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WSEG REPORT 148

STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

VOLUME I

Main Paper

August 1969

Including
IDA REPORT R-160

A. R. Barbeau, *Project Leader*

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2520-0133-8/69

ASSESSMENT OF WSEG REPORT 148

1. (U) The Joint Chiefs of Staff have noted this report and regard it as a source of background information for strategic objectives and operational planning and for further study of strategic offensive weapons systems.

2. ~~(TS)~~ There are important cautions which must be observed to avoid making erroneous conclusions when using the report. For proper understanding, the principal findings and conclusions, as summarized in Volume I of the report, must be considered in context with the purpose of the study and with the analyses contained in the topical studies, Volumes II - X. Footnote comments in the report must be noted carefully to assure complete understanding of each discussion. Following are specific comments:

(b)(1) [redacted]

c. The conclusions of the effectiveness and vulnerabilities of strategic forces should also be considered with caution in light of inherent study limitations and uncertainties, some of which are pointed out in various parts of the report. For example, analyses of penetration capability of reentry vehicles do not include all the effects of

(b)(1)

OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WEAPONS SYSTEMS EVALUATION GROUP
WASHINGTON, D C 20305

26 August 1969

MEMORANDUM FOR THE CHAIRMAN, JOINT CHIEFS OF STAFF

SUBJECT: Strategic Offensive Weapons Employment in the Presence of Defenses (WEPS)(U)

I. FOREWORD

The Abstract of WSEG Report No. 148 is contained in Section II below. Detailed WSEG comments on the study are contained in Section III.

II. ABSTRACT

Title: WSEG Report No. 148, *Strategic Offensive Weapons Employment in the Time Period About 1975 (U)*, August 1969. Short Title: WEPS.

Conducted by: WSEG *For:* JCS

(U) This study is responsive to the principal requirements contained in SM-351-67, dated 13 May 1967 as modified by the Phase I Study Plan (WSEG Report 132) approved by J5M 1169 dated 16 July 1968.

Purpose:

(U) The general purpose of the weapon employment study is to illuminate and explore the problems and issues related to the employment of U.S. strategic forces in the middle 1970's; particular emphasis is placed upon the problems associated with MIRV weapons and defended targets.

Methodology:

(U) The capabilities of U.S. strategic offensive forces, programmed for the middle 1970's, are first examined to determine the main features of a set of possible attack alternatives. The outcomes of attacks by force components (POSEIDON, MINUTEMAN, BOMBER FORCE) are examined, at first separately and then in mixes, against a full range of potential urban-industrial and military targets that are represented by detailed data bases. Major uncertainties in U.S. force capabilities, enemy target characteristics, intelligence projections of Sino-Soviet capabilities, and the manner in which hostilities develop are considered by applying wide but appropriate ranges of values to a few aggregated force factors (like force sizes, probabilities of arrival, and CEP) and target characteristics (like silo hardness). The attack alternatives and planning guidelines so developed are then refined, where necessary, on the basis of detailed "topical" studies. Major topical studies deal with footprint constraints associated with the employment of MIRVs; enemy ABM defenses; bomber penetration; and the vulnerability of strategic systems to nuclear effects.

Principal Findings:

(b)(1)

[redacted]

(b)(1)

(b)(1)

~~(TS)~~ 7. In addition to the preceding findings, new methods have been developed to handle problems involving:

- Sensitivity of damage to the detail characteristics and geographical distribution of (b)(1) value in the target data base.
- Sensitivity of damage to erroneous planning factors.
- Allocation of MIRV systems taking into account range and footprint constraints.
- Penetration of area missile defenses involving imperfect interceptors, unequal valued targets, and a defense that does not possess foreknowledge of the attack allocations.
- Penetration of bomber defenses taking into account multiple target sorties and distributed defenses.
- Cross targeting of weapon systems taking into account the possibility of system-wide catastrophic failure.

III. WSEG COMMENTS

(b)(1)

(b)(1) [redacted]

(b)(1) [redacted] Reduction of these uncertainties, and correction of weaknesses identified, seem to be the most important tasks for improvement in our strategic capabilities, but may be most difficult to accomplish to any substantial degree.

(b)(1) [redacted] Such a study should consider technical feasibility, operational utility, inter-dependency of programs, and costs.

~~(TS)~~ 4. It should be noted that the WEPS study concerns itself largely with broad force planning rather than with the details of individual force element application. Thus, the finding on the modest effect of footprint and range constraints for the MIRV systems relates to total force allocation against the entire target data base, rather than to the important constraints on individual weapons. Uncertainties receive prime consideration in the study with parametric treatment confined to realistic ranges. The study results are, of course, very sensitive to the programmed appearance of large numbers of U.S. MIRV warheads by 1975. The study develops useful methodologies for treating uncertainties; examples are: the analyses dealing with the concept of graduated objectives, and force application which recognizes possibilities of catastrophic system failure. The enclosure dealing with system vulnerabilities to nuclear weapon effects provides a useful compilation of known data in this uncertain area. Procedural findings of the study which pertain to SIOP preplanning address allocation techniques and MIRV footprinting which should be of value to the Joint Strategic Target Planning Staff. The ABM penetration investigations in both the general analytical solution and the simulation of blackout effects illuminate a number of problems in the attack of defended targets, but as indicated in the study, other such problems require further investigation.

~~(TS)~~ 5. This study represents a very comprehensive treatment of many important strategic planning factors for the mid-1970's. While the overall evaluation of these matters in Volume I highlights significant results, the thorough and detailed analyses in the many enclosures should be of considerable value to planners.

K. S. MASTERSON
Vice Admiral, USN
Director

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REPORT R-160

STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

A. R. Barbeau, *Project Leader*

VOLUME I
Main Paper

A. R. Barbeau *et al.*

August 1969

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in response to the Weapons Systems Evaluation Group Task Order SD-DAHC15 67 C 0012-T-140, dated 21 December 1967.

In the work under this Task Order, the Institute has been assisted by military personnel assigned by WSEG.

Controlled Dissemination markings applied to this document were directed by the Director, WSEG.

IDA

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FOREWORD

(U) This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in conjunction with the Weapons Systems Evaluation Group. The research and analysis that form the basis for this report were carried out by a project staff under the general leadership of A.R. Barbeau. The members of the project staff are listed below:

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(U) The principal authors are indicated in the Table of Organization.

(U) A special WEPS Advisory Panel reviewed the validity of the work and assisted by comments and advice. The members of the Panel were:

Daniel J. Fink
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Brockway McMillan
Wolfgang K.H. Panofsky
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(U) Editorial coordination and supervision were by J.P. Byrd and J.S. McManus.

TABLE OF ORGANIZATION

VOLUME VIII

Enclosure H: *ABM Defense Employment, Engagement and Penetration*
Authors: T.E. Sterne, J.A. Ross

VOLUME IX

Enclosure I: *Bomber Employment and Penetration Study*
Authors: D.N. Beatty, E. Marcuse

VOLUME X

Enclosure J: *Nuclear Weapons Effects on Strategic Missile Systems*
Authors: H.A. Knapp, J.A. Ross, D.H. Williams

CONTENTS

I. INTRODUCTION

(C) The complete statement of the WEPS task[1] includes a considerable list of topics to be studied in the context of a broad framework of strategic studies. The central area of interest, however, is the employment and effectiveness of U.S. strategic offensive forces in the middle seventies.

(C) The scope of the assignment is indicated by the following statement taken from the study directive:

> "The study should examine force employment considerations in the context both of U.S. initiation and U.S. retaliation, with both sides scheduling missile attacks, combined with bomber attacks where appropriate, against a full range of counterforce and countervalue objectives."

(C) The first phase of the study included a preliminary assessment of the problem but was mainly devoted to defining the approach to be followed in carrying out the task. The present report is, therefore, the first substantive and formal response to the referenced directive. The WEPS Report represents a comprehensive effort to respond to the principal questions raised by the Joint Chiefs of Staff but is not intended to completely fulfill the original request. A program proposed for continuation of this work would extend the study into areas deferred in this report, and particularly into the post-1975 time period.

1. (U) WSEG Task Order (T-140) to IDA, dated 22 December 1967 (TOP SECRET), referring to Joint Chiefs of Staff Directive to WSEG by SM-351-67, dated 13 May 1967 (TOP SECRET).

II. THE WEPS STUDIES

(S) The context of the WEPS studies is the employment and effectiveness of U.S. strategic offensive[1] forces in the period about 1975. The major substantive areas are:

- The application of MIRVs[2] and other U.S. force elements to realistic target data bases and the consideration of smaller yield weapons in conjunction with more finely detailed target representations.

(b)(1)

- The role of the manned bomber forces and the problem of penetrating air defenses.

(b)(1)

(S) The time period considered is one in which: (1) the U.S. MIRV systems, currently under development, are deployed in force, but subsequent generations of U.S. offensive systems have yet to appear; and (2) (b)(1) and are either projected[4] as thereafter remaining fairly stable for a few years, or else are regarded as being still so uncertain as to discourage further projection.

(S) The investigation of U.S. offensive force employment is developed around the allocation of weapons (and weapon mixes), as that choice is affected by uncertainties in several major areas: the effectiveness of U.S. weapons; enemy capabilities and tactics; and the manner

1. (C) Only the hard core U.S. strategic offensive forces are considered (SAC missiles, SAC bombers, and SLBMs–Sea Launched Ballistic Missiles). U.S. ABM defenses are considered in a very limited way. U.S. air defenses are not examined as such but only reflected in the aggregated probability of arrival of enemy bombers.

(b)(1),(b)(3):42 USC § 2162 (a) (RD),(b)(3):42 USC § 2168 (a) (1) (C)

3. (C) Investigations of ASW actions against the sea launched ballistic missile fleets of either side were excluded from the scope of the study program.

4. (U) By intelligence.

in which hostilities develop. Also critical to this selection are the implications of conservative versus higher risk employment plans, the coupling between different missions and objectives, and the overall question of confidence levels for meeting specific objectives.

~~(S)~~ The question of how to deal with the uncertainties associated with the capabilities of opposing strategic forces and the conditions of their potential employment is a recurring theme in the WEPS analyses. For the period up to 1975, and possibly 1977, the size and composition of U.S. offensive forces[5] are relatively well defined and limited to existing systems or systems currently programmed and under development.[6] U.S. intelligence lead times on (b)(1) [redacted] however, could permit the introduction, within a period of a few years, of Soviet systems not now identified. (b)(1) [redacted] actions could, therefore, result in new weapons as well as in changes in currently projected force levels and system characteristics by the middle seventies. The analyses conducted account for intelligence uncertainties in three basic ways:

- By developing methodologies that are applicable over a wide range of input values.
- By recognizing that the performance of U.S. forces may vary widely under different initiation or engagement conditions, and depend, in part, on the size and performance of enemy forces.
- By considering the full range of intelligence projections for the middle 1970s as well as further upward excursions from these values.

~~(S)~~ In specific calculations, projections of (b)(1) [redacted] capabilities are generally kept within the approximate order of magnitude of the official estimates.[7] To facilitate presentation, the results given generally refer to the conditions of 1975. They are not meant, however, to be narrowly restricted to that date but to apply to the middle 1970s or roughly to the interval, 1973-77.

---

5. ~~(S)~~ The U.S. strategic offensive forces used in the study are listed in Table 2, page 30. The force sizes indicated for both the U.S. and USSR systems refer to the deployed forces and, therefore, include the fraction that would be generated to an alert condition in periods of serious tension (or given strategic warning).

6. ~~(S)~~ More advanced systems would not be operational before 1976 or 1977.

(b)(1) [redacted]

III. SUMMARY OF FINDINGS

(b)(1)

[redacted]

(U) The most general conclusions of the study are stated below, briefly elaborated upon in the subsequent paragraphs of the summary, placed in the context of the development of the total study program in the main paper and, finally, fully supported in the Enclosures.

A. GENERAL CONCLUSIONS

(b)(1)

[redacted]

(b)(1)

(b)(1)

[redacted]

6. ~~(C)~~ Only the hard core U.S. strategic forces are considered, i.e., SAC missiles, SAC bombers, and U.S. SLBMs.

7. ~~(S)~~ The concept of force-wide failure (or catastrophic failure) is used to cover the range between zero and something approaching 0.25 for the probability of arrival of weapons at their intended targets.

8. ~~(TS)~~ The optimal defense referred to in the preceding sentence is degraded and rapidly tends to approach the effectiveness of a random defense doctrine if relatively small fractions of the attacking warheads are not seen.

(b)(1)

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Weapons Systems Evaluation Group
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B. COMPETING OBJECTIVES

~~(S)~~ As implied in the statement of general conclusions, the analysis considered both pure countervalue and pure counterforce objectives before proceeding to examine the effects of competing objectives.

(b)(1)

[redacted]

~~(TS)~~ The counterforce objectives[14] considered in the study can be briefly stated as follows:

(b)(1)

[redacted]

(b)(1)

~~(TS)~~ The comparative results for two levels of U.S. forces can be summarized as follows:

(b)(1)

The general effect of the reduced force sizes was that missiles were drawn off the hard point targets to achieve the required damage levels on the soft targets. The effect was mitigated in various cases by reserving fewer defense suppression weapons, by reducing the damage levels on the soft targets, or by assuming that design specification CEPs were achieved.

~~(TS)~~ The relative weight of effort applied to the hard point targets was found to be much less dependent on the CEP of the attacking weapons or the assumed vulnerability of the targets than on decisions concerning the total counterforce effort and to a lesser degree on the damage objectives for the soft military targets. As might be expected, however, the resulting damage levels on the hard point targets were strongly dependent on the vulnerability numbers and the CEPs assumed. The impact of the reduction, in U.S. forces assigned to counterforce, on the average damage expectancy (DE) of the (b)(1) was found to be as follows.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

(S) The range of values at a given vulnerability and force level arises almost entirely from the range of CEP values considered.[21] The bounding values generally correspond to the same conditions and assumptions at different attack levels. The results presented can, therefore, be used as a measure of the effect of competing countervalue objectives.

(S) The competition between countervalue and counterforce objectives may be reduced by the introduction of options designed for different initiation and engagement conditions. In the analysis, it is first assumed that one plan must serve all situations, and that forces cannot be reassigned to respond to changing initiation or engagement conditions. The merits are then considered of planning options designed for more specific engagement conditions. A summary of the assessment follows.

(S) The hazards of plans optimized for either extreme objectives, i.e., pure counterforce or pure countervalue, are obvious and hardly need elaboration. Practical and safe options can probably involve only modest transfer of forces away from the countervalue objectives if these objectives are assumed to be invariant. A more sizable transfer of forces away from the

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

insensitive plans[23] and limited transfers of forces attractive. The desirability of basically insensitive plans is increased by their lack of severe penalties or disadvantages, even in comparison with extreme counterforce or countervalue optimizations.

C. SOVIET CAPABILITIES AGAINST U.S. STRATEGIC FORCES

(b)(1)

[redacted]

23. (S) The expression "insensitive plans" should not be taken to imply either inflexible plans or plans devoid of options for meeting either specific or limited objectives. It does suggest, however, that diversion of a substantial fraction of force from one objective to another, particularly from countervalue to counterforce, is risky if it must depend on judgments made during the engagement.

24. (C) The "force" refers to the total deployed force, i.e., all units attached to operational squadrons including the fraction that could be generated to alert in periods of serious tension (or given strategic warning).

25. (S) In a pure counterforce commitment of all their available missiles, sea-based forces included.

weapon could destroy one U.S. ICBM, i.e., DE = PA.[26] If, instead, U.S. ICBMs are assumed to [redacted]

29. (TS) The U.S. ICBM force is slightly greater than [redacted] as it consists of approximately [redacted] MINUTEMAN and [redacted] TITAN II.

30. (U) Or alternatively, under a set of specific conditions or assumptions.

vulnerability to enemy attack and the extensive operational verification which they receive in test and evaluation programs. The BOMBER and MINUTEMAN systems then follow, with precedence going to one or the other according to the relative weight assigned to such factors as the proven dependability of the aircraft systems, the defense penetration advantage of MINUTEMAN, the ability of the aircraft to launch on warning, etc.

(S) The real significance of any ranking of systems depends on the magnitude of the difference between the suitability of the successive systems when so ranked. The consequence at one extreme would be to assign one system exclusively (or predominantly) while at the other extreme, with the differences estimated to be insignificant, the indicated solution would be to have all systems contributing equally.

(S) The alternatives indicated in the study, while far from all inclusive, emphasize some of the fundamental considerations involved in selecting the composition of forces to be applied to the (b)(1) [redacted] The need for assurance against force-wide failures, for example, would tend to direct the choice to alternatives with representation from all three forces. Judgments and decisions regarding the likelihood of force-wide failures and the degree of confidence required for the achievement of specified objectives would then resolve the question of whether it suffices to provide a diverse mix of systems, or whether each force element in the mix must in addition, independently meet the full requirements established in the previous section.[31] The absence of a factual basis for the probability of force-wide failure makes the choice of one approach over the other essentially a matter of deciding on the degree of optimism or conservatism to be adopted. A number of illustrative cases are examined in the detailed discussion. One such case applying to (b)(1) [redacted] is given as follows:[32]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

(U) The mix of forces selected may be allocated to maximize the damage inflicted by the combined force, or to maximize the damage inflicted by each of the

---

31. (S) The weight of effort required to meet specified objectives before consideration of force-wide failure (or catastrophic failure).

32. (S) In all cases the forces referred to include all operational units that could be generated to alert in period of tension or given strategic alert.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

(b)(1) [redacted]

~~(S)~~ One alternative to the "overall damage maximization" allocation is an "allocation in isolation." In this laydown, the weapons are allocated to targets so as to maximize the damage that is achieved by each system acting independently. The total damage achieved by this laydown is less than by the overall damage maximization laydown, but the damage that would be achieved if a number of systems failed catastrophically is considerably higher. Figure 1 presents results for the illustrative force described above when the allocation is "in isolation," and when it is "for overall damage maximization."

~~(S)~~ The results presented up to this point for the MIRV systems have assumed the reentry vehicles or warheads to be free from range and footprint constraints. The effects of these constraints have, in fact, been investigated quite thoroughly with results that can be summarized as follows:

(b)(1) [redacted]

E. SELECTION OF SYSTEMS FOR COUNTERFORCE APPLICATIONS

(b)(1) [redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

SLBM force and the ability of (b)(1 [redacted] land-based forces to leave their bases before the arrival of U.S. weapons. However, it is appropriate to compare the suitabilities of U.S. forces, for counterforce application, on the basis of damage expectancy to the targeted missiles or installations directly, rather than on the basis of the effects of such damage in turn upon damage to U.S. cities.

(C) Whereas the assurance of arrival under a wide range of possible engagement conditions was considered the controlling criterion when dealing with countervalue objectives, system reaction time followed by yield-accuracy and force sizes are the controlling factors in counterforce application.

(C) Reaction time divides the forces into two major groups, missiles and bombers, and provides a basic reason for excluding the latter from counter-ICBM attacks at least in preemptive situations.[37] Accuracy becomes the all-important factor in attacking hard sites when the weapons are assumed to reach their destination before the target missiles have been launched.

(b)(1) [redacted]

(S) In summary, therefore, it may be said that all three of the major missile force elements are appropriate for application against ICBMs and fixed based IRBMs and MRBMs, but that their effectiveness would be highly dependent on the vulnerabilities and the state of occupancy of the silos.

IV. DEVELOPMENT OF THE STUDY

(C) The report first examines the capabilities of the U.S. strategic forces programmed for the middle seventies and determines the main features of a set of possible attack alternatives from very basic considerations (Chapter V). The report then adjusts and refines these planning guidelines (Chapters VI through X) on the basis of detailed investigations. The Summary of Findings, presented in Chapter III, integrates the principal results of the study as a whole. The final chapter (Chapter XI) briefly describes the program proposed for further studies.

A. THE CONTEXT STUDY

(C) The first part of the discussion (Chapter V) deals with the basic attack alternatives open to the U.S. in the time period considered. Simple analyses using highly aggregated force factors but detailed data bases characterize this search for first order effects and controlling factors. The impact of major uncertainties associated with U.S. force capabilities, enemy target characteristics, and intelligence projections o (b)(1) for example, is revealed by selecting appropriate ranges of values for the few essential force factors and target characteristics[1] needed in these analyses. Deficiencies in information generally justify the consideration of these uncertainties in such highly aggregated forms. The major topical studies then indicate the more likely values in specific situations and show the distribution of effects among attacking elements across the target bases. Both context and topical studies are meant to provide methodologies and guidelines applicable beyond the specific cases or conditions examined.

(U) The context study is presented in the main paper along with the principal findings of the topical studies. The topical studies are presented in full detail in the Enclosures (see Table of Organization).

---

1. (C) While detailed data bases (described in Enclosures A and B) are used in these analyses, the uncertainties associated with their characterization can be related to a few simple factors.

B. THE TOPICAL STUDIES

~~(C)~~ The general content and character of the topical studies is described briefly below. The findings of the first group of studies "Analyses Related to the Employment of U.S. Offensive Forces" are considered in the context of the discussion of Chapter V (U.S. Capabilities and Basic Attack Alternatives i.e., the "context" study). The principal results of the other topical studies are presented as Chapters VI through X.

1. Analyses Related to the Employment of U.S. Offensive Forces

~~(C)~~ The purpose of these analyses is to determine the effectiveness of the U.S. strategic offensive forces against a full range of potential (b)(1) and military targets. Detailed studies of offense-defense interactions are explicitly excluded from the scope of these studies, as are analyses of weapon range and footprint constraints, and the possible mechanisms for the catastrophic failure of missile and bomber systems.

~~(C)~~ The studies of the U.S. capabilities against (b)(1) and military objectives are largely carried out in isolation. However, the considerations involved in the division of the U.S. strategic forces between (b)(1) and military objectives are taken into account by reserving a variable fraction of the force for the attack on the objective that is not under direct study.

~~(C)~~ The determination of U.S. capabilities against potential (b)(1) targets is carried out in two steps. First, the capabilities of individual weapon systems are determined, and then the capabilities of a mix of systems.

~~(C)~~ The capabilities of individual weapon systems, such as POSEIDON and MINUTEMAN III, are determined for a broad range of accuracy and probability-of-arrival parameters

(b)(1)

~~(C)~~ The second step in the determination of U.S. capabilities against (b)(1) targets is concerned with the capabilities of a force consisting of a number of different weapon systems. Different weapons mixes are compared and a study is made of the tradeoffs between the objective of maximizing damage when all weapon systems operate properly, and the objective of assuring a high level of damage even should one or more of the systems fail catastrophically.

~~(C)~~ Two military objectives are considered in the evaluation of U.S. capabilities against potential military targets: (1) to destroy the (b)(1) offensive capability in order to limit damage to the U.S.; and (2) to destroy a comprehensive (b)(1)

(b)(1)

(b)(1)

~~(C)~~ The ability of U.S. forces to destroy a comprehensive (b)(1) (b)(1) is also studied in both preemption and retaliation. Much of the analysis in this investigation is devoted to a translation of this objective into more precise and measurable terms.

2. Footprint Constraints in the Allocation of MIRV Systems

~~(C)~~ The objective of this study is to investigate the impact of the footprint and range constraints of the MIRV systems (POSEIDON and MINUTEMAN III) on weapon allocations. Both manual map-template techniques and a footprint-constrained computer allocation model are developed, and employed in the analyses.

(b)(1)

various allocation levels. The impacts are also analyzed of requirements for (b)(1) minimum RV spacing (to avoid multiple kill by ABM), and launch-area availability.

~~(C)~~ A series of POSEIDON and MINUTEMAN III allocations on (b)(1) systems are studied, and booster requirements for various levels of target coverage developed. The impacts are also studied of requirements for (b)(1) and launch-area availability.

3. **ABM Defense Penetration Studies**

(b)(1)

4. **Bomber Employment and Penetration Studies**

~~(C)~~ The purpose of the bomber employment studies is to ascertain the influence of bomber penetration capabilities on the allocation of bomber weapons. The emphasis is on the division of the allocation between objective and defense-suppression targets. The analyses determine which defenses are candidates for attack and the effect, on other tasks, of expending weapons on their destruction.

~~(C)~~ For this study, only those aircraft associated with the Strategic Air Command are used. Suppression of bomber defenses is carried out through bomber and missile attacks of varying weight. The effects of attacks are shown on selected components of the defense, such

(b)(1)

~~(C)~~ The attacking bomber force makes sorties directed at both (b)(1) and military targets. The measure of effectiveness for the (b)(1) sorties involves the (b)(1) value destroyed and the number of penetrating aircraft (probability of arrival). The number of defense-suppression targets that require attack to permit penetration by all sorties is determined, and the number of weapons available to attack the military target system is considered.

5. **Vulnerability of U.S. Strategic Forces**

(b)(1)

[redacted]

6. **Nuclear Weapons Effects**

~~(C)~~ The purposes of this study are:

- To summarize what is known concerning the vulnerability to nuclear-weapon effects of U.S. strategic missiles in silo, in powered flight, and during reentry, for the time period 1970-1975.

- To develop such guidance for the targeting and timing of U.S. missiles as follows from consideration of missile-system vulnerabilities to nuclear-weapon effects.

- To consider how nuclear-weapon effects from a Soviet first strike against the MINUTE-MAN, TITAN, and POLARIS missile systems might cause one or all of these systems to fail catastrophically or suffer severe degradation.

V. U.S. CAPABILITIES AND BASIC ATTACK ALTERNATIVES

A. INTRODUCTION

~~(C)~~ The basic considerations and controlling factors relating to the employment of U.S. strategic forces in the middle seventies are discussed in this chapter in the context of the following general development:

- The capability is established of each major U.S. force element for all potential applications.
- The total U.S. capability to meet pure countervalue and pure counterforce objectives is examined.
- The major U.S. force elements are ranked for each specific application (or objective) and criteria are developed for mixed allocations.
- The assignment of U.S. forces to competing requirements is resolved in terms of a limited number of alternatives.

(b)(1) [redacted]

~~(C)~~ In the analysis that follows, the action and effects of opposing forces are, in most cases, considered separately, and their interactions accounted for in the adoption of basic force factors (primarily the probability of arrival factor,[1] i.e., PA). For U.S. attacks on targets

1. (U) The probability that the weapons assigned reach their intended targets, i.e., survive to be launched, operate reliably, and penetrate to detonate at the target.

(b)(1)

1. **Forces and Targets**

(b)(1)

~~(S)~~ Four basic factors are used to characterize the attack capability of each major force element: force size (in numbers of weapons), yield, accuracy (CEP), and the fraction of weapons assigned which are expected to reach their targets (i.e., the aggregated probability of arrival). For U.S. forces in 1975 force sizes and yields are constants but three sets of PA and CEP, designated respectively as the high (for high PA and high accuracy), central, and low sets,[5] are used. The high accuracy factors generally correspond to design goals, whereas the central and low accuracy factors represent substantial degradation in performance from these stated system objectives. The reasonableness of these lower performance figures is supported by past investigations and evaluations.[6] The values for the PA (b)(1) (b)(1) is also used to provide a limiting case. Here the selection is based in part on past studies,[7] and also in a general way on the vulnerability considerations which are (b)(1) (b)(1)

2. (U) Hardened to withstand nuclear explosions.
3. (b)(1)
4. (U) Enclosure A gives a detailed description of the data bases used in WEPS, and includes analyses related to their characteristics.
5. ~~(C)~~ Mixed sets of high and low factors are also considered when appropriate.
6. (U) A comprehensive evaluation of the accuracy of the strategic missile systems considered in this study is contained in WSEG Report 129.
7. (U) WSEG Reports 56 (I and II), 73, 78, 84, 87 and 140 on the Operational Effectiveness of Ballistic Missiles.
8. (U) See Enclosure J.

factors are made. Generally, one accuracy value is used (the more likely value indicated by the official intelligence source) and one or two PA values from the set used for U.S. forces. Two levels of force size, however, are examined: one corresponding (approximately) to the central estimate of official intelligence and one representing a threat greater than that currently indicated in the official source. Tables 2 and 3 summarize the U.S. and [redacted] (b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

2. Defenses

(C) The engagement and penetration of [redacted] (b)(1) examined in detail in later chapters of the report.[11] While no comparable investigations are made of U.S. defenses, many of the analyses conducted (and particularly those involving ABMs) are of general applicability.

(C) As noted earlier, in the analysis developed in this section defense penetration is implicitly included in the probability-of-arrival factor (PA). The potential effectiveness of the U.S. and [redacted] (b)(1) in dealing with attacks on [redacted] (b)(1) is also indicated through simple calculations. U.S. air defenses are considered in only a very cursory way.

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9. (C) With no distinction between models.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

11. (U) Chapters VII and VIII.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1)

TABLE 4 ~~*(TS)*~~ *ABM Forces - 1975 (U)*

ABM FORCES 1975

U.S. FORCES		USSR FORCES
SAFEGUARD PHASE I[a]		(b)(1)
COVERAGE		
Up to 4 Wings of MINUTEMAN Missiles	(b)(1)	
ACQUISITION RADARS (Perimeter Acquisition Radars)		
TARGET TRACKING RADARS (Missile Site Radars)		
AREA INTERCEPTORS (SPARTANS)		
TERMINAL INTERCEPTORS (SPRINTS)		

[a]Additional options have been proposed which would include up to (acquisition radars, (b) tracking radars, (b) area interceptors, and (b) terminal interceptors. However, no single option would include all these totals. Extensions of the system beyond Phase I would provide coverage over most of the United States.

(b)(1)

~~(C)~~ Table 4 summarizes the features of the U.S. and USSR ABM systems considered in the WEPS study. The information is presented to permit a general appreciation of the levels of defense that confront the forces summarized in Tables 2 and 3. The three tables provide a background of reference data for the development that follows.

B. U.S. CAPABILITIES AGAINST (b)(1) TARGETS

~~(S)~~ This first part of the general analysis relates U.S. strategic capabilities in 1975 to countervalue objectives. It develops a rationale for determining the total weight of effort required to meet countervalue objectives and defines the composition of U.S. forces that would best provide it, were there no competing requirements (like possible counterforce objectives). The principal steps in the analysis are as follows:

(b)(1)

(b)(1)

- The effectiveness of the major force elements in damaging the target system is compared, and the notion is introduced of an equivalent (or "reference") weapon.

- The total U.S. capability against each element of value of (b)(1) (b)(1) is established, and the weight of effort determined that would achieve specific damage levels with high, central and low PAs and CEPs.

- The weight of effort required to achieve minimum objectives under the worst assumptions is established and the damage levels, obtained with the same weight of effort and the best (or high) performance factors, determined. Conversely, the weight of effort required to achieve high objectives[12] under the most favorable assumptions (i.e., high PAs and CEPs) is established and the damage levels, obtained with the same weight of effort and the worst performance factors, determined. Upper and lower bounds of expected damage corresponding to high and low performance factors for U.S. forces are thereby obtained, and an approximate weight of effort is identified with countervalue objectives.

- The major U.S. force elements are ranked (b)(1) application on the basis of three principal criteria: (1) the likelihood that they will, in fact, arrive to damage their targets; (2) the yield and CEP of the weapons and their effectiveness in specific applications (i.e., weapon-target match); and (3) the reaction time and relative dependability of their command and control links.

- The manner in which forces can be crosstargeted to insure against the possibility of force-wide failures is investigated, and so is the more general question of the efficiency of mixed force allocations. Rules are then developed for determining the assignment of U.S. forces to meet the weight of effort established for countervalue objectives.

12. (b)(1) percent damage expectancy (DE) (on any or all elements of value) is taken to correspond to maximum objective as the validity of damage estimation beyond that level is considered to be highly questionable.

(b)(1)

[redacted]

(b)(1)

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force) is seen to provide approximately (b)([redacted] percent damage on the total data base. As can also be seen in Fig. 4, the corresponding damage for attacks on [redacted]

(b)(1)

26. ~~(S)~~ These results do not reflect the refinements of the "celled" city data which were used to obtain the damage response curves in Fig. 4.

(b)(1)

(b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

(b)(1)

~~(S)~~ Up to this point in the presentation of the capabilities of individual force elements, it has been implicitly assumed that the true values of the system parameters under the conditions of execution were known and used in the laydown. However, if a single plan is designed for a broad spectrum of conditions then substantial differences can exist between the true system parameters under the conditions of execution and the values of the planning factors used in the laydown.

~~(S)~~ The influence of the use of non-optimum planning factors on the effectiveness of (b)(1) POSEIDON warheads (b)(1) is shown in Fig. 8. The laydown (i.e., the assignment of warheads to target complexes and to aim points within target complexes) of each of three weapon systems (i.e., sets of true system parameters) is optimized for three different sets of planning factors. For example, (b)(warheads with true system parameters of PA(b)(1) are assigned to targets using each of the three sets of planning factors: (b)(1) (b)(1) The maximum damage with this system (b)(1) occurs, of course, when the laydown planning factors equal the true (intermediate) system parameters. (b)(1) in damage occurs for this system when the "pessimistic" planning factors are used, while (b)(1) in damage occurs when the "optimistic" planning factors are used.[27a]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

FIGURE 8 ~~(S)~~ Sensitivity of Expected Damage to the Accuracy of the Laydown Planning Factors (U)

(b)(1)

Highlights and Observations

~~(S)~~ The results that have been presented, pertaining to the capabilities of the four major elements of U.S. strategic offensive force against the (b)(1) can be summarized in terms of the following general observations:

- Each of the four forces (POSEIDON, MINUTEMAN III, BOMBER, MINUTEMAN II) (b)(1) (b)(1) under moderately conservative assumptions about the performance factors of U.S. systems.

- For a given fraction of damage on the (b)(1) the requirements are least for (b)(1) and greatest for (b)(1) The numbers of weapons required for the same level of damage on the combined elements are generally slightly less than those required for (b)(1) The requirements for (b)(1) are frequently one-half of those indicated for population or the combined elements.

(b)(1)

- The damage is also sensitive to the target representation used in the calculations. The detailed characteristics and distribution of values within target complexes, and particularly the distribution and vulnerability of population within cities, has a significant effect on the damage expectancy (or alternately on the force-sizes required to achieve specific damage objectives).

- The distribution of damage across the USSR (b)(1) data base is very similar for all systems examined (POSEIDON, MINUTEMAN III, BOMBER (b)(1) weapon, MINUTEMAN II).

- Finally, it is noted that while the true probability of arrival very directly affects the resulting damage, errors in the planning factors used to allocate weapons are much less significant.

4. Capabilities of Individual U.S. Force Elements Against the (b)(1) (b)(1)

~~(S)~~ The capabilities of U.S. forces against the (b)(1) are calculated in a manner similar to that used in dealing with the (b)(1) but generally with fewer parametric variations. The results are summarized in Fig. 9. Although the same set of four weapons is represented in Figs. 4 and 9, two other weapons, appropriate for application to (b)(1), are represented by essentially the same response curves. These are: (1) the (b)(1)

~~(S)~~ The principal observations regarding the damage response curves obtained for the (b)(1) are as follows:

- The force sizes required for corresponding fractional damage[30] are approximately (b)(1) of those required for the (b)(1)
- As in the case of the (b)(1) data base, the forces required for given damage levels are substantially less when targeting (b)(1) alone than they are when dealing with (b)(1) alone or the combined elements. The requirements are roughly equal in the latter cases.
- If current plans and procedures are assumed to hold firm, it is possible that neither POSEIDON nor MINUTEMAN would be applied (b)(1) The capabilities of POLARIS A3 and the bomber weapons are, therefore, most relevant.

5. Total U.S. Offensive Capability Against the (b)(1) (b)(1)

~~(S)~~ In this section a determination is made of the total U.S. offensive capability and its relation to the weight of effort which may be required to meet (b)(1) targeting objectives. In the development which follows, the total capability of all U.S. forces[31] is represented by an equivalent force of reference weapons (b)(1) The weight of effort required for countervalue objectives is then arrived at through a procedure that develops from the premise that a very substantial variability in capabilities might obtain in

28. (b)(1)

(b)(1)

(b)(1)

31. (U) See Section V.A.1.

actual engagements. The procedure, described through a specific illustrative example, leads to the determination of one force level (a quantity of reference weapons) to cover a wide range of conditions and force factors.[32] Consideration of planning options to meet more narrowly defined conditions is treated in a subsequent discussion.

Total Equivalent Force

(C) In considering the requirements of various objectives, it was found convenient to refer to the concept of an equivalent force of reference weapons to represent the combined capabilities of all U.S. force elements in a given application. An equivalent force is, therefore, obtained for (b)(1) and combined (b)(1) values, and later on for different classes of military targets. The concept retains its usefulness for competing objectives as the equivalent forces are easily related to each other and, in addition, quite stable across a range of application.

(C) The equivalent force, in each case, is formed by assuming that the capabilities of the individual forces are simply additive and therefore, produce the same effects in mixes as they would in pure applications. While this assumption may slightly underestimate the effectiveness of mixed forces, the error is relatively small in practice and the validity of the process for the purpose at hand is unimpaired.[33]

(S) The procedure first determines the maximum potential capability of all U.S. forces combined and then relates the total obtained from lesser performing forces (i.e., forces characterized by more modest performance factors) to the full potential. The maximum combined capability is established by using the best performance factors[34] and referring each force to an equivalent number of reference weapons. The reference weapon, a (b)(1) warhead with a CEP of (b)(1) and a probability of arrival of (b is selected for its applicability to both counterforce and countervalue objectives and also because its yield is similar to currently deployed forces.[35] The equivalent forces are formed using, as a conversion factor, the ratios of force sizes required to achieve a specified level of damage on the total data base. The conversion factors are obtained at a DE of (b) percent when dealing with total equivalent forces and at lower DE levels (e.g., (b percent) when the resulting effects are to be in these lower damage regions, i.e., in dealing with small fractions of the total equivalent force and pessimistic performance factors. The difference between conversion factors at different damage levels is small, however, and represents a second-order consideration in this process.

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32. (C) Other sets of scaled objectives can also be accommodated in a similar manner while retaining the same general concept, i.e., one invariant allocation for all conditions.
33. (S) More precise procedures for determining the capabilities of a mix of forces are discussed in Section V.C.3.
34. (U) See Section V.A.1.
35. (C) The analytical development is not dependent, however, on the choice of reference weapon made and could have been carried out with any of the weapon yields represented in the 1975 forces or with any of a number of hypothetical weapons.

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(b)(1)

(b)(1)

(b)(1)

Pacific, for example, could alone provide damage levels of (b) [redacted] percent and ([redacted] percent assuming probabilities of arrival of (b)(1) [redacted], respectively. A force of (b)(1) [redacted] bombs[39] could provide similar damage levels.

C. U.S. CAPABILITIES AND COUNTERVALUE OBJECTIVES

1. Objectives, Force Factors and Corresponding Force Levels

~~(C)~~ To a considerable extent, both countervalue and counterforce objectives are viewed as variable in the WEPS analyses. This flexibility regarding objectives is due, in part, to the absence of rigid specifications in current statements of policy and further justified by the desirability of exploring a range of possible prescriptions for future time periods, e.g., 1975.

(b)(1) [redacted]

~~(S)~~ With respect to countervalue objectives, the analysis first asserts that (b) [redacted] percent damage on the total base represents a limit beyond which no meaningful incremental effects are obtained. Accordingly, the most extreme countervalue objective would consist in achieving (b)([redacted] percent damage on each of the two countries with the most conservative assumptions for U.S. force capabilities (i.e., worst force factors). As can be seen from Figs. 10 and 11, the total U.S. capability would be needed to meet this extreme objective. Reducing the damage to (b) [redacted] percent while retaining the clause that it be achieved under the worst conditions would still maintain the total requirement at a very high level. In both cases, a large number of weapons

(b)(1) [redacted]

40. ~~(S)~~ It also adds that the objective is to be met with available capabilities and with full consideration of the military objectives which are included in other tasks.

41. ~~(S)~~ Developed for the specific purpose of implementing the NSTAP.

(b)(1) [redacted]

would be used ineffectively (in effect be wasted) were better force factors to apply unless it was further assumed that the weight of effort varied accordingly. (As indicated earlier, the question of options for more narrowly defined conditions is taken up in a subsequent discussion.) The next step in the consideration of descending countervalue objectives leads quite naturally to the concept of scaled objectives including minimal objectives for worst conditions.

~~(S)~~ The idea of scaled objectives to correspond to different engagement conditions and their associated force factors is easily visualized through the sets of damage response functions represented in Fig. 12.[43] The individual set in each case represents one major force element, e.g., POSEIDON, against one element of target value, e.g., (b)(1) and consists of four damage response curves representing respectively: (1) the full potential capability of each force or the ideal limiting capability in each case (PA = (b)(1) specification CEP); (2) the response which might obtain under very favorable initiation conditions, i.e., with "peacetime performance factors" (b)(1) somewhat poorer than design specification); (3) the conditions that might apply in actual engagements excluding major unanticipated events but including some operational degradation for errors and deficiencies only occasionally observed or suggested in peacetime test and evaluation programs (PA (b)(1) and finally (4) pessimistic estimates of force capabilities but still falling short of those that would imply catastrophic force-wide failures (b)(1) substantially degraded CEP (b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

would be required. Once again, (b)(percent of that component force (b)(1) warheads) would approximate the requirements.

~~(S)~~ As can be seen in Fig. 12, the principle of scaled objectives generally applies to all (b)(1)

(b)(1) These observations suggest a variety of related criteria for determining the weight of effort to assign to countervalue objectives. The criteria used here simply illustrate a procedure and allow the general analysis to proceed to a more specific definition of the attack alternatives.

2. **Selection of Systems for Countervalue Application**

~~(C)~~ So far the analysis has assumed that the same performance factors apply uniformly to all systems. A simple rationale is now advanced for ranking the systems and (b)(1)

~~(C)~~ Three criteria are used throughout the analysis in ranking systems for application to different target categories: (1) the relative degree of assurance that the system will deliver under a wide range of possible engagement conditions,[49] i.e., the degree to which it combines the characteristics of survivability, dependability, and ability to penetrate; (2) the suitability of the yield, CEP and force size relative to target characteristics and total target list; and (3) the degree of controllability and the reaction delay associated with the system from command to execution and impact.

~~(S)~~ From the standpoint of yield, CEP, and force size, and in the absence of other competing requirements, all weapons[50] may be considered suitable for (b)(1) application. Similarly, reaction time may be considered of secondary importance in targeting (b)(1) resources. Assurance of arrival,[51] therefore, emerges as the controlling criterion. On that basis, POSEIDON might be ranked first for application to the (b)(1)

48. ~~(S)~~ The same procedure can be applied to the (b)(1) data base and the damage response curves of Fig. 9. As noted earlier, however, the objectives attained in the (b)(1) quite so high under favorable conditions once the weight of effort (number of weapons allocated) has been established by minimal objectives and worst force factors.

49. (U) Or under a set of specific conditions or assumptions.

50. ~~(C)~~ The selection is restricted to the Category A weapons at this stage of the discussion.

51. ~~(S)~~ The aggregated factor representing the full sequence: survival, launch, reliable operation, penetration of defense and detonation in the target area.

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(b)(1) [redacted] the sea-based systems being chosen for their low vulnerability to enemy attack and the extensive operational verification which they receive in test and evaluation programs.[52] The BOMBER and MINUTEMAN[53] systems then follow with the precedence going to one or the other depending on the relative weight assigned to such factors as: the proven dependability of the aircraft systems; the defense penetration advantage of MINUTEMAN; the ability of the aircraft to launch on warning, etc.

~~(S)~~ The real significance of any ranking of systems depends on the magnitude of the difference between the suitability of the successive systems when so ranked. The consequence at one extreme would be to assign one system exclusively (or predominantly) while at the other extreme, with the differences estimated to be insignificant, the indicated solution would be to have all systems contribute equally. The two extreme alternatives are identified as follows:

a. One system, the most appropriate for the specific application, is used exclusively to meet the full objective.

(1,0,0)[54]

b. All three systems contribute equally and jointly meet the full objective.

(1/3,1/3,1/3)

Additional alternatives include:

c. Two or three systems contribute equally and in sufficient force sizes to independently meet the full objective.

(1,1,0) or (1,1,1)

d. Two types of contribution are represented in the mix: (1) the principal component forces are sized to separately support the specified objectives; and (2) the supplemental forces[55] are then included to provide additional assurance against force-wide failure of the principal forces.

$(1,\Delta,0)(1,\Delta,\Delta)(1/2,1/2,\Delta)(1,1,\Delta)$

(S) The indicated alternatives, while far from all-inclusive, emphasize some of the fundamental considerations involved in selecting the composition of forces to be applied to the

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52. ~~(S)~~ Including comprehensive demonstration and shakedown at sea, and missile firing from each submarine with operational crew and equipment in the normal environment.

53. ~~(C)~~ The MINUTEMAN systems (i.e., II and III) are considered as one at this stage.

54. ~~(S)~~ The notation indicates the fraction of the total requirement that is met by each of the three forces considered, for example (1,0,0) could be read to mean that the full requirement is met by POSEIDON warheads only. Only three forces are represented as the two MINUTEMAN systems are considered as one. An additional variation could include representing each MINUTEMAN system separately.

55. ~~(S)~~ Making a smaller contribution, Δ

(b)(1) [redacted] The need for assurance against force-wide failures, for example, would tend to direct the choice to alternatives with representation from all three forces. Judgments and decisions regarding the likelihood of force-wide failures and the degree of confidence required for the achievement of specified objectives, would then resolve the question of whether it suffices to provide a diverse mix of systems[56] or whether each force element in the mix, must in addition, independently meet the full requirements established in the previous section.[57] The absence of a factual basis for the probability of force-wide failure makes the preference of one approach over the other essentially a matter of deciding on the degree of optimism or conservatism to be adopted. Two illustrative cases are used in the further development of the analysis. The compositions selected (1/3,1/3,1/3) and (1,1,Δ) are associated with the following rationales:

Case 1:, If all systems are assumed to be nearly equally applicable and competing requirements for specific force elements are disregarded, the (1/3,1/3,1/3) mix is a reasonable resource-conserving solution. It offers assurance against force-wide failures (the forces are assumed to be independent of each other with respect to force-wide failures) and approaches the established objectives for expected damage provided the probability of force-wide failure (P_c) is estimated to be very low. As P_c is increased, the probability of falling substantially short of the established objective increases, however, and the effect is not compensated by simply adjusting the three component forces to maintain the same damage expectancy. In essence, in this case, high assurance against the total failure of the effort is obtained but the effects of P_c (on damage expectancy) are accommodated within the total weight of effort established without consideration of P_c.

Case 2: With the presumption that P_c can assume very substantial values, but that the conditions (or situations) that would affect one element would not impact on the others, the conservative solution of course, would be the combination identified as (1,1,1). The case actually selected (1,1,Δ) is based on the argument that two independent forces, each capable of meeting the full objective, would suffice if, in addition, they were supplemented by a smaller force that could by itself provide substantial damage levels. With this rationale, the sea-based systems and the bombers might constitute the principal components, and MINUTEMAN the supplemental force. Although the role of MINUTEMAN and the bomber could be interchanged, the bomber is chosen as the second principal component on the basis that it gains more from its association with the sea-based missiles than would MINUTEMAN, and also

---

56. (S) The weight of effort established without consideration of force-wide failure is simply met through the joint contribution of all elements. This corresponds to alternatives (1/3,1/3,1/3), (1/2,1/2,0), etc.

57. (S) The weight of effort established without consideration of catastrophic failure determines the contribution of each force element selected. Alternatives (1,1,1) or (1,1,0).

because it provides for a more diverse mix of capabilities and vulnerabilities (or invulnerabilities). Additional arguments for assigning the principal role to the bomber will emerge when counterforce objectives and particularly the targeting of missile silos are considered and strong competing requirements for the MINUTEMAN system are established.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

3. **Capabilities of Mixed Forces Against** [redacted]

(S) The mix of forces selected may be allocated to maximize the damage inflicted by the combined force, or to maximize the damage inflicted by each of the constituent forces. The merits of "overall damage maximization allocations" and "allocations in isolation" against [redacted] are described in full detail in Enclosure B. Table 7 and Fig. 13 illustrate the relative merits of the two extreme procedures as well as a number of intermediate cases.

(S) In the "overall damage maximization" allocation the weapons are assigned to targets so as to maximize the total damage which could be inflicted by all systems acting simultaneously. While the total damage which could be achieved is maximized by this laydown, it is found that there is very little crosstargeting; most targets are attacked by only a single weapon system. This lack of extensive crosstargeting makes the laydown sensitive to the catastrophic failure of some of the systems. For example, [redacted] percent damage is achieved on the [redacted] data base by the illustrative force in Table 7 when it is allocated so as to maximize the damage achieved by the total force. [redacted]

(S) One alternative to the "overall damage maximization" allocation, is an "allocation in isolation." In this allocation, the weapons are allocated to targets so as to maximize the damage which is achieved by each system acting independently. The total damage achieved by this laydown is less than that for the overall damage maximization laydown, but the damage which would be achieved under conditions of catastrophic failure of a number of systems can be considerably higher. For the illustrative allocation given in Table 7 the total damage achieved by an "allocation in isolation" laydown is [redacted] percent, compared with the maximum possible [redacted] percent; however, the POSEIDON force, acting alone would now achieve its maximum damage of [redacted] percent, rather than th[redacted] percent which it would achieve when allocated in order to maximize the total damage of a mixed force.

(S) A large number of allocations intermediate between the allocation for overall damage maximization and allocation in isolation can be generated. In the construction of these intermediate laydowns, it has been found convenient to use the parameter, P_C. When P_C is equal to zero, the "overall damage maximization" laydown is generated and there is little

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

crosstargeting. As P_c approaches unity, the laydown approaches that of "allocation in isolation" and the most important complexes are heavily attacked by a number of different weapon systems. The effect of intermediate values of the hedging parameter[64] is also illustrated in Table 7 and Fig. 13. In this example, the illustrative force is allocated using four different values for P_c. As the hedging parameter (b)(1) the total damage achieved by the four systems acting simultaneously (b)(1) percent to (b)(1) percent[65] decrease in the total damage which could be achieved by the four force systems is accompanied by rather large increases in the damage which could be achieved by the systems acting independently (b)(1)
(b)(1)

~~(S)~~ The choice of a particular value of the hedging parameter, P_c, depends upon the relative weight given to the maximization of damage under design conditions and the assurance of a large degree of damage under the catastrophic conditions of the gross failure of some systems.

~~(S)~~ The capabilities of six different weapons mixes, allocated both "in isolation" and for "overall damage maximization" are presented in Fig. 14. It should be noted that the relatively small MINUTEMAN forces do not contribute greatly to the total damage achieved by the exemplary allocation (b)(1) percent POSEIDON (b)(1) percent BOMBER, (b) percent MINUTEMAN III and (b)(percent MINUTEMAN II), but can provide a significant hedge against the catastrophic failure of the POSEIDON and BOMBER forces. Reducing by (b)(1) the POSEIDON and BOMBER forces in the exemplary allocation reduces the damage by approximately (b) percent.

D. U.S. COUNTERFORCE CAPABILITIES

~~(S)~~ The achievement of counterforce objectives is highly dependent on the character and capability of the opposing forces and on reaching the target installations before the missiles or aircraft have been launched. In the time period of interest (1975) (b)(1)
(b)(1)

64. (U) The hedging parameter is the same as the probability of force-wide failure. The allocations are chosen to maximize the damage expectancy, as calculated with stochastic allowance for force-wide failures. The damage expectancies in Table 7 and Figure 13 are those caused by such allocations when the specified forces survive.

65. ~~(S)~~ The changes in expected damage are given as a percent of the damage a (b)(1) or example, the increase (b)(1)

66. (U) See Tables 2 and 3.

(b)(1) [redacted]

~~(C)~~ The problems of countering the diverse elements of (b)(1) [redacted] somewhat separable issues and suggest a different development from that followed for countervalue objectives. First attention is directed at targets that pose a direct nuclear threat to the U.S. The effects of diverting resources from targets which threaten the U.S. to those representing threats to our allies or to other military installations are examined in the next section in a discussion of competing counterforce objectives.

~~(C)~~ The forces posing a nuclear threat to the U.S. are considered in the following manner:

(b)(1) [redacted]

THIS DOCUMENT

COULD NOT BE

REPRODUCED BASED

ON SIZE OR

CONFIGURATION.

[redacted] and Other Soft Nuclear Threat Targets

[redacted] while both groups combined number approximately [redacted] targets. The POSEIDON and BOMBER forces required to achieve [redacted] percent expectancy of [redacted] on these target bases are summarized in Fig. 15. Weapon scaling factors for all of the weapon systems, when targeting these same installations, are shown in Table 8. Figure 15 and Table 8 permit the following observations:

[redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1)

(b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1)

[redacted]

~~(S)~~ Figure 16A illustrates the problem of silo occupancy and also the effects of wide-ranging assumptions for the vulnerability of emplaced missiles. With full occupancy, and (b)(1) to any one of a possible number of failure mechanisms to be negated by one arriving (and functioning (b)(1) (b)(1)), U.S. counterforce attacks with the MINUTEMAN II, MINUTEMAN III, and POSEIDON inventories could reduce the retaliatory threat to that represented by the SLBM force alone. On the other hand, even with full occupancy at time of arrival, the combination of assumptions which implies very hard systems (b)(1) weapons) and somewhat degraded accuracy for U.S. system (b)(1) for MINUTEMAN II) would allow a large fraction of the total USSR missile force to survive even if the total U.S. missile inventories were used in the counter-ICBM attacks. The implications of different levels of occupancy and the impact of different assumptions for the vulnerability of USSR ICBMs and U.S. missile force performance factors are readily seen by projecting the specific conditions on Fig. 16A to the damage response function of Fig. 16B.

~~(S)~~ Figure 17A shows how the total (b)(1) might be decreased with increasing application of U.S. force. The U.S. attack capability is represented by a reference weapon of (b)(1) CEP and the reduction in (b)(1) is indicated as a function of the number of reference weapons employed. The total (or maximum) number of reference weapons provided by the actual missile forces, i.e., MINUTEMAN II, MINUTEMAN III, and POSEIDON is indicated in Fig. 17A by the symbol ⊙.[71] Full silo occupancy at arrival of U.S. weapons is assumed in all cases but different assumptions regarding target vulnerability (b)(1) and the performance of the U.S. offensive missile system (reference weapon with (b)(1) are considered.

~~(S)~~ Two curves from Fig. 17A are used in conjunction with Fig. 16B to develop Fig. 18 and emphasize the possibilities of damage limiting attacks under favorable assumptions. While admittedly optimistic, the cases selected illustrate the very substantial reduction in U.S. casualties that might result from counterforce attacks on the land-based systems. The results (b)(1)

attack could effectively utilize the entire inventory of U.S. missiles. The requirement for high probability of severe damage to all enemy ICBMs, therefore, generally exceeds the total U.S. capability.

~~(S)~~ The relative effectiveness of the three major U.S. missile forces against fixed land-based ICBMs is indicated in Fig. 19 where each force is converted, once again, into an

71. ~~(S)~~ The capabilities of the actual U.S. missile forces are related to equivalent forces of reference weapons in Fig. 19 for specific assumptions regarding the performance of the U.S. forces.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

(b)(1)
[redacted]

6. **Selecting Systems for Various Counterforce Applications**

~~(C)~~ In the discussion of countervalue objectives, three criteria were used to rank systems for application to different target categories: (1) the relative degree of assurance that the system will deliver under a wide range of possible engagement conditions, i.e., the degree to which it combines the characteristics of survivability, dependability, and ability to penetrate; (2) the suitability of the yield, CEP and force size relative to target characteristics and total target list; and (3) the degree of controllability and the reaction delay associated with the system from command to execution and impact.

~~(C)~~ Whereas the assurance of arrival under a wide range of possible engagement conditions was considered the controlling criterion when dealing with countervalue objectives, system reaction-time followed by accuracy and force sizes are the controlling factors in counterforce application.

(b)(1)
[redacted]

33. (U) Separate treatment would be required in an evaluation of the proposed U.S. ABM systems. As noted earlier, the U.S. ABM forces were not examined critically in this phase of WEPS.

(b)(1), (b)(3):42 USC § 2168 (a) (1) (C)
[redacted]

MINUTEMAN II might be given precedence since it achieves its rank on the basis of yield more than CEP and greater confidence is assumed to be associated with that factor. If force sizes are considered, however, the total POSEIDON force is approximately[79] equal to the MINUTEMAN III force, and the MINUTEMAN II force represents a substantially lower capability.

(b)(1) [redacted]

(S) The essential arguments pertaining to the selection of systems for application to the soft military targets can be briefly stated as follows:

(b)(1) [redacted]

E. COMPETING OBJECTIVES

1. Competing Counterforce Objectives

(C) Current guidance and practices are used as references and points of departure for investigating a full set of potential counterforce objectives for the years about 1975.

(TS) Two strategic objectives in the current National Strategic Targeting and Attack Policy (NSTAP) concern the counterforce objective: Paraphrased, they are:

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

The critical parameters in the analysis are the average damage expectancy and crosstargeting constraints which are imposed on the allocation. Upper and lower bounds on the average damage expectancy (DE) are prescribed for each category. These bounds approximate the DE objectives in the current SIOP. (b)(1) [redacted] are treated exceptionally and are not associated with specific constraint[82] due to the impossibility of consistently meeting the high damage objectives desired. The nature of the analysis is to achieve the damage levels specified for the soft targets and let the ICBMs absorb all of the inventory not otherwise assigned.[83]

81. (U) The inclusion of these weapons would have little effect on the overall results of the analyses.
82. (U) This is also in accord with current practices.
83. ~~(S)~~ The allocation procedure is described in Appendix A to Enclosure E.

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

(S) The allocation process operates in the following way in providing coverage to the different categories of military targets: both missile and aircraft weapons are employed against the soft nuclear threat and against other soft Task A targets, while only missile weapons are

(b)(1) [redacted]

(b)(1) [redacted] The allocation is further affected when the second option for Task B targets is taken, i.e., that POSEIDON is made available for assignment to these targets. The forces and targets used in the allocations are given in Tables 11 and 12.

(S) The forces and targets described above were considered in a wide range of (b)(1) [redacted]

(S) The first set of cases involved the use of almost all U.S.[86] forces, and produced allocations that were contained in the ranges indicated in Table 13 for all the combinations (b)(1) [redacted] can be said that the allocations remain essentially unchanged under any combination of the following assumptions:

(b)(1) [redacted]

- Best or degraded[87] CEPS for the U.S. missile forces.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

- Two levels of DE objective for the soft targets (see Table 10).

(S) If the SRAM and [redacted] weapons are entirely reserved for defense suppression but all other forces are still available for counterforce application, the allocations are contained in the ranges indicated in Table 14. Somewhat greater variations are observed in this table. The removal of the SRAM and [redacted] weapon shifts the burden of the soft targets to the other

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1)

(S) An excursion which allowed POSEIDON on the Task B targets was also examined. Significant variations from the allocations of Table 13 resulted only when the following conditions existed: the lower DE objectives were in force; the SRAM and (b)(1) weapon package was included; the design CEPS (or best CEPs) were assumed. The principal effect produced by these conditions is that approximately (b)(1) POSEIDON weapons are drawn off Task A targets and employed against Task B targets. The POSEIDONs removed are then replaced by an equal number of SRAMs.

(S) The most noteworthy aspect of the preceding groups of allocations is that the weight of effort against the hard point targets ((b)(1) remained constant at (b)(1) going to ICBM sites. The range in the average DE on the (b)(1) resulting from these allocations is:

(b)(1) when the targets are assumed to be vulnerable at (b)(1),
when the targets are assumed to be vulnerable at ,
when the targets are assumed to be vulnerable at , and
when the targets are assumed to be vulnerable to one arriving (b)(1)

The range in the DE is due almost entirely to the two levels of accuracy used for the U.S. forces.

2. Competing Countervalue-Counterforce Objectives

(C) The preceding analyses indicate that counterforce objectives cannot, in general, be fully realized even in the absence of competing requirements but that countervalue objectives, on the other hand, can be achieved, with moderate to high confidence, with only a fraction of the total U.S. forces. The question of most interest regarding competing objectives, therefore, involves the extent to which the weight of effort assigned to countervalue objectives might further detract from U.S. counterforce capabilities. The analyses discussed in the previous section are, therefore, extended to explore this point and more generally, to examine the distributions obtained with levels that might be compatible with countervalue objectives.

(S) The forces available for counterforce targets are now taken to be as follows:

- [redacted] percent of the POSEIDON force.
- [redacted] percent of the [redacted] component of the BOMBER force.
- [redacted] percent of the MINUTEMAN II and MINUTEMAN III forces.

The allocations obtained for all the combination of assumptions and conditions discussed above are contained in the ranges of values indicated in Tables 15 and 16. In the first set of allocations (Table 15) [redacted] percent of the SRAMs and [redacted] percent of the [redacted] weapons are assumed to be available for counterforce targets (see Table 11), while for the set of allocations on Table 16 all SRAM and [redacted] weapons are assumed to be required for defense suppression.

~~(S)~~ The comparative results for the two levels of U.S. forces are briefly summarized as follows:

1. With [redacted] percent of the forces committed to counterforce objectives, the weight of effort against the hard point targets remained constant at [redacted] weapons (between [redacted] against the ICBMs) over the full range of conditions considered.

2. When the forces committed to the counterforce objective are reduced by removing [redacted] percent of the BOMBER weapons and [redacted] percent of the POSEIDON weapons, the number of weapons allocated to the hard point targets drops into the range [redacted] weapons, with from [redacted] assigned to the ICBMs. Improved CEPs, reduced DE objectives, and use of the SRAM [redacted] weapons are responsible for releasing the [redacted] weapons indicated as the total magnitude of the range for the allocations to the hard point targets. The range obtained for allocations against the [redacted] was [redacted] weapons, and [redacted] for the soft targets.

The general effect of the reduced force sizes was that missiles were drawn off the hard point targets to achieve the required damage levels on the soft targets. The effect was mitigated in various cases by reserving fewer defense suppression weapons, by reducing the damage levels on the soft targets, or by assuming that design specification CEPs were achieved.

~~(TS)~~ The relative weight of effort applied to the hard point targets was found to be much less dependent on the CEP of the attacking weapons or the assumed vulnerability of the

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

targets than on decisions concerning the total counterforce effort and to a lesser degree on the damage objectives for the soft military targets. As might be expected, however, the resulting damage levels on the hard point targets were strongly dependent on the vulnerability numbers (b)(1)

3. **Options for Different Engagement or Initiation Conditions**

~~(S)~~ The development up to this point has generally assumed that forces are not reassigned to respond to different initiation or engagement conditions. The basic characteristics of intensitive attack plans for the (b)(1) of the total targeting task have been outlined. The capabilities of each major element of the U.S. strategic offensive forces have been established and the effects of erroneous planning factors and erroneous assumptions regarding target conditions (including occupancy) have been considered. The total capabilities of U.S. forces when assigned exclusively to counterforce objectives have been noted. The effect of reducing the counterforce attack level by an amount corresponding to the forces

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88. ~~(S)~~ Approximately (b)(1) weapons, and approximately (b)(1) weapons.

(b)(1) [redacted]

(S) The competition between countervalue and counterforce objectives may be reduced by the introduction of options designed for different initiation and engagement conditions. The discussion now goes on to briefly consider the possibility of such planning options.

(S) The hazards of plans optimized for either extreme objectives, i.e., pure counterforce or pure countervalue, are obvious and hardly need elaboration. Practical and safe options can probably involve only modest transfer of forces away from the countervalue objectives if these objectives are assumed to be invariant. (b)(1) [redacted] A variety of attacks reflecting possible options for conditions of retaliation as well as preemption are explored in considerable detail in Enclosure E.

89. (b)(1) [redacted]

90. (S) The expression "insensitive plans" should not be taken to imply either inflexible plans or plans devoid of options for meeting either specific or limited objectives. It does suggest, however, that diversion of a substantial fraction of force from one objective to another, particularly from countervalue to counterforce, is risky if it must depend on judgments made during the engagement.

91. (S) In the analysis of Enclosure E BOMBERS are allocated (b)(1) [redacted] in retaliatory attacks whereas they are not assigned to these targets in preemptive attacks.

VI. FOOTPRINT CONSTRAINTS IN THE ALLOCATION OF MIRV SYSTEMS

A. INTRODUCTION

(S) The footprint capabilities of the MIRV systems introduce an additional constraint into an already complex allocation problem. The Post Boost Vehicles or buses of the MINUTEMAN III and POSEIDON systems are limited in the incremental velocity they can impart to the individual reentry vehicles (RVs) in order to establish trajectories to separate targets. Consequently, a MIRV booster/bus of some particular configuration can deliver its RVs only to targets that are relatively close together. When targeting a large target set with a force of MIRV systems, it is not feasible to optimally target each RV nor to target a full load of RVs with all boosters.

(S) The purpose of this study is to investigate the impact of the MIRV footprint and range constraints on the weapon allocation process. Base case POSEIDON and MM III (b)(1) [redacted] range-constrained allocation model, FOOTCALL,[1] are presented. The results of these allocations are compared to the results obtained if the systems has infinite footprint and the magnitudes of the effects of the footprint and range constraints of both MIRV systems are determined. The effects of the utilization of (b)(1) [redacted] of deployment to various launch areas, of the minimum RV spacing requirement, and of correlated reliability when targeting (b)(1) [redacted] are also examined.

(S) A series of POSEIDON and MM III footprint accessibility trials[2] for allocations on various military target sets are also presented. The effects of POSEIDON deployment to various launch areas and the employment of MM III pen-aid configurations are examined.

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1. (S) FOOTCALL is a marginal return allocation computer model which incorporates the footprint and range constraints in the allocation and operates on a data base where the targets have relative value.

(b)(1) [redacted]

(S) In the (b)(1) analyses, the controlling input is the number of boosters allocated and the output is the damage expectancy and average number of RVs per booster. In the military studies, the RV to target allocation is the controlling input and the output is the number of boosters required and the average number of RVs per booster. Hence, booster loading is an open-ended output of both the (b)(1) and military analyses.

(b)(1)

the programmed procurement levels. Several exemplary joint allocations (with task purity) across (b)(1) and military target systems are presented for both POSEIDON and MM III.

B. SUMMARY OF RESULTS

(b)(1)

1. POSEIDON

(b)(1)

(S) It is quite apparent that the POSEIDON footprint and range constraints have a modest effect on the capability of the system. An infinite footprint system could achieve 11 percent greater damage with the same number of boosters if 14 RVs per booster were available. If RVs are limited, the infinite footprint system could still achieve 5 percent greater DE with 25 percent fewer boosters.

---

3. (b)(1)

(b)(1)

[redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

[redacted]

(b)(1)

(b)(1)

(b)(1)

(b)(1)

(b)(1)

[redacted]

(b)(1)

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

VII. EFFECTS OF ABM DEFENSES

A. GENERAL

~~(S)~~ Up to now, the effect of ABM defense has been discussed as though it merely decreased the probability of arrival, PA, of U.S. reentry vehicles. Actually, however, the effects (b)(1) [redacted] have been specially considered in a study (ABM Defense Employment, Engagement, and Penetration) that appears as Volume VIII of the present report. The special study addresses a situation that may occur in 1975, when the intelligence forecast is that Soviet ABM defenses will probably be area defenses, with interceptors that can be directed to intercept reentry vehicles that endanger any targets within a sizable defended area. The study analyzes how the enemy could most effectively employ a defense of such a type, and of how the defense could be most effectively engaged and penetrated by a U.S. offensive force; whether by a simple "objective" attack (an attack on the targets) that penetrates the defense (b)(1) [redacted]

B. DEFENSE ENGAGEMENT STUDY: GENERAL ANALYSIS OF OBJECTIVE ATTACKS

(U) A high (although necessarily incomplete) degree of realism has been sought and achieved in the general analysis of objective attacks. The interceptors are imperfect, with single-shot kill probabilities, k, that are less than unity. The yields of the reentry vehicles (called "attackers") are such that each penetration destroys some specified fraction (alpha) of a target's remaining value; the fraction alpha can have any value from zero to unity, and can vary from target to target. The targets may have any assigned values. The analysis assumes that the offense is without intelligence of the defender's doctrines or of his planned allocations of interceptors, while the defense has no intelligence of how strong the attack on any particular target is to be, and is not sure during the attack whether or not he has seen the last of it. The offense is supposed to have some knowledge, but only a rough knowledge, of the number of area interceptors, and the defense is supposed to have only a rough knowledge of the total number of attackers that are allocated to targets in the defended area. The defense is supposed to know which target is threatened by each incoming attacker. This assumption really defines that is meant by "target", and makes the definition depend upon the accuracy with which the defender can predict the burst position of an unintercepted reentry vehicle. In the application of the analysis that is made, to the Moscow-Leningrad defended area, the targets are taken to be cities. The general analysis allows for the possible use of decoys by the offense to the extent that such use tends to increase the number of apparent "attackers" and to decrease the effective values of alpha. However, it does not allow for possible obscuring effects of chaff.

(U) The general analysis deals with the situation as it would exist after the offense has completed any attacks ("defense-suppression" attacks) which it may make on the area defenses themselves. In the general analysis the numbers (A)of remaining reentry vehicles that can be assigned to the attack of targets in the defended area have fixed but unspecified values. The offense seeks the greatest expected damage to such targets that it can reliably cause, by suitably allocating its A attackers to them while the defense seeks to keep the expected damage as low as it reliably can, by suitable employment of its D interceptors. In the situation contemplated by the general analysis, penetration of the defenses can occur only by exhaustion (no interceptors are assigned to some attackers) or by leakage (some assigned interceptors are ineffective). The effects of the possible prior defense-suppression attacks are not considered explicitly in the general analysis itself, although they are considered later and explicitly in connection with its application to the Moscow-Leningrad area defense. Then, the general analysis is applied to the situation that follows the defense-suppression attacks.

(U) The general analysis finds that the most effective way for a defender to employ his area interceptors is for him to select prior to the attack and randomly, but in accordance with calculated probabilities (P_d), some targets to defend and the rest to abandon. Those to be defended are defended strongly by intercepting each of their attackers with some calculated number n of interceptors. The values of P_d and of n vary from target to target since they depend on a target's value and on its alpha. The optimal defense involves random choices, that deny to the offense the ability to improve his attack by guessing which targets the defense will abandon. The preceding policy is optimal for the defense, in the sense that it minimizes the greatest expected damage that the offense can cause, whatever may be the assignments of attackers to targets. There is no better defense under the assumed conditions. In particular, it permits less damage to occur than could occur under a defensive policy of randomly intercepting a fixed proportion of all attackers without regard to the identity of the threatened targets or under a defensive policy of assigning fixed numbers of interceptors (even if the numbers are randomly chosen) to defend particular targets.

(U) The optimal attack, it is found, does not involve a comparable random feature, but merely the specific assignment of particular numbers (W) of attackers to particular targets in a manner that depends upon the values, numbers and alphas of the targets, on k, and on the total numbers A and D of attackers and interceptors. The values of P_d and n, that define the defense's optimal defensive tactics, depend upon the same quantities.

(U) An optimal engagement (an engagement with optimal employment of attackers and interceptors) is characterized by the near constancy (near, because of whole-number limitations), for all targets, of two parameters. One is the marginal expected value that is destroyed by a target's last attacker in the presence of the defense; the other is the marginal expected value that would be saved by an interceptor if it were employed in the target's defense. From optimal employment of the A attackers and D interceptors in an engagement involving a set of targets, there results some value F of the damage (the DE[1]). If the attack is optimal but the defense is not, the DE equals or exceeds F. By employing its attackers in the optimal fashion, the offense can thus insure that the damage will be at least F.

(U) In a typical engagement, optimized by both offense and defense, the attack concentrates on the more valuable targets even more strongly that it would in the absence of area defense. The defense concentrates on the more valuable targets still more strongly than the offense, by assigning a larger number n of interceptors to each attacker of a valuable defended target than it does to attackers of less valuable defended targets. Only a fraction of the attacked targets are defended. The probability of defense that is employed for each target, in the drawing of lots to decide whether or not to defend it, varies from target to target in accordance with its value and its alpha and may show no particular tendency to decrease or increase, systematically, with descent in the target list until the point is reached below which no targets are defended.

~~(S)~~ The expected damage DE depends upon the targets (their numbers, values, and alphas), upon k, and upon the total number of attackers A and interceptors D. In the cases that have been examined, however, once k, A and D are fixed the expected damage does not appear to depend appreciably upon the offense's knowledge of D and k. In an extreme example, for instance, calculations showed that an optimal attack by (b) [redacted]ttackers, against a

1. (U) In Volume VIII the symbol ϕ is used for the Expected Fractional Damage rather than DE.

(b)(1) targets defended by (b)(area interceptors with k-values of 3/4, would cause an expected fractional damage o(b)(percent. The calculations also showed, however, that an attack by (b)(attackers against the same targets, similarly defended, would have caused an expected fractional damage o(b)(percent even if the offense had optimized its allocations of attackers to targets in accordance with a mistaken belief that there were no interceptors at all. (Had there really been no interceptors, the expected damage would have been (b) percent.) It is suspected that the type of insensitivity that has been instanced may be general, since moderate departures from optimal allocations may be expected to have only small effects.

(b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(U) The value 3/4 of k has been used in many of the calculations simply because it lies half-way between its absolute upper limit of unity and a lower limit, one-half, that may be thought to represent the poorest performance of an ABM system that any nation would be willing to construct and employ. The value of k, however, must be regarded as being in fact widely uncertain. Included in k are not only effects of the uncertain probabilities of specific mechanical and electrical malfunctions, and of the possible systemwide overloading of computing and communications facilities, but also the probabilities that radars, necessary to the employment of the interceptors, may be unable to function through atmospheric layers heavily ionized (nuclear "blackout" phenomena) by the bursts of earlier attackers and interceptors. The value of k is not (and probably will never be) accurately known by the offense; it may not even be accurately knowable by the defense.

2. ~~(S)~~ Fractional damage here, and in the following pages of this chapter, refers to the total damage to the (b)(1)
(b)(1)

(b)(1)

[redacted]

[redacted]

[redacted]

(b)(1)

(b)(1)

The (b)(area interceptors are a low estimate, the (b)(interceptors a high estimate[3] of the

(b)(1)

2. **Decoys**

(S) The situation of the offense need not be as unsatisfactory, if it takes the proper steps, as the preceding considerations have indicated. The offense can employ some of its attackers in defense suppression attacks to impair the area defense and permit the remaining

(b)(1)

(U) The preceding discussion of the effect of decoys considers only the dilution that they cause of the apparent attack: since the defense sees more attackers, it cannot defend as

3. (TS) Intelligence indicates from (b)(1) for 1975; see Table 4.

(b)(1) [redacted]

3. Degradations of Defense Toward Randomness

(b)(1) [redacted]

E. [redacted] ATTACKS PRECEDED BY DEFENSE SUPPRESSION

[redacted] are, are considered in Volume VIII. It was necessary in dealing with the more complex situation to make more numerous, specific, and probably more doubtful assumptions than when considering attacks on the [redacted] The offensive force is considered to consist of [redacted] arriving attackers and the defensive force to consist of [redacted], and [redacted] launcher-interceptor farms each with [redacted] interceptors for a total of [redacted] interceptors. Two extreme cases are considered. In one, the radars are perfectly "netted", so that the defense is unimpaired unless all [redacted] radars are rendered inoperative; in the other, the radars are not netted at all, each covering the whole defended area but controlling only its own [redacted] interceptors. The probability that a penetrating attacker will destroy a radar on which it has been targeted is taken to be [redacted] based on the yield, the CEP and on DIA vulnerability data. The probability that a penetrating attacker will render a complete interceptor farm, on which it has been targeted, inoperative is taken to be [redacted] based on the same type of data, and it is assumed that the farm may be treated as a point (rather than area) target so that if it is not completely inoperative it will be fully operative.

[redacted] varying the number of attackers assigned to the defense-suppression phase, as well as varying the number of interceptors assigned to the defense of the defenses. The analyses were carried out for each of three values of the single-shot kill probability, k, of an interceptor: 1/2, 3/4, and 15/16. In all cases the expected fractional [redacted] damage was obtained from Figs. 26 and 27, the diagrams being entered with expected numbers of attackers and usable interceptors remaining after the suppression attacks. The results are shown in Figs. 28 and 29, taken from Volume VIII.

~~(S)~~ The effects [redacted] of suppression attacks on the radars were found to be highly dependent on the netting of the radars, the degree of netting being as important as k. With perfect netting, radar-suppression attacks were useless or disadvantageous to the offense. With no netting, radar-suppression attacks were highly advantageous to the offense; more advantageous than suppression attacks on launcher farms. If each radar could not cover (as had been assumed) the whole defended area, suppression attacks on radars that

(b)(1)

(b)(1)

(b)(1)

(b)(1) [redacted]

(U) With regard to area defenses other than (b)(1) [redacted] the general analysis of Volume VIII is expected to be applicable to them, although it has not yet been so applied. It is applicable without further development (and it is believed, rigorously) to enlarged or to completely separate regions protected by area ABM defense. If different area defenses overlap incompletely, so that some but not all targets could be protected by interceptors from more than one defensive system, then the analysis of Volume VIII is not rigorously applicable. It can be applied, nevertheless, to obtain offense-conservative estimates of the offensive forces required, and of expected damage done, because when so applied it would treat the combined defensive systems as a single system with complete overlap, any target being defensible by an interceptor, and such a treatment would tend to exaggerate the effectiveness of the defense.

4. (U) Ibid.

(S) Terminal ABM defenses, designed to protect cities or other very limited areas, may appear. Effective methods of employing terminal defenses, and of effectively attacking targets defended by them, have been the subject of many studies since 1948. Both their employment and their penetration are believed to be well understood. Basically, they offer less protection per interceptor than area defenses, because the limited coverage of their interceptors allows the offense with its inherent flexibility to concentrate its force on whatever targets it chooses to destroy. The comparatively poor effectiveness of terminal defenses, per interceptor, is to a degree offset, however, by the low cost per interceptor which permits the employment of large numbers of such interceptors; it may be offset to a degree also by the comparatively low vulnerability, of a set of separate terminal defenses, to impairment by a defense-suppression attack to which an area defense might be more vulnerable.

(U) Basic studies will be needed of the most effective ways to employ, and to penetrate, ABM defenses that consist of terminal and area systems used in combination.

H. SYNTHETIC NATURE OF THE SINGLE-SHOT KILL PROBABILITY, k. SIMULATIONS

(U) The single-shot kill probability, k, of an interceptor appears as an important parameter in many studies, including the present studies, that involve the performance of ABM defenses. The parameter is of a synthetic character. As has been pointed out, it includes not only the effects of possible mechanical and electrical malfunctions, and of the possible systemwide overloading of computing and communications facilities, but also of the possible impairment of radar performance by atmospheric ionization arising from the nuclear explosions of offensive and defensive weapons.

(U) The atmospheric region that appears to be most important for such nuclear blackout phenomena is at an altitude of about 60 kilometers, where air molecules can be ionized by electrons that have spiralled down lines of force in the earth's magnetic field after having been originally released as beta-particles by some high-altitude nuclear explosion.

(U) Impairment of the performance of an ABM defense by the nuclear blackout of its radars can undoubtedly occur. However, whether or not it *will* occur in any particular attack, on a particular set of targets protected by a particular ABM defense, is critically dependent not only upon the times and places (since the ionization persists in any one place for only a few minutes, unless renewed) of the high-altitude nuclear bursts, but also upon the locations of the particular paths along which particular radars must look (to acquire and track particular reentry bodies, or guide particular interceptors) and upon the times when the paths must be clear. It seems that it would be extraordinarily difficult, in view of the particularity of the events on which the impairment of the defense would depend, to calculate the contribution of nuclear blackout to k and allow for it, in any general way, by purely analytical procedures. However, it might be possible to plan the attack in such a way as to render probable the presence of ionized layers (or "patches") at particular places and times through special offensive bursts ("precursors") or forced defensive bursts ("forerunners"). Were such ionization insured, some definite degree of defense-impairment could conceivably be relied upon by the offense in the conduct of its attack. Such reliance, however, would appear to demand a degree of control, over the times at which critical missiles would have to be launched, that may be at variance with the uncertainties of war.

I. A SIMULATION INVOLVING BLACKOUT

(U) By employing a detailed simulation, tests have been made of the possibility of

(b)(1) [redacted]

(U) The simulation that was employed was a modification (IDA-BAGATEL) of a defense engagement simulation, BAGATEL, that had been developed by the General Research Corporation but which was unable without modification to deal with sufficiently large numbers of objects. The IDA-BAGATEL simulation contained a blackout model that closely duplicated the results of a code (DASA RANC IIIA) that is widely accepted as the best available for predicting the effects of nuclear bursts on electromagnetic propagation.

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VIII. BOMBER EMPLOYMENT AND DEFENSE PENETRATION

A. INTRODUCTION

~~(S)~~ The effects of enemy air defenses on the ability of the U.S. bomber force to penetrate to their assigned targets has been considered implicitly, up to this point, through the aggregated probability of arrival factor (PA). The bomber employment and penetration study is a more detailed investigation of the impact of [redacted] (b)(1)

B. SCOPE

~~(S)~~ For this study only those aircraft associated with the Strategic Air Command are used. Suppression of bomber defenses is carried out by different levels of both bomber and missile weapons.

~~(TS)~~ Although the magnitude of the U.S. bomber force is fixed, the number of aircraft which may be expected to attempt to penetrate the defenses depends on [redacted] (b)(1)

~~(S)~~ A wide range in the number of aircraft which attempt to penetrate the defenses is possible, depending on the conditions of war initiation. This study concentrates on the extremes of the range of possibilities, short of catastrophic failure. [redacted] (b)(1)

1. ~~(TS)~~ Current plans are under way to [redacted] (b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

C. DEFENSE SUPPRESSION TARGETS

(b)(1) [redacted]

---

2. ~~(TS)~~ An increase in the alert rate could offset any anticipated reduction in PLS, and therefore, it is reasonable to conside (b [redacted] percent of the force reaching the defenses as one end of the range.

3. ~~(S)~~ 100 percent of the unit equipment aircraft.

4. ~~(S)~~ The defenses are also degraded where possible by the use of decoys. The decoy used is the QUAIL. Although new decoys ((b)([redacted] for example) might be introduced by 1975, none have so far been programmed.

(b)(1) [redacted]

(b)(1) [redacted]

D. BOMBER FORCE CAPABILITIES

(U) The previous discussion recognizes four major conditions under which the performance of the bomber force should be assessed. These are represented by the limits of the major variable in the defense capability,[7] and the forces which would be executed.[8]

~~(S)~~ For any condition, the available weapons can be divided among the targets in various ways. (b)(1) [redacted]

(b)(1) [redacted]

(b)(1) then no matter how well they penetrate, insufficient numbers of objective weapons will be available to produce extensive damage to the objective targets. Hence, there is a tradeoff involved in the allocation of bomber weapons.

(b)(1)

9. (C) The corresponding figure for the fully generated force vs. the low estimate of the defense is (percent.

(b)(1)

(S) The damage achieved depends on the particular conditions under consideration, and the spectrum of conditions (force levels and defense levels) results in a range of damage (b)(1) [redacted] the case of the fully generated force are sufficient weapons available to cover all of the Task A and most Task B targets.

(S) The greater defense capability envisioned for the 1975 time period requires that expeditures of weapons for bomber defense suppression be increased beyond that of current plans. Although this attack achieves a high probability of arrival for most conditions, the increased weight of effort on defense suppression is accomplished by a reduction in the weight of effort on military objective targets.

E. ALLOCATION OF MISSILES TO BOMBER DEFENSES

(S) It is of interest to consider what benefits might be accrued through the use of missile weapons as a hedge against loss of defense suppression weapons. It is recognized, however, that this couples the bomber and missile forces, making the level of bomber probability of arrival dependent on the missile forces executed.

(S) When the bomber defense suppression attack achieves high damage levels on the defense, there is little additional gain from the application of missiles (other than an assurance to account for possible non-arrival of defense suppression weapons). Additional assurance can also be gained by the application (b)(1) [redacted] since the damage expectancy resulting from the bomber attacks on these defenses is only (b)(1) [redacted]

(S) For the consideration of a missile-assisted bomber attack, one condition—the execution of the alert force against the high intelligence estimate of the defenses—was chosen, and a missile weapon applied to each of the defense suppression targets. In this situation, (b)(1) [redacted] weapons are used (about (b)(1) [redacted] of the alert missile force).

(b)(1) [redacted]

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F. EXECUTION OF DEFENSE SUPPRESSION SORTIES

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G. UNCERTAINTIES

~~(S)~~ The analyses indicate that there is a range of values associated with the bomber probability of arrival. However, this planned probability of arrival is under the control of the offense in that sufficient weapons can be expended to achieve any desired level (as discussed above) of this parameter, and in particular to keep it high. In this sense, the range is not associated with uncertainty. This is not meant to imply that there are no uncertainties in the (b)(1) however. There are several sources, the magnitude of which can only be qualitatively addressed.

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IX. VULNERABILITY OF U.S. STRATEGIC FORCES

A. INTRODUCTION

(U) The achievement of national countervalue and counterforce objectives is critically dependent on both the availability and dependability of the U.S. strategic forces. It is thus most appropriate that the vulnerability of these forces to a Soviet counterforce attack be investigated as part of the WEPS study. Brief summaries of these investigations are presented in the next two chapters of this report. The first of these chapters (i.e., this one), presents the results of the study of Soviet counterforce capability against U.S. strategic forces in the 1975 time frame. The next chapter summarizes what is currently known about specific nuclear weapon effects, and the vulnerabilities of the forces thereto.

B. SLBMs

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even when (b)(1) [redacted] the force is committed to that objective and when (b)(1) [redacted] of the committed warheads arrive at their intended targets.

C. LAND-BASED SYSTEMS

1. General

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

4. (S) The results are easily scaled for the slightly larger numbers which comprise the MINUTEMAN and TITAN forces.

5. (S) Some artificiality is produced, however, in that the slopes of the damage expectancy curves are discontinuous where the number of *reference* weapons is just sufficient to cover the U.S. force, rather than when the number of *actual* weapons reaches this value.

6. (U) See Table 3.

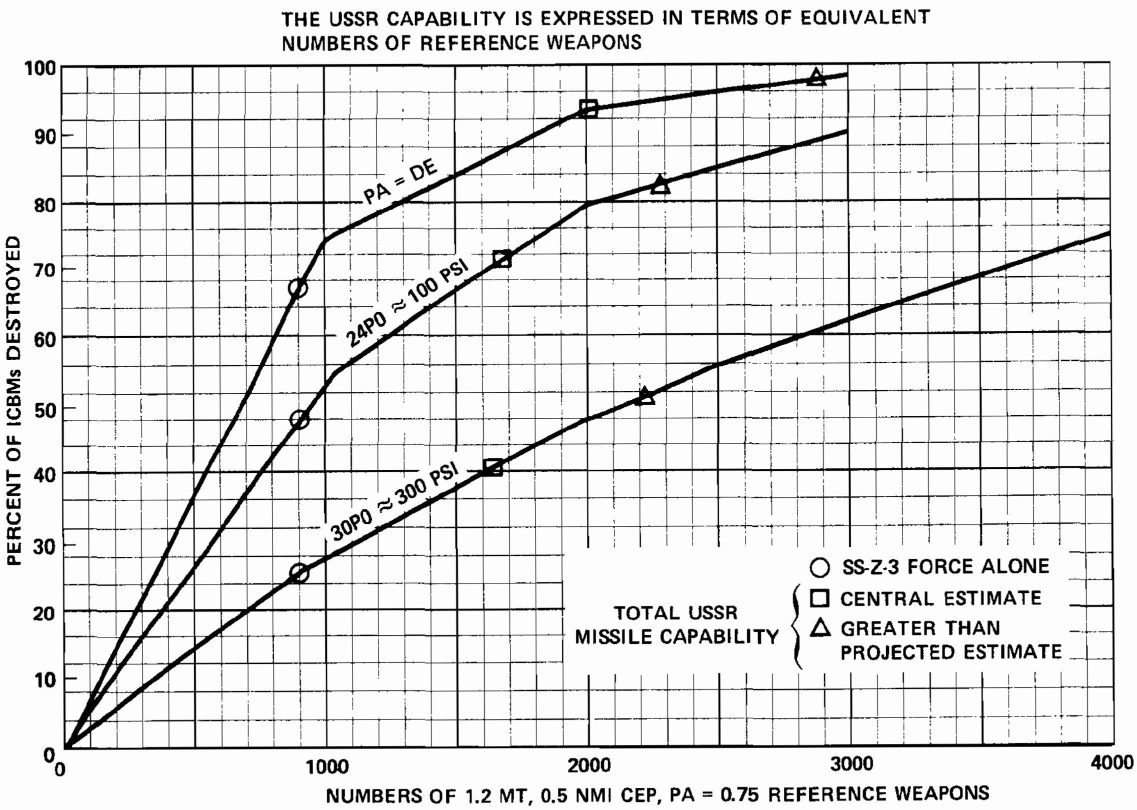

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FIGURE 30 (TS). Total USSR Missile Capability (1975) Against 1000 U.S. ICBMs at Three Assumed Levels of Vulnerability (U)

would destroy approximately 95 percent of our land-based missiles if one arriving USSR weapon could destroy one U.S. ICBM, i.e., if DE = PA. If, instead, U.S. ICBMs are assumed to be able to withstand the equivalent of 24P0 (≈100 psi) or 30P0 (≈300 psi), the Soviet forces could destroy only approximately 70 percent or 40 percent, respectively, of the total U.S. land-based forces. The projected SS-Z-3 force alone (900 warheads, 1.2 MT, 0.5 nmi CEP) could destroy 50 percent of the U.S. ICBMs if the latter were characterized by 24P0 (≈100 psi) and if 75 percent of the Soviet warheads launched were assumed to reach U.S. silos, i.e., if the probability of arrival were PA = 0.75.

(TS) Figure 31 illustrates the capability of the SS-Z-3 force alone against the U.S. silos. The SS-Z-3 force levels highlighted in the figure are (1) the projected intelligence estimate of 900 (1.2 MT) warheads, (2) a greater-than-projected force of 1800 warheads, and (3) an even greater force level of 3000 warheads. It is seen from Fig. 31 that only 50 percent

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X. NUCLEAR WEAPONS EFFECTS ON OFFENSIVE MISSILE SYSTEMS

A. INTRODUCTION

(TS) There has been a growing awareness in recent years of the subtle and unanticipated nuclear weapon effects to which strategic missile systems could be subjected in the event of nuclear war, and which could lead to widespread failures were the missile systems employed in the manner envisioned at the time of their design. Many systems vulnerabilities have been identified, and design changes made and verified to remedy them. All missiles will not have been corrected and redeployed, however, until 1975, and there is, of course, no assurance that additional problems yet unknown will not be discovered. It is thus instructive to consider the known vulnerabilities which will still be present in the time era mid-1969-mid-1972, both for their current importance, and because they illustrate the inherent risk which accompanies reliance on systems which have not been tested under operationally realistic conditions. They also serve as a reminder of the uncertainties which attend all computations of the consequences and outcome of a nuclear exchange.

(U) The following summarizes what is known about individual weapon effects on the MINUTEMAN, TITAN, and POLARIS forces.

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XI. PROPOSED FOLLOW-ON STUDY

(U) The main features of a new study program are briefly outlined below. The program proposed would extend the analyses to the post-1975 time period and to areas deferred in the current study.

(U) The program envisioned has three major aspects: One for studies emanating directly from the findings and recommendations of the completed study; another for investigations dealing with the changes that would affect the capabilities of U.S. forces as established in the earlier study, i.e., studies dealing with developments that would represent significant deterioration in the ability of U.S. forces to meet the present range of objectives; and finally, an aspect concerned with the advantages provided by various possible alternative force elements or system characteristics in the recomposition of future U.S. strategic forces. This general proposal relates quite closely to the original directive which referred to design implications and force planning methodologies in addition to the force employment consideration.

(U) The approach in the two new areas of emphasis would consist in first identifying the changes that would affect our strategic posture in a significant way in the years following 1975 if we assumed that our forces were to be held at the 1975 level. The next step, in part concurrent with the first, would consider the merits of realistic alternative solutions and improvements in the years immediately following 1975. The intention would not be to establish the most likely threat or pick the next generation of systems to be procured but to relate plausible and possible trends and developments to current and projected objectives, strategies and procedures. While based on the background of the WEPS effort in most of its aspects, the study envisioned would have a definite and separate identity.

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WSEG REPORT 148

STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

VOLUME IV

Enclosure C: Soviet Capabilities Against U.S. Cities

Enclosure D: U.S. and Soviet Capabilities Against Military Targets

August 1969

Including
IDA REPORT R-160
A. R. Barbeau, *Project Leader*

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REPORT R-160

STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

A. R. Barbeau, *Project Leader*

VOLUME IV

Enclosure C: Soviet Capabilities Against U.S. Cities

J. R. Transue
R. Y. Pei

Enclosure D: U.S. and Soviet Capabilities Against Military Targets

J. R. Transue
R. Y. Pei
J. A. Seaman

August 1969

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in response to the Weapons Systems Evaluation Group Task Order SD-DAHC15 67 C 0012-T-140, dated 21 December 1967.

In the work under this Task Order, the Institute has been assisted by military personnel assigned by WSEG.

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FOREWORD

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in conjunction with the Weapons Systems Evaluation Group. The research and analysis that form the basis for this report were carried out by a project staff under the general leadership of A. R. Barbeau. The members of the project staff are listed below:

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TABLE OF ORGANIZATION

TABLE OF ORGANIZATION (Cont'd)

VOLUME VII

ENCLOSURE G - Soviet ABM Defense Capabilities and Selective Simulation of Defense Engagements
Authors: J. H. Daniel, J. G. Healy, J. A. Ross, M. G. Degnen

VOLUME VIII

ENCLOSURE H - ABM Defense Employment, Engagement and Penetration
Authors: T. E. Sterne, J. A. Ross

VOLUME IX

ENCLOSURE I - Bomber Employment and Defense Penetration Study
Authors: D. N. Beatty, E. Marcuse

VOLUME X

ENCLOSURE J - Nuclear Weapons Effects on Strategic Missile Systems
Authors: H. A. Knapp, J. A. Ross, D. H. Williams

ENCLOSURE C

SOVIET CAPABILITIES AGAINST U.S. CITIES

CONTENTS

APPENDICES

I. INTRODUCTION

(C) It is not a primary objective of the WEPS study to evaluate Soviet capabilities against the U.S. However, it was necessary to conduct a limited investigation of these capabilities in order to develop a proper perspective regarding the significance of U.S. preemptive strikes against Soviet strategic forces. For example, the difference between being able to destroy 5 percent of the Soviet forces on the one hand or 40 percent on the other may appear to be very significant if one does not look further. But suppose the Soviets can destroy, say, 85 percent of the U.S. urban population with 60 percent of their force and can increase this only to, say, 90 percent of the population by using 95 percent of their force. Knowing this, the difference between destroying 5 percent or 40 percent of the Soviet force may be considered much less significant.

(C) Because the investigation of Soviet strikes on U.S. cities was not a primary objective of the WEPS study, it was considered adequate to carry out the investigation with a relatively high level of aggregation in the population data base. The data base employed is that developed by DoD Systems Analysis and the NMCSSC to represent the 1968 urban

(b)(1) [redacted]

presented in this enclosure are given in percentage of this (b)(1) million destroyed, not in percentage of the total population. The hardness, or vulnerability, of the U.S. population is taken as (b)(1) (b)(No estimate of total deaths after an extended period is provided.

(U) The computer model used to calculate the effectiveness of Soviet strikes on U.S. cities is called CODE 50. CODE 50 is an expected-value model developed for DoD Systems Analysis by Lambda Corporation. It allocates weapons to targets in such a way that the expected value of target value destroyed is maximized. In the current application, the value of each target (metropolitan area) in a target class was taken as the average population of the metropolitan areas in the target class.[1] Thus, the CODE 50 allocations maximize U.S. casualties.

(U) U.S. defenses against Soviet attacks were not explicitly modeled.[2] Rather, the probability of arrival (PA) of Soviet weapons was considered a parameter. PA values of 0.25, 0.5, 0.75 and 1.0 were used for most Soviet force elements.

(U) Several different force sizes were used for most elements and in one case, two different values of weapon accuracy CEP were used. Most of the results presented are for "pure" force attacks, i.e., attacks composed of a single weapon type like SS-9s. More limited results are presented for various mixes of Soviet missile forces, bomber forces and both missile and bomber forces. This enclosure does not consider U.S. attacks on the Soviet Union. These latter attacks are considered in Volume III (using a relatively

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[1] (U) If the reader wishes to neglect the fact that there are several cities within many of the metropolitan areas, he may read "city" in place of "metropolitan area." The two terms are used interchangably in this enclosure.

[2] (U) Code 50 contains a simple model of both bomber and missile defenses; however, the WEPS project chose not to use this defense model.

detailed data base) and in Enclosure D (in this Volume) and in Volume V (using an aggregated data base).

(U) Appendices to this enclosure present the most commonly used theory of damage analysis and the most commonly used methods of representing area targets. The theory and methods presented in the appendices are not new. They are presented for reference because they form the basis for most of the effectiveness calculations in Enclosures C and D in this Volume, and Enclosure E in Volume V.

II. SUMMARY

(S) For estimated[1] 1975 Soviet force yields, CEPs and inventories and with a probability of arrival of 0.5 for each warhead, single elements of the Soviet force could be expected to destroy the following percentages of the U.S. urban population:

Weapon Type	Yield (MT)	CEP (nmi)	Number of Warheads	Urban Population Destroyed
(b)(1)				

The bomber forces shown above, if used together, could destroy (b)(percent of the U.S. urban population. A Soviet mixed force composed of the SS-9s, SS-13s, and mobile SS-13s, along with (b)(1) the estimated 1975 SLBM force could destroy (b) percent of the U.S. urban population. The urban population used as a data base includes (b)(1) million people.

[1] (U) Weapon characteristics and inventories are from intelligence sources.

III. DESTRUCTION OF U.S. URBAN POPULATION

(U) The expected number of prompt U.S. casualties resulting from Soviet attacks has been calculated for attacks by single force elements, such as SS-9 missiles alone, and for combinations of force elements. Attacks by single force elements will be considered first.

A. SINGLE SOVIET FORCE ELEMENTS

~~(TS)~~ Each Soviet force element was investigated separately to determine the relative effectiveness of each force element. Table 1 lists the force elements, their yields and CEPs, and the 1975 intelligence estimates of force levels. Force levels are given in number of warheads. The SS-Z-3 carries six warheads per missile so the estimated number of missiles is 150. Other missiles carry one warhead each.

(b)(1)

[redacted]

(U) CODE 50 was used to compute the expected damage (DE) which various quantities of each force element could inflict upon the U.S. urban population. Four values of probability of arrival (PA) were used. These are 0.25, 0.50, 0.75 and 1.00. PA includes the probability of prelaunch and launch survival, the probability that the missile or bomber suffers no reliability-type failure, the probability of penetrating U.S. defenses, if any, and the probability of successful reentry and warhead detonation. The arrivals of individual warheads were assumed to be statistically independent events.

(S) Figures 1 and 2 show the results for missiles and bombers, respectively, for (b)(1) [redacted] Note that DE differs markedly from weapon type to weapon type (when compared at equal numbers of warheads). Figure 1 suggests that (b)(1) [redacted]

(b)(1) [redacted]

(U) Much of the difference in effectiveness between high and low yield weapons can be explained by the concept of equivalent yield. The area within the effective radius of a warhead scales with yield to the two-thirds power. If weapons were used against an infinitely large area target of uniform value per unit area, effectiveness would also scale with yield to the two-thirds power. However, against real targets of finite size, the increase in effectiveness due to an increase in yield is less than this theoretical value. This has led DoD Systems Analysis to the concept of equivalent yield which is defined as

$$Y \text{ equiv.} = \begin{cases} Y^{1/2}, & Y \geq 1 \text{ MT} \\ Y^{2/3}, & Y \leq 1 \text{ MT} \end{cases}$$

(b)(1)

(b)(1)

[redacted]

~~(TS)~~ Perhaps the most meaningful method of comparing Soviet force elements is to use the estimated 1975 force levels as a basis. For PA = [redacted] the expected fraction of the U.S. population which could be destroyed by each force element is:

[redacted]

Any one of the first five of the missile systems listed could destroy at least [redacted] percent of the U.S. urban population.

~~(S)~~ Thus far, the discussion has used PA = [redacted] as a base case. Figure 4 presents the effect of PA on the effectiveness of the SS-9 [redacted] Note that PA does not enter as a direct multiplier of the number of warheads, i.e., one cannot replace number of warheads and PA by their product (which would be expected number of warheads arriving). For example, [redacted] warheads with PA = [redacted] achieves [redacted] warheads with PA = [redacted] achieves DE = [redacted] The difference results from the fact that [redacted]

(b)(1)

[redacted]

(U) Table 2 lists the CODE 50 results on which the preceeding discussion is based.

B. COMBINATIONS OF SOVIET FORCE ELEMENTS

~~(S)~~ There is no simple way to combine the data presented in the previous chapter to compute the effectiveness of attacks by combinations of Soviet force elements.[1] Therefore, the effectiveness of a few combinations was computed directly with CODE 50; the results are presented in Table 3.

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[1](U) By use of the equivalent reference warhead concept, the results for individual force elements could be utilized to find approximate DEs achievable with combinations of Soviet force elements. However, one would expect the optimum combined-force attack to be somewhat more effective than would be indicated by such an approximation because the optimum attack would use each type weapon against those targets it is best suited for.

(b)(1)

(S) In that table the first five lines present an attack

(b)(1) [redacted]

(b)(1) [redacted]

(b)(1) [redacted]

[2](U) In terms of equivalent yield.
[3](U) The residual force includes all of the Soviet SLBMs.

(b)(1)

APPENDIX A

DAMAGE ANALYSIS AND TARGET RESPONSE

APPENDIX A

I. INTRODUCTION

(U) This paper addresses the problem of an extended area target[1] attacked by a multiplicity of weapons. It summarizes the state of the art from both open and classified literature. It is motivated by the need for aggregation in the study of force effectiveness. Specifically, there is a need for some computationally efficient method for computing damage inflicted as a function of the number of weapons employed. Ideally, one would like such an expression to include target and weapon characteristics as variables. Unfortunately, this introduces excessive complication and renders the analysis infeasible (as will be explained later). In practice, then, one response curve[2] is used to represent a given target-weapon combination.[3] Before treating the problem of the generation of a response curve, some fundamentals of damage analysis are presented.

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[1](U) Targets whose value or importance is distributed over an area, as contrasted to a point target.

[2](U) Also known as the "response function," i.e., a function depicting the response of the target (damage infliction) as the number of weapons used against it varies.

[3](U) A higher degree of aggregation is obtained by grouping a number of targets whose response curves are reasonably alike.

II. DAMAGE ANALYSIS

(U) The problem is primarily that of determining the probability of achieving damage of a certain kind on a target (or given fraction of a target) under given circumstances. It is to be emphasized that damage is considered only as a "go/no-go" concept; damage is not considered as a continuous variable. By "achieving damage to some fraction of the target" is meant damaging that fraction of the target elements.

~~(C)~~ The relationship between probability of damage and distance from ground zero (GZ) is called the damage curve. The damage curve is determined by the vulnerability of the target or target element in relation to a particular effect, the weapon yield, and the height of burst. This relation is idealized in the form of various analytical functions. We shall adhere to a form known as the PV (physical vulnerability) curve.

~~(C)~~ The concepts and techniques of physical vulnerability analysis have been a matter of development and evolution since the early fifties. Target types are characterized by a parameter called the vulnerability number (VN). The same target type may carry more than one VN, depending upon the type of damage being considered.

~~(C)~~ Briefly, the VN system is a scheme to represent a target's susceptibility to blast damage by a simple combination of numbers and letters. Targets are categorized in the system so that the effects of weapon yield, height of burst, wave duration, and probability of damage may be quickly accounted for.

(U) Damage analysis encompasses many diverse physical and mathematical disciplines. There are a large number of variables. The coupling of causes and effects is often so complicated as to render a complete theoretical framework and mathematical modeling impossible. The uncertainties are great and there is a shortage of experimental data. All these considerations combine to render any detailed phenomeno-structural analysis impractical.

~~(C)~~ Introduction of the PV system reduces the number of variables used to describe the effect of a particular weapon (yield, HOB) on a particular target. A three-part alpha-numeral like (b)(1) [redacted] (the VN) delineates the target's response[1] to a reference weapon in terms of the peak pressure, the dominant pressure type[2], and the transient-loading response characteristics usually referred to as the K factor. It is used in conjunction with a given weapon yield and scaled HOB to determine the target's susceptibility to damage by the particular weapon in question, thus obviating the need to conduct individual multidisciplinary analyses with the many attendant variables.[3] It should be emphasized that in no case is the true relationship at all well known.

(U) As mentioned earlier, the analytical function giving the probability $\bar{p}(r)$ of damage of a given type to a target of given vulnerability, as a function of the distance r from ground zero (GZ), is called the damage curve. This damage

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[1](U) For a given level of damage at a given probability (usually 0.5).

[2](U) P designates overpressure and Q designates dynamic pressure.

[3](U) For example, structural resistance, drag coefficient, natural period, ductility ratio, actual damage probability distribution function, yield-sensitive blastwave behavior, HOB dependence, etc.

curve is essential to the calculation of the weapon radius (WR).[1] To understand WR, consider an infinite array of identical targets with a weapon detonated at the center. The WR may then be visualized as the radius of the circle, with its center at ground zero, within which, on the average, there are as many undamaged targets (i.e., damaged to a lesser degree than specified) as there are damaged targets outside the circle. The weapon radius is neither a "lethal" radius[2], nor is it properly associated with any particular value of probability of kill for individual target elements. The equation expressing the WR is given below:

$$\pi(WR)^2 = \int_0^\infty \bar{p}(r)\ 2\pi r dr$$

where r is the distance from GZ and $\bar{p}(r)$ is the probability of damage (to the degree specified).

(U) Thus, the weapon radius may be viewed as one parameter contributing to the definition of the particular damage curve $\bar{p}(r)$ related to a specific target-weapon combination. It does not completely define the damage curve. To do so, one must first consider a special function known as the circular coverage function.

THE CIRCULAR COVERAGE FUNCTION

(U) The circular coverage function is the integral of a circular Gaussian distribution $(1/2\pi) \cdot \exp(-\rho^2/2)$ over a circle of radius R with center at a distance r from the origin

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[1](U) Computer Computation of Weapon Radii, B-139-61, USAF, ACS/ Intelligence, September 1961, UNCLASSIFIED.

[2](U) A "lethal radius" is usually associated with a discontinuous function giving the probability of damage as unity for all target elements within this radius and zero for all target elements outside the circle defined by this "lethal radius."

(center of the distribution). This integral will be designated as p(R,r). The distance variable ρ in the Gaussian distribution is measured from the origin.

(U) This integral p(R,r) can be viewed as the probability that a missile will hit within a circle of radius R if it is aimed at a point at a distance r from the center of the circle and if it is subject to a Gaussian impact probability law of unit standard deviation. It can also represent the probability that a circular disk of radius R will cover a point a distance r from the point of aim, if the probable position of the disk is described by a Gaussian distribution of unit standard deviation.

(U) The analytical expression used for the PV damage curve is the circular coverage function, that is

$$P(r,\ WR,\ \gamma) = p\left(\frac{WR}{\gamma},\ \frac{r}{\gamma}\right)$$

where γ is a parameter whose significance is discussed below. This function has been tabulated by H.H. Germond.[1]

(U) It may seem strange that the circular coverage function should be used as a damage function. However, the function does have the necessary shape for a damage function, and the two parameters WR and γ allow enough freedom to fit the function to any empirical damage curve with more than necessary accuracy. Furthermore, the function has a desirable mathematical property which will be pointed out later.

(U) It remains to discuss the significance of the second parameter γ which, together with the weapon radius WR, defines the damage curve. Consider Fig. A-1. If we define a cumulative distribution function of r as:

[1](U) Germond, H.H., The Circular Coverage Function, the RAND Corporation, RM-330, 26 January 1950, UNCLASSIFIED.

$$F(r) = 1 - p\left(\frac{WR}{\gamma}, \frac{r}{\gamma}\right),$$

it can be shown that the ratio[1] $\sigma_r/\bar{r}$ for the damage curve in question is quite close to the ratio $\frac{\gamma}{WR}$.

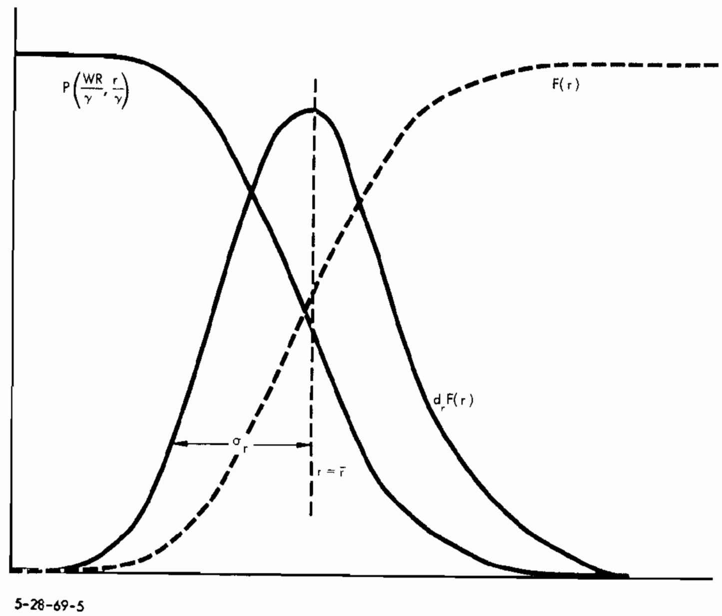

FIGURE A-1.

(U) The two parameters WR and γ define the damage curve or, in other words, the target's susceptibility to damage by the particular weapon in question. They are determined with the aid of the target VN number, the weapon yield, and the scaled height of burst as mentioned earlier in the discussion of the PV system.

(U) The ratio γ/WR, expressed in percent, is often used as a subscript (as in σ_{20} or σ_{30}). This ratio will be referred to here as the percent label. It can be thought of as a measure of the ratio of the standard deviation in distance σ_r to the

[1](U) σ_r is the standard deviation of the r variable as defined by the distribution, and $\bar{r}$ is the mean distance.

mean distance $\bar{r}$ for a class of target structures. That is, it is a measure of how sharply the damage curve falls off.

(U) Next, consider the problem of calculating the damage to a point target located a distance x from the DGZ, where the damage curve is given by the function $\bar{p}(r)$, and the delivery error is circular normal with standard deviation σ. If actual GZ is within the annular region shown in Fig. A-2, the probability of damage to the target is approximately $\bar{p}(y)$. If we let

$$\bar{p}(y) = p\left(\frac{WR}{\gamma}, \frac{y}{\gamma}\right).$$

then it can be shown that the damage to the point target is given by:

$$D = p\left(\frac{WR}{\beta}, \frac{x}{\beta}\right)$$

where $$\beta^2 = \gamma^2 + \sigma^2 .$$

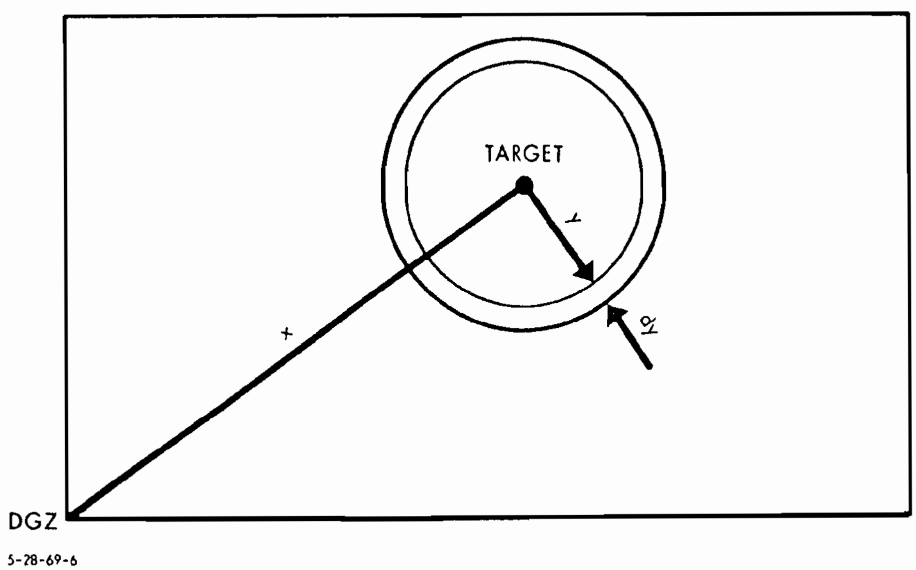

FIGURE A-2.

(U) It is this mathematical result which makes the circular coverage function desirable for use as a damage function. Thus, knowing the damage curve parameters WR and γ, the standard deviation σ of delivery error, and the distance x between target and the DGZ, one has at once, from tables of the circular coverage function, the probability of damage to the target.[1]

(U) To this point, our discussion relates to damage to point targets or to target elements. Now consider area targets. Expected damage to targets whose values have a circular normal distribution may be approximated by the so-called R-95 method. Let R-95 denote the radius of the smallest circle which will encompass 95 percent of the target elements. Then the expected damage to the target may be approximated by treating it as a point target located at the center of the circle and using the circular coverage function. In this case, the weapon radius and point target distance are used along with an adjusted σ given by

$$\text{Adjusted } \sigma = \sqrt{\sigma^2 + 1/6\ (R\text{-}95)^2}$$

This method is primarily useful for determining expected fatalities and casualties (or average probability of fatalities and casualties) to personnel dispersed in a circular normal distribution.

[1](U) For numerical computations, a closed form analytic expression is often introduced to approximate the circular coverage function. For example, in Program CODE 50, the single shot kill probability has the form:

$$SSKP = 1 - \left\{ \frac{FN \cdot \sigma^2}{FN \cdot \sigma^2 + (WR^2/2)} \right\}^{FN}$$

where the parameter FN is chosen according to the value of the (γ/WR) ratio in question. Similar algorithms used in other WEPS studies have been documented (IDA Computer Library).

(U) If several warheads are employed against a single, point target and if the warheads are independent, the probability that at least one warhead damages the target is easily calculated. Let P_s be the probability of damage to a point target due to each shot. Then the desired probability, P_d, that at least one shot damages the target can be estimated from

$$P_d = 1-(1-P_s)^N \qquad (1)$$

where N is the number of shots.

(U) If several warheads are employed against an area target, instead of a point target, their combined effect is not so easily calculated. In this case, the average damage to the target P_c is given by

$$P_c = \frac{1}{V_t} \iint V(x,y) P_d(x,y)\,dx\,dy$$

where $P_d(x,y)$ is given by (1) for an element at (x,y), V(x,y) is the target value per unit area at (x,y) and V_t is the total value of the target. It is a common practice to apply (1) directly to the case of area targets as well as to point targets but this practice is not technically correct and can lead to significant errors. The magnitude of these errors is explored in Volume III.

III. RESPONSE CURVE

(U) We have reviewed the PV concept and technique that have been developed for the purpose of computing the expected damage to

1. A point target, or
2. A circular area target with a Gaussian value distribution.

(U) In both cases the DGZ of the weapon(s) is known. Otherwise, one must determine such aimpoint(s) according to some criterion such as maximizing the resultant expected damage. The solution to this problem is obvious if there is but one point target to destroy, viz; the desired ground zero (DGZ) should coincide with the point target. The corresponding response curve then would be typified by Equation (1) for WR large compared with target radius.

(U) The situation becomes more complicated if there are two or more point targets or if the area target has a value distribution other than circular Gaussian.[1] In the latter case, the area target is usually replaced by a conglomeration of constituent circular Gaussian targets referred to as the P-95 circles,[2] thus reducing it to a case of multiple point targets each giving rise to an adjustment to the weapon CEP. The optimum DGZs for a given number W of weapons depend on the geometry of such a target system and the values associated with the constituent P-95 circles. As the number W varies,

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[1](U) Or if the target radius is large compared to the weapon radius and several weapons are to be used against the target.

[2](U) In all cases treated so far involving U/I targets, population has been chosen as the measure for target value. Hence, the notation P-95 in place of R-95 used previously.

so does the optimum DGZ configuration. If the total expected damage sustained by the entire area target is plotted against W for the corresponding optimum DGZ configurations, every weapon inflicting damage on every constituent point target, the result is a response curve. As mentioned earlier, there will be one response curve for every target-weapon combination. The complex functional relationships among the weapon radius WR, γ, target vulnerability, and weapon characteristics (yield, height of burst), as well as their associated damage curve (e.g., the circular coverage function) render their inclusion as free parameters in the generation of response curves impractical for many applications.

(U) There exist several computer programs[1] designed to generate DGZ configurations after some form of optimization. In most cases, the optimization is based on some iterative procedure and/or gradient technique. At each step, damage calculations (such as the use of circular coverage functions described in this paper) are carried out for the particular target-weapon combination.

(U) In our introduction, we stated the motivation of the present analysis. Specifically, we referred to the need for some computationally efficient expression for the response curve. In the most common approach to filling this need, one searches for some closed form approximation to such an expression. Once developed, the approximation is matched to the response curve obtained by one of the several numerical means mentioned earlier. The square root law is an example of this approach.

[1](U) e.g., WALOPT (GE), SOOT (IDA), DGZSEL (IDA), GREENP (IDA), OPTIMIZE (JSTPS), SOAP (JSTPS).

(U) The square root law is a mathematical model developed for use in Program CODE 50.[1] For ready reference, it is recapitulated below.

$$S_{N\to\infty} = \left(\exp\left(-\frac{\sqrt{KW}}{\pi\sigma_t^2}\right)\right)\left(1 + \frac{\sqrt{KW}}{\pi\sigma_t^2}\right)$$

where:

$S_{N\to\infty}$ = surviving fraction of an area target.

K = expected lethal area of one weapon.
$= P_A \pi R^2$

P_A = Probability of arrival of a weapon

W = number of weapons.

σ_t = standard deviation of Gaussian target value density distribution assumed.

(U) The formula applies to multiple weapon attacks where the WR/L (L being a representative linear target dimension) and WR/CEP ratios are small and where it is assumed that some "optimum" choice of individual aimpoints (micro-targeting) exists. The square root law is obviously not sensitive to the choice of such aimpoints.

(U) In deriving the square root law, a payoff functional[2] is optimized subject to the constraint that the total number of weapons assigned to the target is fixed. The methodology implies a simplified damage function and a two dimensional weapon distribution in a continuum sense.[3]

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[1](U) R.J. Galiano and Hugh Everett, III, Defense Models IV, Paper 6, Lambda Corporation, March 1967 (U).
[2](U) An area integral of which the integrand contains an unknown function (the "weapon density") to be determined.
[3](U) Discontinuities will accompany a discretization of weapons.

(U) The square root law is an asymptotic solution in the sense that it assumes the weapons to be not only uniformly distributed at random, but also infinitely divisible. It gives no direct information as to the choice of aimpoints although some inference can presumably be made.

(U) In an attempt to relate the square root law to real life, the following procedure has been adopted.[1] A given weapon yield/CEP/HOB combination is considered for an extended area target. Program WALOPT is used to determine the aimpoints for a given number of weapons W. The expected damage DE is computed. This is repeated for a range of values for W until some specified DE is reached. The resultant DE vs W plot is used as a basis for determining the value of K in the square root law by means of a least square fit using all the data points generated.

(U) Having thus determined the value for K, the single shot kill probability, SSKP, is deduced from the square root law by setting W equal to unity. The SSKP thus obtained is substituted into the circular coverage damage function (or an approximation form) which is then solved for the "target radius." The quantity thus obtained is known as the Q-95[2].

(U) The square root law derives its realism from the fact that the value of K (and consequently that of Q-95) are determined on the basis of a least square fit to a response curve resulting from a set of "optimally" determined aimpoints. Thus, it can be said, qualitatively at least, that an idealized model is matched to a more realistic one after both have been optimized in some manner. Owing to the fact that information about the aimpoints obtained by WALOPT no longer needs to be carried along, the use of the square root law and the Q-95

[1](U) Used in conjunction with Program Code 50 inputs.

[2](U) To distinguish it from the R-95 normally used in circular coverage functions.

permits a high degree of aggregation suitable for weapon allocation routines.

(U) This same approach has been applied with a variety of closed form approximations to the response curve. Equation (1) was used in generating the "one-point damage-matching data base" and a slight variation of (1) was used in the "two-point damage-matching data base." These two cases are described fully in Volume III and will not be repeated here.

(U) One distinction between use of the square root law and use of Equation (1) is that the development of the former explicitly recognizes the need for optimal DGZ selection. Such an optimization is carried out in the development of the square root law and damage is assessed on that basis. Since the DGZ optimization is included, one would expect that the square root law might fit optimized data from more detailed metholologies better than Equation (1).

IV. CONCLUSION

~~(C)~~ Summarizing, the PV-system aggregates information about a target. It employs a three-part alphanumeral, in which the first number and the middle letter denote, respectively, the peak damage pressure and the dominant pressure type. The target's transient-loading response characteristics, which are yield-sensitive, are accounted for by the last number known as the K-factor.

~~(C)~~ The K-factor is used to adjust the VN for weapon yields other than a reference yield of 20 KT. The adjusted VN is a linear function of the logarithm of either the peak overpressure or the peak dynamic pressure for a given level and probability of damage.

~~(C)~~ A reference WR (1 KT) at the proper HOB is determined. This is, in turn, scaled to the given yield. The WR, CEP, R-95 (for non-point targets) and the "percent label" of the damage probability curve are usually sufficient to determine the single shot kill probability of a given target and aimpoint. Formulae are developed which permit the use of these parameters to directly evaluate the expected damage without performing the integrations of the kill function over the appropriate density functions (e.g., delivery error distribution, etc.). Although the form of computational aids (nomograms, circular slide rules, etc.) may vary, the underlying formulae are based on the circular coverage function.

(U) For multiple weapon attacks on large, extended targets (small WR/L), the locations of optimal individual aimpoints are not obvious. These will either have to be given without optimization, or the optimal aimpoints must be determined. In order to attain a similar degree of aggregation and computational effectiveness, a closed-form approximation to the response curve is fitted to the output from numerical programs which select DGZs to maximize total damage. The first example discussed uses an "optimum" response curve derived on an analytical basis for an area target for the approximation. The second example uses the multiple-shot kill probability expression of a point target for the approximation.

APPENDIX B

THE P-95 AND Q-95 REPRESENTATIONS OF AREA TARGETS

I. INTRODUCTION

(U) This Appendix briefly describes three methods of representing the geometrical distribution of an area target and the related methods of damage assessment. One method, the Q-95 method uses more highly aggregated data than the others. Data for the Q-95 method are derived from results of the other, more detailed methods. The procedure used to derive the data required by the Q-95 method is presented. Then, results of using the Q-95 method are compared with the results that formed the basis for deriving the Q-95 data.

(U) The purpose of this Appendix is to show how well or how poorly the Q-95 method can reproduce results of a more detailed method. The Q-95 method was used to calculate the results of Chapter III of the present Enclosure and most of the results of Enclosures D and E. This method is also used by DoD Systems Analysis to derive the well-known Force and Effectiveness Tables.

II. TARGET REPRESENTATIONS, DATA BASES AND RELATED DAMAGE-ASSESSMENT METHODS

(U) There are three methods of representing area targets that are commonly used in analysis. These are (1) by a set of point targets, (2) by a set of circular-normal density functions, and (3) by one "equivalent" circular-normal density function. The first of these three can be considered a limiting case of the second method of representation.

(U) Related to these three representations, there are two commonly used methods of damage analysis. These are called the power law and the square root law. Both employ the circular coverage function discussed in Appendix A. The only theoretical difference between the two damage-analysis methods is in the manner in which the effects of a number of warheads is calculated.

(U) The power law, used with sets of point targets or with sets of circular-normal density functions, is based on the assumption that each element in the target representation remains equally susceptible to damage regardless of the number of warheads that have been detonated near it. Thus, if a particular warhead has a 20 percent damage expectancy against a target element, then a second identical warhead detonating at the same place as the first would also have a 20 percent damage expectancy against that target element. Of course, the expected survival after the first warhead would be only 80 percent so the increase in damage expectancy achieved by the second warhead would be only 80 percent of 20 percent. This can be stated concisely as $DE = 1 - (1\text{-}SSKP)^N$, where DE is damage expectancy, SSKP is single-warhead damage expectancy[1] and N is the number of (statistically independent) warhead detonations.

(U) The theoretical basis for the square root law, used with an "equivalent" circular-normal representation of an area target, is presented in Appendix A. This law follows from the assumptions that (1) the target value is distributed in accordance with a circular-normal density function, (2) that the weapon effects radius is small compared to the area covered by the target, and (3) all parts of the target value are equally hard (resistant to damage). The resulting equation for multi-warhead damage expectancy has the form $DE = 1 - (1+\sqrt{CN}) \exp(-\sqrt{CN})$ where C is a constant.[2]

(U) Volume II describes various data bases and target representations used in the WEPS study. Urban population data are commonly available as (1) tract data, (2) cell data, (3) P-95 data, and (4) Q-95 data. Data concerning other types of targets are commonly in the form of (1) point-target data and (2) R-95 data.

(U) Tract data and cell data simply show the locations of numerous tracts or cells and the number of people in each tract or cell. The distribution of population in the tracts or cells is not specified. However, the tracts and, particularly, the cells are small enough that they are commonly assumed, for analytical purposes, to be point targets.

(U) P-95 data and R-95 data have the same theoretical basis. The distinction is only in nomenclature, R-95 referring

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[1](U) To simplify the discussion, probability of arrival is considered to be included in SSKP in this section and the probability of catastrophic failure, i.e., that all weapons of a given type fail, is neglected.

[2](U) Appendix A gives the theoretical physical significance of C. However, in practice C is found by curve fitting as explained later.

to non-population targets. A P-95, or R-95, is a circle used to describe a circular-normal density function. The density function, in turn, represents a distribution of target value. The data presented for each circle are the circle's total value, radius and location.

(U) A Q-95 is a circle used to describe an "equivalent" circular-normal density function representing the population distribution of one entire metropolitan area. In practice, Q-95 data are derived from one of the other types of population data. The Q-95 method, then, could not be expected to give results that are more accurate than those which could be obtained directly from the more basic data. The big advantage of the Q-95 method lies in its simplicity, its speed and the relatively small amount of data that must be stored and processed in its use. In many applications, this advantage is very important.

III. THE P-95 AND Q-95 METHODS

A. THE P-95 METHOD

(U) With the P-95 method, the population of each metropolitan area is represented by a number of P-95 circles. Each P-95 circle is described by the location of its center, by its radius and by the population it represents. The population of each P-95 is assumed to be distributed in accordance with a circular normal density function[1], i.e., the population density at a radius r from the center of a P-95 is proportional to $(2\pi\ \sigma^2)^{-1}\ \exp\ (-r^2/2\sigma^2)$, where σ^2 is a constant. The P-95 radius defines a circle which includes 95 percent of the population represented by that P-95 so

$$.95 = -\exp\ (-r^2/2\sigma^2) \Big|_{r\,=\,0}^{r\,=\,P\text{-}95}$$

giving $P\text{-}95 = [\ln\ (400)]^{1/2}\sigma = 2.4477\ \sigma.$

(U) P-95 circles can overlap and the populations they represent can overlap. The fact that populations overlap is of no consequence since each person in the metropolitan area, whether he is located within a P-95 or not, is included in the population represented by exactly one P-95.

(U) The P-95 data used in the WEPS project were obtained from NMCSSC but originated in the U.S. Census Bureau and the Library of Congress. The rules followed in establishing P-95s

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[1](U) The NMCSSC uses a uniform population distribution over each P-95 circle when assessing damage to the Soviet Union. This is discussed later.

are rather arbitrary. Many different sets of P-95s could be derived for any fairly large city[1].

(U) There are several computer programs which use the P-95 representation of population, select aimpoints that are in some sense optimal, and compute expected damage (fraction destroyed) of the population represented by each P-95. WALOPT, GREENP, SOOT and MARGEN are examples of such computer programs[2].

(U) The fundamental differences among these programs concern the way aimpoints are selected. WALOPT and GREENP both find locally optimal sets of aimpoints for the weapons placed on a target and they both use the Greenwood iteration technique described in Volume III. WALOPT and GREENP obtain an initial (non-optimal) set of aimpoints in somewhat different manners and implement the iteration procedure differently. SOOT and MARGEN select the centers of P-95s (and point targets) as aimpoints, choosing for each successive weapon that center which would result in the highest marginal return. All of these methods face difficult combinatorial problems when several different types of weapons (weapons with different yields, CEPs or PAs) are used on one target complex. Most applications of these methods consider only one weapon type. Use of GREENP with multiple weapon types is discussed in Volume III.

(U) WALOPT, GREENP, SOOT and MARGEN all consider collateral damage, i.e., a weapon aimed at or near one P-95 center may damage population represented by other P-95 circles as well. One theoretical difficulty shared by these programs when using P-95 data is that they assume that each successive weapon

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[1](U) In this Appendix, no attempt is made to compare results of the P-95 method to results of methods using data that is less aggregated. For such a comparison, the reader is referred to Enclosure B (Volume III).

[2](U) All of these programs can be used with point-target data also. In some application described later WALOPT and SOOT are used with point-target data.

aimed at a particular point achieves the same expected damage (SSKP or fraction destroyed) of the remaining value of each P-95 as that achieved by earlier weapons. Actually, however, each weapon aimed at some distance from the center of a P-95 would destroy the population associated with that P-95 in an asymmetric manner so that, even if the P-95s initially give a good representation of the target complex, the representation becomes less valid after a few weapons are assigned. This difficulty can be remedied by using a more detailed representation of the target because, as the physical size of the target elements is reduced, the asymmetry in damage caused by an offset burst becomes less pronounced. When using WALOPT, NMCSSC overcomes this difficulty by breaking each P-95 into a set of points and assigning an appropriate value (weighting factor) to each point. One would not expect this set of points to be a better representation of population than the P-95s, but it does allow the assessment of damage without the problem of asymmetric damage. In effect, the NMCSSC approach uses point-target rather than P-95 data, but the point-target data is obtained from P-95 data since no less aggregated data has been available for most target cities. Of course, when one is converting P-95 data to point-target data it is possible to introduce other modifications to the data. For Communist-Bloc cities, NMCSSC assumes that the population associated with each P-95 is uniformly distributed over the area within the P-95 circle. By assigning value to each point target in accordance with this uniform distribution instead of in accordance with a circular-normal distribution, NMCSSC introduces U.S. conservatism. Examples of this are presented in Volume III.

B. THE Q-95 METHOD

(U) Although P-95 circles are aggregations of more detailed data, use of P-95s is excessively time-consuming for some types of investigations. A still higher level of aggregation uses a single Q-95 circle for each metropolitan area. When using Q-95s, collateral damage from metropolitan area to metropolitan area is assumed not to occur, and collateral damage within a metropolitan area is implicitly included.

(U) In the Q-95 representation, the population of an entire metropolitan area is assumed to be distributed in accordance with a single circular-normal density function. Conceptually, this is like replacing all P-95s (or more detailed data) with one big P-95. But if one does this by any reasonable means, he may well get a P-95 that is large compared to the effective radius of a weapon. In this case, the assumption that each successive weapon destroys the same fraction of remaining value as that destroyed by each earlier weapon is clearly not acceptable[1]. The problem of calculating damage in this case has been investigated by the Lambda Corporation. The result was the development of what is widely called the square root law. Appendix A to this Enclosure includes a brief description of the square root law and its application in CODE 50. Very briefly it is this: If one assumes that target value is distributed in accordance with a circular-normal density function, that the effective radius of a weapon is small compared to the radius of the target (or that weapons are infinitely divisible), and that all parts of the target are of equal hardness, then the square root law can be derived as the expected damage resulting from N optimally aimed weapons. The law is simply $DE = 1- (1+\sqrt{CN}) \exp(-\sqrt{CN})$ where DE is damage expectancy, the expected fraction of the target value destroyed, and C is a constant which, in practice, is determined as described below.

[1](U) At least it is clear that in general, not all weapons should be aimed at the center of the population distribution.

(U) For each metropolitan area, point-target data derived from P-95s, are used with WALOPT to determine damage expectancy as a function of number of weapons[1]. The square root law is then fitted to the damage expectancy data from WALOPT by least squares. All WALOPT data for DEs between 0.5 and 0.9 is used. This gives a value for the constant C for each city and weapon type being considered. This C is then used in the square root law with N set equal to one to give a single-warhead damage probability (SSKP). Next, a damage equation[2] (based on the circular coverage function) that gives SSKP as a function of weapon radius, weapon CEP and target radius is set equal to the SSKP from the fitted square root law and the resulting equation is solved for the "equivalent" target radius, or Q-95.

(U) CODE 50 is the most widely known program employing Q-95s. The process described above, that of going from C to SSKP to Q-95, is reversed in CODE 50 in that Q-95s become the basis for computation of DE as a function of number of warheads N. The entire process is illustrated in Fig. B-1. The steps from WALOPT data to a Q-95 are shown on the left. The CODE 50 steps are shown on the right. The square-root-law DE curves in the sketches at the top of the figure would be the same if

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[1](U) Each type of weapon is considered separately in this process. The process described here is performed by NMCSSC for DoD Systems Analysis. Note that the point-target data could come from any source but P-95 data has been the only data available for most cities.

[2](U) The equation used is $SSKP = 1 - \left[\frac{FN \cdot S^2}{FN \cdot S^2 + WR^2/2}\right]^{FN}$

where FN is a constant, S^2 is $((CEP/1.1774)^2+(Q95/2.4477)^2)$ and WR is weapon radius. The function approximates the circular coverage function in which the variance of target value has been added to the variance of accuracy. It is an approximation to SSKP based on use of the circular coverage function as a damage function.

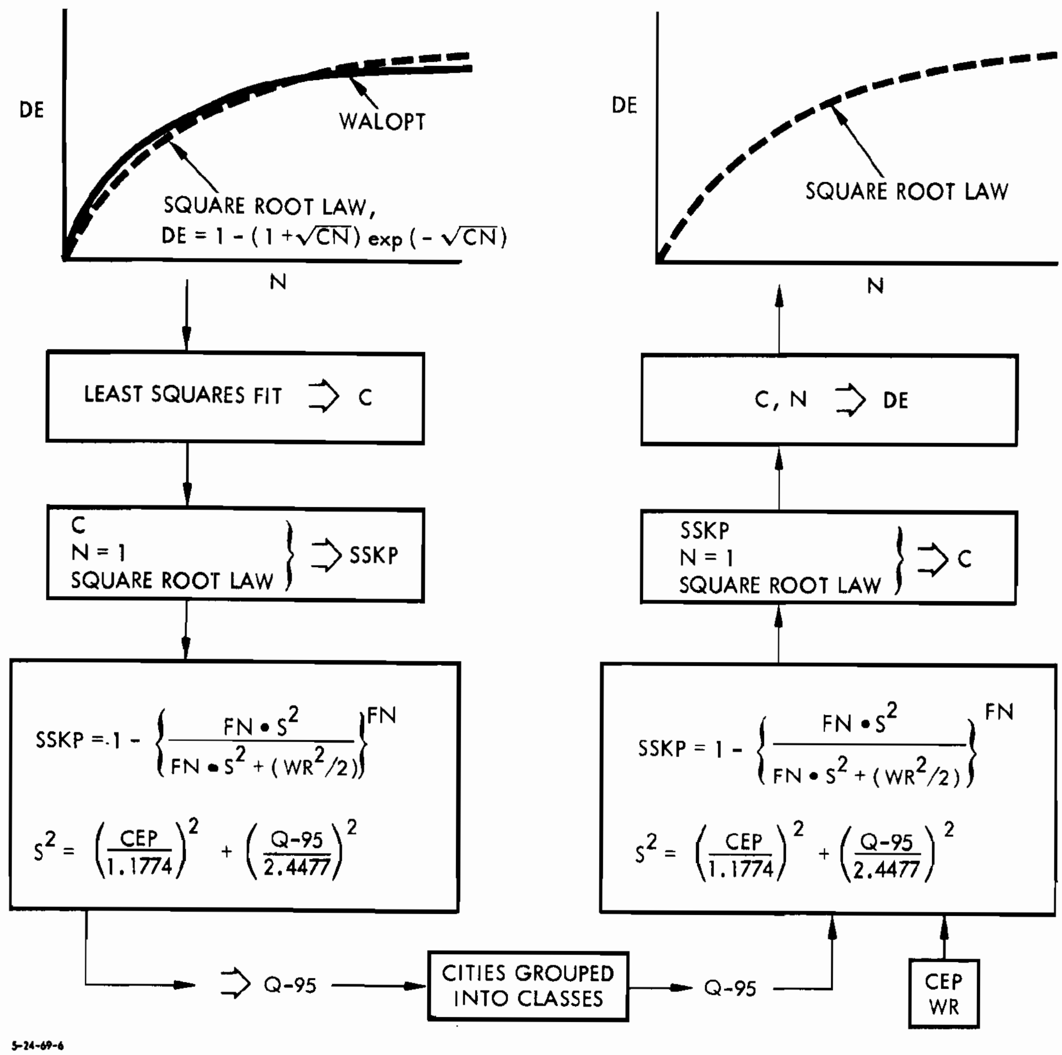

FIGURE B-1 (U). The Process of Determining Q-95s and Using Them in Code 50 (U)

the Q-95 computed for a city were used in CODE 50 for that city. However, CODE 50 is limited in number of differenct city types and, therefore, cities must be grouped into city classes. The grouping is performed on the basis of population; each class is assigned a population and Q-95 equal to the average values of population and Q-95 of all the cities in the class. The 23 U.S. city classes used in the computations in Chapter III are shown in Table B-1. The comparisons in Chapter IV of the present Appendix are based on Q-95 values for 1978 U.S. and Soviet population rather than the 1968 data shown in Table B-1. The values of Q-95s for individual cities are correlated with population, so the grouping of cities into classes may be less serious than one would suppose. This is discussed in Chapter IV below.

Table B-1 ~~(S)~~. U.S. CITY CLASSES, 1968 (U)

City Class	Number of Cities in Class	Q-95 nmi	Population in 1000s
(b)(1) [redacted]			

IV. COMPARISON OF Q-95 RESULTS WITH RESULTS OF A MORE BASIC METHOD

(U) NMCSSC provided the WEPS study team with recently derived Q-95s for U.S. and Soviet cities for 1978. They also provided graphs of WALOPT-computed DE as a function of number of weapons applied to each of about two dozen cities (for several combinations of yield, CEP, and PA). Results of the Q-95 method are compared with the WALOPT-computed DEs in this section.

(U) NMCSSC employed P-95 data as the basis for their computations. However, the P-95 data for each city was used to derive a set of point-target elements and these point-target elements were the target data input to WALOPT. The number and locations of the point-target elements were determined by an algorithm with arguments of weapon-effects radius and P-95 radius. For U.S. cities, each point-target element was assigned a value (weighting factor) so that the set of elements replacing a particular P-95 approximated the circular-normal distribution represented by that P-95. For Communist-Bloc cities, the assignment of values approximated a uniform distribution. This practice is followed by NMCSSC to be U.S. conservative, i.e., the use of a uniform distribution usually results in a lower calculated DE than does the use of a normal distribution.

A. COMPARISONS USING INDIVIDUAL CITY DATA

(U) Some of the WALOPT data from NMCSSC and corresponding results of the Q-95s and square root law are shown in Figs. B-2 through B-10. The Q-95s used for Figs. B-2 through B-10 are those derived for the specific cities, not the average values for city classes. Recalling that one of the assumptions necessary for the analytic derivation of the square root law is that the radius of the city be large compared to the weapon effects radius, it is not surprising that the square root law and WALOPT results agree closely for [redacted]

(b)(1)

(U) WALOPT and square-root-law results do not agree as closely for the Soviet cities as for the U.S. cities. Agreement is better for the larger cities, Moscow and Leningrad, than for the smaller ones, as one would expect. Note that for the Soviet cities, the square-root-law DEs are consistently higher than the WALOPT DEs at low numbers of weapons and are lower than WALOPT DEs at high numbers of weapons. This tendency, not apparent in results for U.S. cities, may reflect the use of uniform distributions to replace P-95s for Soviet cities. If the slope of the square-root-law DE curves were always the same fraction of the slope of the corresponding WALOPT DE curves, the "error" in slope would not affect the CODE 50 allocation of weapons among cities. However, it appears that the tendency to lower slopes may be more pronounced for small cities than for large cities.

(U) Most mathematical methods of optimizing weapon allocations to targets, such as the generalized Lagrange multiplier techniques used in CODE 50, depend on the slope of the DE curves. If the slope of a DE curve is too low in the vicinity of the supposed optimal allocation, then the allocation is actually less than the optimal. Since the decision to use uniform distributions to replace P-95s for Communist-Bloc cities was taken for purposes of conservatism rather than for realism, results shown in Figs. B-6 through B-10 should not be interpreted as a demonstration that CODE 50 techniques and results are incorrect.

(b)(1)

(b)(1)

[redacted]

(b)(1)

B. EFFECTS OF GROUPING CITIES INTO CLASSES

(S) As mentioned before, cities are grouped into city classes in CODE 50. To develop an appreciation for the effect of this, the class containing (b)(1) and that containing (b)(1) have been investigated further. (b)(1) is grouped with four other cities as shown below:

City	1978 Population	Q-95 (nmi)
(b)(1)		

The class population is (b)(1) and the class Q-95 is (b)(1) Figure B-11 presents DEs computed for the extreme Q-95s and for the class Q-95. Similar data are presented for the class containing (b)(1) In this latter case, the class contains (b)(1) cities with populations ranging from (b)(1) down to (b)(1) and with Q-95s ranging from (b)(1) down to (b)(1) Average population is (b)(1) and class Q-95 is

(U) Figure B-11 shows that the number of warheads required to achieve a given DE, say 80 percent, varies widely within the city classes shown. The single-warhead DEs of the smallest Q-95 is roughly twice that of the largest Q-95 for both city classes. An illustration of the combined effects of using the Q-95 method and of grouping cities into city classes is given in paragraph C below.

C. NATIONWIDE FORCE EFFECTIVENESS RESULTS

(U) In many investigations, e.g., Enclosures C, D and E, one is interested in force effectiveness rather than in the

(b)(1)

[redacted]

allocation of warheads to targets. To determine the effect of using the Q-95 method and the effect of grouping cities into city classes, it would be desirable to compare the following three nationwide cases:

	Basic Target DATA[1]	Q-95 Target Data
Individual Cities	1	2
City Classes		3

Unfortunately, the data available for such comparisons is limited. There is presently no computer program available to allocate weapons and estimate DE nationwide on the basis of DE curves such as those produced by WALOPT. Furthermore, CODE 50 is limited to 48 target classes and there is no other program available at present to apply the Q-95 method to the entire set of cities. Such programs could be developed but, as we shall see, they are not required for force effectiveness calculations.

(S) As shown in Volume III and in preliminary work done for this Enclosure, the asymmetric damage effect is neglibible for (b)(1) weapons although it is significant (say about (b percent in DE at DE (b)(1) Also, the effect of using a uniform distribution in place of the normal distribution theoretically associated with P-95s has been investigated by NMCSSC[2]. In the NMCSSC investigation, this effect has been found to be about (b)(1) percent in DE at (b)(1) One would expect, then, that use of P-95s (not broken into points) for computing an "optimum" attack with (b)(1) weapons on the U.S. would give essentially the same results as use of P-95s broken into point-target elements. And one would expect that use of P-95s (not broken into points) for

[1](U) For example, using DE curves produced by WALOPT.

[2](U) T.R. Epperson, "Representations for Determining Population Fatalities from Nuclear Attack for Aggregated Gaming Models," NMCSSC TR 48-69, to be published (S).

computing an "optimum" attack with (b)(1) weapons on the Soviet Union would give DEs that are higher (by about (b)(percent) than DEs computed for P-95s broken into point-target elements and weighted according to a uniform distribution.

(U) Figure B-12 shows resulting DEs from using 1 MT weapons on the U.S. when (1) calculations are performed with P-95s (not broken into points) and (2) calculations are performed with CODE 50 using Q-95s based on WALOPT DE curves and grouped into 23 city classes. The agreement is entirely satisfactory for all purposes in this case.

(U) Figure B-13 shows resulting DEs from using 40 KT weapons on the Soviet Union when (1) calculations are performed with P-95s (not broken into points) and (2) calculations are performed with CODE 50 using Q-95s based on WALOPT DE curves (in turn, based on P-95 circles broken into points and weighted in accordance with a uniform density function) and grouped into 27 city classes. The P-95 results are about 20 to 25 percent higher than the CODE 50 results. This increment is higher than the 15 percent expected, but still indicates that use of CODE 50 for low yield attacks on the Soviet Union are within about 10 percent of what one would calculate directly from the more detailed data that are used to get the Q-95s. Thus, for force effectiveness studies, the target representation and damage assessment methods of CODE 50 appear adequate[1]. Note that this appendix does not investigate the adequacy of P-95 data. For a comparison of P-95 data with cell data, see Volume III.

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[1](U) CODE 50 contains many other elements, e.g., penetration and defense models. Those other elements of CODE 50 have not been used in the WEPS study and have not been investigated by the WEPS study.

(b)(1)

ENCLOSURE D

U.S. AND SOVIET CAPABILITIES AGAINST MILITARY TARGETS

ENCLOSURE D CONTENTS

APPENDICES

ACKNOWLEDGEMENT

The authors wish to acknowledge the preparation of scenarios and the assignment of relative values to various target elements performed by Colonels W. T. Kuykendall, O. T. Reeves and D. J. Zoerb, USAF members of the Weapons Systems Evaluation Group. They directly contributed the material in Appendix A.

I. INTRODUCTION

~~(S)~~ The purpose of the study reported in this Enclosure is to investigate the counterforce capability of the U.S. against the Soviet Union ICBM and SLBM forces. More specifically, the purpose is (1) to determine the relative effectiveness of different elements of the U.S. force when used in a counterforce role, (2) to estimate the ability of the U.S. ICBM and SLBM force to limit U.S. prompt deaths from a Soviet strike by preempting against the Soviet ICBM force, (3) to assess the U.S. and Soviet capabilities to destroy (b)(1) targets and (4) to evaluate the adequacy of the R-95 method of representing (b)(1) and computing damage to (b)(1)

(U) The focus of this Enclosure is on counterforce strikes. Chapter III considers single elements of the U.S. ICBM and SLBM forces and then combinations of force elements in strikes against Soviet ICBMs. Chapter IV presents capabilities of U.S. and Soviet forces against "other military targets" and Chapter V investigates the use of the R-95 method for computing damage to (b)(1)

(U) As in Enclosure C, only blast effects are explicitly considered; thus, the wide range of other effects discussed in Volume X are ignored. Defenses are not treated explicitly. The effect of Soviet defenses is included in the probability of arrival PA of U.S. warheads and visa versa for U.S. defenses, if any, and Soviet warheads. Prelaunch survival is normally included in probability of arrival PA; however, the Soviet force survival of U.S. counterforce attacks is explicitly calculated, that being one measure of the effectiveness of the U.S. strike.

When Soviet-force survival has been calculated, values referred to as Soviet PA are, in fact, PA given survival of the U.S. strike. PA includes command reliability, launch reliability, missile and post boost vehicle reliability, reentry reliability, warhead reliability, survival of defenses and, when not treated explicitly, prelaunch survival.

(U) Throughout this Enclosure, mobile missile systems (SLBMs and mobile ICBMs) are treated as invulnerable. This assumption establishes a minimum value of surviving Soviet force and, in turn, a minimum Soviet capability to retaliate against U.S. population. The hardness of Soviet ICBM silos is treated parametrically. Bombers are not considered as part of the U.S. preemptive forces nor as part of the Soviet retaliatory forces.

(b)(1)

[redacted]

II. SUMMARY

~~(S)~~ Chapter III presents calculated effectiveness of U.S. preemptive strikes against Soviet strategic missile forces.[1] Two measures of effectiveness are used, percentage of the Soviet force destroyed and percentage of the U.S. urban population destroyed by a Soviet second strike. A few of the results are summarized below. Consider the Soviet force to consist of the following:

Type	Inventory[a]	Yield (MT)	CEP (nmi)
(b)(1)			

[a]Warheads.
[b]Including retrofitted missiles.

These Soviet forces are assumed to have a probability of arrival (PA) (excluding the normal prelaunch survivability factor) of (b)(1) In the results summarized here, PA of the U.S. forces is also assumed to be (b)(1) The Soviet SLBMs are treated as invulnerable. Then, if half of the Soviet forces which survive U.S. preemption are employed against the U.S. urban population the results are as shown in Table 1 and Fig. 1. Data in Chapter III show that a (b)(1)

(b)(1)

[1](U) Computed with CODE 50.

(b)(1)

~~(S)~~ For the central values of CEP, MINUTEMAN III and POSEIDON are about equally effective as counterforce weapons if compared missile (booster) to missile. Both types are more effective than MINUTEMAN II; however, the comparisons are very sensitive to the CEP values assumed. These results are summarized in the following table of equivalency among the missile and warhead types (all assumed to have (b)(1)

(b)(1)

The numbers of equivalent warheads and missiles are to be interpreted as in these examples. Against a (b)(1) target, one MINUTEMAN II warhead at design specification accuracy is equivalent to (b)(1 POSEIDON warheads at design specification accuracy. Against a (b)(1) target, (b)(POSEIDON missiles with central case accuracy are equivalent to (b) MINUTEMAN III missiles with central case accuracy, or one POSEIDON missile is equivalent to (b) MINUTEMAN III missiles.

~~(C)~~ Chapter IV presents some data on U.S. and Soviet capabilities against military targets in order to compare the relative effectiveness of selected weapon systems against given targets. For the soft targets, the probability of arrival and the level of damage required on the target are generally more important in determining effectiveness than are other weapon system characteristics; this is particularly true for the large yield Soviet systems.

(U) Chapter V presents the findings of a brief investigation of the problem of military area-target representation. Specifically, attention is focused on an exemplar data base of eleven selected airfields. An exposition of the current methodology based on the so-called R-95 representation is presented first. This is followed by a comparison of (a) damage calculated on the basis of the R-95 representation and (b) damage which would be sustained by selected individual target elements if targeting were based on R-95 representation.

(U) The analysis then considers the effect of the simultaneous introduction of several categories of target elements and the impact of variations in value systems. Finally, a simple model is used to illustrate the interaction of the value system with "microtargeting," i.e., with the selection of aimpoints for individual weapons when considering a complex target.

(b)(1)

[redacted]

III. U.S. CAPABILITY AGAINST SOVIET STRATEGIC MISSILE FORCES

~~(C)~~ Four distinct sets of data are presented in this chapter. The first set considers U.S. strikes by MINUTEMAN II alone, by MINUTEMAN III alone, and by POSEIDON alone. The relative effectiveness of these systems is shown. The second set considers strikes by a reference U.S. weapon with a yield of [redacted] The third set presents strikes by a combination of the MINUTEMAN and POSEIDON forces. The fourth set simply assigns a fixed damage expectancy to each U.S. weapon launched against a Soviet ICBM.

(b)(1),(b)(3):42 USC § 2168 (a)(1) (C)

(b)(1)

[redacted]

(U) All results presented in this chapter were computed with the CODE 50 model mentioned in Enclosure C (Chapter I and Appendices A and B) of this Volume.[1]

(U) Two U.S. targeting doctrines are used extensively throughout this chapter. They are (1) allocate U.S. weapons so that expected "equivalent yield" destroyed is maximized and (2) allocate U.S. weapons so that the expected number of Soviet missiles destroyed is maximized. Equivalent yield of a warhead is defined as

$$Y_{equiv} = \begin{cases} Y^{1/2} & \text{for } Y \geq 1 \text{ MT} \\ Y^{2/3} & \text{for } Y \leq 1 \text{ MT} \end{cases}$$

where Y is the warhead yield. For a group of warheads, equivalent yield is the sum of the equivalent yield of the individual warheads.

(U) Three measures of effectiveness were computed in most cases. These are: (1) expected percent of Soviet equivalent yield destroyed (used with the equivalent-yield targeting doctrine), (2) expected percent of Soviet missiles destroyed (used with the equal-valued-missiles targeting doctrine), and (3) expected percent of the U.S. population which a Soviet second strike could destroy (used with both targeting doctrines).

A. SET 1: SINGLE U.S. FORCE ELEMENT ATTACKS

(C) The two U.S. targeting doctrines just described were employed to assign MINUTEMAN II, MINUTEMAN III and POSEIDON missiles in strikes against the Soviet force listed in Table 2. Each attack considered only one type of U.S. weapon. For each

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[1](U) For a detailed exposition of Code 50 see either of the following reports: Thomas R. Epperson, "Representations for Determining Population Fatalities from Nuclear Attack for Aggregated Gaming Models," NMCSSC TR 48-69, to be published; (S), Paul F. Maykrantz, "CODE 50 System, User's Guide," NMCSSC TR 49-69, 15 May 1969 (U).

combination of U.S. missile PA and CEP given in Table 3, computations were performed for several U.S. missile quantities and for four different hardnesses of Soviet silos. No Soviet return strikes were computed, so the measures of effectiveness are just expected percentage of Soviet equivalent yield destroyed and expected percentage of Soviet missiles destroyed. Soviet bombers and land-mobile ICBMs were not included.

Table 3 ~~(SRD)~~. CEP AND PA VALUES USED FOR SET 1 COMPUTATIONS (U)

Yield	CEP (nmi)	PA Values

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

~~(S)~~ Complete results of these computations are given in Tables B-1, B-2 and B-3 in Appendix B. Figure 2 compares the three missiles for two Soviet silo hardnesses. Data presented in that figure includes 594 Soviet SLBMs that are assumed invulnerable. If the CEP values and the PA value are realistic, data given in Fig. 2 illustrate that (b)(1) [redacted]

(b)(1) [redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1)

(b)(1) To illustrate this fact, the capability of warheads of POSEIDON yield delivered with CEP = (b)(1) is shown on the lower part of Fig. 2.

~~(C)~~ An effectiveness ratio based on the damage capabilities of one weapon system relative to another is developed in Chapter IV. This ratio is obtained by using the power law to determine the number of weapons required by each system to achieve the same expected damage on a single target. In order to relate all weapons to a single system, a reference weapon having a yield of (b)(1) and a CEP of (b)(1) has been used.

~~(SRD)~~ The effectiveness ratios, relative to the reference weapon, are given in Tables B-10 and B-12 of Appendix B for a variety of yields, CEPs, HOBs, and targets. The values pertinent to the following discussion are included in Table 4 and provide a direct comparison of the effectiveness of MINUTEMAN II, MINUTEMAN III and POSEIDON against point targets if all warheads have the same PA. For example, (b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(U) Code 50 also uses the power law to calculate damage to point targets. Consequently, the equivalence ratios developed

(b)(1)

on the basis of a single target are approximately preserved over a wide range of allocations.[1] Therefore, the employment of reference weapons provides a first order approximation for the capabilities of various weapon systems. Figure 3 is an example of this approximation. The solid curve in the figure reflects the damage achieved through a direct allocation of the reference weapons, whereas the highlighted points result from the specific MINUTEMAN II, MINUTEMAN III and POSEIDON allocations, described in Figure 3, converted to an equivalent number of reference weapons. As can be noted, the specific allocations closely approximate the reference curve.

B. SET 2: EMPLOYING REFERENCE U.S. WEAPONS

(U) U.S. preemptive strikes using a reference U.S. weapon were computed for the two U.S. targeting doctrines. Doctrine 1 assigns U.S. weapons to maximize the expected amount of Soviet equivalent yield destroyed. Doctrine 2 assigns U.S. weapons to maximize the expected number of Soviet missiles destroyed. The first Soviet force considered is the same as in Table 2, i.e., no land-mobile ICBMs or bombers are included. Then additional cases with augmented Soviet forces are considered.

~~(S)~~ Three return Soviet attacks were computed in all cases. These correspond to use of [redacted] percent [redacted] percent and [redacted] percent of the residual of each Soviet force element for the return strike. Recognize that the effectiveness of a Soviet return strike could be increased if the Soviets could tell which of their weapons would survive the U.S. strike. It is

[1](U) Damage response curves for groups of identical targets are actually a sequence of straight line segments. Due to the requirement for integral weapon assignments, allocations employing a particular weapon system and an equivalent number of reference weapons will not produce the same sequence of straight lines. However the curves will converge rapidly as the weapon inventory is increased and will coincide when smoothed.

(b)(1)

assumed that they cannot know this but that they can and do know the percentage of each force element that would be destroyed. Soviet PA is assumed to be (b)(1) This factor includes the probabilities of all events necessary for success except prelaunch survival of the weapons, and probability of severe damage, given successful arrival. Soviet silo hardness was a parameter with values of (b)(1) and (b)(1)

~~(S)~~ The reference U.S. weapon has yield equal to (b)(1), a CEP equal to (b)(1) and parametric PA values of (b)(1) and (b)(1) U.S. force size is a parameter ranging from 150 to 9600 warheads.

(U) Tables B-2 and B-3 in Appendix B give complete results for the first Soviet force considered for the two U.S. targeting doctrines. As one would expect, targeting to maximize expected percentage of equivalent yield destroyed is better than targeting to maximize expected number of weapons destroyed. However, the differences in U.S. lives lost is very small if the Soviet silos are hard, say (b)(1)

~~(S)~~ Some of the results for the case in which the U.S. targets equivalent yield are plotted in Figs. 4 and 5. Part (a) of Fig. 4 shows that if Soviet silos have a hardness of (b)(1) several thousand U.S. reference weapons would be required to destroy even (b) percent of the Soviet force. Part (b) of the figure shows that (b)(percent of the surviving force could destroy (b)(1) of the U.S. urban population. Similar results for Soviet silos with hardness of (b)(1) are shown in Fig. 5.

(b)(1)

(b)(1)

[redacted]

(b)(1)

[redacted]

~~(S)~~ One can use the concept of equivalent reference weapons to combine the results of the three types of weapons. For example, the projected U.S. force of (b)(1 MINUTEMAN II, (b)(1) MINUTEMAN III and (b)(1) POSEIDON warheads is equivalent to (b)(1) reference weapons if Soviet silos are (b)(and (b)(1) reference weapons if Soviet silos are (b)(1) hard. For U.S. PA equal to (b)(1) Figs. 4 and 5 or Table B-2 in Appendix B shows that this U.S. force can destroy (b)(percent of the Soviet force if Soviet silos are (b)(1) and that (b)(percent of the surviving Soviet force can destroy (b)(percent of the U.S. urban population. If Soviet silos are (b)(1) the corresponding figures are (b percent of the Soviet force and (b)(percent of the U.S. urban population. These results are confirmed by data presented in Set 3, Paragraph C, below.

~~(S)~~ Figure 6 shows how the percentage of U.S. urban population destroyed varies with Soviet targeting strategy and silo hardness for two different quantities of U.S. reference weapons used in preemption. For silo hardnesses up to (b)(1) the (b)(1) -weapon strike destroys essentially all of the Soviet land-based missile force considered. In this case, the destruction of the U.S. urban population results from the Soviet SLBM force only. In this extremely optimistic[1] situation, if the Soviets would respond with only (b)(percent of their SLBMs on the U.S. cities, then (b) percent of the U.S. urban population would be destroyed by prompt effects.

~~(S)~~ For the targeting doctrine based on equivalent yield, calculations of Soviet force destroyed and U.S. urban population lost were performed for two larger Soviet forces. The first of these is an augmentation of (b)(additional SS-Z-3 missiles, (b)(1) The second is a further augmentation of (b) SS-Z-10 land-mobile ICBMs and (b)(1)

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[1](U) From the U.S. point of view.

(b)(1)

additional SLBMs.[1] Land-mobile ICBMs and SLBMs are treated as invulnerable. Including more of these forces raises the fraction of the Soviet force that a U.S. preemption cannot destroy. This, then, causes a decrease in the U.S. "damage limiting" capability. The effect on U.S. damage limiting is greater for soft Soviet silos than it is for hard silos. For example, for (b)(1) U.S. reference weapons and U.S. PA = (b)(1)

	Percent of U.S. Urban Population Destroyed by (b)(percent of Surviving Force		
Soviet Silo Hardness	Soviet Force Level One	Soviet Force Level Two	Soviet Force Level Three
(b)(1)			

Figures 7 and 8 present limited results for the two augmented Soviet forces. Complete results are given in Appendix B, Tables B-4 and B-5.

C. SET 3: MIXED ATTACKS BY MINUTEMAN II, MINUTEMAN III AND POSEIDON

~~(S)~~ The base case Soviet forces and force characteristics used in Sets 1 and 2 were used in Set 3. These are presented above in Table 2, page 67. Four levels of U.S. preemptive forces were allocated to the Soviet weapons by the two targeting doctrines described before. The four levels of U.S. attack are:

1. (b)(1) MINUTEMAN II
2. MINUTEMAN II, (b)(1) MINUTEMAN III
3. MINUTEMAN II, MINUTEMAN III, (b)(1) POSEIDON
4. MINUTEMAN II, MINUTEMAN III, POSEIDON

[1] ~~(S)~~ The land-mobile ICBMs are assumed to have PA = (b)(1) like all other Soviet missile systems.

(b)(1)

Quantities given are warheads. The fourth level is the projected 1975 force. Three different sets of U.S. missile CEP values were used along with several PA values to give the following five combinations:

MM II CEP (nmi)	MM III and POSEIDON CEP (nmi)	U.S. PA 0.25	0.50	0.75	1.00

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

Each of these cases was considered with three Soviet return strikes and four Soviet silo hardnesses.

~~(S)~~ Results for these 480 sets of conditions are given in Tables B-6 and B-7 in Appendix B. The two tables correspond to the two U.S. targeting doctrines. Some of the results from Table B-6 (U.S. attempting to destroy maximum Soviet equivalent yield) are presented graphically in Figs. 9, 10 and 11. Fig. 9 shows that the U.S. force cannot save a large fraction of the U.S. urban population even if all of the force is used in preemption. Figure 10 shows that the percentage of U.S. urban population destroyed would be about 10-15 percent lower for the more accurate set of CEPs than for the less accurate set (for the highest U.S. attack level). Figure 11 indicates that the incremental effect of changing U.S. PA from 0.5 to 0.75 is considerably less than that of changing from one set of U.S. weapon accuracies to the other.

D. ARRIVAL EQUIVALENT TO DESTRUCTION OF TARGET

~~(S)~~ As mentioned before, only blast effects have been explicitly considered as the destruction mechanism in this enclosure. However, Volume X discusses numerous other effects which could potentially be far more significant than blast.

(b)(1)

(b)(1)

Because of this possibility it is desirable to establish an upper limit to the effectiveness of U.S. missiles when used against Soviet missiles. Toward this end, assume that every U.S. missile arriving at its target destroys that target (by any destruction mechanism). This situation was investigated for the Soviet force of Table 2. U.S. PA values of 1.00, 0.75 and 0.50 were considered for a range of quantities of U.S. weapons. Six different Soviet return attacks were chosen to represent a reasonable spectrum of retaliation strategies. The six return attacks, in percent of surviving Soviet missiles, are as follows:

	Soviet Return Attack[c]					
Weapon Type	R1	R2	R3	R4	R5	R6
SS-Z-3	(b)(1)					
SS-9						
SS-9						
SS-11[a]						
SS-13[b]						
SLBMs						

[a] Retrofit SS-Z-9s are included with SS-11s.
[b] Retrofit SS-Z-10s are included with SS-13s.
[c] Table entries are percentages of surviving Soviet weapons used in a return attack on the U.S.

~~(S)~~ The percentage of the Soviet force destroyed and the resulting percentage of U.S. urban population destroyed are shown in Fig. 12 for U.S. PA = (b)(1) . Additional results are given in Table B-8 in Appendix B.

(b)(1)

(b)(1)

Soviet SS-Z-3. The estimated 1975 force of SS-Z-3s is 900 warheads (150 missiles). From Table B-3 in Appendix B, one can compute that if the Soviet Union were to employ SS-Z-3s against a U.S. force of (b)(1) fixed, land-based missiles and if the allocation were designed to maximize the expected number of missiles destroyed, then the results would be as given in Fig. 13. More complete results are given in Table B-9 in Appendix B. If the U.S. missile silos were (b)(1) and the Soviet PA were (b)(1) the 900 Soviet SS-Z-3 warheads could destroy (b)(1) percent of a (b)(1) missile U.S. force. As would be expected, the effectiveness of the Soviet force is (b)(1)

(b)(1)

(b)(1)

FIGURE 13 ~~(S)~~ Effectiveness of the SS-Z-3 in Destroying a 1290-Missile, Land-Based Force (U)

IV. U.S. AND SOVIET CAPABILITIES AGAINST INDIVIDUAL MILITARY TARGETS

(U) The purpose of this Chapter is to compare the capabilities of individual offensive weapon systems against single categories of military targets. The emphasis is on the relative efficiency of particular weapon systems against particular targets; inventory constraints and strategic objectives are considered only in very general fashion, since these considerations are addressed in Volumes I and V. Other constraints, such as range and footprint, are also excluded.

A. U.S. CAPABILITIES AGAINST SOVIET TARGETS

1. Soviet Targets

~~(S)~~ For the purposes of this analysis, the Soviet targets were grouped into categories according to physical characteristics and the nature of the threat they represent. These categories are described in Table 5.[1] The number of targets in each category was taken from the FSTL for 1975, except that some types of installations were split into two target (threat) categories. These installations are (b)(1) (b)(1) [redacted] The numbers of these installations considered in each threat category was based on an extrapolation of current SIOP targeting practices.

2. U.S. Weapons

~~(S)~~ The characteristics of the U.S. weapons systems considered are shown in Table 6. Note that the POLARIS A3 has

[1] (U) The hard nuclear threat targets are included here for completeness, although the emphasis in this Chapter is on the soft military targets.

(b)(1)

(b)(1)

[redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

3. Discussion

(U) For each combination of weapon and target, it is possible to compute a probability of kill, P_k.[1] This kill probability multiplied by the probability of arrival (PA) for the weapon gives the single shot kill probability (SSKP). If more than one weapon is applied to a single target, the resulting kill probability, called the damage expectancy (DE), is computed by assuming that the target is destroyed with probability SSKP for each weapon independently of the other weapons. If N

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[1] (U) For this analysis, the values for P_k were computed in accordance with DIA Physical Vulnerability Model.

(b)(1)

for the target and weapon systems of interest here, and the values are given in Table B-10 in Appendix B. These ratios are given in Table 7 for selected targets[1] and weapon systems. (b)(1) [redacted]

(b)(1) [redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

~~(U)~~ The effectiveness ratio as computed above does ignore two important, closely related considerations. One is that the number of weapons applied to a given target must be an integer. The other is that if weapons are to be allocated to a target until some DE is achieved, then some DE objectives will not discriminate between weapon systems, while other DE objectives will force an artificial discrimination. For example, a DE

(b)(1) [redacted]

(b)(1) might have an SSKP of (b)(1) while the POSEIDON might have an SSKP of (b)(1). Alternatively, a DE objective of (b)(1) for a (b)(1) nautical mile target would require (b) POSEIDON warheads per target while a DE objective of (b)(1) would require (b) POSEIDON warheads per target.[1] These effects are of greatest importance for soft targets. To determine how these two considerations affect the relative effectiveness of particular weapon systems against the soft targets, Table 8 was prepared. This table provides, for selected targets and weapon systems and PA, the number of weapons of each type required per target to achieve each of two DE objectives, (b)(1) if the objective is to apply equally to all targets in the category. A more complete set of values is given in Table B-11 in Appendix B.

4. Observations

(U) The observations here will be restricted to the soft military targets, and only general comments can be made. More precise comments must take inventory restrictions and other strategic objectives into account; these parameters are considered in Volumes I and V.

(b)(1),(b)(3):42 USC § 2168 (a)(1) (C)

~~(SRD)~~ For the soft military targets, if the [redacted] HOUND DOG and [redacted] POSEIDON are excluded, then the DE objective and the value of PA are the dominant factors in determining weapon requirements. Examination of Table 8 or of Table B-11 in Appendix B shows that the effect of these two factors is more pronounced than the effect of either differences in target vulnerability or of other weapon system characteristics. For the POSEIDON (and HOUND DOG) system considered separately, basically the same considerations apply: PA and DE objectives are relatively more important in determining the number of weapons required to meet a specified DE than are the target characteristics.

(b)(1),(b)(3):42 USC § 2168 (a)(1) (C)

[1](U) All at a PA of 0.75.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

~~(SRD)~~ The DE objectives considered here do tend to favor certain weapon system/DE objective combinations. For a PA of (b)(1) high DE objectives (b)(1) or low DE objectives (b)(1) favor the use of the (b)(1) aircraft or MINUTEMAN systems, and in the best CEP case, the (b)(1) aircraft or the MINUTEMAN III systems as well. The central DE objective of (b)(1) (again at a PA of (b)(1) favors the remaining weapon systems, since they result in less "overkill" (DE higher than the objective). At a PA of (b)(1) the DE objectives considered here discriminate only between the POSEIDON/HOUND DOG systems, and the rest of the force. In this case, the very much larger POSEIDON inventory must be taken into consideration. Finally, at a PA of (b)(1) the generally high weapon requirements again make inventory restrictions an important consideration.

B. SOVIET CAPABILITIES AGAINST U.S. TARGETS

1. U.S. Targets

~~(C)~~ For this analysis, the soft U.S. military targets were grouped into three categories, as given in Table 9. These three categories do not allow a very detailed description of the U.S. targets, and therefore the accuracy of this representation is somewhat reduced. However, because the Soviet weapons are virtually all large yield weapons, the effects of PA and DE objective are even more important than the weapon-target combination. The three categories used here are therefore felt to be adequate. The number of targets in each category are also approximations, based on current RISOP practices.

~~(U)~~ The hardened U.S. missile sites are also included as targets, and as in the case of the Soviet sites, several values are considered for their vulnerabilities.

(b)(1)
[redacted]

2. Soviet Weapons

(U) The characteristics of the Soviet weapon systems considered in this analysis are given in Table 10.

Table 10 ~~(S)~~ SOVIET WEAPON CATEGORIES (U)

Category	Yield in MTs	CEP (nmi)	HOB
Aircraft Gravity Bomb	(b)(1) [redacted]		
Aircraft ASM			
SS-9			
SS-9			
SS-11/SS-N-5/ SS-N-6			
SS-13			
SS-Z-3			

3. Discussion

~~(S)~~ As described in Section A, two tables have been prepared for Soviet weapons and are given in Appendix B. Table B-12 gives the weapon effectiveness ratios for each of the Soviet systems, as compared with (b)(1) [redacted] SS-Z-3 missile. Table B-13 gives the number of weapons required per target to achieve a fixed DE objective on all targets in a category.

V. REPRESENTATION OF SELECTED (b)(1)

A. THE R-95 REPRESENTATION

~~(TS)~~ In the current NSTDB, extended military targets such as (b)(1) are listed in terms of the so-called R-95 representation. This consists of the geographic coordinates of a reference point (RP), a vulnerability number (VN), a radius expressed in nautical miles (the R-95), and a point count reflecting the value of the target (see Volume V). (b)(1) (b)(1) is thus replaced by an artificial counterpart with a continuous value distribution that is circularly normal and centered about RP.

(U) R-95 denotes the radius of the circle encompassing 95 percent of the target value. The expected damage (b)(1) (b)(1) thus represented may be obtained via the circular coverage function,[1] by treating it as a point target located at RP. In this method, the weapon radius and point target distance are used along with the adjusted CEP, which is given by

$$\text{Adjusted CEP} = \sqrt{(\text{CEP})^2 + .231\ (\text{R-95})^2}$$

or

$$\text{Adjusted } \sigma = \sqrt{\sigma^2 + 1/6\ (\text{R-95})^2}\ .$$

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[1] See Enclosure C, Appendix A, this Volume.

(U) Two questions arise in connection with this representation, viz:

1. What is the impact of such a representation to the computation of inflicted damages?
2. What would be the effect of "microtargeting"[1] on the employment efficiency of multiple weapons (particularly those of smaller yield) on the target representation?

(U) This chapter reports findings of a short-term investigation. It addresses the first question by comparing the damages inflicted on the fictitious R-95 circle with those sustained by the actual installations if the same RP given by the R-95 representation were used as the DGZ. Similar comparisons are made for cases where the actual damages to the installations are weighted. It also addresses some aspects of the second question. The (b)(1) is optimally targeted with respect to one or more selected installations resulting in a set of optimal DGZs. The weighted total damage is then compared to the result obtained by computing the damages to the fictitious R-95 circle if the RP were used as the DGZ.

~~(S)~~ The numerical computations for the first part are based on a restricted data base of (b)(1) selected from among each of (b)(1) TDI categories. Those for the latter part of the investigation are based upon a simplified model of an exemplar (b)(1) Weighting of damages is carried out parametrically to demonstrate the effect of changes in priorities.

B. DAMAGE INFLICTION COMPARISON

~~(TS)~~ The (b)(1) TDI categories from which the exemplar data base has been extracted as well as the NSTDB description of the selected (b)(1) are as follows:

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[1](U) See Volume III, Chapter IV.

[2](U) The geographical coordinates are not shown as they do not enter the present analysis.

(b)(1)

(b)(1)

(b)(1)

[redacted]

(U) The impact of the R-95 representation to the computation of damages inflicted on the [redacted] is illustrated in Figs. 14 through 24 for the eleven exemplar [redacted] The [redacted] has been chosen because it has a higher VN and average distance from the RP and, thus, reflects an upper bound. The methodology used is as follows.

(U) Let the damage obtained on the complex with the R-95 representation be denoted as D_{R-95} and the corresponding damages actually inflicted on the [redacted] with DGZ at RP be denoted by [redacted] The ratio [redacted] is shown as a function of weapon yield for a given number of weapons, N. In the left-hand portion of Figs. 14 through 19, a CEP of [redacted] was used for ratios calculated at yields of [redacted] and [redacted] A CEP value of [redacted] was used for the [redacted] yield.

(U) The right-hand portion of these figures shows the effect of CEP variation for weapon yields of 40 KT and 1 MT. It is interesting to note the changes in the behavior of such

[1](U) When there are more than one [redacted] area, the damages are weighted equally.

variations. Briefly, a small CEP would confine the weapon effects to an area surrounding the DGZ. A low yield weapon with its concomitantly smaller weapon radius results in a lower damage probability to an installation at some distance away from the RP. On the other hand, the increased weapon radius of a large weapon may extend to and exceed the distance of the installation in question from the RP. A small CEP thus insures a high damage probability to the installation. This explains somewhat qualitatively the drastic changes in the behavior of the [redacted] curves as compared to that of the 1 MT curves. The effect is particulary dramatic in the case of the [redacted] weapon, resulting from its high sensitivity to the physical geometry of the airfield, i.e., the distances of the POL from the RP.

(b)(1),(b)(3):42 USC § 2168 (a)(1) (C)

(U) The ratio [redacted] approaches unity as weapon yields increase. Depending upon the hardness of the target element in question and its distance from the RP, this ratio may exceed unity.

(U) Figure 25 represents a composite picture of the eleven cases studied. A new index is introduced. This is the quotient obtained by dividing the point value of a target complex by the total yield tonnage applied to it. While the ratio [redacted] approaches unity for all eleven [redacted] as the point/yield index falls below 10^{-3}, there is a spread of almost 80 percent among the lower bounds (at high values of the abscissa) as a result of differences in the configuration of target complexes. Between the upper and lower bounds, the ratio exhibits an essentially exponential relationship with respect to the point/yield index.[1] As this index decreases, the R-95 representation increases in its realism.

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[1](U) Note that in this range the damage ratio is nearly linear with the logarithmic point/yield index.

(b)(1)

(b)(1)

(b)(1)

(b)(1)

(b)(1)

(b)(1)

(S) Figure 26 aggregates the data by presenting the percent maximum deviation of (b)(1) as a function of the percent cumulated target point values for a given value of the point/yield index described above. Points derived from Fig. 25 are shown for the K = 10^{-1} case. Curves show trend only. For example, if the number of weapons applied is such that the targets receive (b)(1) for each value point assigned (K = 10^{-2}), then (b percent of the value points in the exemplar data base could be represented by R-95s without exceeding (b)(percent error in damage inflicted on (b)(1) On the other hand, if the point/yield index were increased such that the targets receive (b)(1) for each value point (K = 10^{-1}), less than (b)(1) percent of the value points in the data base qualify.

(TS) The following weapon allocations have been selected from typical SIOP-like attack plans.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

The allocations apply to (b)(1) (TDI Category (b)(1) Consequently, the point/yield index for typical SIOP-like attacks lies in the range from (b)(1) per value point assigned. The corresponding values of the index K are (b)(1) By interpolating among the curves shown in Fig. 26, it is seen that the error is small for nearly all of the exemplar data base for an attack typical of current SIOP allocation.

(b)(1)

[redacted]

(b)(1)

(b)(1)

(b)(1)

(U) When it is possible only to rank the relative importance of the installations, the resultant impact of the R-95 representation may be estimated by ranking the damage inflicted on each category. No examples have been computed for this case.

D. OPTIMIZATION

(U) For a given value distribution postulated by the relative importance attributed to the several installations, appurtenances and equipment, it is conceivable that some point other than the reference point (RP) should be chosen as the DGZ to maximize expected damage to (b)(1) In case of multiple weapon attacks, one searches for an optimum set of DGZs. This process is called microtargeting.

(U) Optimal microtargeting depends on the criteria or objective function chosen. If it is desired to maximize the total weighted damage, such criteria may vary according to the weights (b)(1) To shed some light on the effect of such variations, a simplified model is used. It consists of a number of point targets representing the several installations (b)(1) and (b)(1) (b)(1)

(U) First, hypothesize that the optimization has been carried out on the basis of only one type of installation, say (b)(1) i.e., set (b)(1) Then consider the impact of a representation based on this criterion when the weighting factors assume values other than those specified. The analysis is similar to the one carried out in the previous section. Results for a typical staging base are presented in Fig. 28. For a single weapon, the error can be as high as 50 percent. For five weapons, the maximum error in the exemplar case is five percent. Similar cases in which

(b)(1)

the optimization is carried out for (b)(1) [redacted] are shown in Figs. 29 and 30.

(U) Next, consider the optimization to be carried out with respect to two categories weighted equally, e.g., (b)(1) [redacted] The impact of such a basis for target representation is illustrated in Fig. 31 for the case of one weapon. When the weighting factors assume values other than those assumed in the optimization, there ensues an error in computed damage infliction. Similar results are presented in Figs. 32 and 33 for optimization based on (b)(1) [redacted] respectively.

E. CONCLUDING REMARKS

~~(C)~~ The R-95 representation of a (b)(1) [redacted] permits its treatment as a point target. Based on this representation, however, the computed target response to weapons applied may be at variance with the damages inflicted on the individual installations, appurtenances and equipment (b)(1) [redacted] The disparities are due to the differences in VNs and the locations of individual installations with respect to the reference point of the R-95 circle. Disparities become more pronounced with a decrease in weapon yield and number.

(b)(1) [redacted]

(b)(1)

(b)(1)

(b)(1)

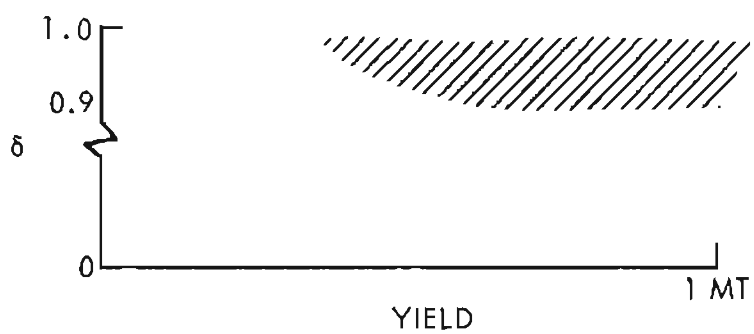
[redacted]

for each facility. In equation (5), δ is the ratio of the actual damage inflicted to that computed with the R-95 representation, i.e., D_{R-95}.

(U) For a given (b)(1) D_{R-95} is a function of weapon yield for a given CEP and number of weapons applied. The ratio δ is also a function of yield, CEP and number of weapons (Figs. 14 through 24). These two functions can be combined, then, to define a minimum δ for given yield, CEP and number of weapons. The sketch represents such an admissible region based on the criterion of Equation (5).

(U) The lower boundary of the admissible region being asymptotic to the line δ = 0.9, it follows that in many cases only a small portion (towards the high yield end) of the curves in Figs. 14 through 24 will be intercepted by this admissible region. Since Figs. 14 through 24 depict the impact on (b)(1) the situation would perhaps improve for the (b)(1) (see Section B).

(U) In other words, use of the R-95 representation could lead to discrepancies in the evaluation of objectives achieved. Such discrepancies accumulated over a number of targets could conceivably have a serious effect on the overall weapons allocations against a range of military objectives (Volume V).



(U) As one varies the relative values assigned to the several categories of installations and equipment, so does the efficiency[1] of weapon employment based on the R-95 representation. Microtargeting of a (b)(1) to optimize weapon employment efficiency obviously depends on the value scheme. Representations based on optimization with respect to one value scheme yield different results with respect to another.

(U) In general, it appears advantageous to optimize with respect to target elements of higher VN. For example, part (e) of Fig. 21 shows the effect when (b)(1) weapons are applied against the (b)(1) of an exemplar (b)(1) (b)(1) If the value system were changed, by decreasing the weight assigned to (b)(from unity and increasing those assigned to the (b)(1) the maximum error in the resultant weighted damage is less than 5 percent. The corresponding error increases to 20 percent and 45 percent if the optimization were carried out against the (b)(1) (b)(1) respectively.

(U) Any improved representation of extended military targets should incorporate weapon employment efficiency gained due to microtargeting. The latter depends on the configuration of the target complex, the hardness of the target elements and the value system ascribed to the several categories of target elements. The value system could vary from target to target as well as with the scenario. A satisfactory representation is one which results in computed damage which realistically reflects the expected damages sustained by the various target elements when aggregated according to the value system in question. Such a representation is important not only because of the level of aggregation necessary in

---

[1](U) That is, the ratio $\delta = \bar{D}/D_{R-95}$.

weapon allocation studies, but also in the evaluation of objectives achieved. The deficiencies in the R-95 representation are particularly pronounced in the case of low yield weapons. The (b) [redacted] target representation used in the detailed microtargeting described in Volume III need not suffer from the deficiencies of the R-95 system. For military targets, however, further study would be desirable to develop a system which would be as fast and simple as the R-95 system but more realistic. No such system is known.

APPENDIX A

DGZ PRIORITIES FOR MILITARY AIRFIELDS

I. GENERAL

(U) The following analysis was carried out to support paragraph C of Chapter V.

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APPENDIX B

DETAILED TABULAR RESULTS

APPENDIX B

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(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

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WSEG REPORT 148

STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

VOLUME VII

Enclosure G: Soviet ABM Defense Capabilities and Selective Simulation of Defense Engagements

August 1969

Including
IDA REPORT R-160

A. R. Barbeau, *Project Leader*

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REPORT R-160

STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

A. R. Barbeau, *Project Leader*

VOLUME VII

Enclosure G: Soviet ABM Defense Capabilities and Selective Simulation of Defense Engagements

J. H. Daniel
J. G. Healy
J. A. Ross
M. G. Degnen

August 1969

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in response to the Weapons Systems Evaluation Group Task Order SD-DAHC15 67 C 0012-T-140, dated 21 December 1967.

In the work under this Task Order, the Institute has been assisted by military personnel assigned by WSEG.

IDA

INSTITUTE FOR DEFENSE ANALYSES
SYSTEMS EVALUATION DIVISION
400 Army-Navy Drive, Arlington, Virginia 22202

FOREWORD

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in conjunction with the Weapons Systems Evaluation Group. The research and analysis that form the basis for this report were carried out by a project staff under the general leadership of A. R. Barbeau. The members of the project staff are listed below:

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The principal authors are indicated in the Table of Organization.

TABLE OF ORGANIZATION

TABLE OF ORGANIZATION (Cont'd)

VOLUME VII

ENCLOSURE G - Soviet ABM Defense Capabilities and Selective Simulation of Defense Engagements
Authors: J. H. Daniel, J. G. Healy, J. A. Ross, M. G. Degnen

VOLUME VIII

ENCLOSURE H - ABM Defense Employment, Engagement and Penetration
Authors: T. E. Sterne, J. A. Ross

VOLUME IX

ENCLOSURE I - (b)(1) [redacted]
Authors: D. N. Beatty, E. Marcuse

VOLUME X

ENCLOSURE J - Nuclear Weapons Effects on Strategic Missile Systems
Authors: H. A. Knapp, J. A. Ross, D. H. Williams

CONTENTS

APPENDICES

I. INTRODUCTION

(U) This Volume is concerned with the capabilities of Soviet antiballistic missile (ABM) defense systems and how to penetrate them. Its approach to the penetration problem is complementary to that of Volume VIII. By employing simulation of defense engagements, it attempts to fulfill a need for more detailed treatment of engagement features whose effects can only be aggregated in an idealized way in the analytic or game theory approach of Volume VIII.

(b)(1)

(U) With an analytic approach to evaluation of various tactics for offense-defense engagements, tractability of analysis requires representation of the results of complex engagement factors (including system characteristics, deployment, and tactics) by simple parameters such as single-shot kill probabilities. Because of such simplifications, the relevance of the analysis to specific situations of interest may be difficult to establish. Different situations may result in quite different effective values for such parameters which the analysis cannot supply.

---

[1](U) See Section A of Chapter V.

(b)(1)

(U) A simulation approach, even if confined to the more critical features of such engagements, is also subject to limitations imposed by complexity. However, it is a more direct approach, which, if it can be successfully carried out, can properly combine the non-linear interactions of "pure" penetration modes[1] to provide improved relation of postulated engagement situations to their outcomes, or possibly to parameters which can be used in further analysis.

(U) When it was proposed to implement such simulation for WEPS, no computer model was available which could handle the number of objects characteristic of a massive attack. While it appeared feasible to increase the capacity of the BAGATEL defense engagement model developed by General Research Corporation, and to modify it to incorporate many of the features which would ultimately be desired, there was uncertainty as to how much computer running time would be required for large engagements and to what extent this might limit the usefulness of such a model. Thus, for the modified model (IDA-BAGATEL), only those modifications considered either necessary to such exploratory investigations, or else relatively straightforward, were implemented.

(U) After such modifications were accomplished, only a limited time remained for their exploration in this study. Thus only nuclear blackout effects on an otherwise perfect defense have been investigated. The results of this investigation are significant and could have been achieved only through simulation, but the unique potentialities of simulation for properly incorporating multiple cumulative sources of

---

[1](U) Penetration modes are discussed in the Pen-X Report (U), Section 1.5, IDA Report R-112, 1 August 1965 ~~(SRD).~~ Difficulties of isolation and classification of such modes is illustrated in WSEG Report 119, Vol. II, pages 25-32, November 1967 ~~(SRD)~~.

defense degradation have not yet been exploited. Initial experience with IDA-BAGATEL indicates that realization of such potentialities for large attacks will require larger amounts of computer time and/or further work to reduce the run time of a single engagement, particularly the time devoted to blackout calculations.

II. SOVIET ABM DEFENSES[1]

A. CURRENT SYSTEMS

(b)(1) [redacted]

[1](U) Intelligence estimates of the technical characteristics of current and projected (to 1975) Soviet ABM systems, an indication of the nature of the evidence on which such estimates are based, a brief history of the development of current systems, and intelligence estimates of 1975 deployments are outlined in more detail in Appendix A.

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(U) Although the simulation model (IDA-BAGATEL) developed is capable of including other defense-degrading effects,[2] the combination of simulation complexities, intelligence uncertainties, and available time have limited its use in this study to investigation of nuclear blackout effects in large attacks involving an otherwise perfectly performing defense. Thus the defense was credited with 100 percent reliability, zero miss-distance, no saturation limits, and complete radar and interceptor netting, but was vulnerable to penetrating RVs. Its

---

[1](U) This type attack is defined in Chapter IV, Section A, paragraph 4.

[2](U) For example, interceptor unreliability, saturation, and netting limitations.

IV. CONCLUSIONS

(b)(1) [redacted]

[2](U) The defense was given 100 percent reliability, zero miss-distance, no saturation limits, and complete radar and interceptor netting, but was vulnerable to penetrating RVs.

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V. DISCUSSION

A. IMPLICATIONS OF CURRENT SIOP DEFENSE SUPPRESSION

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(S) Examples of trade-offs which probably influenced this suppression attack are:

[1](U) Plus appropriate reliability and vulnerability estimates for U.S. attacking missiles.

(b)(1)

(b)(1) [redacted]

B. THE NEED FOR SELECTIVE SIMULATION OF DEFENSE ENGAGEMENTS

(b)(1) [redacted]

(U) Effects of the type indicated in Items 1, 2, and 3 of Table 1 determine what can be identified and how accurately it can be tracked by the defense radars. Effects of Item 4 determine how much of the information potentially available to the defense system can actually be utilized. Integration or superposition of effects as in Item 5 is significant because defense degradation from the combination of such effects may

[1] (U) End-game kill probabilities (i.e., probabilities resulting from interceptor miss-distance and lethality) were assumed near unity.

(b)(1) [redacted]

Table 1 (U). EFFECTS WHOSE IMPORTANCE IN DEFENSE ENGAGEMENTS (1975) IS DIFFICULT TO DETERMINE WITHOUT APPROPRIATE ENGAGEMENT SIMULATIONS (U)

---

1. Nuclear Blackout effects on radar detection and tracking.
2. Other radar confusion effects, both nuclear and non-nuclear (e.g., refraction, clutter, debris, multipath, scintillation, noise).
3. Confusion and saturation effects of chaff.
4. Effects of extent, effectiveness, and vulnerability of data processing, communication, and command and control networks.
5. Combination of such effects in large attacks on extensive defenses.

(b)(1) [redacted]

[1](U) As well as others more closely related to tactics, such as use of selectable yields by the defense, or timing and selection of trajectories by the offense.

(U) Complex and changing geometry and time relations between radars, attacking objects, and ionized regions due to nuclear bursts make simulation necessary for determining blackout effects in large attacks. The elaborate simulation structure required to evaluate the effects of blackout should allow most of the other effects in Table 1 to be incorporated in a computer model with relatively small additional cost and effort.

C. DESCRIPTION AND USE OF SIMULATION MODEL DEVELOPED FOR WEPS

(b)(1) [redacted]

1. Model Description

(U) The basic tracking doctrine of both the original BAGATEL and IDA-BAGATEL can be illustrated with the aid of Fig. 3. When an object comes within radar detection range, blackout tests are made (if bursts have occurred) at every time

(b)(1) [redacted]

[2](U) The 500-600 object capacity is based on use of a CDC 6000 series computer with a 64 k memory. Without requiring further program modifications, the new IDA-BAGATEL can be run on 6000 series machines with larger memories, permitting over 3000 objects in the attack. However, the running time when blackout is effective may increase roughly as the square of the number of objects.

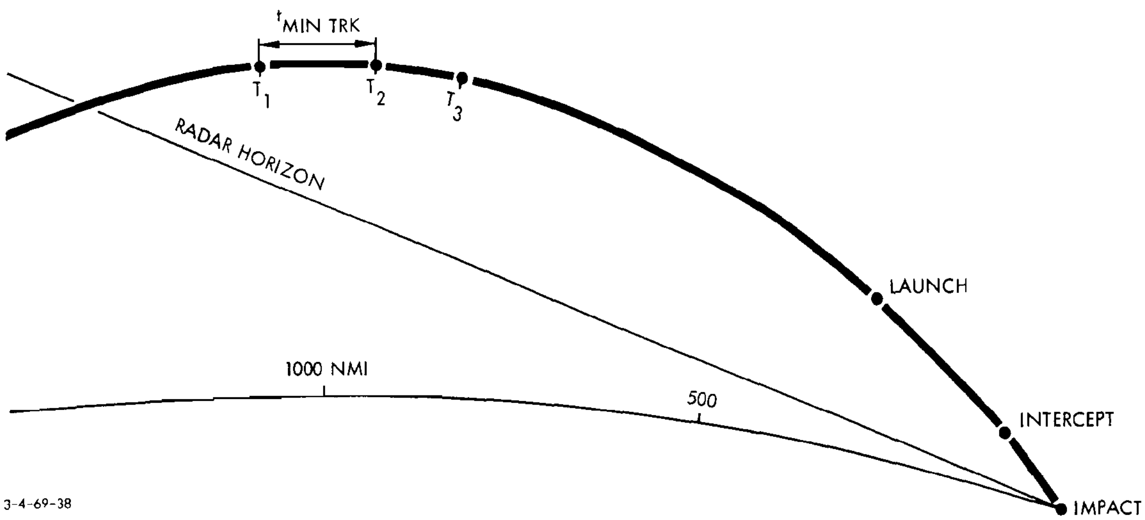

FIGURE 3 (U). Geometry Illustrating BAGATEL Area Defense Tracking Doctrine (2000 NMI Min E Trajectory)(U)

step[1] until the object can be seen (T_1), or until intercept is impossible from any missile site. Such tests are the most time consuming feature of the program. If the object is detected at T_1, it is assumed that sufficient tracking could occur to allow the radar to either track or continue searching to T_2, where T_2 - T_1 is the tracking time which would be required in a clear environment to give the desired intercept accuracy. At T_2, blackout tests are resumed until the object is seen again, as at T_3. If T_1 and T_3 can be established, the intercept is considered successful if at launch time an interceptor is available and if it is subsequently reliable. If T_1 or T_3 cannot be established prior to last possible interceptor commit time, the object penetrates.

(U) The basic firing doctrine for the defense is to attempt to intercept at a preferred altitude (to minimize blackout). If intercept at the preferred altitude is not

[1](U) The time increment between successive situations for which the computer makes complete calculations.

possible, intercept will be attempted at an altitude as close to the preferred one as possible, within a selected altitude band.

(U) Table 2 shows the modifications made to BAGATEL. The increased storage was required to obtain the increase in numbers and types of objects, targets, radars, and interceptors. The faster blackout model is still the time bottleneck. Radar and interceptor assignment is determined by availability and type priorities, and any desired netting can be established for information transfer between radar sites and/or interceptor sites.[1] If a radar or interceptor site is targeted by an RV which penetrates the defense, it may be removed from the engagement as determined by appropriate kill probability. Interceptor reliability can be taken into account by specifying abort probability as a function of time after launch; after an abort, intercept is rescheduled if possible. Radar track time is made dependent on radar range, intercept prediction range, radar type, and reduction in signal-to-noise due to blackout. Multiple kill of RVs is taken into account for each intercept (it should not occur if the attack is properly designed), but there is no provision for taking interceptor fratricide into account. A limit can be set on the number of objects which can be simultaneously tracked by any radar, and on the number of simultaneous airborne interceptors which can be handled by any interceptor site. Any of these modifications can be turned off or on in order to test individual effects.

---

[1](U) Thus, if perfect netting is used, all radars having an object in field-of-view will be tested in order of priority to establish first T_1 and later T_3 (only radars with search capability can be used for T_1, but handover to a higher priority tracking-only radar might then be accomplished immediately).

Table 2 (U). MODIFICATIONS OF BAGATEL FOR IDA (U)

	BAGATEL	IDA-BAGATEL
Program written for	CDC 3600 (32 K core)	CDC 6400 or 6600 (at least 64 K core)
Capacity	55 attacking objects (3 types) (50 targets)	600-3000 attacking objects, depending upon computer memory size. Commensurate increases in object types and number of targets.
Blackout Model	Essentially RANC IIIA attenuation	Faster model
Radar & Interceptor Assignment & Control Logic	First-come-first-serve	More Realistic
Radar & Interceptor Site Kill	Not Included	Included
Interceptor Reliability	Not Included	Included
Variable Radar Track Time	Not Included	Included
Multiple-Kill of RVs by Interceptors	Not Included	Included
Radar (data processing) Saturation	Not Included	Included
Interceptor Tracking Saturation	Not Included	Included

2. Model Use

(b)(1)

[redacted]

(U) The objective targeting within the Moscow-Leningrad area was essentially that resulting from marginal gain allocation for an attack on the entire Soviet Union, subject to MIRV footprint constraints, in the absence of defense (results of a manual procedure developed prior to the automated procedure described in Volume VI were used). Thus, the relative timing and trajectories of RVs from a single booster (several RVs from a booster may go to each of several targets) are constrained, but the timing of each booster launch or arrival can be set as desired. One IDA-developed program can test for RV fraticide, and another takes booster reliability into account to arrive at the individual RVs and trajectories which enter IDA-BAGATEL. Finally, the RVs which IDA-BAGATEL allows to penetrate can be used in an IDA damage assessment model.

D. SIMULATION RESULTS

(b)(1)

[redacted]

---

[1](U) That is, the defense was given 100 percent reliability, zero miss-distance, no saturation limits, complete radar and interceptor netting. Thus RVs penetrated only if blackout prevented acquisition by any of the radars at any two points (T_1 and T_3 in Fig. 3, Section C1 above) on the RV trajectory separated by less than the clear-environment tracking time required for accurate prediction of intercept position. Since no saturation limits or miss distances were involved, results were not sensitive to reasonable values of this tracking time.

(U) Appendix B lists in Table B-1, and discusses in some detail, pertinent data and results for most of the computer runs made. The more significant features are briefly discussed in this section. Forerunner type attacks are considered first, followed by precursor type attacks. Both types are defined in the third paragraph of Section A, Chapter IV (Conclusions) above, and further discussed in the first paragraph of Chapter I, Appendix B.

(b)(1)

[redacted]

(U) For subsequent test sequences where it was desired to eliminate the variation due to booster reliability while other variations were being investigated, either one of the two base case runs providing the lower percentages of penetration and damage expectancy was used.

(b)(1)

[redacted]

[2](U) The objective attack employed in all runs is described in Table B-2 of Appendix B, Chapter II, Section A; its derivation is discussed in the second paragraph of Section C2 above.

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

(b)(1)

(b)(1)

(b)(1)

(b)(1) [redacted]

E. OBSERVATIONS ON FURTHER USE OF THE SIMULATION MODEL

(U) This section presents further observations on certain features of the preceding results, and a brief discussion of the possible usefulness of additional features or modifications of IDA-BAGATEL.

1. Atmospheric Heave Effects on Blackout

(U) The blackout screens produced by both forerunners and precursors were the result of "waves" of individual bursts spaced within a time interval short compared to the 5 minutes separating the waves. The blackout model sums the individual burst attenuation effects as though there were no influence of one burst on another. One possibly serious deficiency of this assumption arises from the effects of "heave" - the term used to describe the atmospheric disturbance following a burst which leads to changes in the density-altitude profile.[1]

(U) It seems likely that for bursts below 200 km such changes would take place too slowly to affect the first wave, and that the largest changes would be over by the time of the following wave, even if they were large enough to be significant. For waves of bursts above 250 km, heave is more important, but its effects upon engagement results are difficult to predict. However, such effects would be due primarily to changes in the sizes and rise and expansion rates of the debris fireball due to the changed density, and these factors were investigated in Runs 5C and D (Table B-1, Appendix B) for low-altitude bursts, and

(b)(1) [redacted]

Run 5E for high-altitude bursts. The limits chosen there had little effect on engagement results, especially at the high altitudes, where heave is most significant.

(U) Heave effects are being studied[1] in connection with DASA's development of RANC IV (successor to RANC IIIA). Based on the results of such studies, calculations of density profiles appropriate to high-altitude precursor patterns might be made. Such profiles could be used in IDA-BAGATEL, and might allow upper bounds to be determined for engagement effects. Time was not available for such investigations.

2. Improved Forerunner-Precursor Tactics

(U) Little effort was devoted in this study to "optimizing" either forerunner or (particularly) precursor attacks. Of course both types of attack could be more efficient if the 0.75 forerunner or precursor booster reliability could be increased, either directly, or by detection and replacement of failures.

(U) With the coordination assumed attainable between NOR, ATL, and MED subs, more advantageous allocations of forerunners and objectives from these three attack areas should be achievable by further adjustment to the tendency of forerunners to be more effective from the south and objectives from the north (Appendix B, Chapter II, Section D). Perhaps this asymmetric effect of forerunners might be more efficiently dealt with by combining favorable forerunners with the more advantageous placement possibilities of precursors. In either case (and perhaps especially in the former case) low-angle trajectories would appear to give considerable improvement (Appendix B, Chapter II, Section M). Present results suggest the possibility

[1](U) As are other effects pertinent to multiple bursts.

of further improvements in both forerunner and precursor timing and patterns (Appendix B: Chapter II, Section M, last paragraph, and Chapter III, Section A, footnote 1). Offsetting such improvements are the effects of possible poor attack coordination (somewhat akin to booster reliability effects), which could also be investigated (Section D3 above).

(b)(1)

[redacted]

(U) In view of the number of runs which could be required for further optimization of tactics with the deployment assumed in this study, and the possible dependence of such detailed results on unique features of that deployment, it would seem more desirable for further exploratory studies to first consider the newer deployment, or (Section 3 below) the inclusion of MINUTEMAN, or (Section 4 below) the effects of some defense degradations other than blackout.

---

[1](U) This could be true despite the results of Run 12A.

(b)(1)

b. With Chaff Option

(U) The chaff options of MINUTEMAN MIRV are of considerable interest from an operational standpoint, and would provide a good illustration of how IDA-BAGATEL could handle pen aids. How successful the chaff would be in obscuring the RV positions from particular radar types would be determined outside IDA BAGATEL from analysis based on test and simulation results.[1] IDA BAGATEL could then use the analysis results to show the effect of reasonable assumptions as to defense doctrine on the results of selected attacks. Here again there are three possible approaches: (1) IDA-BAGATEL as it now exists could be used to investigate the effects of chaff on "pure" blackout attacks, (2) it could be used to investigate such attacks including other degradations (mainly interceptor reliability), (3) additional modifications could be incorporated (mainly miss distance, as described in section 4 below) to include other defense degradations (and capabilities) for more realistic results.

4. Further Model Modifications

(U) Attacks relying primarily on blackout, even if aided by other defense degradations, would still have to stretch out (in time) the forerunner or precursor waves which must be sacrificed to obscure objective RVs. Thus, adding other degradations to a blackout attack may not greatly reduce the number of RVs exacted by the defense unless such degradations could have done so without blackout. The stretch-out in time required in the blackout attack may not be compatible with best utilization of other degradations suitable to defense-suppression. Conceivably such degradations might

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[1](U) These are available, but would have to be collected, and then evaluated for the different radar types in question.

be sufficient to make concurrent, maximum-rate launching of defense-suppression and objective attacks more efficient than the timed, sequential launchings necessary for the "pure" blackout attack, thus making attack coordination problems less critical. For such reasons, even aside from the danger that blackout attacks might be made ineffective or uncertain by improved radars, clean interceptors, selectable yields, etc., attacks designed to take advantage of degradations other than blackout should be investigated.

(U) Modifications of IDA-BAGATEL to include a miss distance controlled by pertinent features of the intercept (such as signal-to-noise, track and prediction time, interceptor guidance, etc.) would complement the interceptor-reliability and variable-track-time modifications already included, and would allow the introduction of some of the degradations of Table 1, Section B above. Such modifications would incorporate the "late-look" by radars required for the defense to make use of exoatmospheric interceptor guidance.[1]

(U) As in the use of IDA-BAGATEL with chaff, basic input parameters for the miss-distance feature would be determined outside IDA-BAGATEL, and therefore could represent either technical state-of-art or intelligence values. With this method of procedure, blackout calculations would probably remain the pacing item in computer run time. Although an attack (such as a simultaneous defense-suppression and objective attack) not requiring prior sustained blackout from forerunners or precursors would have a heavy blackout-calculation load only toward the latter part of the attack, the time-saving short-cut

(b)(1) [redacted]

employed in all the runs of Table B-1, Appendix B (except Run 7A)[1] would no longer be valid. In addition, the Monte Carlo aspects of the miss-distance feature (as well as the interceptor-reliability feature) might require several runs to establish variability. Thus, if blackout is to be retained in combination with other defense degradations, it appears that it would be desirable to reduce the computer time devoted to blackout calculations and/or to develop other appropriate time-saving features.

---

[1](U) This short-cut consisted essentially of sampling objective RVs (see Appendix B, Chapter II, Section A, second paragraph). Run 7A confirmed its validity (and that of a 20-second instead of 10-second time step) for attacks relying on a blackout screen (forerunner or precursor) for objective RVs.

APPENDIX A

SOVIET ABM SYSTEMS AND DEPLOYMENT

APPENDIX A

I. INTRODUCTION

(b)(1)

[redacted]

(b)(1)

(b)(1)

(b)(1)

(b)(1)
[redacted]

(U) Some of the basic characteristics of the Moscow system radars are listed in Table A-1. Estimated GALOSH missile characteristics appear in Table A-2 and Fig. A-1.

Table A-1 (SNF) CHARACTERISTICS OF SOVIET ABM RADARS[a] (U)

(b)(1)
[redacted]

Table A-2 (SRDNF). ESTIMATED GALOSH INTERCEPTOR CHARACTERISTICS (S)

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

[redacted]

(b)(1)

(b)(1)

[redacted]

(b)(1)

(b)(1)

(b)(1)

(b)(1)

(b)(1)

APPENDIX A

SOVIET ABM SYSTEMS AND DEPLOYMENT

APPENDIX A

I. INTRODUCTION

(U) Results of the most significant computer runs made during the simulation studies are tabulated in Table B-1. Three elements may be distinguished among the attacks of Table B-1 as follows:

(b)(1)

[redacted]

Table B-1 ~~(S)~~. RESULTS OF REPRESENTATIVE COMPUTER RUNS (U)

(b)(1)

[redacted]

(b)(1)

(b)(1)

(b)(1) [redacted]

B. ESTABLISHMENT OF AVERAGE INTERCEPT ALTITUDE MOST ADVANTAGEOUS TO DEFENSE

(U) To determine if there is an intercept altitude most favorable to the defense, the attack resulting from the RV selection in Run 1C was chosen (to avoid variability due to booster reliability) and repeated in Runs 2A-D using different preferred intercept altitudes for the defense. These results, plus those of similar Runs 2 E-I based on the RV selection of Run 1B,[2] are shown in Fig. B-1.

(b)(1) [redacted]

[1] (U) In no run did acquisition of intercepted RVs take place after the arrival of the last wave.

[2] (U) The runs for the new preferred intercept altitudes based on the 1B attack were made after the incorporation of variable tracking time and blackout model improvements in IDA-BAGATEL (see Run 6A, Section F below).

(b)(1) [redacted]

(b)(1)

(b)(1)

[redacted]

[redacted]

[redacted]

(U) In the first row and column of the above matrix, the anomaly of 1 being less than 9 and much less than 41 can be explained by reference to a map and/or construction of appropriate diagrams (as in Fig. B-2 of Section E below) to show that the β patches from ATL drift into the NOR line-of-sight. Run 4D indicates that 14 forerunner RVs from the two preferable directions (ATL and MED) are as good or better than 15 from all three directions (Run 1C), although this argument is weakened by the fact that only one of the three successful boosters (out of seven) from MED in 1C went to Moscow. Comparison of Runs 1C and 4E indicates further that additional RVs from the least preferred direction (NOR) can make an appreciable difference.[1] The complications introduced by nonlinear effects of numbers of RVs, and temporal and geometric aspects of the situation, are further illustrated in Run 5B (Section E) below.

E. VARIATION OF BLACKOUT PARAMETERS

(b)(1)

[redacted]

(b)(1)

(b)(1)

F. VERIFICATION OF MODIFIED BLACKOUT MODEL AND VARIABLE TRACK TIME

(U) Base case Run 1C was repeated as Run 6A after the incorporation of (1) minor improvements in the blackout model which were not expected to alter results appreciably, and (2) a variable (instead of fixed) tracking time (T_2-T_1) whose roughly two orders-of-magnitude variation from maximum to minimum ranges was not expected to be significant since saturation and/or miss-distance were not taken into account. Results are seen to be identical except for one more penetration from ATL.

G. VERIFICATION OF APPROXIMATIONS USED TO CONSERVE COMPUTER TIME

(b)(1)

[redacted]

H. RELATIVE CONTRIBUTION OF β-PATCH AND FIREBALL ABSORPTION

(U) Base case Run 1C, low-intercept-altitude Run 2I and high-altitude intercept Run 13E were repeated with 0 (actually 1 ton) fission yield, thus removing the source of β-patch absorption. In all three cases the radars experienced very little blackout, and the defenses had no trouble making all intercepts, indicating that β-patch absorption was the only effective mechanism, and that fireball absorption and X-ray flash had negligible effect on results.

(b)(1)

(b)(1)

(b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

[redacted]

(b)(1)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

WSEG REPORT 148

STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

VOLUME VIII

Enclosure H: ABM Defense Employment, Engagement and Penetration

August 1969

Including
IDA REPORT R-160

A. R. Barbeau, *Project Leader*

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REPORT R-160

STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

A. R. Barbeau, *Project Leader*

VOLUME VIII

Enclosure H: ABM Defense Employment, Engagement and Penetration

T. E. Sterne
J. A. Ross

August 1969

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in response to the Weapons Systems Evaluation Group Task Order SD-DAHC15 67 C 0012-T-140, dated 21 December 1967.

In the work under this Task Order, the Institute has been assisted by military personnel assigned by WSEG.

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FOREWORD

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in conjunction with the Weapons Systems Evaluation Group. The research and analysis that form the basis for this report were carried out by a project staff under the general leadership of A. R. Barbeau. The members of the project staff are listed below:

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TABLE OF ORGANIZATION

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SUMMARY PAPER - Strategic Offensive Weapons Employment in the Time Period About 1975
Author: A. R. Barbeau with Project Staff

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Author: M. E. Miller

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Authors: J. L. Freeh, P. Gould, E. Ratigan

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Authors: J. H. Daniel, J. G. Healy, J. A. Ross, M. G. Degnen

VOLUME VIII

ENCLOSURE H - ABM Defense Employment, Engagement and Penetration
Authors: T. E. Sterne, J. A. Ross

VOLUME IX

ENCLOSURE I - (b)(1) [redacted]
Authors: D. N. Beatty, E. Marcuse

VOLUME X

ENCLOSURE J - Nuclear Weapons Effects on Strategic Missile Systems
Authors: H. A. Knapp, J. A. Ross, D. H. Williams

CONTENTS

CONTENTS (Cont'd)

I. SUMMARY

A. THE OBJECTIVES

(U) The studies described in this volume relate to the employment of area ABM defenses, and of their engagement and penetration by reentry vehicles. The general purpose of the studies is to find effective methods for attacking area-defended targets; whether by a simple "objective" attack (an attack on the targets) that penetrates the defense by exhaustion and leakage, or by a "defense-suppression" attack (an attack on the defenses) followed by an objective attack through such defenses as may remain. A more specific purpose has been the finding of effective allocations of reentry vehicles in objective attacks on (b)(1) targets in the (b)(1) (b)(1) area-ABM-defended region, and the estimation of the offense-enforceable damage that may be expected from such attacks generally, in terms of the number of reentry vehicles available for the attack and the number of interceptors available for the defense. Another specific purpose has been to examine the merits of defense-suppression attacks under certain conditions, and to find the proportion of its force that the offense should allocate to defense suppression under such conditions in order to cause the expected (b)(1) damage to be as high as possible.

B. REALISM

(U) A high degree of realism has been sought. The interceptors are imperfect, with single-shot kill probabilities, $\underline{k}$, that are less than unity. The reentry vehicles (called "attackers") have limited yields such that each successive penetration destroys some fraction, alpha (which may vary from target to target), that is less than unity of a target's remaining value. The targets have unequal values. The offense has no intelligence of the defender's doctrines or of his planned allocations of interceptors, while the defender has no intelligence of how strong the attack on any particular target is to be, and is not sure during the attack whether or not he has seen the last of it. The offense is supposed to have only a rough knowledge of the number of area interceptors, and the defense to have only a rough knowledge of the total number of attackers available for allocation to targets in the defended area. The defense is supposed to know which target is threatened by each incoming attacker. This assumption really defines what is meant by "target", and makes the definition depend upon the accuracy with which the defender can predict the burst position of an unintercepted attacker. In the application that is made in this volume, the "targets" are taken to be (b)(1)

(U) A limitation of the analyses in this volume is that all the attackers are presumed to have the same yields. If a uniform proportion of the attackers are decoys, however, the analyses are applicable provided that appropriate decreases are made in the alphas of the targets.

C. THE STUDIES

(U) The studies have been of two types: basic and applied. The basic studies (contained in Chapters II through VI) have been aimed at acquiring general understanding, at finding simple formulas for estimating the expected damage from particular offensive and defensive allocations, and at developing general methods for determining optimal allocations of attackers and area interceptors in objective attacks. Chapter VII applies the methods and results of earlier chapters to possible objective attacks on (b)(1) targets in the (b)(1) (b)(1) area-ABM-defended region. Chapter VIII does the same thing, but includes defense suppression, under somewhat more restricted conditions.

(U) No previously developed theoretical model or simulation was found, for the attack of area-defended targets, that appeared to be sound and to include all (or even nearly all) of the desired realistic features. A suitable model therefore had to be developed. The development started with the consideration of equally-valued targets.

D. EQUALLY VALUED TARGETS

(U) A very thorough analysis was made, using the concepts of the theory of games, of the attack of a collection of equally valued targets, whose number was not specified, by an average number W of attackers per target when there was available an average of I area interceptors per target. To any pair of offensive and defensive allocations, there corresponds some expected fractional damage ϕ. It is known from game theory that there must exist optimal offensive and defensive allocations such that the optimal offensive allocation leads to an expected damage equal at least to ϕ^*, whatever the defensive allocation may be, and such that the optimal defensive allocation leads to an expected damage equal at most to the same ϕ^* whatever the offensive allocation may be. Thus the achievement of the expected damage ϕ^* is offense enforceable by the offense's making the optimal attack; then the best that the defense can do is to hold the damage to the value ϕ^* by using the optimal defense, otherwise the offense may achieve a higher fractional damage than ϕ^*.

(U) All possible attacks were considered that involved an average of W attackers per target. One attack consisted of the assignment of exactly W attackers to each target. The others involved the assignment of varying numbers of attackers to the various targets. The defenses that were considered included what may be called stochastic preferential defenses, in which varying numbers of interceptors were assigned to different targets in accordance with fixed probabilities. The defenses also included random defenses, in which the defender assigned interceptors to attackers regardless of the targets that they threatened. The defenses included a type in which the defender selected randomly, but in calculated proportions, some targets to abandon. Those not abandoned were defended by intercepting each of their attackers with some calculated number $\underline{n}$ of interceptors. Finally, the defenses included a type, closely related to the last-mentioned, in which the defender selected randomly some of the targets to defend through interception of each attacker with $\underline{n}$ interceptors, the other targets being defended with n+1.

(U) The optimal defense was found to be one or the other of the two types last mentioned, which can be called, respectively, the "n-to-one" defense and the "n-plus-one-to-one" defense. Which type, and the value of $\underline{n}$, the defender should employ depends on the values of W, I, α, and $\underline{k}$. The optimal attack was found to be the simple attack that assigns exactly W attackers to each target. The analysis appears in Chapter V.

(U) Although the equations describing the optimal engagements (and the demonstrations of their optimal character) that appear in Chapter V turned out to be relatively and unexpectedly simple, the simple results were obtained only after several false starts, one of which led to a prolonged analysis of stochastic preferential defenses. The simple demonstration that was finally found (and that appears in Chapter V), that such defenses are always dominated by n-to-one or n-plus-one-to-one defenses, showed the prolonged analysis never to have been necessary.

E. UNEQUALLY VALUED TARGETS

(U) Since the number of targets in the collection of equally valued targets has not been specified, it can be taken to be unity. The results of Chapter V thus showed that the best attack of a single target (which can be taken to be any target in a collection of unequally valued targets) is to assign some definite number, W, of attackers to it; but that the best defense is to draw lots, based on a calculated probability, to decide whether to defend it or not. If the outcome of the drawing of lots is that the target is to be defended, then the defense intercepts each of the target's attackers with some calculated number n of interceptors. Under special conditions, the target is defended in any case and the drawing of lots, instead, determines whether to defend it by intercepting each of its attackers with n or with n+1 interceptors. Thus the optimal attack of the target is non-stochastic but the optimal defense, involving a number of interceptors whose statistically expected value is I before the drawing of lots, involves either no interceptors or a number of interceptors according to the outcome of the drawing, and is thus of a stochastic nature.

(U) The numbers W and I are not determined by any of the preceding considerations. Their determination is discussed in Chapters IV and VI, for all the targets in the collection of unequally valued targets defended by the area defense. Any particular optimal engagement (consisting of an optimal attack and an optimal defense) of this whole collection of targets is characterized by two parameters, μ and λ, that are constant for all the targets. The parameter μ is intuitively identified as the value destroyed by the last attacker of any target, and the parameter λ as the value saved by the last interceptor employed in any target's defense. Methods are developed in Chapters IV and VI for finding the W and I of each target from the parameters μ and λ and from its value, its α, and from k.

F. OPTIMAL ATTACKS OF TARGETS IN THE (b)(1) [redacted] DEFENDED AREA, WITHOUT DEFENSE SUPPRESSION

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

(U) The theoretical analyses were completed too late in the year to permit their practical application to be programmed on fast computers. Instead, the application had to be made by the use of a desk calculator, assisted by approximations and by time-saving short-cuts that included the use of graphical procedures. The details are described in Chapter VII. Some twenty-five different optimal engagements were evaluated, corresponding to 27 pairs of values of μ and λ (two did not furnish new engagements). From the evaluated engagements, the results were obtained that are shown in Figs. 1 and 2. The curves indicate the overall expected fractional damage from A attackers when there are D area interceptors. Since the fractional damage is optimal, it is offense-enforceable.

(U) The same curves, in Figs. 1 and 2, may be used to obtain closely approximate values of the offense-enforceable fractional damage when the D area interceptors have a single-shot kill probability, $\underline{k}$, that differs from 0.75. The general rule for such use, given in Chapter VII, takes the simple form when $\underline{k}$ = 1/2 that the diagrams should be entered with arguments A and D/2, and when $\underline{k}$ = 15/16 that the diagrams should be entered with arguments A and 2D.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1)

(b)(1)

(U) The engagements involved suppression attacks on either radars or interceptor farms, followed by objective attacks on the (b)(1 targets through the remaining defenses. The defense was in all cases optimized to cause the expected (b)(1 damage to be as small as possible; the offense to cause it to be as large as possible. This involved varying the number of attackers assigned to the defense-suppression phase. The analyses were carried out for each of three values of the single-shot kill probability, k, of an interceptor: 1/2, 3/4, and 15/16. In all cases the expected fractional (b)(1) damage was obtained from the diagrams in Figures 1 and 2, based on Chapter VII, the diagrams being entered with numbers of attackers and usable interceptors remaining after the suppression attacks. The results are shown in Figures 3 and 4, taken from Chapter VIII.

(b)(1)

(b)(1)

(b)(1)

(b)(1)

II. INTRODUCTION

A. THE OBJECTIVES

(U) The studies to be described in this volume will relate to the employment of area ABM defenses, and of their engagement and penetration by reentry vehicles. The general purpose of the studies is to find effective methods for attacking area-defended targets; whether by a simple "objective" attack (an attack on the targets) that penetrates the defense by exhaustion and leakage, or by a "defense-suppression" attack (an attack on the defenses) followed by an objective attack through such defenses as may remain. A more specific purpose is the finding of effective allocations of reentry vehicles in objective attacks on (b)(1) targets in the (b)(1) area-ABM-defended region, and the estimation of the offense-enforceable damage that may be expected from such attacks generally, in terms of the number of reentry vehicles available for the attack and the number of interceptors available for the defense. Another specific purpose is to examine the merits of defense-suppression attacks under certain conditions, and to find the proportion of its force that the offense should allocate to defense suppression under such conditions in order to cause the expected (b)(1 damage to be as high as possible.

B. THE DESIRED DEGREE OF REALISM

(U) A high degree of realism is sought. The interceptors will be imperfect, with single-shot kill probabilities, $\underline{k}$, that will be less than unity. The reentry vehicles (called "attackers") are to have limited yields such that each successive penetration destroys some fraction, α (which may vary from target to target), that is less than unity, of a target's remaining value. The targets are to have unequal values. The offense is to have no intelligence of the defender's doctrines or of his planned allocations of interceptors, while the defender is to have no intelligence of how strong the attack on any particular target is to be and will not be sure, during the attack, whether or not he has seen the last of it. The offense will be supposed to have only a rough knowledge of the number of area interceptors, and the defense to have only a rough knowledge of the total number of attackers available for assignment to targets in the defended area. The defense, however, will be supposed to know which target is threatened by each incoming attacker. This assumption really defines what is meant by "target," and makes the definition depend upon the accuracy with which the defender can predict the burst position of an unintercepted attacker. In the application that will be made in this volume, the "targets" will be taken to be cities.

(U) A limitation of the analyses to be given in this volume is that all the attackers are presumed to have the same yields. However, if a uniform proportion of the attackers are decoys, the analyses will be applicable provided that allowance is made for them by appropriate decreases in the alphas of the targets.

C. THE STUDIES

(U) No previously developed theoretical model or simulation was found, for the attack of area-defended targets, that appeared to be sound and to include all (or even nearly all) of the desired realistic features. A suitable model had, therefore, to be developed; and the development was started by considering equally valued targets, although the treatment of such targets was influenced by the desire to incorporate them eventually in a collection of unequally valued targets.

(U) Chapter III will describe the model of the overall engagement, whose optimization from the points of view of the offense and of the defense will be formally discussed in Chapter IV. A very thorough analysis will be given in Chapter V of the optimization of attacks and defenses of collections of equally valued targets. Chapter VI will show how the results of Chapter V may be incorporated in the more general analysis of the overall engagement in order to find optimal offensive and defensive allocations in an attack on a collection of unequally valued targets. In Chapter VII, a specific application will be made to attacks, without previous defense suppression, on the collection of (b)(1) targets in the (b)(1) area-ABM-defended region. Chapter VIII will consider the possible advantage to the offense, under certain conditions, of allocating some of its force to attack the area defenses before employing the remaining force to attack the same targets as in Chapter VII.

III. THE MODEL

(U) The entire collection of targets T_1, T_2,...T_N, with values V_1, V_2,...V_N, is considered that is protected by an area defense having at its disposal D area interceptors whose single-shot kill probabilities are k. It is assumed that the number D is known roughly by the offense. It is presumed that the defender, before launching an interceptor at any particular attacker (R/V), can determine which of the targets the attacker would endanger if not intercepted. This presumption in effect implies the meaning of the word "target" as it is used here and in later discussions. If the defender can predict only coarsely the unintercepted impact or burst locations, then the "targets" must be taken to be (b)(1) (b)(1) on the other hand, if the defender can predict more accurately then the "targets" must be taken to be (b)(1) (b)(1)

(U) The offense is considered to have at his disposal, for the attack of all the area-defended targets, a number A of attackers having equal yields, such that if an attacker is not successfully intercepted, it will produce an expected damage given by some fraction, α, of the remaining value of its target before the burst. The fraction α may vary from target to target. It is presumed that the defender has a rough idea of the value of A.

(U) The values V_1, V_2, etc. are here taken to be the values placed upon the targets by the offense, so that an optimal attack will lead to the optimal expected damage if the defense is optimized on the same value scale. If the defender optimizes the defense with a different value scale, the offense will cause even greater damage, if anything, as measured on the offense's value scale.

(U) Although each side is presumed to have a rough idea of the other side's total numbers D or A, the offense is presumed to have no knowledge of the defender's missile allocations among the various targets. The defense is presumed neither to have advance knowledge of the offense's planned allocations of attackers to the different targets, nor to be able to see the general attack as a whole. Thus during the general attack, the defender does not know whether or not the attacks on particular targets have ended.

(U) An attack on the whole collection of targets can be described by the numbers W_1, W_2,...W_N of attackers allocated by the offense to the various targets. A defense can be described by the number of interceptors I_1, I_2,...I_N allocated to the defense of the various targets, in case fixed allocations are decided upon; or by a classification of targets into those not to be defended, those to be defended with one interceptor per attacker, or two, or three, etc.; or by the specification of some tactic like the assignment of interceptors to a random selection of arriving attackers. It is desirable, however, to generalize the preceding concepts somewhat. Thus W_x may denote not the actual number of attackers assigned to the x'th target, but the mean of some population from which the actual number is to be randomly drawn; thus W_x may denote an expected value. Similarly, the defender may choose to defend each target in some group of targets with an expected number I of interceptors; but his actual defense may be (for instance) to assign no interceptors to 2/3 of such targets, randomly selected, and $3 \cdot I$ interceptors to each of the remaining targets in the group. Sometimes, therefore, I_x may denote an expected value. In any case the sum of the W's must be A, and that of the I's must be D.

IV. OPTIMIZATION OF THE OVERALL ENGAGEMENT

(U) The conditions for the optimization of the overall engagement are easily formulated if the expected damage to the x'th target is expressed in the form $V_x \emptyset_x$ where $\emptyset_x$, the expected fractional damage to the x'th target, is a function

$$\emptyset_x = \emptyset(W_x, I_x, \alpha_x, \underline{k})$$

of $\underline{k}$ and of the W, I, and α of the x'th target.

(U) The total expected damage from the attack is the sum

$$DE = \sum_x V_x \emptyset_x \quad .$$

For the sum to be a minimum with respect to variations of the I's, it is necessary that

$$\sum_x V_x(\partial \emptyset_x / \partial I_x) \delta I_x = 0 \tag{1}$$

for all small variations δI_x of the I's that satisfy (since the sum of the I_x's is D, a constant) the relation

$$\sum_x \delta I_x = 0 \ . \tag{2}$$

Equation (1) can hold, for all such variations, only if

$$-V_x(\partial \emptyset_x / \partial I_x) = \lambda \ , \tag{3}$$

a constant (the minus sign has been inserted to make λ positive).

(U) Similarly, for DE to be a maximum with respect to variations of the W's it is necessary that

$$\sum_x V_x(\partial \emptyset_x/\partial W_x) \ \delta W_x = 0$$

for all small variations δW_x of the W's that satisfy (since the sum of the W_x's is A, a constant) the relation

$$\sum_x \delta W_x = 0$$

so that

$$V_x(\partial \emptyset_x/\partial W_x) = \mu \ , \qquad (4)$$

another constant. Equations (3) and (4) are necessary conditions for the engagement to be optimal. Although they have not been proved rigorously to be sufficient to determine the optimal attack and defense, it seems intuitively clear that in general they should be expected to be sufficient. For once k and the α's and V's are specified, then specification of the values of λ and μ fixes, by equations (3) and (4), the partial derivatives with respect to W and I of all the $\emptyset_x$'s. But if α and k are fixed, as they are for any particular target, then $\emptyset_x$ is a function merely of the two variables W and I and can be represented by a two-argument table, of which examples will later be given. In such a table, a specification of the partial derivatives of the tabulated function generally serves to determine the two unknown arguments W and I. Thus specification of the λ and μ should be expected to determine the W_x's and I_x's and thus their respective sums. These sums will not in general equal A and D, respectively, as they should, unless λ and μ have their correct values, and so one intuitively expects that equations (3) and (4) suffice to determine the optimal engagement.

(U) In a trial with a very small collection of three targets, having widely different values, little difficulty was found in closely satisfying the A and D constraints by varying the W and I of the most important of the three targets. Although it turned out that for fixed W the partial derivative of Ø with respect to I was in some instances independent of I for limited ranges of values of I, this merely caused the total DE to be nearly completely independent of some sets of changes δI. In fact, the solution involved a DE that was exceedingly insensitive to variations δW and δI that corresponded to some very generous subsequent trial reassignments of attackers and interceptors among the three targets.

(U) Thought should be given to the propriety of regarding the W's and I's as continuous variables rather than integers in the preceding equations. If the W's and I's have to be actual rather than expected values they would have to be integers, but it will turn out that the I's in general are expected values, which need not be integers in principle. Because the W's, however, will be integers the partial derivatives in the equations should rightly be replaced by finite differences; but trials with numerical examples soon convince one that the effect of such replacement is usually trivial. Actually, the "derivatives" are often most readily found by formulas of finite differences, and by taking I and W to be integers. The mathematical distinctions between derivatives and finite differences appear likely to be of little practical importance.

(U) It is necessary next to determine the form of the function Ø(W, I, α, $\underline{k}$) and this requires one to study the optimization of attacks and defenses of targets all of which have the same values and the same α's.

V. THE ATTACK AND DEFENSE OF EQUALLY VALUED TARGETS. OPTIMIZATION OF TACTICS

A. THE MODEL

(U) One considers a collection of equally valued targets, defended by an area defense which has at its disposal a number of interceptors equal to I times the number of targets, so that the average number of interceptors per target is I. The targets are attacked by a number of attackers equal to W times the number of targets, so that the average number of attackers per target is W. It is assumed that each attacker that is not successfully intercepted by the defense causes an expected damage to its target equal to a constant α times the expected value of the target prior to the penetration. The value of an undamaged target is taken to be unity. If an attacker is intercepted by a single interceptor, the probability that the interception will be successful is taken to be k. The offense is supposed to know I, and the defense to know W, at least roughly.

B. UNIFORM ATTACKS, VARIOUS DEFENSES

(U) For the present, uniform attacks are considered in which each target is attacked by W attackers; other attacks will be considered later, when uniform attacks will be found to be the best attacks.

1. When $I \leq W$, consider first a purely random defense in which a fraction $I/W = x$ of the attackers are intercepted without regard to which targets they are attacking. The probability that an attacker will be intercepted is x; that it will be successfully intercepted is xk; that it will penetrate the defense is 1-xk. The expected damage done to a target by its

first attacker is thus $\alpha(1-xk)$ and the expected remaining value is $1 - \alpha(1-xk)$. Each successive attacker multiplies the remaining value by the preceding quantity, so the expected damage per target is

$$\emptyset = 1 - \left[1 - \alpha(1-xk)\right]^W ,$$

which can be written in the alternative form

$$\emptyset = 1 - \left[(1-x)a + x\ a_1\right]^W , \qquad (5)$$

where $a = 1 - \alpha$ and $a_1 = 1 - \alpha p$ in which p, the probability that an interceptor will be unsuccessful, has been written for 1-k. It will be noticed that a is the factor that multiplies the expected remaining value for each unintercepted attacker, and that a_1 is the factor multiplying the remaining value for each intercepted attacker. Equation (5) has been derived in a semi-intuitive fashion. It can be established rigorously, however, by noting that the probability that exactly s of the attackers of a target will not be intercepted, and that exactly W-s will be intercepted, is

$$(1-x)^s\ x^{W-s}\ \binom{W}{s}$$

and that in this event the expected damage is $1 - a^s\ a_1^{W-s}$. Multiplication of the two expressions together, followed by summation of the product over all s from zero through W, yields the right-hand member of equation (5), just as it has been written.

2. Consider next a defense in which a set of targets equal in number to the fraction 1-x of all the targets is randomly chosen and then left undefended, while all the attackers of the remaining targets, equaling in number the fraction x of all the targets, are intercepted with one interceptor each. The expected damage is then

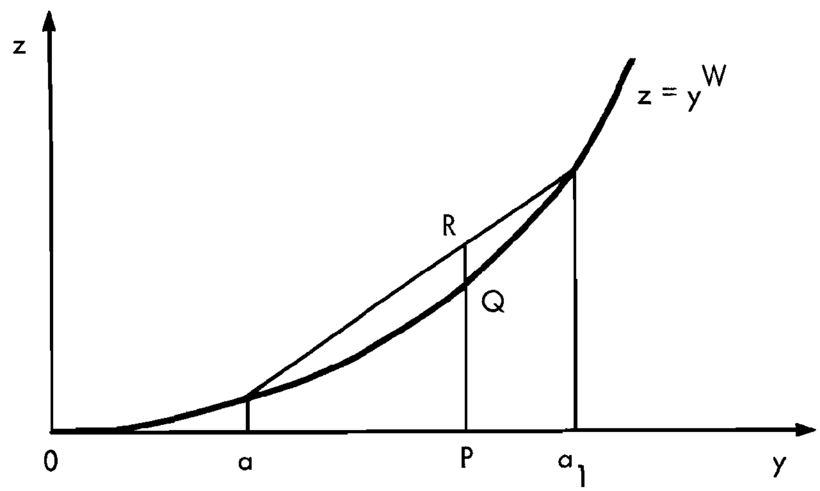
$$\emptyset = (1-x)(1-a^W) + x\ (1-a_1^W)$$

$$= 1 - \left[(1-x)a^W + x\ a_1^W\right] . \qquad (6)$$

Unless k = 0 (the case of completely worthless interceptors), a_1 is larger than a. Now the function y^W of y, plotted vertically upward against y plotted horizontally, is concave upward (its second derivative is positive) so long as W exceeds unity, which in practical cases it will usually or always do. Thus, as will be shown,

$$(1-x)a^W + x\, a_1{}^W > \left[(1-x)a + x\, a_1\right]^W ,$$

and hence the right-hand member of (6) is smaller than the right-hand member of (5). Thus the present defense is a better defense (its Ø being smaller) than the defense considered in paragraph 2a.



(U) The argument to justify the inequality is followed most easily when it is put into geometrical form. In the above diagram, the distance OP (which may be called a_2) equals $(1-x)a + xa_1$. Then the distance PR, which equals $(1-x)a^W + xa_1{}^W$, clearly exceeds the distance PQ, which equals $a_2{}^W$. This establishes the inequality.

3. If I > W, let n and n+1 be two consecutive integers that bracket I/W

$$n \leq I/W < n+1$$

and denote (I/W) -n by x. Then it is better for the defense to intercept all the attackers of a fraction x of the targets with n+1 interceptors each, and all the attackers of the remaining fraction 1-x of the targets with n interceptors each, than to intercept without regard to their targets a fraction x of all attackers with n+1 interceptors each and a fraction 1-x of all attackers with n interceptors each. For the latter defense leads to an expected damage

$$\emptyset = 1 - \left[(1-x)a_n + x\ a_{n+1}\right]^W$$

while the former leads to an expected damage

$$\emptyset = 1 - \left[(1-x)a_n{}^W + x\ a_{n+1}{}^W\right] \qquad (7)$$

where

$$a_n = 1 - \alpha p^n$$
$$a_{n+1} = 1 - \alpha p^{n+1}$$

and equation (7) gives the smaller damage because of the positive curvature of the function y^W of y. The quantity a_n will be recognized as the factor by which the expected remaining value of a target is multiplied, when its attacker encounters n interceptors.

4. It thus appears that a purely random defense, that assigns interceptors to attackers in a manner that ignores the identity of the targets that are being attacked, is always inferior either to (1) a defense that elects to abandon a fraction of the targets and to intercept all the attackers of the remaining targets with one (or possibly more) interceptor each, or to (2) a defense that elects to defend a fraction of the targets by intercepting all of their attackers with n interceptors each and to defend the remaining targets by intercepting all of their attackers with n+1 interceptors each. The particular targets that constitute the preceding fractions should be selected by chance, to deny to the offense any ability

to improve his attack by guessing which targets the defense will favor, and also because there is no reason for a defensive preference when all the targets are equally valued and when the defense is ignorant of the offense's tactics.

5. If k is unity, the best defense is clearly to abandon 1-I/W of the targets and to defend the rest with one interceptor per attacker. The resulting $\emptyset$ is $(1 - \frac{I}{W})(1-a^W)$, which becomes zero if there are more interceptors than attackers. If $k < 1$, however, it may be better for the defense to engage attackers with more than one interceptor each. Consider a defense in which the fraction $1 - I/nW$ of all the targets is abandoned, and the remaining fraction I/nW of the targets is defended by intercepting all their attackers with n interceptors each. The expected damage per target is then

$$\begin{aligned} \emptyset &= (1 - I/nW)(1-a^W) + (I/nW)(1 - a_n^W) \\ &= 1 - a^W - (I/nW)(a_n^W - a^W) . \end{aligned} \qquad (8)$$

The expected damage is least when the quantity j_n/n, regarded as a function of n, is greatest where

$$j_n = a_n^W - a^W .$$

The value n^* of n that maximizes j_n/n and thus minimizes $\emptyset$ is a function of W, α, and k and can be found readily by trial in any particular case. The quantity j_n/nW can be intuitively interpreted in the light of equation (8) as the value saved per interceptor (and per target) since $1 - a^W$ is the expected damage when there is no defense. This defense, with $n = n^*$, is possible when $I \leq n^* W$ and can be called the "n-to-one" defense, or the "one-to-one" defense in case n^* is unity.

(U) When $I > n^* W$, the best defense of the preceding type against a uniform attack is, clearly, to allocate n interceptors to each attacker of a randomly selected fraction 1-x of the targets and n+1 interceptors to each attacker of the remaining fraction x of the targets where $x = (I/W) - n$, and where n is the largest integer equal to or less than I/W:

$$n \le I/W < n+1 \ .$$

Then

$$\phi = (1-x)(1 - a_n{}^W) + x(1 - a_{n+1}{}^W)$$

$$= 1 - a^W - (1-x)j_n - x\, j_{n+1} \ . \qquad (9)$$

This defense may be called the "n-plus-one-to-one" defense and it, or the preceding one (according to whether I does or does not exceed n* W) will be shown later to be actually the optimal defense, and the uniform attack the optimal attack. The demonstration, however, must involve other types of defenses and attacks.

C. INTERACTION OF OFFENSIVE AND DEFENSIVE TACTICS. OPTIMAL TACTICS

(U) Some general features of the interaction of offensive and defensive tactics are now noted.

1. Only uniform attacks have so far been considered. However, the offense may elect to make a non-uniform attack, in which he assigns a number y of attackers to each of a fraction A(y) of the targets. The A(y)'s can have any values, except that the sum of the A's over all y's must be unity, and the sum of yA(y) over all y's must be W because the average number of attackers per target is W. The targets constituting the various fractions A(y) are presumed to be randomly selected, since the targets all have equal values and α's, since the offense does not know how the defense will respond, and because there is no reason for the offense to prefer one target to another. This type of attack may be called a "stochastic" attack, of which the uniform attack may be thought of as a special type in which the only non-zero A(y) is A(W). Although the y's must be integers, W need not be an integer. For simplicity, however,

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W is here supposed to be an integer. It is found that when W is not an integer no significant changes, but only some complexity, are introduced.

(U) To simplify consideration of the offense's numerous alternatives, the function A(y) may be regarded as a mixture (a linear combination with non-negative coefficients whose sum is unity) of simpler constituent offensive tactics of which one is the uniform attack A(W) = 1, and the others are all of the form $A(y_1) = (y_2-W)/(y_2-y_1)$ and $A(y_2) = (W-y_1)/(y_2-y_1)$, the other A's all being zero. Here y_1 is zero or any positive integer less than W, and y_2 any integer greater than W. Each of these constituent tactics is a possible attack (the sum of its A's being unity, and the mean of its y's being W), and it is easy to show that any possible attack must be some mixture of the preceding attacks. As an example, the attack for which A(W-1), A(W), and A(W+1) all equal one-third can be obtained by combining one-third of the uniform attack A(W) = 1 with two-thirds of the constituent attack in which y_1 = W-1 and y_2 = W+1.

2. To any attack, and to any defense, there corresponds some value Ø of the expected damage. The values of Ø may be supposed to be arranged in the form of a table (the "game matrix"), whose rows correspond to the various possible defenses. The top row of the table is here chosen for ease of reference to correspond to the uniform attack A(W) = 1, and the right-hand column is chosen to correspond to the defense that has been said in paragraph B5 to be optimal. For definiteness it is here supposed that $I \leq n^* W$ so that the right-hand column corresponds to an n-to-one defense. The order of the other rows and columns is immaterial.

In each row of such a table, there is some smallest value of Ø. Among the rows, there are one or more rows for which this smallest value is largest; denote this largest value by $Ø_1$. An attack corresponding to the row (or, if there is more than one such row, to any of the rows) whose smallest $\emptyset$ is $\emptyset_1$ is certain to cause an expected damage equal at least to $\emptyset_1$, whatever defense is chosen. In the same way, in each column of such a table there is some largest value of $\emptyset$.

	Defense No. 1	Defense No. 2			Defense No. j (= n-to-one defense)
Uniform attack (1)	$\emptyset_{11}$	$\emptyset_{12}$	. . . . .		$\emptyset_{1j}$
Attack No. 2	$\emptyset_{21}$	$\emptyset_{22}$	. . . . .		$\emptyset_{2j}$
Attack No. 3	$\emptyset_{31}$	$\emptyset_{32}$	. . . . .		$\emptyset_{3j}$
.	.	.	. . . . .	.	.
.	.	.	. . . . .	.	.
.	.	.	. . . . .	.	.

Among the columns, there are one or more columns for which this largest value is smallest; denote this smallest value by $\emptyset_2$. A defense corresponding to the column (or to any of the columns) whose largest $\emptyset$ to $\emptyset_2$ is certain to lead to an expected damage no greater than $\emptyset_2$. It is always true that $\emptyset_1 \leq \emptyset_2$, but it need not be true that $\emptyset_1 = \emptyset_2$. Should it be true that $\emptyset_1 = \emptyset_2 = \emptyset^*$, say, then an intersection of a $\emptyset^*$ row with a $\emptyset^*$ column is called a "saddle point" of the game-matrix. The corresponding attack is an optimal attack, and the corresponding defense is an optimal defense. An optimal attack causes the expected damage to be at least $\emptyset^*$ while an optimal defense causes the expected damage to be at most $\emptyset^*$.

(U) It will be shown that the present table has in fact a saddle-point at the intersection of the top, uniform attack, row with the right-hand, n-to-one defense, column.[1] The demonstration will consist of showing that there is no Ø in the top row that is smaller than the Ø denoted by Ø* (given by equation 8), of its most right-hand element; and that there is no Ø in the right-hand column that is larger than Ø*. For then no other row can have a minimum Ø larger than Ø* (if it did, some element in the right-hand column would have to exceed Ø*), and no other column can have a maximum Ø smaller than Ø* (if it did, some element in the top row would have to be smaller than Ø*). Thus the most right-hand element Ø* of the top row must be both the largest of all row minima and the smallest of all column maxima, and must be a saddle-point.

3. It must be shown that against a uniform attack, no defense gives a smaller Ø than the n-to-one defense when $I \leq n^* W$. It has already been shown that a random defense that ignores the identity of the targets of attackers yields a Ø that is larger than Ø*. Another type of defense with which the n-to-one defense must be compared is one that may be called a "stochastic preferential" defense, which can take various forms all of which, however, involve the assignment of _x_ interceptors to each of a fraction D(x) of the targets in such a way that the sum of the D's is unity and the sum of xD(x) is I. It is clear that against the uniform attack, no such defense can compete with the n-to-one defense unless it assigns interceptors n* at a time to each attacker of a defended target; otherwise

[1]Had there been no saddle-point, a fundamental theorem (believed to have been first proved by von Neumann and Morganstern) asserts that there would nevertheless exist a new row, consisting of some mixture of the constituent attacks, and a new column, consisting of some mixture of the various defenses, that would intersect at a saddle-point.

a stochastic preferential defense will save less value per interceptor than the n-to-one defense and yield a larger Ø than Ø*. The best the stochastic preferential defense can hope to do is to take D(0) = 1 - I/n*W, and D(n*W) = I/n*W, with all other D's equal to zero. It then yields a Ø just equal to Ø*, against a uniform attack. For all the possible defenses, therefore, of which the writer has been able to conceive, none furnishes a smaller Ø than Ø*. To establish the important result that the uniform attack and n-to-one defense correspond to a saddle-point in the game matrix and are optimal, it now remains only to show that the constituent non-uniform attacks described in paragraph 3a lead to an expected damage, against the n-to-one defense, that is not larger than Ø*.

4. Before considering the n-to-one defense against non-uniform attacks, it should perhaps be indicated why stochastic preferential defenses, which it has been shown can be as effective as the n-to-one defense against uniform attacks, are not to be further considered. The reason is that they were suddenly found (late in March, 1969) in the midst of extensive studies (the defenses are much more difficult to optimize than n-to-one defenses) to be considerably inferior to n-to-one defenses against non-uniform attacks. Before this was discovered, most of the time in the present study had been devoted to them. The relative ineffectiveness of the stochastic preferential defenses arises from their allocations of interceptors to targets rather than to attackers. If n*W interceptors are allocated to a particular target in the group of targets that is to be defended by the stochastic preferential defense, and if fewer than W attackers should be assigned to that target by the offense, then some interceptors will be wasted by never being used. On the other hand, if more than W attackers should be assigned to that target by the offense, then the defense will run out of interceptors for that target before the attack is over and although some value will be saved, the value saved

per interceptor will be less than it would be if each attacker were to encounter n* interceptors. The n-to-one defense, on the other hand, assigns n* interceptors to each attacker not of a particular target but of a group of targets. The result is that the defense is "banking" with one large pool of interceptors rather than with many smaller pools, and hence that the non-uniformity of an attack not only does not impair the defense but actually benefits the defense, as will next be shown.

5. Consider a non-uniform constituent attack involving $A(y_1)$ and $A(y_2)$, with y_1 less than W and y_2 greater than W, as described in paragraph 3a. Against the n-to-one defense this attack, according to equation (8), causes an expected damage that can be written (if one denotes I/n*W by x, and groups separately the terms involving a and a_n)

$$\emptyset = 1 - (1-x)\,[A(y_1)a^{y_1} + A(y_2)a^{y_2}] - x\,[A(y_1)a_n^{y_1} + A(y_2)a_n^{y_2}]$$

while the uniform attack with $W = A(y_1)y_1 + A(y_2)y_2$

causes an expected damage

$$\emptyset^* = 1 - (1-x)\,a^{A(y_1)y_1+A(y_2)y_2} - x\,a_n^{A(y_1)y_1+A(y_2)y_2}\ .$$

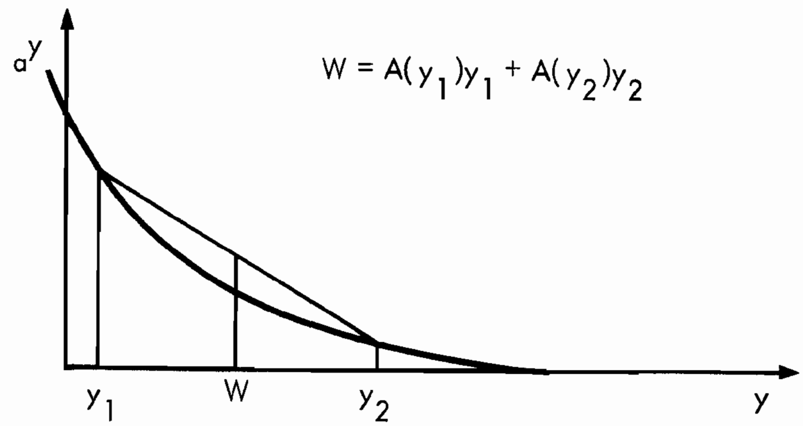
Now the second derivative of the function a^y of y is positive (unless a is unity, which it cannot be for attackers with non-zero yields) and accordingly, as the accompanying diagram indicates, the weighted mean of the values of the function corresponding to y_1 and y_2 must be greater than the value of the function of the weighted mean, W, of y_1 and y_2. A similar remark applies to a_n^y. Thus[1]

$$A(y_1)\,a^{y_1} + A(y_2)a^{y_2} > a^{A(y_1)y_1 + A(y_2)y_2}$$

[1]With perfect interceptors, a_n would be unity and part of the argument in the text would break down in that the second of the inequalities would become an equality. The conclusion would still be true, however, that $\emptyset < \emptyset^*$ unless I were also equal to W, since n* is unity for perfect interceptors. If I and W were equal, Ø and Ø* would both be zero and the uniform attack would still be "optimal" (the non-uniform attack would be no better).

$$A(y_1)a_n^{y_1} + A(y_2)a_n^{y_2} > a_n^{A(y_1)y_1 + A(y_2)y_2}$$

and therefore $\emptyset < \emptyset^*$.



Thus all the $\emptyset$'s in the right-hand column of the game matrix, corresponding to the non-uniform attacks, are smaller than the $\emptyset^*$ for the uniform attack. This completes the demonstration that when $I \leq n^*W$ the uniform attack and n-to-one defense correspond to a saddle-point of the game-matrix, and that the optimal attacks are uniform attacks and the optimal defenses are n-to-one defenses.

6. When $I > n^*W$, a similar discussion shows that the uniform attack and the n-plus-one-to-one defense corresponding to equation (9) are optimal.

D. SUMMARY OF CHAPTER

(U) A collection of equally valued targets, with equal α's, are attacked by an average of W attackers each and defended by an average of I interceptors each. It has been shown that the optimal attack under the preceding conditions is the assignment of exactly W attackers to each of the targets, but that the optimal defense is stochastic. If $I \leq n^*W$ then a fraction $1-I/n^*W$ of the equally valued targets are randomly selected and abandoned, while the remaining targets (constituting a fraction I/n*W of the total number) are defended by intercepting each of their attackers with n* interceptors. If I > n*W, then a fraction n+1-I/W of the targets are randomly selected and are defended by intercepting each of their attackers with n interceptors, while the remaining targets (constituting a fraction (I/W)-n of all the targets) are defended by intercepting each of their attackers with n+1 interceptors. Here n and n+1 are integers which bracket the value of I/W thus: $n \leq I/W < n+1$.

VI. EXTENSION TO SINGLE TARGETS. OPTIMAL ATTACKS ON AREA-DEFENDED, UNEQUALLY VALUED, TARGETS. METHOD OF APPLICATION.

A. EXTENSION OF THE PRECEDING RESULTS TO SINGLE TARGETS

(U) In Chapter IV, nothing was assumed about the number of equally valued targets in the collection of such targets that were under attack; the results were independent of the number. The results are therefore applicable to a single target (that is, to a collection containing but a single target). The only modification that is required is of the random division of the equally valued targets into those to be defended and those to be abandoned, or into those to be defended n-to-one and those to be defended n-plus-one-to-one. Since a single target cannot be so divided, the defense instead draws lots to determine whether, or how, the single target is to be defended. When $I \leq n^*W$, the defense performs a random experiment, so devised that the probability of a "success" is I/n^*W. If the outcome of the random experiment is a "success", then the defense defends the target by intercepting each of its attackers with n^* interceptors. If the outcome is a "failure", the defense abandons the target. When $I > n^*W$, the defense performs a random experiment so devised that the probability of success is $(I/W)-n$. If the outcome is a success then the defense defends the target by intercepting each of its attackers with n+1 interceptors, while if the outcome is a failure then the defense intercepts each of its attackers with n interceptors.

(U) The single target has here exactly the same status, prior to the drawing of lots, that any target has in the collection of many equally-valued targets prior to their random division into those to be defended and those to be abandoned. The expected number of interceptors that the defense will employ in the defense of the single target is just I, but the particular number that he will expend will in general be less than I or greater than I; the I having a stochastic significance.

B. OPTIMAL ATTACKS ON AREA-DEFENDED, UNEQUALLY-VALUED TARGETS

(U) Chapter IV optimized, formally, the general attack and area defense of a collection of unequally valued targets that could have differing α's. For the engagement to be optimal, it was necessary that for each target

$$\left.\begin{aligned} \partial\phi/\partial W &= \mu\, V^{-1} \\ -\partial\phi/\partial I &= \lambda\, V^{-1} \end{aligned}\right\} \qquad (10)$$

where V is the target's value, and where μ and λ are two parameters characterizing the engagement as a whole. Practical application of the results depended upon the availability of the function $\phi(W, I, \alpha, k)$ that represents the expected fractional damage to a single target optimally attacked by W attackers and optimally defended by interceptors whose statistically expected number is I. In the light of the preceding section it thus appears that the function has been found, and that the application of the principle of Chapter IV, to the optimization of offense-defense engagements, is now practicable.

1. Mention should be made here of a difficulty, arising from the stochastic nature of the defense, that has proved to be of little importance. The offense has no difficulty in assigning its attackers optimally, since there is nothing stochastic about the W_x attackers that it is called upon by the preceding theory to assign to the x'th target. The defender, however, is asked with a probability p_x (given by $I_x/n{*}W$) to defend the x'th target with D_x (given by $n{*}W$) interceptors, the product $p_x D_x$ being the expected number I_x of

interceptors that will optimize his defense according to the theoretical principles. The statistically expected sum of the D_x's of the targets that are selected randomly for defense is just the sum of the separate expectations $p_x D_x$ for all the targets in the collection and equals D, the stockpile of interceptors; but the particular sum of the D_x's corresponding to any particular set of random selections will in general either exceed or fall short of D. The latter case presents no problem. In the former case, the defense may either repeat the process of random selection until the sum of the D_x's falls short of D, or may make small adjustments arbitrarily to force the sum to fall short of D. The overall expected damage has been found in applications to be exceedingly insensitive to such changes, because of the optimization of the defense. It should be borne in mind in this connection that the defense does not have an accurate but only a rough knowledge of the offense's stockpile A of attackers available for attacking targets within the area defense; and further that the only disadvantage to a completely arbitrary (instead of random) selection of the particular targets to defend is that then the offense may no longer be denied the ability to improve his attack by guessing which targets the defense will favor.

2. Some refinement of the principles described in Chapter IV has proved to be desirable because of the integral character of W, particularly in connection with the numerous targets of low value in a target list (the inventory of attackers corresponding to a particular pair of values of μ and λ is fairly sensitive to the determination of which targets should be attacked with single attackers, and which should not be attacked at all). The fact that W is confined to integral values makes it usually impossible to satisfy the equations (10) exactly. This difficulty is avoided by specifying that μ is to represent the lower limit of the expected value destroyed by

the last attacker of each target. Then, corresponding to whatever particular value of μ may characterize the engagement as a whole, the offense attacks each particular target with the largest integral number W of attackers for which the expected value destroyed by the W'th attacker equals or exceeds μ. Thus the first of the equations (10) is replaced by the condition that W is to have the largest integral value for which

$$\emptyset(W, I, \alpha, k) - \emptyset(W-1, I, \alpha, k) \geq \mu V^{-1}. \qquad (11)$$

The preceding degree of refinement is not really necessary for the number I of interceptors, which can have a non-integral value. It has been found, however, that the fractional damage in a complete and optimized engagement is very insensitive to small changes in the allocation of interceptors. Moreover, the present study is primarily interested in the optimal tactics of the offense. For simplicity, therefore, the I's have been arbitrarily restricted to integral values like the W's and thus the second of the equations (10) has been replaced by the condition that I is to have the largest integral value for which

$$-\emptyset(W, I, \alpha, k) + \emptyset(W, I-1, \alpha, k) \geq \lambda V^{-1}. \qquad (12)$$

Since W and I appear in both conditions, it is necessary further to require that both W and I have the largest values that satisfy both of the relations (11) and (12).

(U) If the targets in a target list are arranged in decreasing order of value from top to bottom, then it usually happens (with given values of μ and λ) that there comes a target in the list below which it is impossible to satisfy both (11) and (12) for any non-zero values of both W and I, but that (11) is satisfied by some largest value W when I is zero, although (12) is not then satisfied. When this occurs the meaning is that in an optimal engagement W attackers are assigned to such targets, but that the defense assigns no interceptors to them because no interceptors that were so assigned could furnish marginal savings as large as λ. Still lower in the target list, a target is usually reached below which no assignment of attackers is made, because no attackers so assigned could result in marginal destruction as large as μ.

3. To apply the preceding results, expressions are needed for the left-hand members of the conditions (11) and (12) which can be rewritten in a shorter notation as

$$\nabla_W \emptyset \geq \mu \, V^{-1} \tag{11'}$$

$$-\nabla_I \emptyset \geq \lambda \, V^{-1} \tag{12'}$$

where ∇_W denotes the backward finite differencing operator that corresponds to a decrease of unity in W, and where ∇_I denotes the backward finite differencing operator that corresponds to a decrease of unity in I. The desired expressions are obtained from equations (8) and (9). When $I \leq n^*W$, it follows from equation (8)

$$\emptyset = 1 - a^W - (I/n^*W)\,(a_n{*}^W - a^W) \tag{8}$$

that

$$\nabla_W \emptyset = \alpha \, a^{W-1} + \frac{I}{n^*W(W-1)} \left[a_n{*}^{W-1} - a^{W-1} + (W-1)\,(\alpha_{n*} a_{n*}^{W-1} - \alpha \, a^{W-1}) \right] \tag{13}$$

where

$\alpha_{n*} = 1 - a_{n*}$, and that

$$-\nabla_I \emptyset = (1/n^*W)\,(a_{n*}^W - a^W) \, . \tag{14}$$

Similarly, when $I > n^*W$ it follows from equation (9), that can be written in the form

$$\emptyset = 1 - (n+1 - \frac{I}{W})a_n^W - (\frac{I}{W} - n)\, a_{n+1}^W \, ,$$

that

$$\nabla_W \emptyset = (n+1)\, \alpha_n a_n^{W-1} - n\, \alpha_{n+1} a_{n+1}^{W-1} + \frac{I}{W(W-1)} \left[a_{n+1}^{W-1} - a_n^{W-1} + (W-1)\,(\alpha_{n+1} a_{n+1}^{W-1} - \alpha_n a_n^{W-1}) \right] \tag{15}$$

and that

$$-\nabla_I \emptyset = (1/W)\ (a_{n+1}^{\ W} - a_n^{\ W}) \qquad (16)$$

where $\underline{n}$ and $\underline{n}+1$ are integers such that $n \leq (I/W) < n+1$.

(U) Although equations (13), (14), (15), and (16) involving finite backward differences were used whenever it was important to use them, earlier calculations based on true partial derivatives (and sometimes on advancing finite differences) were not revised when no significant changes would have resulted; and where the words "partial derivative" appear in later portions of the present volume, they should be interpreted as meaning a backward finite difference.

C. METHOD OF APPLICATION

(U) It was intended to apply the preceding theoretical procedures to a real defended area containing many target (b)(1) whose values and alphas were known. Since the theoretical procedures were devised too late in the year for there to remain sufficient time for their accurate programming on fast computers, it was evident that computations would have to be by a desk calculator, and that many approximate but time-saving artifices (including the use of graphs) would have to be employed. It was decided to adopt a single value, 3/4, for $\underline{k}$ that lay halfway between its upper limit of unity and a lower limit, one-half, that was thought to represent possibly the poorest performance of an ABM system that any nation would be willing to employ.

1. Application of the procedures involves the finding of a pair of values, W and I, that will satisfy the conditions (11) and (12) for a target of known value with a known alpha, corresponding to some particular choice of the engagement parameters μ and λ. The preceding determination must be made for each of many targets, and for many different pairs μ and λ.

Basic graphs were therefore prepared (typified by Figs. 5 and 6 that correspond to an alpha of one-tenth) that showed contours of constant $\nabla_I \emptyset$ and $\nabla_W \emptyset$ in diagrams in which the coordinates were I and W (refined distinctions between partial derivatives and finite differences are not reflected in the captions of such graphs, in some of which the curves labeled as corresponding to constant partial derivatives are really curves of constant finite differences). It will be noticed that the quantity I does not appear in the right-hand members of equations (14) and (16). It follows that lines of constant W in the graphs are also lines of constant $- \nabla_I \emptyset$ (denoted in the graphs as $- \partial \emptyset / \partial I$) throughout the region $I \leq n^*W$ and again throughout all regions $nW \leq I < (n+1)W$ where the integer n equals or exceeds n^*. This circumstance greatly facilitates the use of the charts, since W can be found at once from λ and V. Basic graphs were also prepared that showed contours of constant Ø in the same coordinates I and W, as typified by Figs. 7 and 8. Originally, basic graphs were prepared for values of alpha equal to 0.01, 0.10, and 0.50. It was later found to be desirable to prepare graphs for alphas of 0.032 and 0.25 as well.

Some of the graphs were originally prepared on the basis of true partial derivatives rather than of the more refined backward finite differences of paragraph B3. Because of the need for haste, such graphs were retained and used, unaltered, after the superiority of the backward differences was recognized. Other graphs had been prepared with advancing rather than backward differences; such graphs have been employed on the basis of backward differences by entering them with values of W decreased by unity. Such distinctions, however, between backward differences, forward differences, and true partial derivatives are of little practical importance for most of the targets in most of the engagements that have been considered, because the distinctions can influence the values of W and I that correspond to a given pair of values μ and λ only to the

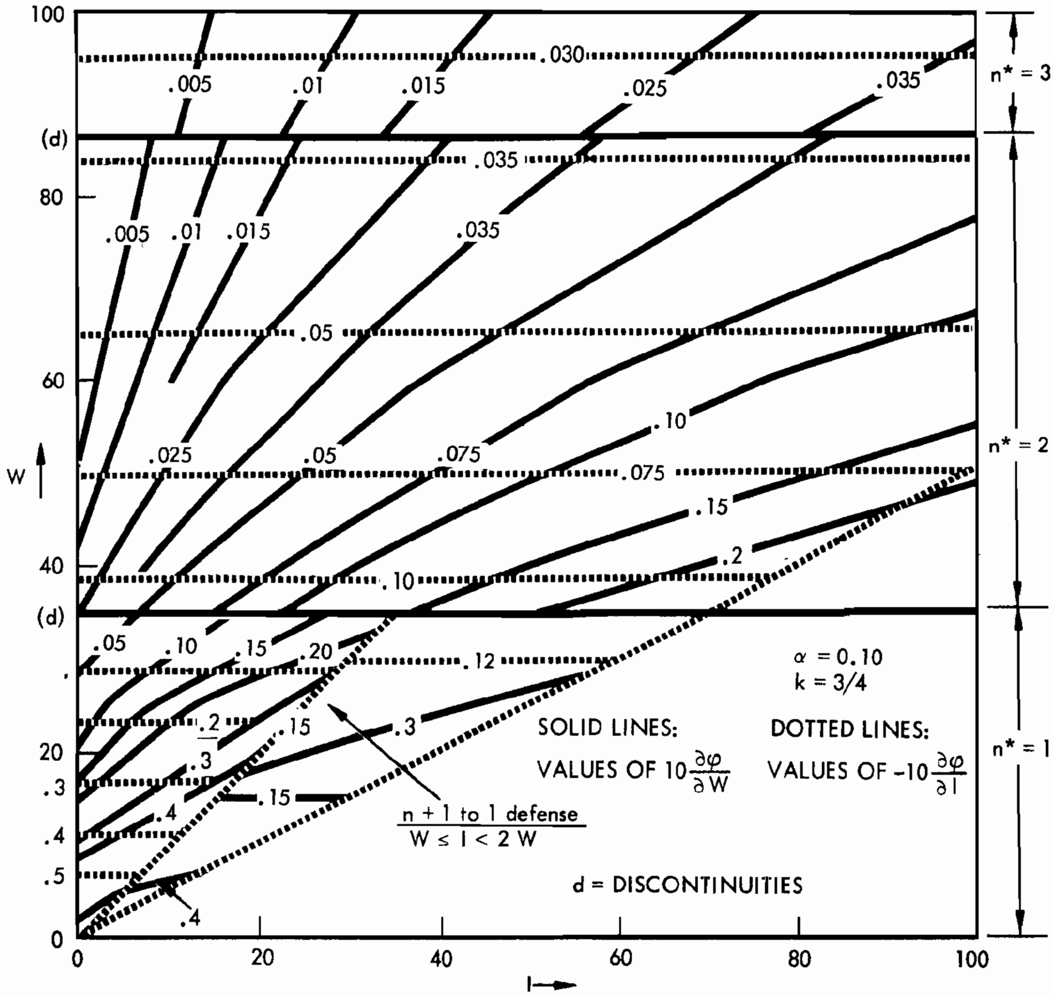


FIGURE 5 (U). Graph to Facilitate the Finding of W and I from Values of $\partial\emptyset/\partial W$ and $-\partial\emptyset/\partial I$, When $\alpha = 0.10$ and $k = 3/4$

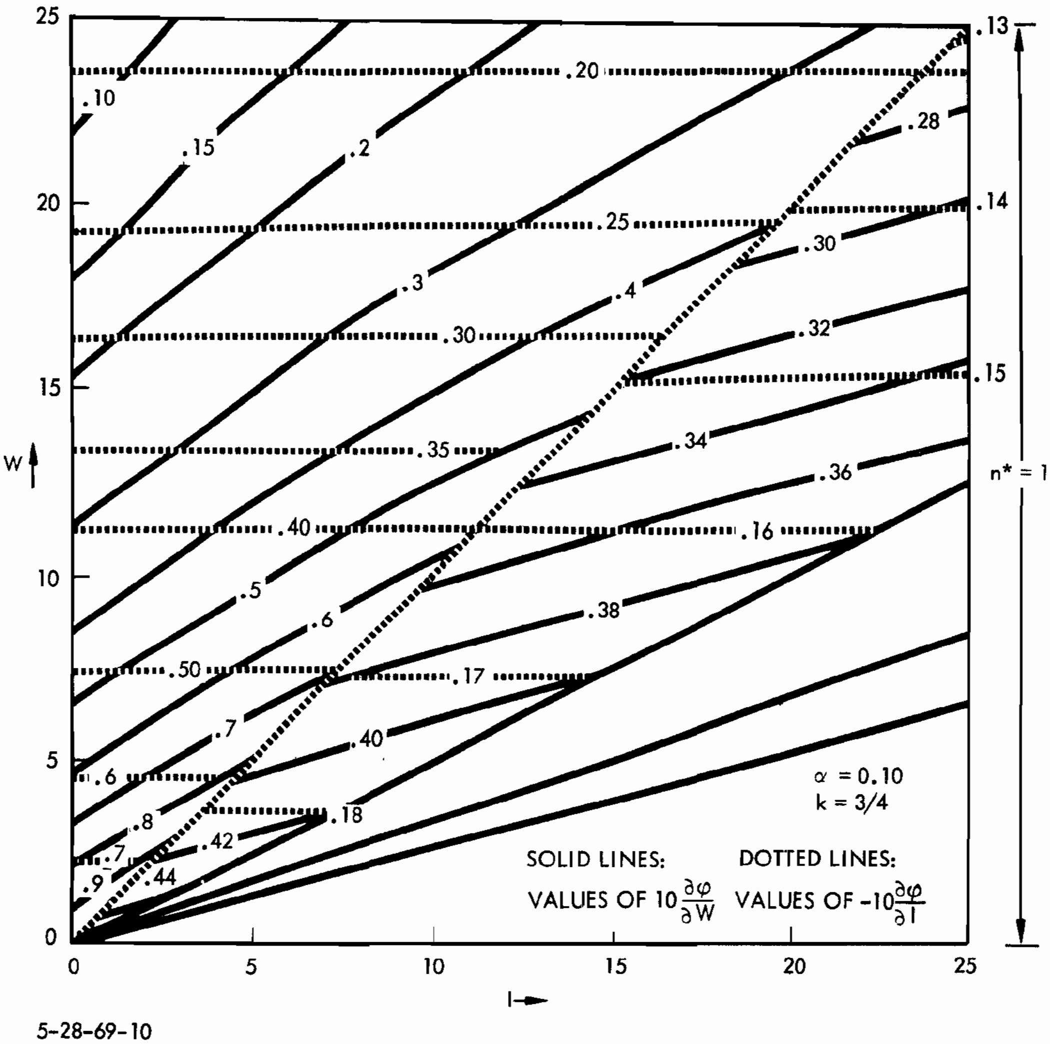


FIGURE 6 (U). Graph to Facilitate the Finding of W and I from Values of $\partial\phi/\partial W$ and $-\partial\phi/\partial I$, When $\alpha = 0.10$ and $k = 3/4$

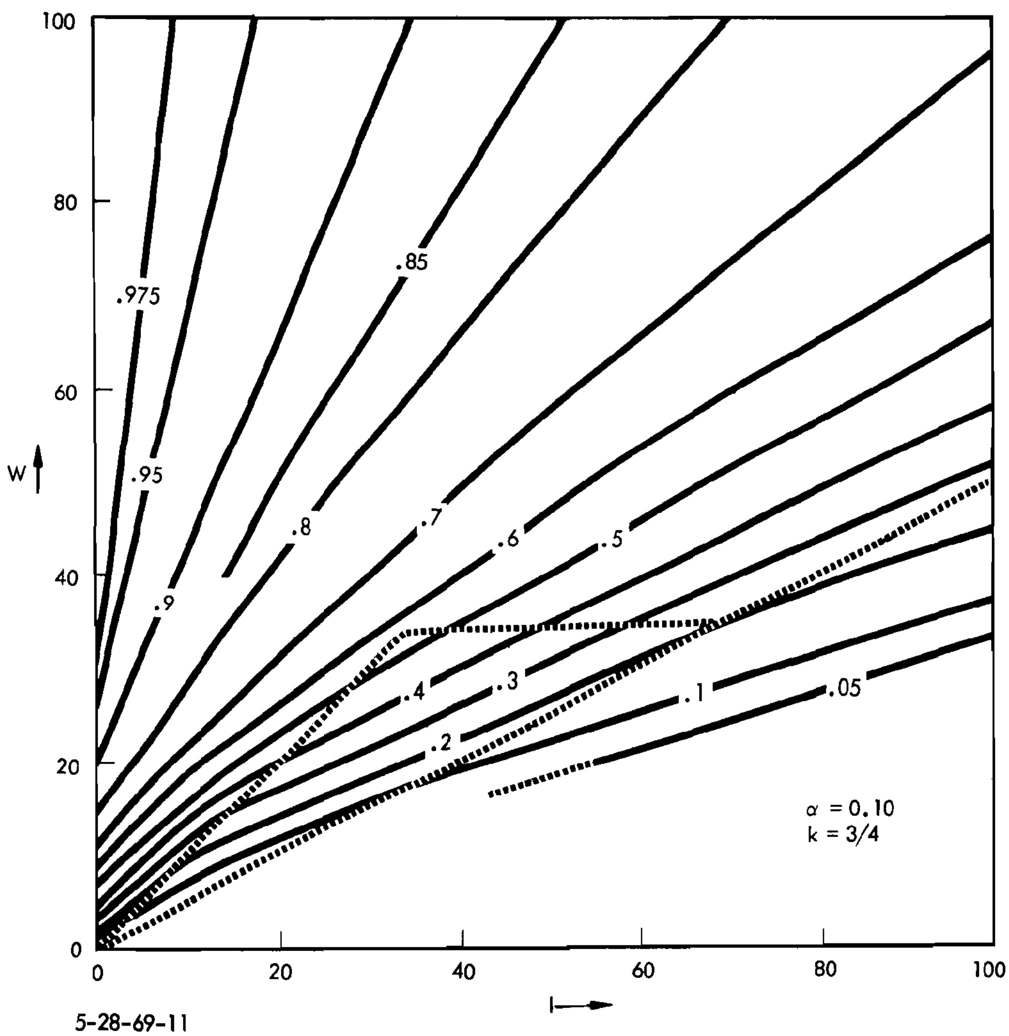


FIGURE 7 (U). Graph Showing Contours of Constant Fractional Damage, Ø, as a Function of the Number W of Attackers per Target, and of the Number I of Interceptors per Target, When $\alpha = 0.10$ and $k = 3/4$

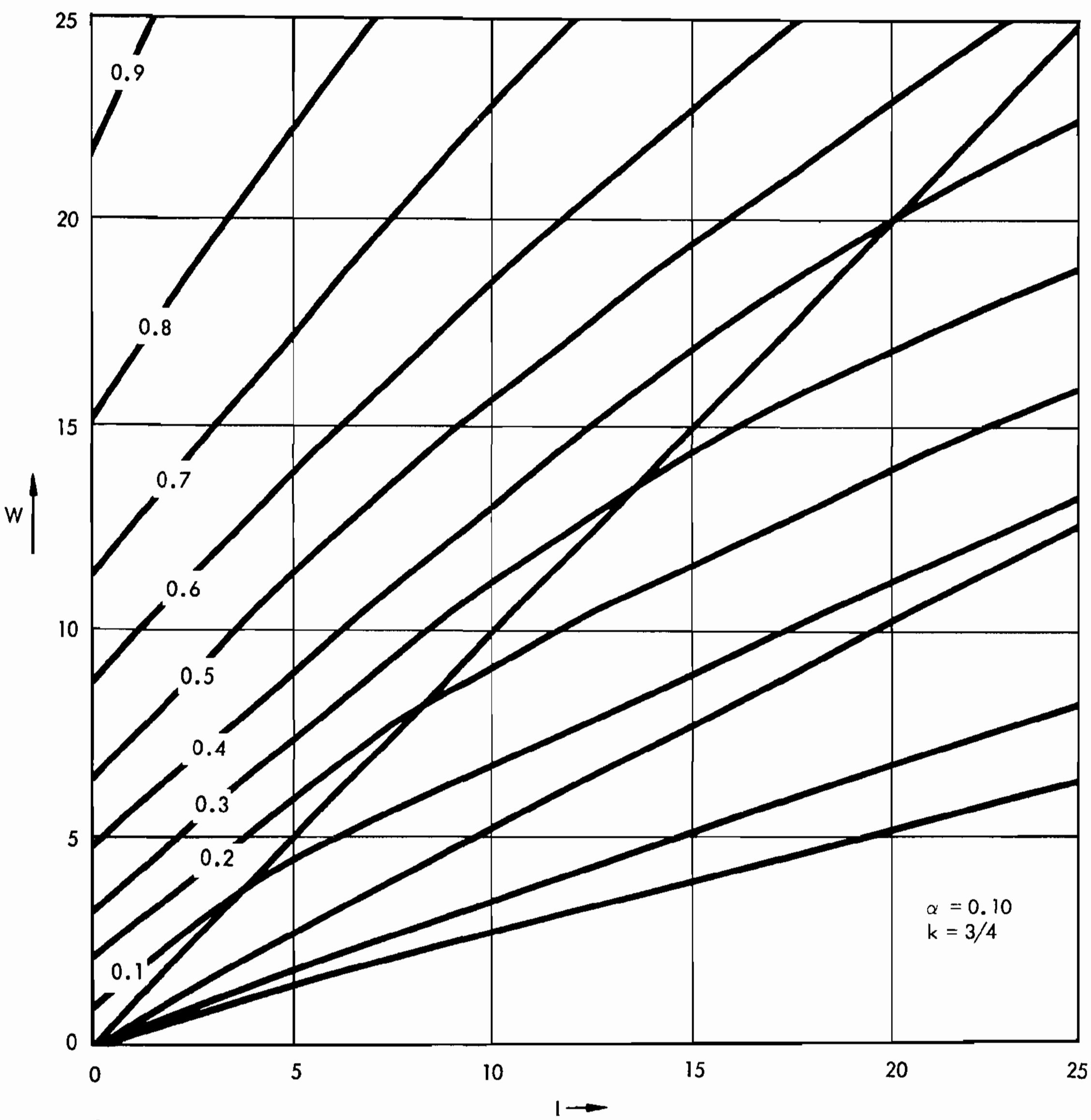


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FIGURE 8 (U). Graph Showing Contours of Constant Fractional Damage, Ø, as a Function of the Number W of Attackers per Target and of the Number I of Interceptors per Target, When $\alpha = 0.10$ and $k = 3/4$

extent of one attacker or one interceptor. Such effects are important only near the point, in a target list, where targets are being assigned only single attackers and where less valuable targets are not being attacked at all. The W's and I's corresponding to values of the differences that fell outside the ranges of values covered by the graphs were found, as required, by direct calculations from the equations of paragraph B3.

2. It was decided to calculate the total number A of attackers, the total number D of interceptors, and the overall fractional damage Ø for each of about 20 or 30 engagements, each corresponding to a particular pair of values of the engagement parameters μ and λ. Originally, five values of μ (.004, .01, .025, .05, and .10) and four of λ (.01, .025, .05, and .10) were selected, furnishing twenty combinations and engagements. Some of the combinations furnished uninteresting engagements, while the results obtained for the remaining pairs suggested the inclusion of still other values, including the value λ equals infinity that furnished attacks optimized against no defense. In all, the A's, D's and overall Ø's were calculated for twenty-seven different engagements, corresponding to combinations (not all that were possible) of five λ's with nine μ's.

3. Interpolations between μ-values with fixed λ then furnished values of A and D corresponding to a few selected values of the overall fractional damage Ø (0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95, and 0.975). Such values of A and D then enabled a final diagram to be prepared, showing the contours of constant overall Ø in a chart whose rectangular coordinates were the total stockpile A, of attackers that were available for the attack of targets in the defended area, and the total stockpile D, of interceptors available for their defense.

VII. OPTIMAL ATTACK OF TARGETS IN THE (b)(1) [redacted] ABM-DEFENDED AREA, WITHOUT DEFENSE SUPPRESSION

A. THE DATA

(b)(1) [redacted]

B. THE GROUPING OF THE DATA

(b)(1) [redacted]

(b)(1)

[redacted]

(b)(1)

(b)(1)

(b)(1)

(b)(1)

C. THE ENGAGEMENTS

(U) Tables 2 through 26 show the details of the engagements. There are only 25 instead of 27 tables because the tables for μ equal to .004 and .01 and λ equal to .10 were the same as the tables for those μ's and for λ equal to infinity. The tables as shown are duplicates of the actual computing sheets, and are believed to be nearly self-explanatory. N is used to denote the number of (b)(1) in a class. V^{-1}, the reciprocal of $\overline{V}$ was listed to facilitate forming the quotients $\mu/\overline{V}$ and $\lambda/\overline{V}$ with which the basic graphs were entered to find the numbers W of attackers, and I of interceptors, that are listed. The Ø column contains the average fractional damage for targets in a class. The sum of the values of ØNV, divided by 100, furnishes the overall fractional damage caused by the engagement, and appears at the bottom of the Ø column.

(U) All the defenses turned out to be of the n-to-one variety, none of the n-plus-one-to-one variety. The value of the <u>n</u> (the n* of Chapters IV and V) is shown in the final column as being of some interest. The defense selects targets to defend in each class by a random choice, with the probability I/n*W, that can be readily found, if desired, from the numbers in the tables.

(U) The results of the engagement studies are summarized in the following tabulation:

		μ =.004	.01	.025	.05	.10	.15	.30	.45	.60
λ .01	A D Ø	2768 831 .911	2724 2236 .772	2508 5039 .446						
.025	A D Ø	1501 141 .956	1391 378 .886	1314 1064 .705	1128 1799 .442					
.050	A D Ø	1126 11 .981	941 57 .946	836 216 .850	723 549 .645	645 882 .413				
.100	A D Ø	1091 0 .986	850 0 .970	631 3 .934	465 85 .800	392 257 .572	246 240 .332			
∞	A D Ø	1091 0 .986	850 0 .970	629 0 .929	444 0 .881	289 0 .784	199 0 .682	94 0 .455	40 0 .248	19 0 .143

D. THE OUTCOMES OF THE OPTIMAL ATTACKS

(U) As indicated in Chapter VI, interpolation between the μ -values, in the tabulation in Section C of the present chapter, at constant λ permitted the determination of the As and Ds corresponding to certain fixed values of the overall fractional damage Ø. These values were plotted in an A, D diagram and permitted the construction of curves of constant Ø. Polynomial processes were used to facilitate the passing of the curves through the discrete calculated points. The final results appear as Figs. 9 and 10.[1] Figure 10 is substantially an enlargement of the portion of Fig. 5 that relates to smaller values of A and D, in which pains have been taken to depict accurately the intersection of the contours of constant Ø with the lefthand edge of the diagram, for which D = 0, and that corresponds to attacks against no defense.

(U) Figures 9 and 10 represent most of the results of the study that has been described in this volume.

[1] (U) Figures 9 and 10 are the same as Figs. 1 and 2 in the Summary.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1)

E. EXTENSION OF THE RESULTS TO OTHER VALUES OF THE SINGLE-SHOT KILL PROBABILITY

(U) It is possible to employ the relations plotted in Figures 9 and 10 to find the expected fractional damage when the single-shot kill probability, k, has a value different from the value, 0.75, on which those figures are based. Before describing the procedure in its most general form, it will be illustrated by a particular example.

(U) An approximate value of the expected fractional damage when the D area interceptors have the much higher value $k = 0.9375$ may be obtained by entering the diagrams with the arguments A and 2D. This is because a single "good" interceptor with a k of 0.9375 is precisely equivalent to a pair of "poor" interceptors with k's of 0.75 in all situations in which the n^* of Chapter V for the poor interceptors is even; while the single good interceptor is equivalent or only somewhat inferior in situations in which the n^* of the poor interceptors is odd. When the n^* for the poor interceptors is even, the n^* for the good interceptors will be half as large; the two j_n values will be the same; thus the value saved per good interceptor will be precisely twice the value saved per poor interceptor. On the other hand, when the n^* of the poor interceptors is odd, the n^* of the good interceptors cannot equal half the n^* of the poor interceptors that maximizes their j_n/n, and thus j_n/n for the good interceptors must be equal to or smaller than twice the j_n/n of the poor ones; which is to say that the value saved per good interceptor must then fall short, if anything, of twice the value saved per poor interceptor. The deficiency, however, should not be large because of the low sensitivity of j_n/n to n in the neighborhood of n^*. Thus D interceptors with $k = 0.9375$ should be anticipated to yield approximately the same expected fractional damage as 2D interceptors with $k = 0.75$, or if anything, a somewhat larger expected fractional damage.

(b)(1)

(b)(1)
[redacted]

(U) A more general extension of the relations shown in Figures 7 and 8, anticipated to hold approximately when <u>k</u> differs from 0.75, is to enter the diagrams with the value of A, and with a value of D obtained by multiplying the number of area interceptors by a factor <u>x</u> that satisfies the relation

$$(1/4)^x = 1-k,$$

so that

$$x = -\log(1-k)/\log 4.$$

The rule can be expressed by the equation

$$\phi(A, D, k) = \phi(A, xD, 0.75), \qquad (17)$$

and includes as a special case (for which x = 2) the procedures, already described, that are appropriate when k = 0.9375.

(b)(1)
[redacted]

(b)(1) [redacted]

(U) The adequacy of equation (17), intuitively expected, and numerically confirmed in the three cases examined, would be more difficult to demonstrate, rigorously, in general than in the special case when $k = 0.9375$. The general case involves the near equivalence of the effectiveness of I interceptors, with some stated k, and the effectiveness of some number (not in general a simple multiple of I) of interceptors with k-values of 0.75. Although it is thought that a rigorous demonstration could be developed, such a demonstration will not be attempted here.

(b)(1) [redacted]

F. SENSITIVITY OF THE EXPECTED DAMAGE TO THE OFFENSE'S KNOWLEDGE OF THE NUMBER OF INTERCEPTORS

(U) It has been assumed in the analyses of this volume that the offense's intelligence provides him with at least a rough idea of the number, D, of area interceptors. Two tests have been made of the dependence of the expected damage upon the accuracy of such knowledge. The dependence is very slight.

(b)(1)

[redacted]

(b)(1)

[redacted]

(U) It thus appears that when the total numbers of attackers and interceptors, assigned to targets in the defended area, are fixed the expected value of the fractional damage caused by the attack is very insensitive to the offense's knowledge of the number of interceptors.

Table 4 ~~(S)~~. ENGAGEMENT μ = .025, λ = .01 (U)

N	Class	α	V^{-1}	W	I	Ø	NV	(n:1) n
1	1	.032	.0335	700	1296	.57	29.87	3
1	2	.032	.0571	462	947	.46	17.52	3
1	3	.10	.137	150	301	.58	7.32	3
2	4	.25	.373	68	135	.49	5.36	3
7	5	.25	.667	44	102	.35	10.50	3
16	6	.50	1.25	22	50	.37	12.80	3
13	7	.50	2.22	14	25	.43	5.85	2
24	8	.50	4.55	7	14	.20	5.28	2
25	9	.50	9.09	2	2	.23	2.75	2
39	10	.50	17.9	0	0	0	2.18	1
13	11	.50	35.7				.36	
9	12	.50	62.5				.14	
6	13	.50	143				.04	
5	14	.50	250				.02	
4	15	.50	500				.01	
			TOTALS	2508	5039	.446	100.00	

Table 5 ~~(S)~~. ENGAGEMENT μ = .004, λ = .025 (U)

N	Class	α	V^{-1}	W	I	Ø	NV	(n:1) n
1	1	.032	.0335	338	45	.96	29.87	3
1	2	.032	.0571	220	22	.97	17.52	2
1	3	.10	.137	86	9	.97	7.32	2
2	4	.25	.373	32	3	.97	5.36	2
7	5	.25	.667	22	2	.97	10.50	2
16	6	.50	1.25	11	2	.94	12.80	2
13	7	.50	2.22	7	1	.93	5.85	2
24	8	.50	4.55	5	0	.97	5.28	1
25	9	.50	9.09	4	0	.94	2.75	1
39	10	.50	17.9	3	0	.88	2.18	1
13	11	.50	35.7	2	0	.75	.36	1
9	12	.50	62.5	1	0	.50	.14	1
6	13	.50	143	0	0	00	.04	
5	14	.50	250				.02	
4	15	.50	500				.01	
			TOTALS	1501	141	.956	100.00	

interceptors, the last Ø should be increased to .461 as shown in row 3' of the tabulation. With 710 attackers instead of 701 in the optimal engagement of row 1, Ø would be .470 as shown in row 1'. Comparison of rows 3' and 1' shows that the offense's underestimation of the number of interceptors by a factor of 2.5, when there are 710 attackers and 878 interceptors, only decreases the expected fractional damage from .470 to .461.

~~(S)~~ A more extreme test is to calculate what would happen if the offense were to optimize, in the preceding situation, against no defense when there were in fact 878 interceptors. In row 4, the offense assigns 700 attackers to targets in a manner that would be optimal, and that would yield a Ø of .950, if there were no interceptors. Row 5 shows the expected outcome when the offense makes the preceding allocations and the defense employs his 878 interceptors in a manner that would be optimal against 701 attackers. (That defense, against the attack in row 5, actually expends only an expected 832 interceptors rather than 878, but the defense could not know this in advance and could not benefit from the circumstance.) Row 6 (No. 1, adjusted to 700 attackers) shows that a perfectly optimized attack with 700 attackers against 878 interceptors would yield a Ø of .460. Thus, in the extreme case where there are 700 attackers and 878 interceptors but the attack is optimized against no interceptors, the expected fractional damage is .443 when perfect optimization would yield an expected fractional damage of .460, only a few percent higher.

(U) It thus appears that when the total numbers of attackers and interceptors, assigned to targets in the defended area, are fixed the expected value of the fractional damage caused by the attack is very insensitive to the offense's knowledge of the number of interceptors.

(U) Tests would be desirable of the sensitivity (anticipated to be, if anything, even smaller) of the expected damage to the defense's intelligence estimate of A. Time has unfortunately prevented the accomplishment of such further tests.

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VIII. OPTIMAL ATTACK OF TARGETS IN THE [redacted] ABM-DEFENDED AREA, WITH DEFENSE SUPPRESSION

A. GENERAL

(U) The objective of Chapter VII was to find effective methods for attacking the [redacted] targets in the [redacted] area ABM-defended region through penetration of the defenses by exhaustion and leakage, without attacking the defenses themselves. Such an attack may be called an "objective" attack. The purpose of the present Chapter is to find methods for increasing, if possible, the expected damage to the same [redacted] targets through earlier attacks (called "defense-suppression" attacks) on the area defenses. The engagements in the present Chapter therefore involve a defense-suppression phase, intended to impair the defenses or render them inoperative, followed by an optimized objective attack of the remaining attackers on the [redacted] targets through such defenses as may remain. The proportion of attackers allocated to defense suppression will be optimized, as well as the proportion of interceptors allocated to defending the defenses. The attackers and operable interceptors, remaining after the defense-suppression phase, cause an expected fractional damage, Ø, to the [redacted] targets in the subsequent objective attack that is given by Figures 9 and 10 (with the associated rule for extending those relations to other values of <u>k</u>) of Chapter VII.

[redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

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STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

VOLUME IX
Enclosure I: Bomber Employment and
Defense Penetration Study

August 1969

Including
IDA REPORT R-160

A. R. Barbeau, *Project Leader*

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REPORT R-160

STRATEGIC OFFENSIVE WEAPONS EMPLOYMENT IN THE TIME PERIOD ABOUT 1975 (U)

A. R. Barbeau, *Project Leader*

VOLUME IX
Enclosure I: Bomber Employment and Defense Penetration Study

D. N. Beatty
E. Marcuse

August 1969

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in response to the Weapons Systems Evaluation Group Task Order SD-DAHC15 67 C 0012-T-140, dated 21 December 1967.

In the work under this Task Order, the Institute has been assisted by military personnel assigned by WSEG.

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FOREWORD

This report has been prepared by the Systems Evaluation Division of the Institute for Defense Analyses in conjunction with the Weapons Systems Evaluation Group. The research and analysis that form the basis for this report were carried out by a project staff under the general leadership of A. R. Barbeau. The members of the project staff are listed below:

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ACKNOWLEDGEMENT

(U) The authors wish to acknowledge the contributions made to this study by Col. Daniel Zoerb, USAF and Col. William Kuykendall, USAF. Their advice on tactics and insights concerning bomber operations provided an input which is implicitly represented in the modeling assumptions. Their critique and assessment of the critical problem areas were also instrumental in the formulation of this study.

TABLE OF ORGANIZATION

TABLE OF ORGANIZATION (Cont'd)

CONTENTS

APPENDICES

I. INTRODUCTION AND SUMMARY

A. PURPOSE

(b)(1)

[redacted]

(b)(1)

[redacted]

D. SCOPE

1. Theater Forces

(b)(1) [redacted]

[1] (U) Ref. SIOP 4 Rev D.

(b)(1) [redacted]

(b)(1)

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3. Bomber Force Generation Levels

(b)(1)

~~[1] (S)~~ Plans are under way to increase the alert rate to (b)(1) percent. See Appendix B.

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measured by the three parameters mentioned previously and the damage expectancy on the (b)(1 was calculated for various force levels and defense capabilities.

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Table ~~1 (S)~~ ALLOCATION OF BOMBER WEAPONS (U)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

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II. PENETRATION AND DEFENSE SUPPRESSION

(U) In order to achieve maximum effectiveness, aircraft utilize various tactics to achieve the highest possible penetration probability. The tactics, insofar as possible, reduce the requirements for defense suppression, and enhance the suppression that is accomplished.

A. TACTICS FOR PENETRATION

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[redacted]

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III. DEFENSE COMPONENTS FOR SUPPRESSION

(b)(1) [redacted]

Table 2 ~~(S)~~. NUMBERS OF POTENTIAL DEFENSE COMPONENTS IN 1975 (U)

(b)(1) [redacted]

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IV. EFFECTS OF DEFENSES ON (b)(1) [redacted] AND MILITARY OBJECTIVES

A. INTRODUCTION

(U) The investigation of appropriate weapons for defense suppression has clearly indicated that there is a tradeoff in their use, with a primary consideration being the determination of the effect that defense suppression has on achieving destruction of objective targets. To determine this effect, two functional relations must be established. The first is a measure of the defense capability and how this capability is reduced through defense suppression. The second is the level of destruction of objective targets which can be achieved under any defense capability.

(U) A combination of the two relationships, with defense capability as a parameter, can be used to provide insights into the effectiveness of defense suppression. In this chapter, the basic relationships are established, based on the target structure identified in Chapter III. In Chapter V, some selected parts of the basic data are discussed in more detail.

B. METHODOLOGY

(b)(1) [redacted]

(b)(1) [redacted]

(U) In general, BOMBALL executes each sortie (the flight of one bomber) individually to the targets it can reach, choosing that set of targets which enables the damage achieved to be maximum. Depending on the area in which it operates and the cities it visits, the sortie probability of arrival at each target is calculated. The probability of arrival depends on the strength of both the area and terminal defenses. The area defense attrition depends on the distance flown in the defended area, and the terminal defenses are expressed as a kill probability for each target.[1] The capabilities of both defenses are dependent upon whether the sortie is at high or low altitude during penetration.

C. (b)(1) [redacted] TARGET RESULTS

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C) [redacted]

---

[1](U) The description of these calculations appear in Appendix C of this Volume.

[2](U) For a description of the data base, see Appendix D of this Volume or refer to Volume III. The [redacted] weapon is the reference weapon chosen to represent the major objective weapons in the bomber force. There are a total of [redacted] weapons in the force.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

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[redacted]

(U) Due to the nature of the curves, the changes in defense capability produces large changes in the number of weapons required to produce a given damage level. To more clearly delineate this effect, the presentation as shown in Figs. 13 through 15 was developed. These figures compare the number of weapons required to achieve the same level of damage between two levels of capability of a component of the defense.

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

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(U) There could also be an interaction between missiles and bomber sorties. This would occur for missiles targeted against any component of the air defense (including (b)(1) . This possibility is discussed in paragraph V C.

E. IDENTIFICATION OF DEFENSE SUPPRESSION TARGETS

(U) The existence of a given level of defense capability (less than full) implies a level of damage to some of its components. The distribution of sortie locations relative to defense component location, indicates the numbers of components which must be attacked. Together, both considerations produce the weight of defense suppression effort. This section addresses the numbers of components for attack, and how damage on them is related to capability.

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(U) Before assessing the significance of these relationships, some specific consideration must be made of the magnitude of the defense suppression attack associated with reduction of the defenses to any given level. A correspondence of this type has been necessary to generate the curves in Figs. 17 and 18, so a discussion of this value is appropriate. For example, such questions as the number of SRAM required for a given probability of surviving terminal defenses should be addressed. These topics are addressed in the next chapter.

G. COMPARISON OF CONSTRAINED AND UNCONSTRAINED BOMBER ALLOCATIONS

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(U) This situation represents a case with no attrition, so another comparison was attempted where attrition was included. Two specific calculations were made, which were chosen to be close to the specific data base so that extrapolation errors would be minimized. The specifics of the two cases are shown in Table 7.

Table 7 (S). ALLOCATIONS[a] (U)

(b)(1) [redacted]

(U) The results of the two allocations are shown in Table 8.

Table 8 (S). RESULTS (U)

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[1] (U) Sum of all individual weapon probabilities of arrival divided by the number of weapons.

I. DIFFERENCES BETWEEN GROUND BURST AND AIR BURST WEAPONS

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[redacted]

FIGURE 21 (S) Comparison Between Damage Caused by Optimum HOB and Ground Burst Weapons (U)

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V. DEFENSE SUPPRESSION CONSIDERATIONS

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(U) A summary of the results of Table 10 are shown in Table 11.

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(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

VI. TOTAL DEFENSE SUPPRESSION REQUIREMENTS

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A. WEAPON ALLOCATION TO DEFENSES

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APPENDIX A

SOVIET DEFENSES

APPENDIX A

I. INTRODUCTION

(U) The capability of Soviet defenses has an effect on the importance which is placed on their destruction. The capability of the defensive system is reflected by not only the capability of each individual part but the numbers of the individual units and their geographical disposition. It is the purpose of this Appendix to present those characteristics of the defensive system which are pertinent to the studies conducted under WEPS. The latter includes subjects such as numbers, vulnerability, and location.

(U) The Protivovozdushnaya Osborona Strany (PVO), Air Defense of the country, is the designation for that branch of the Soviet Armed forces responsible for the defense of the Soviet Union against air attack. The components of this branch are:

1. Surface-to-Air Missiles (and associated radars).
2. Early Warning and Ground Controlled Intercept Radars.
3. Fighters and their supporting airfields.
4. Command and Control.
5. Airborne Warning and Control Systems.
6. Anti-Aircraft Artillery.

In the following, each will be discussed.

II. SURFACE-TO-AIR MISSILES (SAM)

(SNF) The Soviets have deployed four operational SAM systems for strategic air defense. Noteworthy is that all but one have no true low altitude capability, including the latest system introduced. Accordingly, a new altitude SAM system, the SA-Z-1, is postulated[1] by DIA with estimated capability and deployments.

(S) Table A-1 shows the numbers and performance characteristics of the missiles in the SAM order of battle. The level of deployment shown reflects the latest intelligence estimates. Figures A-1, A-2, and A-3 show the SAM deployment locations. The data used in the WEPS study and presented in the figures is based on the 1968 intelligence estimate, contained in the FSTL (Future Strategic Target List) of July 1968. This location data has been utilized when required, and the final results based on the latest intelligence estimates.

(S) The SA-1 has been deployed only in rings surrounding Moskva and was designed to counter medium to high altitude, massed bomber attacks. Its outstanding feature is the ability of a single site to conduct twenty simultaneous intercepts. Due to electronic improvements in the site, its capability approaches that of the SA-2.

(S) The SA-2 is the most widely deployed SAM system, and was designed to counter medium to high altitude threats. Even in 1975 it will exist in substantial numbers. The SA-2 can be equipped with a nuclear warhead. Currently envisioned ECM

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[1] (TS) The FY 1970-74 Defense Program and 1970 Defense Budget prepared January 13, 1969, indicates ". . . no evidence of a new more effective low altitude SAM."

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equipment for bombers cannot generate sufficient miss distances to counter the lethality of this type of warhead.

(S) The SA-3 system is optimized for low and medium altitude performance. Most of the SA-3 deployment has been in coastal areas except for partial rings around Leningrad and Moskva. The future estimates indicate a large number of colocated SA-3 and SA-Z-1 sites.

(S) The new low altitude SAM is expected to be proliferated in relatively large numbers. The SA-Z-1, according to SAC estimates, has a capability against a SRAM missile, even when the SRAM is employed at low altitude. This capability is associated with using a phased array radar with a GAINFUL (SA-6) type interceptor. In this sense, the SA-Z-1 has capabilities much like the U.S. SAM-D. It should be noted that most analyses in the past have not associated this capability with the SA-Z-1.

(S) Figure A-3 shows the SA-5 deployment and the range and number of sites permit extensive area coverage against the medium and higher altitude threat. (The SA-5 is given some capability against the SRAM in a ballistic trajectory with a kill probability of 0.5.)

(TS) The numbers of SAM sites used in the study are shown in Table A-2. These are based on a 1968 estimate. For reference, the latest intelligence estimate is shown in parentheses. The proliferation of the SA-5 as opposed to the earlier estimate of proliferation of the SA-Z-1 is indicated. The location of the 1840 sites is shown in Figure A-1.

Table A-2 ~~(TSNF)~~. SURFACE-TO-AIR MISSILE (SAM) SITES[a] (U)

Type of SAM	Number
SA-1	(b)(1) [redacted]
SA-2	
SA-2 R&D	
SA-2 Unoccupied[c]	
SA-3	
SA-3 R&D	
SA-5	
SA-Z-1	

[a]Reference FSTL high estimate for 1975.
[b]Located around Moskva only.
[c]Would be occupied in times of tension by reserve units.
[d]1969 high NIPP estimate for 1975.
[e]1969 high NIPP estimate for 1975. The low estimate is 0.

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IV. FIGHTERS AND AIRFIELDS

~~(S)~~ The area defenses rest with the fighter force and the airfields that support them. Despite the tendency of the Soviets to retain old models of interceptors as part of an active inventory, the air order of battle for 1975 is estimated to be comprised of the types shown in Table A-4.

~~(TSNF)~~ All of the PVO aircraft are armed with missiles (no guns). These air-to-air missiles (AAMS), shown in Table A-5 are all armed with conventional HE warheads. Considering the fact that AWACS direction would permit a large number of intercepts to occur over water approaches and the much less stringent guidance problems associated with nuclear tipped air-to-air ordnance, it would seem that the introduction of this weapon would be advisable.

~~(TSRD)~~ Nevertheless, there are no estimates of a Soviet AAM with a nuclear warhead[1] despite apparent advantages of such a system. The warhead weights and ranges associated with the current Soviet AA-5 ASH would certainly be sufficient to permit utilization of a nuclear warhead. A comparison with the U.S. nuclear armed AIM-47A shows that the payload is large enough to be consistant with nuclear warheads. As for the capability of the Soviets to construct a missile warhead in the 150- to 175-pound class, it should be noted that a 150-pound nuclear warhead is postulated for the ABM-Z-1.

---

[1](U) NIPP-69 (National Intelligence Projection for Planning).
[2](U) DIA Probability of Kill Handbook ST-HB-17-4-67- INT.

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Table A-4 (TSNF). Estimated Characteristics PVO STRANY Air Order of Battle in 1975 (U)

Fighter	Armament	Combat Radius No Ext Fuel (nmi)	With Ext Fuel (nmi)	Radar Range Search/Track (nmi)	Max Range for ATTACK (nmi)	Attack Aspect	P_{ssk}[f] Detection Given		No.[a] Operational At Mid-Year
							Low	High	
FISHPOT C SU-9	2-AA-3[b]	400[c]	540	22/16	10-12	Tail/Nose	0.09	0.50	625-675
FIREBAR YAK-28	2-AA-3[b]	570	---	22/16	10-12	Tail/Nose	0.09	0.50	300-375
FIDDLER TU-28	4-AA-5[b]	760[d]	1060	32/24	12-16	360°	0.14	0.53	125-175
FLAGON A SU-X	2-AA-3[b]	370	465	22/16	10-12	Tail/Nose	0.08	0.46	650-800
FOXBAT MIG-23	2 or 4 AA-2-2	800[e]	1130	40/30	15-25	360° and look down shoot down	0.37	0.55	225-325

[a]NIPP-69. In addition there are estimated to be 50-150 MIG-17s.

[b]Both the AA-3 and five missiles exist in radar and IR guidance variants.

[c]Optimum Mission.

[d]375 at supersonic speeds (995 knots).

[e]All supersonic (M=3.0) Radius is 428 nmi with four missiles, 580 nmi with two missiles; supersonic out and subsonic return, 470 nmi with four missiles and 670 nmi with two.

[f]Intelligence Estimates.

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Table A-5 (SFRD). MISSILE COMPARISON (U)

Missile	Launch Weight	Warhead Weight	Range
AIM-47A	800	75	20-30[a]
AA-5	1085	150-175	12-16[b]

[a]Mach 3.0 launch - Ref. Standard Aircraft Characteristics.
[b]Subsonic Launch.

(S) In addition to these aircraft assigned to the PVO Strany, aircraft of the Soviet Tactical Air Forces can be utilized in the air defense role. In 1975, the numbers and types of aircraft associated with tactical aviation, located in the USSR are shown in Table A-6. They are armed with cannon and IR missiles.

Table A-6 (SNF). SOVIET TACTICAL FIGHTERS LOCATED IN THE USSR IN 1975[a] (U)

Type	Number
FOXBAT	275
FISHBED (All Types D&F)	665
FITTER	280
FLOGGER	250

[a]Ref. DIA Future AOB Listing CTRY/ALPHA ORDER ICOD, 11 April 1968, PAF A07-0199/003, S-10813/MS6.

(S) These aircraft have a primary role of fighter bomber and only a secondary role of interceptor and would therefore, be expected to have less capability than PVO aircraft of the same type. For example, it is not certain that the TAC version of the FOXBAT will have the look down-shoot down capability that is attributed to PVO FOXBATs. Therefore, they have not been included in attrition calculations.

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[redacted]

(S) The estimated deployment of PVO interceptors in 1975 is shown in Figure A-5. At the time this estimate was made the AWACS was not part of the deployment. Due to the location of AWACS stations, some shift could occur to take advantage of the FOXBAT and FIDDLER range in conjunction with the increased radar coverage. According to the distribution shown, for example, it would be expected that some additional support might be made at the station near Novaya Zemlya. The numbers and bases associated with each type are shown in Table A-7. These have been used in the WEPS study. The differences between the number shown in Table A-7 and the NIPP do not materially affect the results. Since it is not anticipated that all of the high estimates would be reached simultaneously, the deployment has deemphasized the numbers of FLAGON A as compared to NIPP-69.

(S) Like the fighters of the U.S. Air Defense Command, the PVO force is dispersed during hostilities. As indicative of the potential for dispersal, all airfields carried in the FSTL for 1975 are shown in Fig. A-6. This figure shows the 417 airfields in the TDI categories 80010 through 80090. Although the NSTDB lists 57 airfields in the 80100 category, they are not projected in the FSTL. These reserve airfields have a history of being upgraded and serve as a pool for

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V. COMMAND AND CONTROL

~~(S)~~ Little is known about the Soviet command and control network. The major operational unit is the Air Defense District (ADD) the current boundaries of which are shown in Figure A-4. At this level all active and support elements of the defenses, aircraft, SAMs, AAA, radar and command and control are brought together. This information is then passed to area headquarters at Moskva and Khabarovsk. The district headquarters delegates authority to zonal and sector headquarters to give them necessary freedom to deal with the threat.

~~(S)~~ The installation of the semiautomatic handling of early warning information has made the system less susceptible to saturation. The PVO Strany command and control sites are shown in Figure A-4. In Table A-8, the vulnerability listed for the 82 sites contained in the FSTL for the 1975 time period are shown. Some are quite closely together (less than one-half mile apart) and therefore only 74 locations are indicated.

(b)(1)
[redacted]

(S) One of the characteristics of the Soviet air defenses is their reliance on close GCI control. A characteristic difference between the capabilities of the Soviet defensive system, between the present and 1975 will be the inclusion of elements which have larger range, for example, the SA-5 and the FOXBAT interceptor. These systems, in order to be properly utilized will place more demands on command and control functions, and the command sites indicated should, therefore, play an increasing role. Moreover, the incorporation of a SADS (semiautomatic air defense system) and the need for long range control will probably permit each center to conduct operations over a wider area.

(b)(1)
[redacted]

(TS) The command and control network has a high degree of redundancy, flexibility and reliability. Ground-to-air data links are also incorporated into the system. Despite the SADS, however, there are indications that the system remains vulnerable to saturation.[1]

[1](U) NIPP-69.

VI. AIRBORNE WARNING AND CONTROL SYSTEM (AWACS)

~~(TSNF)~~ The Soviets have deployed AWACS aircraft at a limited number of locations. This system, called MOSS, is contained in a CLEAT (TU-114) turboprop transport modified with a flat, circular 35 to 37 foot diameter antenna on top of the fuselage like the U.S. E-2. The current version has four consoles and assuming one manual GCI operator at each station the current aircraft could direct 9 to 12 intercepts (there could be more than one fighter associated with each intercept).

~~(TSNF)~~ The radar, named FLAT JACK, is given a look-down capability over water. The current radar range (and GCI capability is given to this range) is estimated to be 200 miles and for 1975 to be 250 miles.[1] The aircraft are expected to establish a wartime station about 200 miles off the coast at about 25,000 feet altitude and will probably be escorted by a combat air patrol (CAP) of 4 to 6 fighters. Estimates of reliability and mean time to service aborts would indicate that the postulated air order of battle could support such a CAP without severe virtual attrition.

~~(TSNF)~~ The radar capability of the current aircraft does not allow for accurate height estimation for penetrators at altitudes less than about 5000 feet.

~~(TSNF)~~ The performance of the CLEAT aircraft exhibits mission (not station) time that is approximately 12 hours.

---

[1] ~~(S)~~ Theoretical range against a 20 square meter target with a probability detection of 50 percent at a false alarm rate of 10^{-8}.

This would indicate that an aircraft just airborne at the initial attack would still be available to direct fighters against penetration of the alert force.

~~(TSNF)~~ In 1975 the USSR is expected to have 20 to 40 of these aircraft and there is an even chance that, by 1975, some aircraft (estimated to be five) will have the capability to look down over land.

~~(SNF)~~ The AWACS system represents a singular increase in the capability of the area defenses. It permits large area surveillance against low altitude targets and, therefore, permits fighters to attack low altitude penetrators which were not subject to attack when only ground-based radars were available.

~~(TSNF)~~ Currently, three stations have been identified astride the main bomber penetration corridors. One is in the Baltic and two are to the north in the Barents Sea. Other expected deployments are in the Black Sea, and in the East, in both the Sea of Japan and off Sakhalin Island.

(b)(1)

[redacted]

---

[1] ~~(S)~~ While the AWACS can perform the GCI function, the end game--conversion and intercept--is still governed by the fighter capability. The FOXBAT look-down shoot-down capability should materially enhance this portion of the battle.

(b)(1)

[redacted]

VII. ANTI-AIRCRAFT ARTILLERY (AAA)

(U) The last defensive component considered is the Soviet AAA force. Because of their limited ranges,[1] these weapons cannot provide complete area defense coverage. They are normally associated with defense of military units such as the Soviet Combined Arms Army or with terminal defense of fixed installations.

(U) Anti-aircraft artillery was a very significant factor in U.S. combat losses over North Vietnam.[2] However, the AAA threat is considered relatively less important in general, nuclear war. The principal reason for this difference is that in the war in South East Asia, aircraft were used day after day with hundreds or thousands of sorties each day. In this circumstance, even a very low loss rate (well below one percent per sortie in North Vietnam) can be very important. However, in a general war, each bomber aircraft is expected to fly just one mission, and even if AAA exact attrition of several percent the effectiveness of the total bomber force would be reduced very little.

(b)(1)

[redacted]

[2](U) Statements relative to North Vietnam AAA are based on WSEG Report 128, Analyses of Combat Aircraft losses in Southeast Asia, April 1968.

(b)(1)

(b)(1)

(b)(1)

[redacted]

APPENDIX B

BOMBER FORCE CHARACTERISTICS

APPENDIX B

(b)(1)

II. ROUTING CONSIDERATIONS

(b)(1)

[redacted]

[1](U) Reference USAF PD 71-1.

(b)(1)

[redacted]

[redacted]

I. FORCE LEVELS

(b)(1)

[redacted]

(b)(1)

THIS DOCUMENT

COULD NOT BE

REPRODUCED BASED

ON SIZE OR

CONFIGURATION.

III. BOMBER LOADINGS

(b)(1) [redacted]

(U) Based on the above factors the SRAM force loadings are shown in Table B-4.

Table B-4 ~~(TS)~~. SRAM LOADINGS[a] FOR 525 UE (U)

(b)(1) [redacted]

[1](U) Unit equipment.

(U) A breakdown of the weapons on alert is shown in Table B-5.

(b)(1)

[redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

[redacted]

(b)(1),(b)(3):42 USC § 2168 (a) (1) (C)

[redacted]

[redacted]

IV. PERFORMANCE

A. AIRCRAFT

(U) Once bases and payloads have been ascertained, the range performance of the bomber types is required to determine what targets can be reached. In general, the range performance depends on the payload (and the amount carried externally), where the payload is dropped, the amount and location (fraction of mission) of low altitude flight, and the type of refueling(s) performed.

(b)(1)

[redacted]

(U) Table B-7 gives the increment in range for the types of refuelings assumed and Table B-8 shows the range ratio between high and low altitude flight.

(b)(1)

(b)(1)

(b)(1)

APPENDIX C

DERIVATION OF CONSTANTS AND EQUATIONS USED IN BOMBALL ATTRITION CALCULATIONS

I. INTRODUCTION

A. PURPOSE

(U) The purpose of this discussion is to present the data used in the probability of arrival calculations used in BOMBALL. The objective of this was to present an aggregated defense capability based on performance and quantities of the individual defense system components. Due to the nature of their operation, this analysis is primarily focused on the attrition associated with the area defenses.

B. SCOPE

(b)(1)

[redacted]

(U) One of the major efforts which had to be accomplished was to relate the performance of individual defense components in such a way that the system capability could be derived. Moreover, this had to be expressed in such a manner that one could identify the reduction of this capability as weapons were allocated against the defensive system. The reason for this approach was that both the defense capability and its vulnerability are known on a component basis, but the results were required in terms of the system performance against a total attack. This is complicated by the fact that not all defensive components (even those of the area defenses) can engage all portions of the attacking force, nor will they be simultaneously destroyed.

(U) The consideration of the defense sought to represent the capabilities of the terminal (located at the target) and area defenses. The area defenses were considered with and without AWACS.

II. AREA DEFENSES

(b)(1)

[redacted]

A. EQUATIONS FOR SURVIVAL PROBABILITY

(U) The physical situation modeled, then, is one in which the fighters search an area for the bombers and the bombers encounter the fighters on a random basis. Given that the bomber force is engaged by a fighter with kill of probability P_{ka}, the fraction of surviving bombers (or the probability of survival, P_s) is

$$P_s = \frac{N_{B1}\,(1-P_{ka})^{N_1} + N_{B2}\,(1-P_{ka})^{N_2} + \ldots N_{Bo}}{\sum_{i=o}^{k} N_{Bi}}$$

where:

N_i = number of attacks

N_{Bi} = number of bombers attacked N_i times

N_{Bo} = number of bombers in the force not attacked.

(U) Neglecting integer constraints the force probability of survival is minimized when the attacks are split between bombers in such a manner that all N_i are equal, and $N_{Bo} = 0$. Then, neglecting integer constraints,

$$P_s = (1 - P_{ka})^{A/B}$$

where A is the total number of attacks and B is the total number of bombers.

(U) Since the individual distribution of the number of attacks on each bomber is unknown, the worst situation, as represented by the above equation, will be assumed. In this equation, P_{ka} is the probability of kill given a detection.

(U) The number of attacks made on the bomber force is assumed to be the expected number of intercepts. This can be expressed as

$$P_D \times I$$

where P_D is the probability that any one fighter detects and attacks a bomber of detection, and I is the number of fighters.

(U) The fighter searches randomly within an area A, in which the bomber is located. Let the probability that the fighter can detect targets off track be $\overline{P}(x)$, when x is the distance perpendicular to the fighter flight path. This $\overline{P}(x)$ is assumed to be greater than zero out to some distance R_{max} beyond which no detection occurs (e.g., radar search range). Furthermore, the fighter covers a flight path of length L while the bomber is in the area. Let L be divided into N equal segments of length L/N and assume that since both the fighter and bomber are moving about, that the event that the bomber is detected in any one path segment is independent of the event that it is detected in any other segment.

(U) For detection to occur in any segment, two events must take place. First the target must be within the area for which detection is possible. This occurs with probability

$$P(\text{TGT WITHIN DETECTION RANGE}) = \frac{2R_{max}\ L/N}{A} .$$

Secondly, if the target is in this area, the detection probability is

$$P(\text{DETECTION GIVEN TARGET WITHIN RANGE}) = \frac{1}{2\overline{R}_{max}} \int_{-R_{max}}^{+R_{max}} \overline{P}(x)\,dx .$$

The probability of detection in any segment is

$$P(\text{DETECTION}) = \frac{2\ R_{max}\ L/N}{A} \cdot \frac{1}{\overline{2}R_{max}} \int_{-R_{max}}^{R_{max}} \overline{P}(x)\,dx$$

If it is assumed that the detection is certain within range R_{max}

$$P(\text{DETECTION}) = \frac{WL}{NA}$$

where W is the search width from the fighter.

(U) With the independence assumption already introduced, the probability that detection fails to occur during a search of N segments would be $(1 - WL/NA)^N$. The corresponding probability of detection is

$$P_D = 1 - \left(1 - \frac{WL}{NA}\right)^N$$

(U) Noting that

$$\left(1 - \frac{WL}{NA}\right)^N = e^{N \ln (1 - WL/NA)}$$

then if $\frac{WL}{NA}$ is small, the detection probability is approximately

$$P_D = 1 - e^{-WL/A}.$$

(U) If I fighters search independently in the area A, the effect is to simply increase the total length of path searched. If R is the length searched by one fighter, L = RI. Then

$$P_D = 1 - e^{-WR(I/A)}.$$

(U) The equation for the bomber force survival now becomes

$$P_s = \left[1 - P_{ka}\right]^{(1 - e^{-WR\ I/A})I/B}$$

(U) The bombers which pass through a given area do not encounter all of the fighters at once but are subject to attacks throughout the route. For this reason the parameter fighters per mile was introduced into the equation which resulted in the final form of

$$P_s = \left[1 - P_{ka}\right]^{(1 - e^{-WR\ I/A})(I/D)\ \frac{1}{B}\ x\ D}$$

where:

P_{ka} = fighter kill probability per intercept

WR = area searched by one fighter

(I/A)= fighter density

(I/D)= fighters per mile

B = number of penetrators

D = distance traveled

(U) For operation with the AWACS aircraft, it is assumed that the fighters are directed to the target at which point the end game kill probability is unchanged from that without AWACS direction (i.e., the AWACS does not change the character of the terminal encounter). Under these conditions, the bomber force survival is

$$P_{s_{AIN}} = (1 - P_{ka})^{\frac{I_{AW}}{B}}$$

when $P_{s_{AIN}}$ = probability of bomber force survival with AWACS operating

I_{AW} = fighters under AWACS control

B = number of penetrators

B. CONSTANTS FOR EQUATIONS

(b)(1)

[redacted]

(b)(1)

(b)(1) [redacted]

(U) The number of fighters of each type which were capable of supporting AWACS stations are shown in Table C-2.

Table C-2 ~~(S).~~ AWACS FIGHTER SUPPORT (U)

(b)(1) [redacted]

each type available. The kill probability used with the AWACS was based on only those aircraft which were determined to be available for support. In the case of AWACS, the penetrators were the bombers augmented by penetrating reliable decoys. The range of the ADM-20 is too small to accompany the bomber past the AWACS zone. As the bases were destroyed, the constants I/A and I/B were reduced proportionately. The fighters which supported AWACS were also proportionately reduced as the airfields were destroyed.

~~(S)~~ Based on the numbers of bombers and reliable decoys (equal to 0.74 times the number of loaded ADM-20s), the probability of the bomber force surviving the AWACS directed attacks were as shown in Table C-3.

Table C-3 ~~(S)~~ PROBABILITY OF SURVIVING AWACS ATTACKS (U)

FRACTION OF FIGHTERS SURVIVING	FORCE GENERATION CONDITION[a]	
	ALERT[b]	FULL GENERATION
1.0	0.55	0.75
.5	0.73	0.85
.25	0.85	0.92
0	1.00	1.00

[a]This is the force reaching the HHCL.

[b]Prelaunch survival is 1.0 for the 40 percent alert bombers, zero for non alert.

~~(S)~~ Current estimates of the probability of survival made by SAC are between .61 and .68 for a penetration of an AWACS defense in which the AWACS has a 200-mile radar range.

~~(S)~~ Due to the reasons discussed previously, weighted averages also had to be used for P_{ka} and WR. Based on the fighter performance the value of WR that was used was 656 and P_{ka} was 0.1 for low altitude penetrators and 0.5 for high altitude penetrators.

III. TERMINAL DEFENSES

(S) The single shot kill probabilities of various SAMs are given in Table A-1 of Appendix A of this Volume. The kill probability of the SAM terminal defenses against an aircraft then is determined by the number of missiles which can be fired. This depends on firing doctrine as well as the time and geometry of the exposure. Essentially, any exposure of an aircraft to a site will result in extremely high kill probabilities since it is likely that several shots can be fired. This is particularly true due to the overlapping nature of most site coverage, which would permit multiple sites to engage an aircraft if it is visible. Therefore, if aircraft are exposed either to SAMs due to high altitude flight, or the SA-Z-1 coverage, the probability of survival is very low. As a consequence SAM suppression is necessary in corridors of high altitude flight where the coverage cannot be avoided, and for engagements with the SA-Z-1. The terminal kill probability is that which remains after the sites have been attacked and is essentially $(1 - \overline{DE})$.[1]

(S) This assumes, of course, a perfect terminal defense. Even if the SAM kill probability dropped to 0.7, the DE requirements on the sites for a given level of survival do not significantly change. Additionally, it was found that this range did not affect the numbers of weapons allocated for SAM site destruction. For all penetrators, a few percent kill probability was also retained to account for AAA defenses.

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[1](S) $\overline{DE}$ is the damage expectancy to the terminal defense sites averaged over all sites which may engage the penetrator.

Appendix D

BOMBALL--A BOMBER ALLOCATION MODEL

APPENDIX D

I. GENERAL DESCRIPTION OF THE BOMBALL MODEL

A. PURPOSE

(U) The BOMBALL computer model was designed to assist in solving the problem of efficiently allocating bomber-delivered weapons against a specific strategic structure, taking into account the bomber's range constraints, the weapon capabilities against the target structure, and the enemy defenses. It employs a marginal gain approach; i.e., it allocates targets in such a way as to maximize the value destroyed for each sortie, in sequence. It is realized that this is not an optimum solution to the problem, but the determination of such an optimum is not a feasible task, since it would require the generation of all possible allocations.

B. BASIC STRUCTURE OF BOMBALL MODEL

(U) The basic problem which the BOMBALL model attacks is "the choice" of targets for attack by each bomber out of a given list of potential targets. Each bomber is assumed to carry four weapons which are to be delivered to four distinct targets; i.e., a bomber cannot reattack a target it has already attacked. Although there is in concept no reason why this could not be altered to accommodate some number of weapons other than four, this would require the addition of sections of logic to the program and require additional storage space for new arrays; therefore, it would not be a simple input change.

(U) The method by which the "best" sortie is chosen for a given bomber involves the enumeration of all feasible sorties (any set of four targets which are within the bomber's range constraint) except that the enumeration is greatly reduced by the use of algorithms designed for that purpose. These algorithms will be fully described in following sections.

(U) For every potential sortie which is generated, the total damage expectancy is calculated. The damage expected at each target attacked is the product of the probability of damage to that target by the weapon carried, the current value of that target, and the probability of arrival (PA) of the weapon at that target. After each attack, the values of attacked targets are decremented by the damage expected at that target.

(U) The equations used to get the probability of damage to each target are tailored to fit the data base being used, but can easily be changed if needed to accommodate some other data base. Similarly, the equations which are used to calculate the PA can easily be changed if the user prefers to use other attrition equations.

(U) Thus, there are really three categories of possible changes in the BOMBALL model:

1. The normal change of input parameters (as read in by cards) or of a data base, to another of the same type and format as the one currently in use.
2. Easily made program changes such as shifting to a data base of a different type, which requires calculation of damage probabilities from a different equation, use of different weapon characteristics, or a change in assumed attrition equations.
3. Changes which require addition to, or reconstruction of, some of the logic of the model but which still follow the basic model logic, such as a change in the number of weapons carried per bomber or in the assumption that terminal defenses are the same for all targets or that the suppression of enemy fighters is uniform over all areas.

C. INPUTS TO THE BOMBALL MODEL

(U) A given run of BOMBALL assumes a particular data base, a given weapon, a specific bomber campaign (set of bases, exit-entry points, numbers of sorties, altitudes, etc.), a set of assumptions about the enemy's fighter defenses, and an assumption about our suppression of these defenses. The detailed requirements for each category of inputs are given in the following paragraphs:

1. Data Base and Weapon Capabilities Against It

(U) The data base used must contain a list of potential targets, and for each of these targets, a location (latitude and longitude), a rank (which can be based on any ordering of targets), a value (based on any desired criterion), and the single-shot kill probabilities of the weapon against each target (or, alternatively, the data required to calculate the damage from given weapon characteristics, along with the appropriate equation changes in the program). The assumed reliability of the weapon[1] is also an input.

2. Bomber Campaign

(U) A given campaign is defined as a sequence of "attack groups." Each attack group is defined as a combination of exit and entry points, total range (determined by a separate program--see next section), the number of bombers in the group, and the flight altitude (HI or LO). In addition, there is available an optional limitation which specifies that only targets to the east (or west) of the exit-entry line shall be attacked; or if exit and entry points are at the same latitude, only targets to the south (or north).

[1](U) The model assumes a single type of bomber weapon is used.

3. The Enemy's Fighter Defenses

(U) For the area of interest in a particular attack group, within the footprint, two input parameters describe the area defense levels; namely, I/A, the number of interceptors per unit area, and I/BD, the number of interceptors encountered per mile[1] per bomber.

(U) For the campaign as a whole, the capabilities of the enemy defenses are described by the quantities PKAREA, the single-encounter kill probability of the fighter aircraft against the bomber, and PST, the probability of the bomber surviving a target's terminal defenses. These two values are chosen for each attack group from a set of two input values; one for high altitude attacks and one for low altitude attacks. This enables one to take account of the greater penetration capabilities of low altitude attacks. There is also an input, PSAIN, which is the probability of surviving the AWACS defenses, if any, and an input, FUDGE, which is the percentage of enemy fighters remaining after suppression attacks (e.g., FUDGE = 0 means no fighters available to attack the bombers).

D. CALCULATION OF RANGE CONSTRAINTS

(U) Each "attack group" in a campaign is originally defined by:

1. The location (latitude and longitude) of:
    a. Bomber base.
    b. HHCL.
    c. Entry and exit points.
    d. Recovery base.
2. The bomber characteristics, namely:
    a. The HILO ratio (conversion factor between low altitude and high altitude range capability).

---

[1](U) For further explanation of these inputs, see Appendix C.

b. The maximum unrefueled range capability (for specified payload).

c. The additional range made available by refueling.

3. The altitude at which the attack is flown (HI or LO).

(U) Once the above sets of inputs have been defined, and before the first run on BOMBALL can be made for a specified number of sorties in each attack group, the range constraints for each group must be determined, since these are required inputs to the BOMBALL model.

(U) This is done in a short preliminary program called GETRANGE which, using the inputs described above, computes for each attack group the total range, RTOTAL, which can be flown from entry point to all four targets and back to exit point. This determines the bomber footprint within which all feasible targets must lie. In addition, the GETRANGE program will print out the order of attack groups such that their range constraints are in increasing order. This appears to be a sensible order in which to sequence the attacks, on the theory that the bombers with fewest targets to choose from should have first choice of targets. However BOMBALL will fly the attacks in any order desired, as determined by the sequencing of the input cards.

E. ATTRITION ASSUMPTIONS

(U) The levels of enemy area defenses encountered by each attack group are reflected in the associated inputs, I/A and I/BD. Within the footprint defined by the associated range constraint, these fighter defenses are assumed to be uniformly distributed, so that attrition is a direct function of range exposed. In the original BOMBALL model the terminal defenses were assumed to be of equal magnitude for all targets. In a later version, called BOMBALL 3, distinction is made between targets which are or are not defended by SAM sites. The details of this version are described in Chapter II, Section D of this appendix.

(U) Although the BOMBALL model does not directly allocate weapons to defense suppression, it can reflect the effect of such suppression by changes in input parameters. The effect of suppression of terminal defenses is simply reflected in a higher input value for PST. Wherever the quantities I/A and I/BD are used in the equations which calculate attrition to enemy area defenses, they are multiplied by a so-called FUDGE factor. When FUDGE is equal to 1, we are assuming the total number of fighters (based on our estimates) to be present in each area. When FUDGE is 0.5, half of the area defenses are assumed to be suppressed. This suppression applies uniformly over the entire target area. Also in determining the input value of PSAIN, the reduced number of fighters associated with the FUDGE factor is taken into account.

F. THE PROBLEM OF SORTIE GENERATION

(U) For a particular entry-exit point and range combination, one can immediately restrict the list of feasible targets in the data base to those which fall within the bomber footprint and satisfy any given restrictions regarding on which side of the exit-entry line they lie.

(U) Working with this feasible target list, one could, in principle, generate all possible combinations of four targets which satisfy the range constraint, calculate for each the associated damage expected, and pick the one which yields the greatest total damage expected.

(U) However, this turns out to be impractical. For even with high-speed computers, the time required to generate the vast numbers of combinations possible with as few as 30-40 feasible targets is prohibitive. Since target values change in the interim, this procedure would have to be repeated after each attack made. It therefore becomes essential to devise some scheme to shorten this procedure.

G. GEOMETRIC CONSIDERATIONS

(U) In order to cut down on the number of possible attacks to be considered, at first an attempt was made to devise algorithms which would restrict the set in some way relating to the configuration of the attack route, in hope of discarding obviously inefficient routes.

(U) It is clear that if all targets had exactly the same values and were equally damaged by the weapon, then the problem of selecting four targets for a sortie would be reduced to one of minimizing the bomber's exposure time (or equivalently, the range flown) in order to minimize attrition from area defenses. Under these conditions, the problem would indeed become one of geometry. The question that arises is what criterion should be used to determine, a priori, whether an attack plan is inefficient. The criterion used must be one which is quick and simple to obtain and does not require repetitive calculations to apply.

(U) The following illustrates a criterion which could be used but would not meet the above conditions. In Fig. D-1, three attack routes are shown for the same set of four targets. Obviously route (C) is the only efficient one of the three. One might require that an efficient path be one in which the sum of the angles of turn involved not exceed a specified sum (possibly, 360°) to avoid zigzag type routes. However, the calculations required to determine the sum of the angles of turn would be more complicated and time consuming than the calculation of damage expected if the inefficient attack were made, so this approach would be self-defeating.

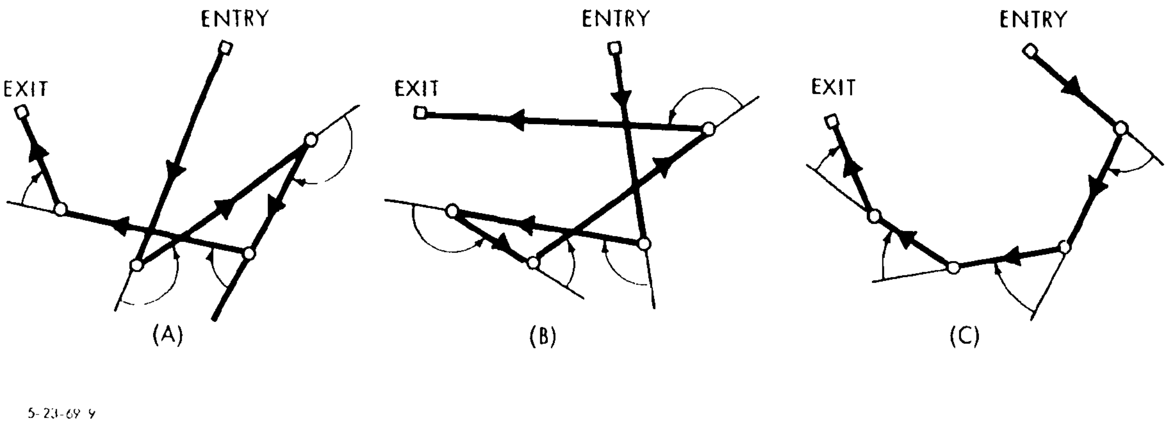

FIGURE D-1 (U).

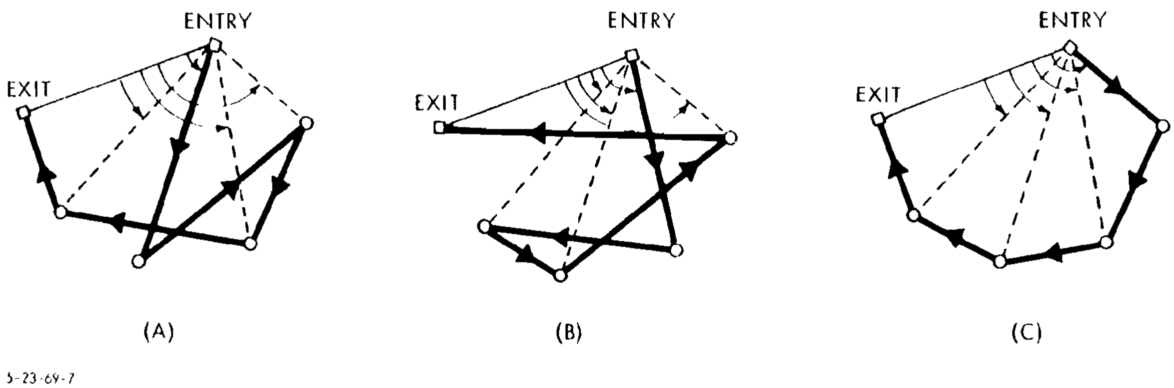

FIGURE D-2 (U).

(U) However, in Fig. D-2, for the same set of attack routes, this time consider the angles, α(i), between the exit-entry line and the line from entry to ith target. It appears that a reasonable criterion for an efficient flight path would be that the alpha angles must be constantly decreasing. To allow a bit more flexibility the "Alpha Algorithm" adopted states that if four targets are attacked in order i1, i2, i3, i4 it is required that

$\alpha(i4) \leq \alpha(i3) + \Delta\alpha$

$\alpha(i3) \leq \alpha(i2) + \Delta\alpha$

$\alpha(i2) \leq \alpha(i1) + \Delta\alpha$, where $\Delta\alpha$ is a program input.

(U) Since the alpha angles need only be calculated once for each target and stored, the testing is quick. Furthermore at each stage of target selection for a particular sortie, the list of targets still available at the next stage is reduced by all targets which do not meet this criterion as well as those which do not meet the range constraint, so that the set of remaining available choices collapses rapidly.

(U) This scheme was tried on a case in which there were 33 feasible targets and a range constraint such that, based on range limits alone, there were over 36,000 feasible sorties. Use of the "Alpha Algorithm" with $\Delta\alpha = 5^\circ$ reduced the list to about 20,000 sorties with no appreciable change in the total damage expected.

(U) Unfortunately the use of this type of algorithm has drawbacks. It involves otherwise unnecessary calculations, it does not cut the time by an order of magnitude, and it is not easy to tell how much the attacks and associated damage have been affected by its use. For almost any geometrical criterion one adopts, it is possible to find occasional exceptions.

H. REDUCING TARGET LIST ON BASIS OF EXPECTED VALUE DESTROYED

(U) The previous section discussed the case in which all potential targets have the same value and same probability of being damaged, so that the criteria for selecting a sortie became minimization of area attrition by minimizing range flown.

(U) If, on the other hand, there were no area defenses to consider, the target selection would be based solely on the "expected value destroyed" if the target were hit. Thus, if the four targets which had the highest 'evd' values could be attacked in some order without exceeding the range constraint, that sortie would be selected.

(U) Of course, neither extreme applies; i.e., all targets are not of equal value and there is some expected area attrition. So neither minimum range nor maximum expected value destroyed is the sole determining factor, but some combination of the two.

(U) After making various test runs for several attack areas using different assumptions about levels of defenses and calculating PAs at each target for all feasible sorties, it became apparent from the results that for any given exit, entry, and range combination, there was very little variation in attrition over the set of feasible sorties. The ranges for the feasible sorties did not fluctuate greatly, so that, in effect, the expected value destroyed if hit became the predominant factor in target selection. Thus it was felt that the list of feasible targets could be reduced to a much smaller list of the targets with the highest evd values, and from this reduced list all feasible sorties generated to determine the best one.

(U) To illustrate the type of reduction obtainable by shortening the target list, consider the number of 4-target sorties which can be generated with a list of N targets. Ignore for the moment the fact that some of these sets will not satisfy the range constraint. The number of such sets is $\frac{N!}{(N-4)!}$ (see Table D-1). Since most of the program time is spent in generating and testing these target sets, it is clear that cutting the target list considerably would reduce the time by a very large factor.

(U) The scheme actually used in BOMBALL to select the reduced target list works as follows: For each new attack group, the target tape is searched to obtain a list of feasible targets. The tape search may be limited to a subset of

Table D-1 (U).

N	Number of Possible Ordered 4-Target Sets
10	5,040
20	116,280
30	657,720
40	2,193,360

the data base by specifying an input, MAXRANK, which is the maximum target rank of interest. For example, if the targets are ranked by value, and practically all the value is contained in the first N targets, one could reduce running time by limiting MAXRANK to the value N. The target values are updated for targets which have already been attacked. The expected value destroyed, if hit, is calculated for each of these targets and listed in order by evd so that the first target on the list is the "best" potential target.

(U) The average evd of the first four targets on the list is obtained. Only those targets whose evd is greater than half of this value are included in the reduced target list. A modification to this rule is provided by a set of inputs called LEASTLO, MOSTLO, LEASTHI, MOSTHI, which provide lower and upper bounds to the size of the reduced target lists for low and high altitude attacks, respectively. These bounds can be used to control the amount of time required to make runs. In general these bounds should be made higher for low altitude attacks because with the same size target list many of the sorties generated for low altitude attacks will be rejected because of range limitations.

(U) In a sample case that was run to test this scheme, the use of this rule reduced the target list from one of 33 feasible targets with over 36,000 feasible sorties to one of 12 targets with 169 feasible sorties without affecting the total damage expected or total value attacked.

I. DAMAGE CALCULATIONS

(U) Each time a feasible sortie is generated from the reduced target list, the damage expected as a result of making this attack, VLOST, can be obtained by calling a DESTROY subroutine. When the reduced target list is determined, the ranges from entry and exit to each target and between each pair of targets are computed and stored for use in the attrition equations. The damage expected at a target is obtained by multiplying the calculated PA at that target by the expected value destroyed for that target.

(U) In practice, the damage calculations for many of the sorties are bypassed in the following way: As the sorties are generated and damage calculations are made, the sortie which has up to that point yielded maximum damage expected[1] is saved and its damage expectancy stored as VALMAX. Each time a new sortie is generated, a quickly calculated upper limit on potential damage expected, VLMAX, is computed and compared with VALMAX. If it is less than VALMAX the damage calculation is bypassed since this sortie is not a possible candidate for best attack. The VLMAX upper limit is computed by ignoring attrition after the first target. Thus

$$\text{VLMAX} = \text{PA}(1) \sum_{i=1}^{4} \text{EVD}(i) \ .$$

(U) Furthermore, after a particular attack group has selected its 'best' sortie for a first attack (with damage

[1](U) At this point the term "damage expected" includes in it the probability of arrival, as distinct from "expected value destroyed" which does not.

expectancy = VALMAX) and is scheduled to make another attack, one can immediately assume that the value of VALMAX for the next attack will be at least equal to the value which would be destroyed if the identical attack were repeated. Therefore, when feasible sorties are generated for attacks subsequent to the first one of a group, the initial value of VALMAX, rather than being set to 0, is set to that value which would be destroyed if the same set of four targets were reattacked, taking into account the reduced values of these targets. This further reduces the number of times the DESTROY subroutine is called.

J. PLOTTING CAPABILITY

(U) The BOMBALL model has built into it the capability of generating an overlay plot for one of the USAF Aerospace Planning Charts of the area of interest. A set of plotting parameters are input. These parameters vary with the scale of the reference map used. The plot output of a run contains three reference points for alignment with reference map and shows each attack made in the campaign, each attack shown as a line from entry to each target in succession and to exit point. The entry and exit points are indicated in symbols ⏀ and △ respectively. Numerals to the left of the entry and exit point symbols were intended to indicate the sequencing of attack groups. However, the same entry and exit points appear in several attack groups, causing an overwrite of numerals, so this feature is of dubious value. The plot label contains a description of the campaign and the date. Figure D-3 is an illustration of one such plot output.

THIS DOCUMENT

COULD NOT BE

REPRODUCED BASED

ON SIZE OR

CONFIGURATION.

K. BOMBALL PRINTER OUTPUT

(U) The following printouts are obtained in a BOMBALL run:

1. On each page: an alphanumeric description of the data base and of the campaign.

2. For each attack group, in sequence:

   a. The input parameters.

   b. The number of feasible targets (a list of these is optionally available).

   c. A list of the targets on the reduced target list with rank, latitude, longitude, current value, expected value destroyed.[1]

   d. The number of feasible target sets generated (an optional printout of all these sorties on tape is available).

   e. For each attack made: the four targets, range, target values destroyed, total value destroyed, probability of arrivals.

   f. After all attacks in a group: a revised list of targets in reduced list--with rank, number of attacks made, value remaining, expected value destroyed.

   g. A summary for this group: total initial value, total attacked value, total destroyed value, percent initial value destroyed, percent attacked, value destroyed. (An illustration of the output for a particular attack group is shown in Fig. D-4.)

3. Summary for the entire campaign.

   a. A table listing for each target up to MAXRANK:

      (1) The number of attacks on it.

      (2) The initial value.

      (3) The remaining value.

      (4) The expected value destroyed, if hit originally.

      (5) The expected value destroyed, if hit at end of campaign.

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[1](U) And in the case of the BOMBALL 3 version, also the product (evd)(PST).

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b. Total values:

(1) Initial value.

(2) Attacked value.

(3) Destroyed value.

c. Percentages:

(1) Percent of initial value destroyed.

(2) Percent of initial value attacked.

(3) Percent of attacked value destroyed.

d. Number of attacks made.

e. The average probability of arrival (over all target attacks).

(U) A partial listing of the summary output for a particular run is shown in Fig. D-5 (targets of rank greater than 54 have been deleted).

L. GENERAL TIMING CONSIDERATIONS

(U) The time required for a BOMBALL run increases of course with the size of the campaign. But it is, to an even greater extent, dependent on the choice of the inputs LEASTLO, MOSTLO, LEASTHI, MOSTHI, and to a lesser extent, MAXRANK. It is possible by making a few experimental runs with different values to get a feel for the size of the limits required to get accurate results. In general, the bulk of the time is spent in generating sorties for high altitude attacks, so that the biggest time saving is achieved if MOSTHI can be made fairly small. This can be done without loss of accuracy if in setting up the attack sequence for a campaign one does not include more than two bombers in a high-altitude-attack group. To do this, for example, a four-bomber-high-altitude attack would merely be broken up into two identical sequential two-bomber attacks. This merely forces the model to reevaluate the target list after the first two attacks and choose new

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targets on the basis of the new order, rather than to be confined to the same target set, which may no longer be the best potential targets.

(U) An indication of the time required for production runs is given by Table D-2.

Table D-2 (U).

No. of Weapons in Campaign	Bounds on Size of Target List		Approximate Run Time
	Low Altitude	High Altitude	
100	15-20	10-15	30 min.
200	15-20	10-15	50 min.
		8-12	30 min.
300	15-20	8-12	40 min.
500	15-20	8-12	50 min.
720	15-20	8-12	75 min.

(U) It is however impossible to generalize about such things as the proper choice of bounds on the target list size, or the maximum/minimum number of sorties to include in an attack, as these would be likely to vary for different data bases, types of campaigns, etc. The point to be made, however, is that before proceeding to make a set of runs based on a given data base and campaign, it would be worthwhile to make a few experimental runs using the base case with FUDGE = 0; then study the attacks generated to see how much the reduced target list size could reasonably be limited. For example, if one set the upper bound of the list size as 20 and found that the actual attacks generated never included more than the first 8 or 9 targets on the list, one could with confidence reset the upper bound to 10 and save considerable time in making a complete set of runs.

(U) Whereas the preceding discussion has been concerned with the general capabilities and methodology of the BOMBALL Program, the following sections will be concerned with the specific way in which it has been used in this study.

II. SPECIFIC APPLICATIONS OF BOMBALL IN BOMBER EMPLOYMENT STUDIES

A. TARGET DATA BASE AND WEAPON CAPABILITIES

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[1](U) For more details about this procedure, see Volume III.

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B. ERRORS CAUSED BY USE OF THIS DATA BASE

(U) It is recognized that the way in which the data base is extrapolated subjects the calculations to errors from several sources.

(U) Since the damage match is made only at one point and for a specific number of weapons, and the number of weapons applied to a target by the BOMBALL model will often differ from this number of weapons, a source of error is thus introduced in the damage calculations.

(U) The single-shot kill probabilities for the single point damage match data base were derived using a PA of 0.5. It was assumed that for other PAs the single-shot kill probabilities could be proportionally scaled, i.e., SSKP = SSKP(PA = 0.5) X $\frac{PA}{0.5}$. Excursions with the data base have indicated that this scaling is not quite correct.

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(U) Alternative approaches to eliminate these sources of error would involve using BOMBALL to drive a MARGEN[1]-type calculation for each target city, taking into account the different arrival probabilities. From a practical point of view, however, these calculations would be so lengthy as to be infeasible.

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[1](U) For details of calculations made in this program, see Volume III.

C. ATTRITION EQUATIONS

(U) In making an assignment of four targets to a given bomber, the PA at the jth target, j = 1,4 was calculated from the following equations:

$$PA(1) = PST \cdot PSAIN \cdot (1 - PKAREA)^{AREAK \cdot R(0,1)} \qquad (D\text{-}5)$$

PA(j) For j > 1

$$= PST \cdot PA(j - 1) \cdot (1 - PKAREA)^{AREAK \cdot R(j,j-1)} \qquad (D\text{-}6)$$

where PSAIN is the probability of surviving AWACS defenses

PST is the probability of surviving terminal defenses at any target

PKAREA is the kill probability of the fighter against the bomber

R(0,1) is the range from entry point to first target attacked

R(j,j-1) is the range from previous target to jth target

and

$$AREAK = (1 - e^{-656\ FUDGE \cdot I/A})(FUDGE \cdot I/BD) \qquad (D\text{-}7)$$

D. BOMBALL3, IN WHICH SAM SITES ARE CONSIDERED

(U) In the original BOMBALL model, it was assumed that the probability of surviving terminal defenses is the same regardless of which target is attacked. In a later version, called BOMBALL3, terminal defenses are handled differently. In this model, information is given for each target as to whether it does or does not have SAM sites defending against (a) LO and (b) HI altitude attacks. When a sortie is flown, the probability of surviving terminal defenses (PST) at each target is either (a) 0.95,[1] if there are no SAM sites defending against the attack at altitude being flown, or (b) PST (= PSTHI or PSTLO), if there are SAM sites defending against attack at the

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altitude flown. The value of PST used is a measure of our assumed success in suppressing these SAM sites.

(U) The only condition under which BOMBALL and BOMBALL3 could be expected to produce identical results is that for PSTHI = PSTLO = 0.95, in which case defended and undefended cities are treated exactly alike. When PST (HI and LO) = 0.9, BOMBALL3 should and did yield a slightly improved total value destroyed because of the bonus obtained when attacking undefended cities. When PST (HI and LO) = 0.5, the improvement is significant. The difference is illustrated in Table D-3 which shows results for the 240 weapon fully generated force with no area attrition, both with PST = 0.9 and PST = 0.5.

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(U) Because of the bonus obtained by attacking undefended cities, it is no longer reasonable to choose the reduced target list on the basis of highest evd values alone. Clearly an undefended target with evd = 2000 (PST = 0.95) will yield more than a defended target with evd = 3000 and PST = 0.5, regardless of the area attrition levels. A better measure to use in choosing the list of best potential targets for BOMBALL3 was found to be (evd)(PST), where PST is the correct value chosen according to whether or not the target is defended by SAM sites for the altitude being flown. For a sortie against four targets, some of which are defended and some not, when PST is considerably less than 0.95, it will no longer be necessarily desirable to choose the route which minimizes the distance flown. It is more important to fly in such an order that the undefended cities are attacked first; for if defended cities are attacked first, the probability of ever reaching the undefended cities will be very low. Since the order in which targets can be attacked and still satisfy the range constraint becomes more critical than in the original BOMBALL model, it is important to let the reduced target list be long enough to allow more leeway in choice of targets, i.e., pick large enough input values of MOST and LEAST. For this reason, runs with BOMBALL3 are more time consuming than with BOMBALL (by a factor of 1.5 to 2).

(U) In the runs made with the data base previously described, all targets of rank 300 or less were assumed to have SAM sites defending against HI altitude attacks, but only about one third of them were similarly defended against LO altitude attacks. For this reason MOSTHI and LEASTHI were not changed from the values used in BOMBALL runs (since MAXRANK was taken as 300), but MOSTLO and LEASTLO were increased by five targets each.

E. SENSITIVITY TO PARAMETERS OF CHOICE

(U) Given a specific size campaign with a given set of assumptions about enemy defenses, there are several ways in which the attack details can be varied, and several inputs which must be chosen. It is desirable to test the sensitivity of the results to such changes.

(U) The first of these is the order in which the attacks are made. Standard procedure has been to make the attacks in the order of increasing range capability. To test the effect of this ordering, the 100 weapon alert force campaign with FUDGE = 0 (all area defenses suppressed) was run, with the order of attack reversed. The results of both runs is summarized in Table D-4, which shows that the difference is not significant.

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(U) The results of these runs and the specific makeup of the various campaigns are detailed in Table D-5. Other than the more favorable results obtained in Case 1, when high altitude flights are eliminated there is really very little change in the results.

(U) Finally, there remains the question of how sensitive the results are to those inputs which determine the length of the run and the amount of choice involved (namely, MAXRANK, LEASTLO, MOSTLO, LEASTHI, MOSTHI).

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Table D-6 (U)

RUN	1	2	3
MAXRANK	300	500	300
BOUNDS ON TARGET LIST			
-LO ALT.	15-20	20-25	10-15
-HI ALT.	8-12	15-20	6-10
App. Time to Run	32 Min.	80 Min.	20 Min.
% Initial Value Destroyed	65.5	65.4	65.5
% Initial Value Attacked	80.6	80.6	79.7
% Attacked Value Destroyed	81.2	81.1	82.2

F. CONCLUSIONS OF SENSITIVITY STUDIES

(U) The results of all sensitivity studies made seem to point to one conclusion. Within the limits of accuracy which one can expect from this type of calculation, there are in the final results very little sensitivity to order of attacks, reasonable switching of number of sorties per attack group, or reasonable choices of the timing constants. Although the details of the attacks generated will vary, the total value destroyed will not be changed much. This seems logical because so many of the attack groups have overlapping footprints--i.e., the same set of targets are available at many times, and what one group misses will be hit by another group. As long as they are within reach of some attacking bomber, the "best" potential targets will be repeatedly bombed until their value is reduced to the point that they are no longer "best" potential targets. In other words, the attack has the effect of flattening out the final "evd" array to the extent possible with the given numbers of bombers and range constraints.

APPENDIX E

VULNERABILITY OF DEFENSE INSTALLATIONS

VULNERABILITY OF DEFENSE INSTALLATIONS

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missile, due to its yield, will require multiple warheads to be placed on the hardest SAMs, airfields and almost all command and control sites.

Table E-1 ~~(S)~~. PROBABILITY OF DESTRUCTION[c] AGAINST DEFENSE INSTALLATIONS (U)

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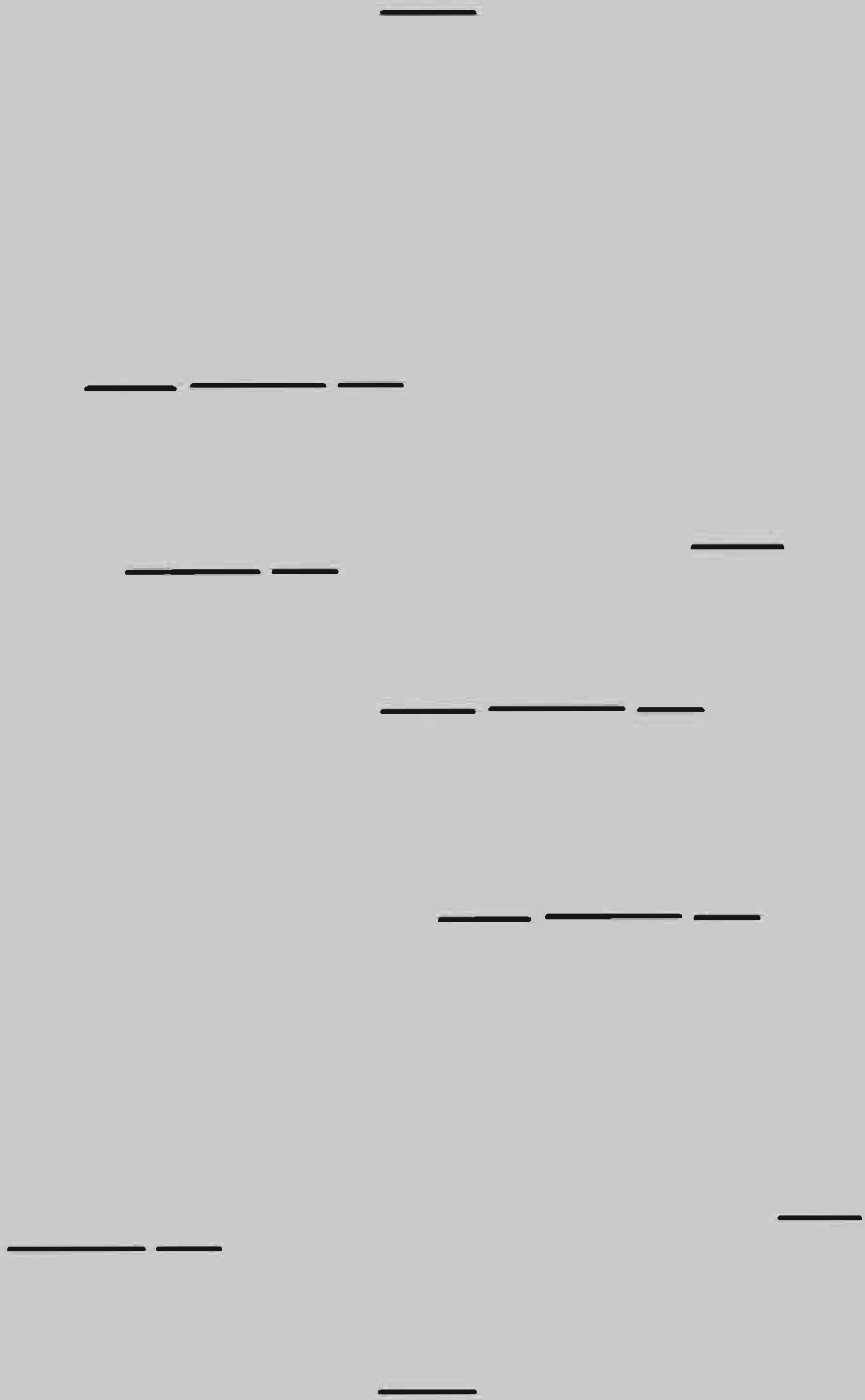

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