic (AX)	2	0	110	0.98	1525	360	1525	210	8000	150	0	400	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	Diesel Conversion - Ballistic (AX)	2	0	110	1.05	1967	
New Diesel - Ballistic (BX)	20	0	110	1.15	1525	360	1525	210	8000	150	0	400	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	New Diesel - Ballistic (BX)	20	0	110	1.37	1967	
Nuclear - Ballistic (CX)	20	0	110	2.																							

Figure 12-2. Weapon System Data Summary - 300 Targets Hit.

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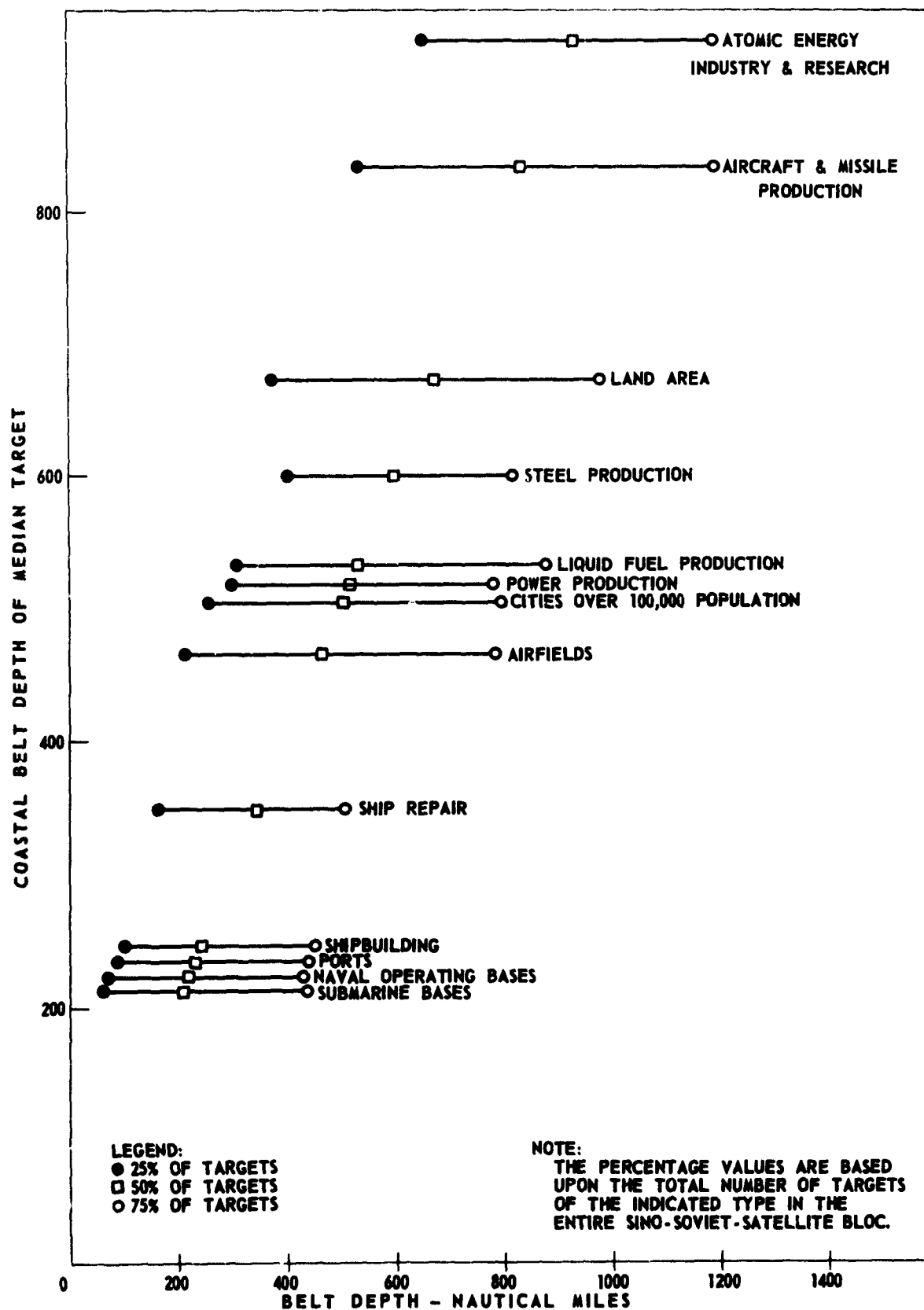
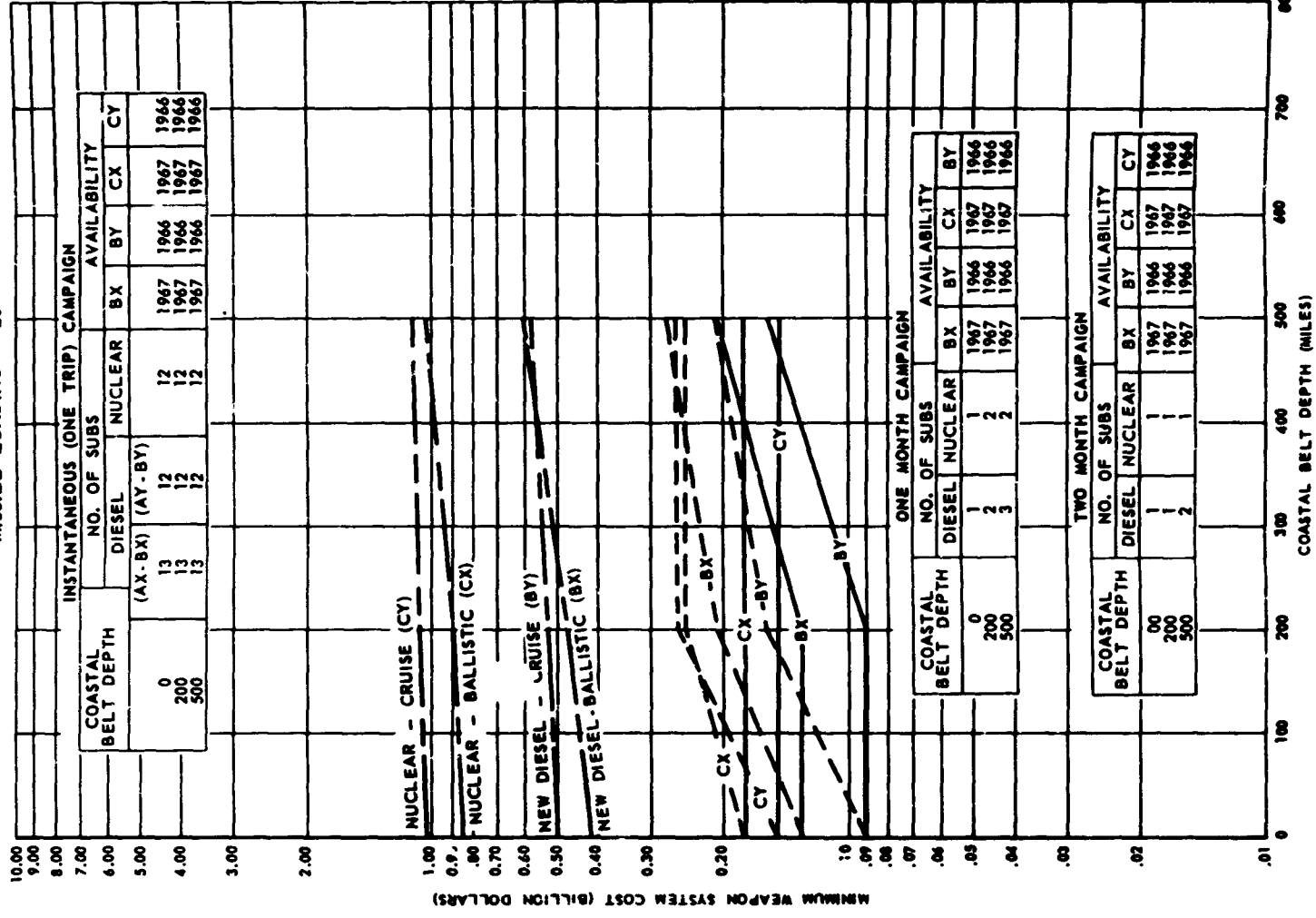


Figure 12-3. Decision Chart No. 1.

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WEAPON SYSTEM COST AND OPERATIONAL AVAILABILITY DECISION CHARTS

LOW LEVEL DEFENSE

MISSILE LOADING - 2

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WEAPON SYSTEM COST AND OPERATIONAL AVAILABILITY DECISION CHARTS

100 TARGETS HIT

HIGH LEVEL DEFENSE

MISSILE LOADING - 20

INSTANTANEOUS (ONE TRIP) CAMPAIGN

ONE MONTH CAMPAIGN

TWO MONTH CAMPAIGN

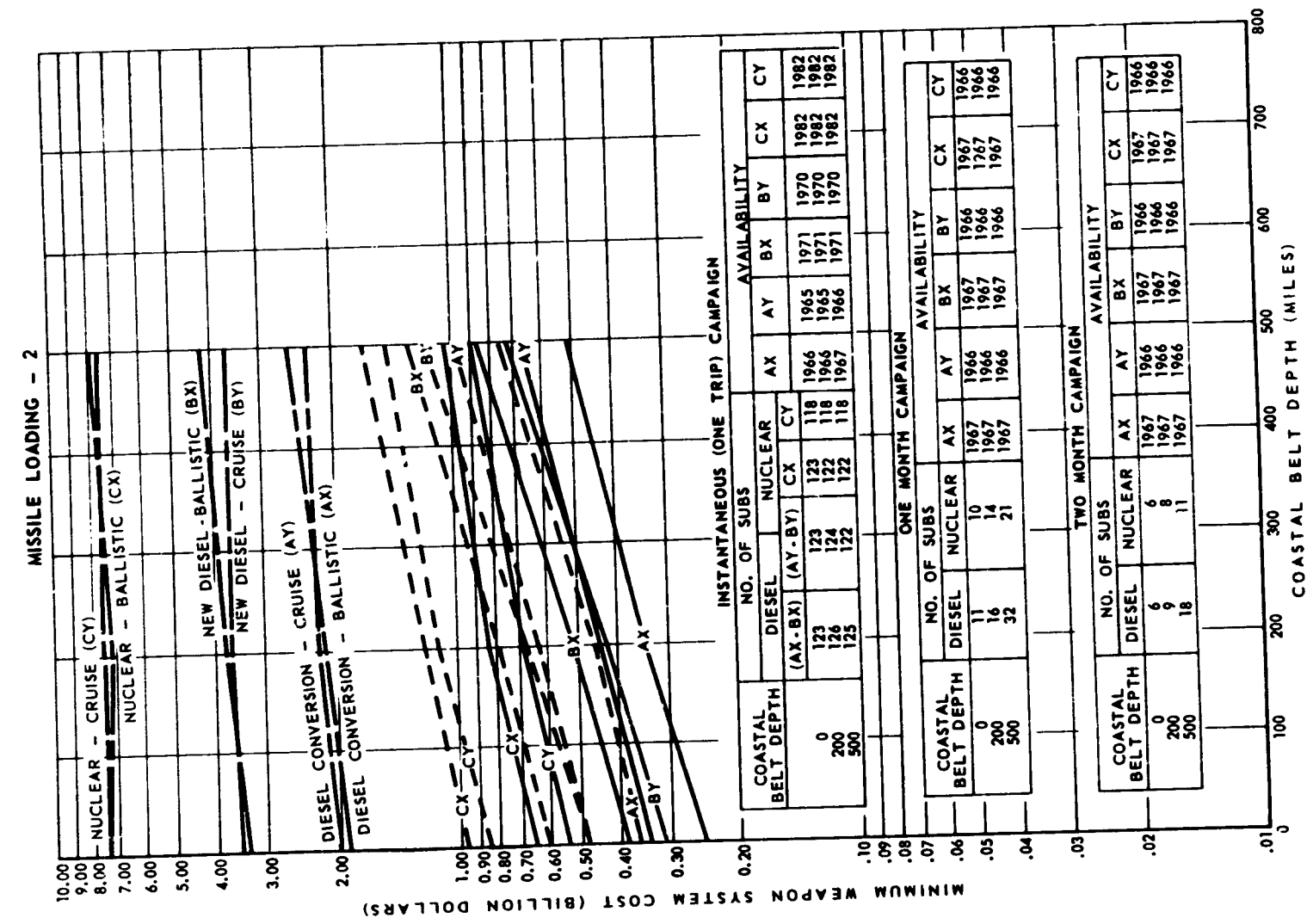


Figure 12-4. Weapon System Cost and Operational Availability Decision Charts Number II - 100 Targets Hit. Sheet 2 of 2

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WEAPON SYSTEM COST AND OPERATIONAL AVAILABILITY DECISION CHARTS

300 TARGETS HIT
LOW LEVEL DEFENSE

----- INSTANTANEOUS (ONE TRIP) CAMPAIGN
----- ONE MONTH CAMPAIGN
----- TWO MONTH CAMPAIGN

MISSILE LOADING - 2

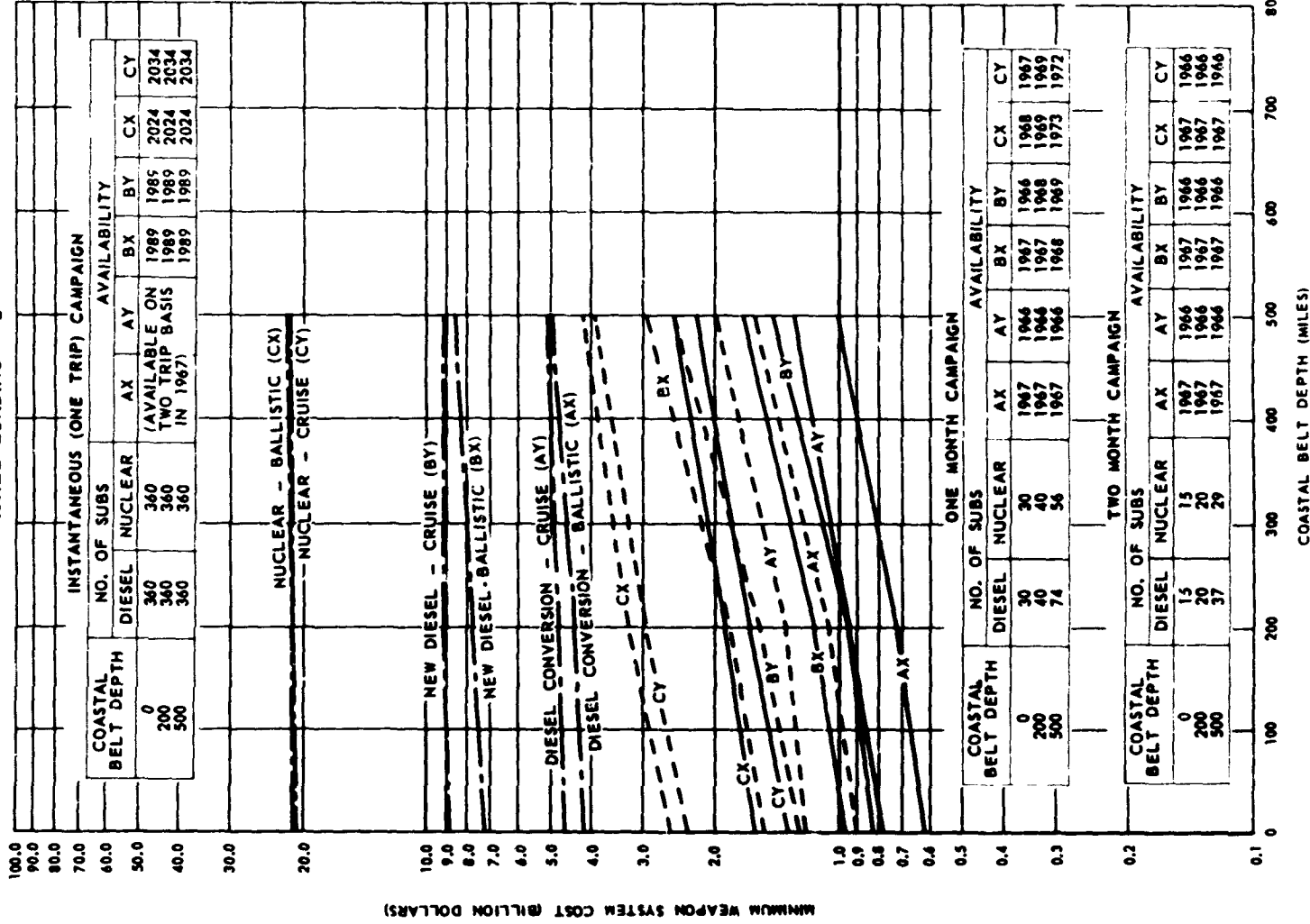


Figure 12-5. Weapon System Cost and Operational Availability Decision Charts - Number II - 300 Targets Hit. Sheet 1 of 2

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WEAPON SYSTEM COST AND OPERATIONAL AVAILABILITY DECISION CHARTS

2

300 TARGETS HIT

HIGH LEVEL DEFENSE

----- INSTANTANEOUS (ONE TRIP) CAMPAIGN
 ----- ONE MONTH CAMPAIGN
 ----- TWO MONTH CAMPAIGN

MISSILE LOADING - 2

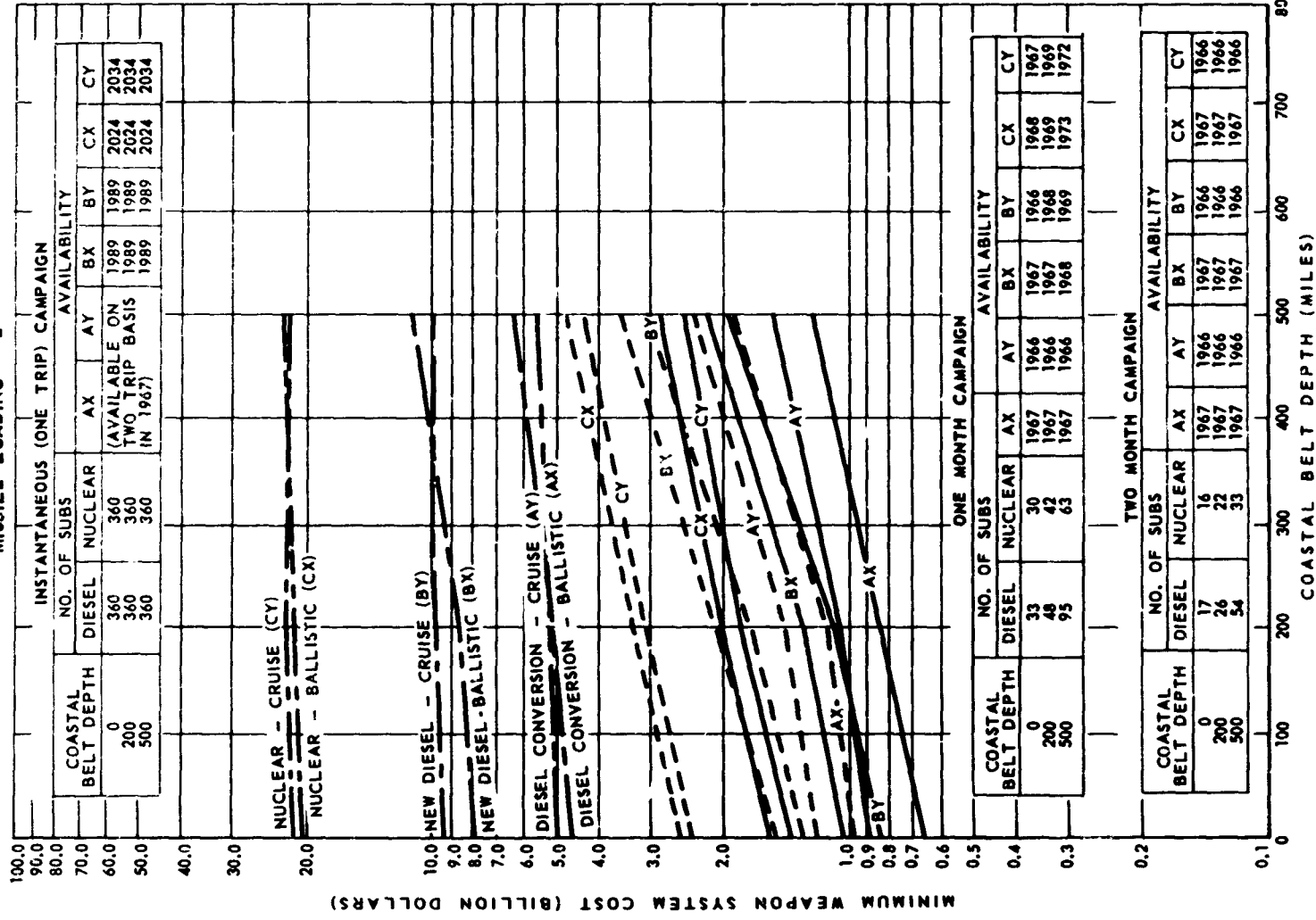


Figure 12-5. Weapon System Cost and Operational Availability Decision Charts - Number II - 300 Targets Hit.

Sheet 2 of 2

the force. For instance, he could decide that personnel requirements, operating requirements and administrative requirements should indicate approximately 20 submarines as a minimum number of submarines to have in the force.

- e. General Trends in Cost, Attrition, and Growth Potential — Selection of weapon system type may be made on the basis of cost consideration alone. However, when system costs are within a cost factor of 2, growth potential and potential attrition superiority should also be considered. As has already been brought out above in General Trends Apparent From Decision Charts, the nuclear submarine-ballistic missile combination is in general about 1.5 times more expensive than other combinations but appears to have superior attrition and growth aspects. For this reason the weapon system planner might select this type combination.
3. Derive possible solutions to weapon system selection.

The weapon system planner now has the problem sufficiently defined to where he can derive possible solutions within the framework of the qualifying considerations by using the following procedure:

- a. From the nuclear submarine-ballistic missile, high level defense, 100-target 500-mile belt depth case of Figure 12-4, cross plot number of submarines versus campaign duration (number of trips) as a function of missile loading. Figure 12-4 gives only missile loadings of 2 and 20. It should be noted that for a given number of trips the product of missile loading and number of submarines is constant. This permits plotting curves for all missile loadings.
- b. To this plot apply condition 2 d above to give a lower cutoff of 20 for the number of submarines.
- c. From Figure 11-5 apply as an upper limit the maximum number of submarines that could be available as a function of missile loading. This satisfies conditions 2 b and c above.
- d. Apply condition 2 a above, giving a campaign duration cutoff at 1 month for the plot.

Note

The result of these steps is Figure 12-6. Possible solutions are contained within the area delimited.

- e. Obtain weapon system costs from cost data of Volume II Part F for the systems. Place these costs on the plot, completing Figure 12-6.
- f. It is now apparent that with all other conditions fixed, weapon system cost increases directly with the number of submarines in the system. Therefore, the system planner would undoubtedly consider only those solutions along the lower limit of 20 submarines. These solutions are:

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5. For a given missile loading, increased campaign duration markedly decreases system cost. Biggest decrease in cost occurs from 0 to 1 month. Thereafter the rate of change is less.
6. For a fixed campaign duration, system cost varies linearly with number of targets.

AN EXAMPLE OF WEAPON SYSTEM SELECTION

Many assumptions are underlying the present pilot study. Some of the important ones may be listed as: the distance of the tender from the enemy coast, the defense model and related enemy capabilities, submarine skill factors and others. Weapon system selection can be viewed only within the framework of stated assumptions.

The decision charts are the result of combining many parameters of the weapon system. These charts do not present a single solution as the optimum system. However, they aid the weapon system planner by presenting candidates meeting certain qualifying considerations from which final choice may be made. These qualifying considerations are in the nature of upper or lower limits tending to narrow the field of choice. The steps outlined below lead to weapon system selection and show how the qualifying considerations are related to the decision charts. An example of weapon system selection is carried through. This example does not in any way represent a "recommended optimum solution".

1. Select a mission and obtain number and coastal belt depth of targets.

From Decision Chart I target distance from accessible coast is shown for several target categories. Number of targets is also shown. For example, the weapon system planner might decide that the destruction of 100 naval targets within a belt depth of 500 miles is the desired mission. Can this be attained? If so, by what weapon system combination, how long would it take, how much will it cost, and what is the earliest operational availability date that can be expected? These are questions that the weapon system planner would now face. Using the selected target belt depth and number of targets to enter Decision Chart No. I it is seen that there are many alternate solutions. The field must be narrowed by qualifying considerations. This leads to the next step.

2. Establish qualifying considerations.

- a. **Campaign Duration** — Time limitations for campaign duration are set. For example, the weapon system planner may decide that this mission should be accomplished in not more than 1 month, if possible.
- b. **Operational Availability Date** — Over-all defense plans should be considered. The weapon system planner may decide, for example, that the weapon system should be available by 1967.
- c. **Budgetary Policy** — Here the upper limit of investment and the rate of expenditure need to be considered. Perhaps the weapon system planner has no reason to think that current fiscal expenditures would be changed drastically and that a total expenditure of not more than 2 billion dollars within a 10-year period could be justified. This would set upper limits on number of units in the weapon system and on the rate at which they could become available.
- d. **Number of Units in Force** — Independent of other considerations the weapon system planner would want to consider the approximate number of units in

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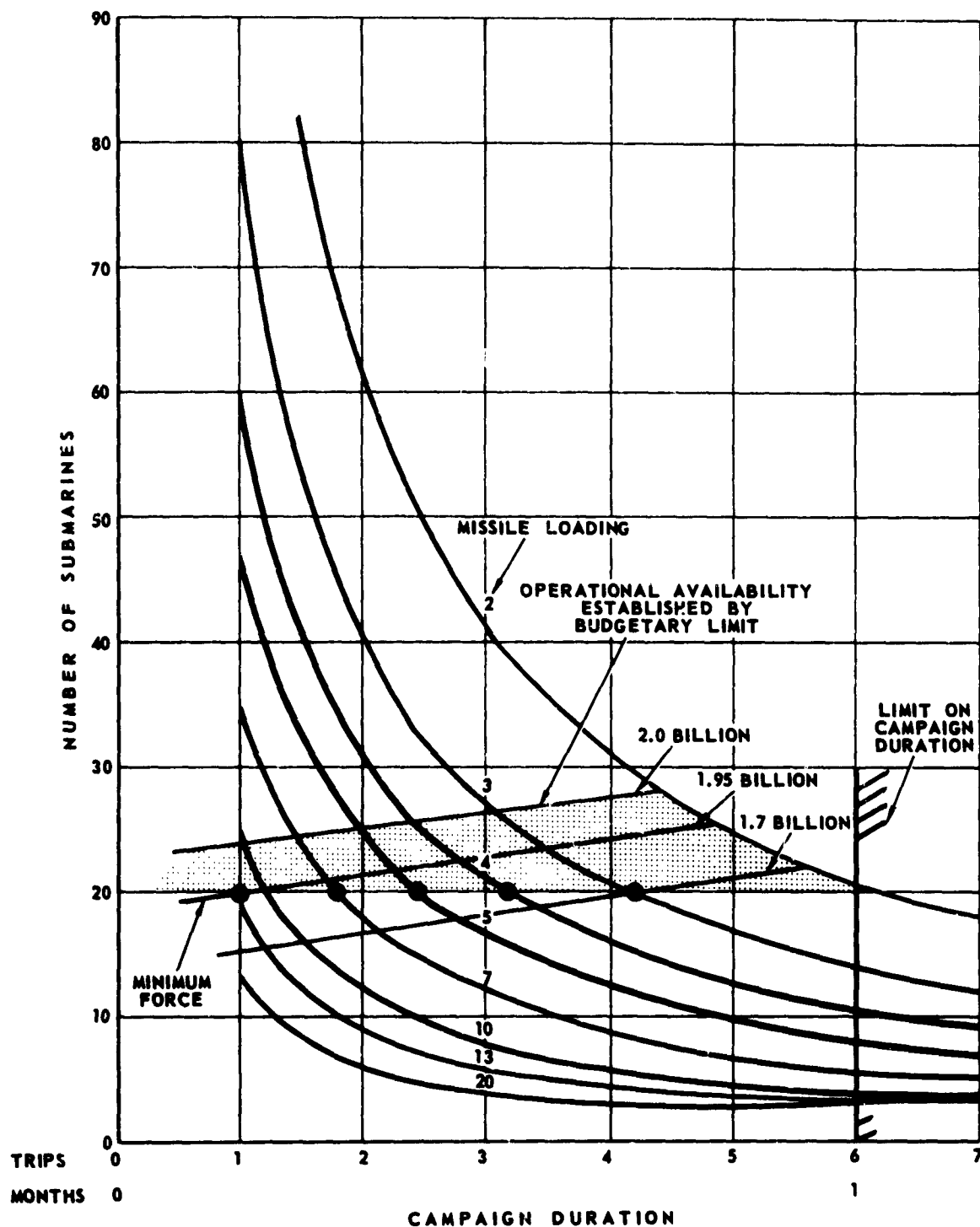


Figure 12-6. Weapon System Selection.

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<u>Solution</u>	<u>Missile Loading</u>	<u>No. Trips</u>	<u>Campaign Duration</u>	<u>System Cost (Billions)</u>
a.	3	5	25	1.70
b.	4	4	20	1.74
c.	5	3	15	1.77
d.	7	2	10	1.82
e.	13	1	5	1.93

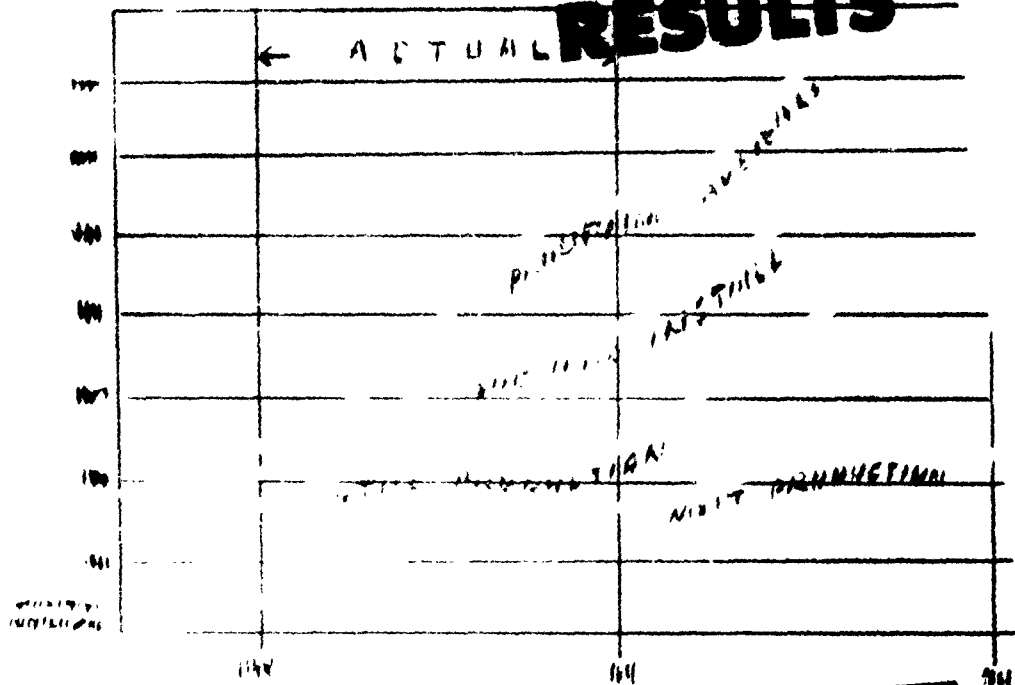
4. Select a weapon system.

All five solutions are viewed as possible systems. A final selection might be made as follows. It can be seen that cost variation between solutions is only 15%. However, a trade-off between missile loading and number of trips is apparent. Solution d, missile loading of 7, looks favorable on the basis that (1) handling and design considerations would probably not be as severe as for solution e, missile loading of 13, and (2) the campaign duration of 10 days appears reasonable. For the selected solution detailed data for the system can now be obtained by reference to Figure 12-1. For solution d above, these data are:

- | | |
|----------------------------------|-------------------------|
| 1. Campaign Duration | - 10 days |
| 2. Number of Trips | - 2 |
| 3. Number of Submarines | - 20 |
| 4. Submarine Type | - Nuclear |
| 5. Submarine Navigation System | - SINS and auto sextant |
| 6. Submarine Tonnage | - 4020 tons |
| 7. Missile Loading | - 7 |
| 8. Missile Type | - Rocket Ballistic |
| 9. Missile Guidance | - Inertial |
| 10. Missile Weight | - 57,500 pounds |
| 11. Warhead Weight | - 1500 pounds |
| 12. Missile Range | - 1000 miles |
| 13. Total Missile Delivery Error | - 1 mile |
| 14. Belt Depth Coverage | - 500 miles |
| 15. Number of Targets Hit | - 100 |
| 16. Offshore Launching Distance | - 360 miles |
| 17. Weapon System Cost | - 1.82 billions |
| 18. Operational Availability | - 1967 |

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RESULTS



PART E

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**Part E
RESULTS**

Objectives of the pilot study were stated in Chapter 1 as:

1. Determination of important factors in the selection of the best submarine missile strike system for attacking targets in the Eurasian coastal belt during the time period 1960-1970.
2. Correlation of these factors by means of a measure of effectiveness to form the basis for weapon system selection.
3. Determination of values of basic design parameters associated with weapon system selection by the measure of effectiveness.
4. Delineation of sensitive areas.

These objectives were implemented in Parts, A, B, C and D of this report. This led to the following results.

IMPORTANT FACTORS IN THE SELECTION OF THE BEST SUBMARINE-MISSILE STRIKE SYSTEM

As a result of the study it is concluded that important factors in the selection of the best submarine-missile strike system are:

1. The Mission Factors

a. Geographic Areas and Target Distribution

- (1) Targets of different categories involving shipbuilding, ship repair, submarine bases, ports, liquid fuel production, airfields, steel production and others located within the Sino-Soviet-Satellite bloc were studied. About 50% of the total number of targets are within a coastal belt of 500 miles. This value increases to 85% for a coastal belt of 1000 miles.
- (2) Most of the Satellite and Chinese targets are within the 500-mile belt. Russia is well protected by distance. 15% of its targets are within a belt of 500 miles and 45% within a belt of 1000 miles.
- (3) A 500-mile belt depth covers nearly all naval type targets within the total Communist bloc. A 1000-mile belt depth would not only cover all naval type targets but nearly all other type targets as well.

2. Total Weapon Delivery Accuracy Factors

The following total weapon delivery accuracies involving submarine navigation error, missile delivery error and target location error probably will be available by 1965:

a. Ballistic Missile System

Submarine: Automatic sextant and submarine inertial navigation system (SINS).

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Missile: Inertial system.

Total Error: 1 mile CEP for missile ranges of 0 to 1000 miles.

b. Cruise Missile System

Submarine: Automatic sextant and submarine inertial navigation system (SINS).

Missile: Inertial system.

Total Error: 1 mile CEP for 0-mile missile range.

1.5 mile CEP for 1000-mile missile range.

c. Cruise Missile System (Alternate)

Submarine: Automatic sextant and submarine inertial navigation system (SINS).

Missile: Radar map matching.

Total Error: 1000 feet at all missile ranges.

3. Warhead Yield Requirement Factors for Target Destruction

The following yield requirements are estimated based on target damage analysis and 1965 delivery accuracies:

- a. For yields not exceeding 1 megaton a CEP of up to 2 miles can be tolerated for a 50% destruction of most target types.
- b. The value of 2 miles allows some margin over the values given above. Above CEP values of 2 miles yield requirements increase sharply. Lowering the delivery error to one-half mile will allow the yield requirements to decrease to the kiloton region for many target types. Cities would still require about .8 KT.

4. Enemy Defense Factors

There are obvious difficulties in trying to project an enemy's defenses several years into the future in order to estimate his capabilities in defeating a weapon system. The pilot study has taken upper and lower defense levels for the enemy based on U. S. effort and technology.

a. Missile Defense

For missiles assumed in this study, Mach 3.5 and above, no effective defenses are anticipated prior to 1965. Time available for detection, tracking and transfer of information would be on the order of minutes for short-range missiles to less than one-half hour in the case of the 1000-mile missiles. This makes automatic defense systems mandatory. Studies are being conducted in this field, but systems of this sort are known to be only in the development stage in the U. S. at this time.

b. ASW Defenses

The ASW defense model, postulated to provide the strike system an adversary, indicates that with present day systems very high defense force levels are necessary to seriously threaten a strike campaign. For example, in a defense depth of 200 miles off a coast length of 1000 miles the submarine could remain 50 hours under a high-level defense and 300 hours under a low-level defense with a probability of detection of 20%.

c. ASW Growth Potentials

The inadequacy of present day ASW systems to defend a large area lies basically in their inability to keep areas under constant surveillance that are in size any appreciable fraction of the total area. This situation gives the submarine ample space to hide in, and submarines have developed

considerable skill in using this opportunity. Developments in ASW are pointed toward systems that will cover much larger areas continuously in order to strike directly at the submarine's skill potentialities. These developments should be analyzed in detail in further study of the submarine strike system.

5. Important Factors Relate to the Weapon System

The following general conclusions were drawn as related to the weapon system:

a. Missiles

- (1) Missiles designed for megaton warheads can accommodate kiloton warheads.
- (2) For ranges exceeding 100 nautical miles, only liquid-propellant ballistic missiles were considered. However, long-range solid-propellant ballistic missiles should be reviewed from time to time.
- (3) For ranges exceeding 400 nautical miles, the ballistic missile configuration would be one and one-half stages (separating nose cone, one powered stage and one non-powered).
- (4) Ballistic missiles appear to offer a greater growth potential from the standpoint of enemy attrition and underwater launch.
- (5) Cruise missiles appear to offer a greater potential from the standpoint of accuracy of delivery.

b. Submarines

- (1) Submarine sizes required to carry 20 missiles of 1000-mile range capability appear feasible to build.
- (2) Converted submarines are limited to a capacity of one or two 500- to 1000-mile missiles, but might be employed to carry twenty to thirty 100-mile missiles.
- (3) Nuclear submarines appear to offer a greater growth potential from the standpoint of endurance and ability to avoid detection.
- (4) Submerged launching of missiles appears to be necessary against high-level defense systems and also feasible, but requires further study.

c. Supporting Systems

- (1) The supporting system will not differ radically from existing submarine support systems.
- (2) Missile depots will have to be increased or enlarged.
- (3) Existing shipyard facilities are adequate.
- (4) Personnel training requirements will be more stringent.
- (5) Missile production facilities are adequate.

6. Force Requirement Factors

Conclusions regarding factors inherent in determination of force requirements are as follows:

- a. Submarine utilization factor is of same importance as enemy attrition factor. Effort on the part of operating forces must be made to devise means to keep as many of the submarines deployed as possible for assignment to the task.
- b. Force requirements viewed in terms of campaign duration are quite sensitive to the trip distance. In order to keep force requirements low for accomplishing a mission involving on the order of a hundred targets in a reasonable time, tenders or advanced bases must be provided as close as possible to the enemy target areas.

- c. For maximum delivery rate (missiles per month) and for shortest time in the defended area nuclear submarine speed capabilities give it a decided advantage over the diesel-electric boat.
- d. For the multiple trip case, missile range of at least 1000 miles reduces the force requirements significantly without increasing the weapon system cost appreciably. For the 1 trip type of campaign a weapon system using a missile range on the order of 500 miles has a slight weapon system cost advantage over the weapon system using the 1000-mile missile.
- e. Missile loading is a direct proportionality factor in determination of the required number of submarines. Highest missile loading consistent with design limitations is indicated.

7. System Costing Factors

The significance of the costing factors can best be seen as part of a cost breakdown for a typical system configuration. This portrays the relative contribution of the various cost components.

a. <u>Installations</u>		
Missile Facilities	.46%	
Submarine Facilities (Nuclear)	1.22%	
Sub-Total		1.68%
b. <u>Equipment</u>		
Submarines	51.31%	
Submarine Facility Equipment	1.53%	
Missile Facility Equipment	.85%	
Sub-Total		53.69%
c. <u>Personnel</u>		5.81%
d. <u>Stock and Expendables</u>		
Missiles	16.66%	
Petroleum, oil and lubr., food and spares	5.44%	
Sub-Total		22.10%
e. <u>Maintenance</u>		
Submarine	16.40%	
Miscellaneous Equipment	.28%	
Facility	.04%	
Sub-Total		16.72%
	Total	100.00%

8. Operational Availability Date Factors

The following factors affect the operational availability of the weapon system:

- a. Guided missile operational availability is directly dependent on the gross weight of the guided missile. Where a second missile design is based essentially on the same knowledge employed in the design of a preceding missile, experience indicates that the second missile design will become operationally available in about 80% of the time required for the original design.
- b. Based on a "go-ahead date" of January 1957, for initiating work on the strike-submarine weapon system, Mach 3.5 ramjet cruise guided missiles with ranges up to 1000 nautical miles will become operationally available in 1965. Liquid-propellant ballistic guided missiles, using liquid oxygen-hydrazine propellant, with ranges of 100 to 1000 nautical miles will become operationally available in 1965 and 1967 respectively.

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- c. The operational availability of submarines is relatively insensitive when the availability is taken as a function of submarine displacement.
- d. Based on a "go-ahead date" of January 1957, for initiating work on the strike-submarine weapon system, the first unit or units of a class of submarines will become operationally available in 1962. However, budgetary limitations relative to the annual rate of expenditure for submarines may dictate a later availability date than 1962. For example, based on an annual rate of expenditure of \$200,000,000 per year, 10 nuclear submarines, with a missile loading capacity of 10 missiles each, will become available in 1963, and 50 nuclear submarines of similar loading capacity will become available in 1971.

CORRELATION OF IMPORTANT FACTORS IN WEAPON SYSTEM SELECTION BY A MEASURE OF EFFECTIVENESS

The pilot study has developed a basic measure of effectiveness which consists of decision charts involving the following decision factors:

1. Cost to obtain and maintain the weapon system and operate it against enemy opposition in order to destroy a selected number of targets in a given campaign duration.
2. Campaign duration.
3. Mission characteristics.
4. Budgetary limitations.
5. System growth factors.

The mission characteristics, enemy defenses and tactical capabilities of the weapons system have been used to set up an operational task. Time to complete the task has been computed. Trade-offs between number of submarines and time, introducing submarine speed and distance of friendly bases from enemy targets, are demonstrated in terms of cost. Attrition due to enemy capabilities is treated as additional cost. Correlation of cost, operational availability and mission requirements is done through the use of decision charts which permit the selection of the "best weapon system" based on weapon system planner decisions as to budgetary ceilings, campaign duration and mission.

VALUES OF BASIC DESIGN PARAMETERS ASSOCIATED WITH WEAPON SYSTEM SELECTION

The quantitative decision charts developed in this report indicate values of basic design parameters in general and help in forming the basis for specific weapon system selection.

1. General Trends Apparent From Decision Charts
Examination of the decision charts provides a number of general conclusions regarding values of basic design parameters associated with weapon system selection.
 - a. Cruise and ballistic missiles are costwise equivalent. Potential attrition superiority favors the ballistic missile.
 - b. Cost differences of a 100-mile and 1000-mile missile are approximately 30%.

- c. Cost is relatively insensitive to variation between high- and low-level defense chosen.
 - d. For zero campaign duration (on station concept) the new diesel-electric submarine shows costwise an advantage over the nuclear submarine of about 2.5:1. However, this advantage becomes progressively more negligible as campaign duration (or number of trips) and missile loading increases. It may be seen that the diesel-electric submarines will enjoy a cost advantage of about 50% for a typical system configuration.
 - e. For zero campaign duration a missile loading of 20 is required to meet operational availability requirements for 100 and 300 targets. If it is assumed that design requirements and minimum force requirements (20) limit missile loading to less than 20, finite campaign durations between 0 and 1 month are indicated.
 - f. Increase campaign duration markedly decreases system cost. Biggest decrease in cost occurs from 0 to 1 month. Thereafter the rate of change is less.
 - g. For a fixed campaign duration, system cost varies linearly with number of targets.
2. Qualifying Considerations in Weapon System Selection
The interpretation of the decision charts leading to weapon system selection requires the following qualifying considerations:
- a. Budgetary limitations are implicit in the determination of operational availability dates. These are based on current fiscal policies. This affects predominantly the submarine. Production wise it imposes no limitations. However, when based on fiscal allocations it may become limiting in many cases.
 - b. Zero attrition has been assumed for both ballistic and cruise missiles. However, the ballistic missile has greater growth potential in relation to attrition resistance. Thus, it may be taken to be superior to the cruise missile, all other factors being equal.
 - c. Growth potential of the nuclear submarine exists in the fields of noise reduction, deep submergence, endurance and range.
 - d. It is assumed that the minimum number of submarines that will be used is approximately 20. This is based on possible organizational requirements of a 2 ocean Navy with 2 major submarine commands.
 - e. High missile loadings are desirable from a short campaign duration standpoint. However, handling and design considerations may provide practical upper limits.

3. An Example of Weapon System Selection

Many assumptions are underlying the present pilot study. Some of the important ones may be listed as the distance of the tender from the enemy coast, the defense model and related enemy capabilities, submarine skill factors and others. The following example of weapon system selection can be viewed only within the framework of stated assumptions:

Campaign Duration	- 10 days
Number of Trips	- 2
Number of Submarines	- 20
Submarine Type	- Nuclear
Submarine Navigation System	- SINS and auto sextant

SECRET

Submarine Tonnage	- 4020 tons
Missile Loading	- 7
Missile Type	- Rocket ballistic
Missile Guidance	- Inertial
Missile Weight	- 57,500 pounds
Warhead Weight	- 1500 pounds
Missile Range	- 1000 miles
Total Missile Delivery Error	- 1 mile
Belt Depth Coverage	- 500 miles
Number of Targets Hit	- 100
Offshore Launching Distance	- 360 miles
Weapon System Cost	- 1.82 billions
Operational Availability	- 1967

MAJOR SENSITIVE AREAS FOR FURTHER STUDY

Areas listed below appear to require further study to increase the validity of the study:

1. Navigation error.
2. Guidance error.
3. Target location error.
4. Pro and antisubmarine warfare using nuclear weapons.
5. Projected ASW kill detection capabilities.
6. Antimissile defense capabilities.
7. Submarine utilization factor.
8. Submarine and missile preliminary design studies.
9. Missile handling and launching.
10. Submarine-strike weapon tactics.
11. Future budgetary policy.
12. Warhead technology.

TERMS AND SYMBOLS

Chapters 1 and 2

"Coastal Belt" and "Belt" are used interchangeably. It is that belt extending to the interior of the country from the effective shoreline. The effective shoreline extends from headland to headland instead of following the true shoreline into narrow waters.

Chapter 3

"Ballistic Missiles" considered have rocket engines.
 "Cruise Missiles" considered have airbreathing engines.

Chapter 4

"CEP" is Probable Circular Error.

Chapter 5

"Radux" is a long-range radio navigation system.

Chapter 7

"SINS" - Submarine Inertial Navigation System.

Chapter 8

A - Area under surveillance.
 E - Expected number of contacts.
 $f = (1-q)$ Assumed to be .25.
 N - Number of searching ships.
 $P = 1 - e^{-E}$ Probability of at least one contact.
 q - % of contact avoidance.
 S_w - Sweep width.
 T - Time.
 v - Ship's speed.

Chapter 9

L - Number of missiles carried per submarine per trip.
 M - Number of missiles expended during t trips.

M_{Fire} - Missiles fired during t trips.

M_{Lost} - Missiles lost due to attrited submarines during t trips.

M_t - Total number of missiles in weapon system.

N - Initial number of submarines in the weapon system.

R_m - Missile range.

R_2 - Off shore distance.

SECRET

- t - Number of trips.
- T_t - Cumulative number of targets destroyed after t trips.
- η_s - Probability of submarine attrition per trip.
- η_u - Submarine utilization factor, fraction of submarines in weapon system available in forward area.
- η_T - Probability of successful missile prelaunch test.
- η_m - Probability of successful missile delivery after successful prelaunch test.

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