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WEAPONS SYSTEMS EVALUATION GROUP
ODDR&E
Washington 25, D. C.

SECOND VOLUME OF

ENCLOSURE "A"

EVALUATION OF PROGRAMMED STRATEGIC OFFENSIVE SYSTEMS 1964-1967

WSEG REPORT NO. 50

27 December 1960

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Second Volume of
Enclosure "A"
WSEG Report No. 50

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SECOND VOLUME OF

ENCLOSURE "A"

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APPENDIX "B" TO ENCLOSURE "A"

MEASURE OF EFFECTIVENESS FOR "POWER LAW" TARGETS

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MEASURE OF EFFECTIVENESS FOR "POWER LAW" TARGETS

INTRODUCTION

The purpose of this Appendix is to describe a measure of effectiveness for weapon systems employed against isolated point targets, or more generally, when employed against those categories of area targets or target complexes which obey the "power law". A target obeys the "power law" if the expected residue surviving a multiple weapon attack can be expressed as the product of the expected surviving residues from each weapon delivered singly.[1/]

This measure is an improvement over measures that assume infinite divisibility of weapons. By including the constraint that weapons may only be delivered in integral numbers, the measure is more precise, and in particular avoids the large errors which can otherwise occur in the case of kill probabilities approaching unity.

DERIVATION

The present measure is based upon a determination of the actual number of weapons (in inventory) required to produce a specified amount of damage against a specified type of target. The inverse of the number so determined is then chosen as the measure of effectiveness (MOE). The measure thus has the following direct significance -- the cost of the weapon divided by this measure of its effectiveness is simply the total cost for obtaining the desired effect on a single target of specified type.

1/ Many area targets (such as urban floor space, blast casualties, ect.) for typical cities appear to follow the power law reasonably well, provided an optimal pattern of desired ground zeros is chosen.

To begin the derivation, consider the case of M missiles attacking N identical targets. Let S be the probability that a target survives any single attacking missile (the single-shot survival probability). Let $K = [M/N]$ represent the "basic coverage," where the bracket symbol is such that $[x]$ denotes the largest integer contained in x. K, therefore, represents the largest number of weapons which can be applied to every target without exceeding the total available number of weapons M. Let $L = M - NK$ denote the "excess," the number of weapons left over after applying the basic coverage to each target. These excess missiles can then be applied to L of the targets, which then have a total $K + 1$ weapons, while the remaining $N - L$ targets have had just K weapons applied to them. The expected fraction of the target system surviving is, therefore,

$$E = LS^{K+1} + (N - L)S^K = \overline{S}N \qquad (1)$$

where E is the expected number of targets in the target system surviving the attack and $\overline{S}$ is the expected fraction of the total target system surviving the attack. Equation (1) can be rewritten in the form

$$\overline{S} = S^K (1 - (L/N) (1 - S)) \qquad (2)$$

If we let $\beta = L/N (0 \leq \beta < 1)$ represent the fraction of the target system to which $K + 1$ weapons are applied, and let $\alpha = K + \beta$ then $\alpha = M/N$ represents the average number of weapons which must be delivered against each target in the target system to achieve the desired overall effect.

Its reciprocal is the desired measure of effectiveness we seek:

$$MOE = 1/\alpha. \tag{3}$$

In order to determine α Equation (2) may be rewritten in the form:

$$\overline{S} = S^K(1 - \beta(1 - S)) \tag{4}$$

which must now be solved for K and β.

Consider for the moment the new equation

$$\overline{S} = S^{K'} \tag{5}$$

where the parameter K' is allowed to take on any real number. If we identify K' with the quantity $K + \beta$ it will be observed that Equations (4) and (5) coincide for all integral values of K'. Now Equation (5) has the solution

$$K' = \ln \overline{S}/\ln S. \tag{6}$$

We can now determine the parameter K in Equation (4). Because Equations (4) and (5) agree for integral values of K' it follows that K must be the largest integer contained in K', so that

$$K = [\ln \overline{S}/\ln S]. \tag{7}$$

It remains now only to determine the value of β. Rearrangement of Equation (4) leads to the solution for β:

$$\beta = (1 - \overline{S}/S^K)/(1 - S). \tag{8}$$

The formulas may be simplified by introducing the following new notation:

$$\mu = \ln \overline{S}/\ln S$$
$$\delta = \mu - [\mu]. \tag{9}$$

μ represents the theoretical number of weapons which would be required if the weapons were infinitely divisible. It is identical to the earlier measure used occasionally by WSEG. δ represents the departure of this theoretical number from integrality. From Equation (7) we have that $K = [\mu] = \mu - \delta$, so that

$$\alpha = K + \beta = \mu - \delta + (1 - \overline{S}/S^{\mu-\delta})/(1 - S) \quad (10)$$

which is simply reduced to the form

$$\alpha = \mu - \delta + (1 - S^{\delta})/(1 - S) . \quad (11)$$

The term $(1 - S^{\delta})/(1 - S) - \delta$ in Equation (11) can be regarded as the term which corrects the measure of effectiveness for the effects of the constraint to integral numbers of weapons.

Summarizing the preceding, the following set of equations is to be used to determine the measure of effectiveness:

$$\mu = \ln \overline{S} / \ln S \quad (12a)$$

$$\delta = \mu - [\mu] \quad (12b)$$

$$\alpha = \mu - \delta + (1 - S^{\delta})/(1 - S) \quad (12c)$$

INCLUSION OF OPERATIONAL FACTORS

The inclusion of the operational factors of reliability, penetrability, survivability, and reprogrammability, will now be developed. We shall recognize three subdivisions of the operational reliability of a weapon system, the on-launcher reliability denoted by RL, The inflight reliability denoted by RF, and the terminal reliability denoted by RT. The on-launcher reliability, RL, denotes the probability that a missile on-launcher will be successfully counted down to the point of lift-off. The inflight reliability, RF, denotes the probability that a missile will perform without malfunction through the burning phase, and terminal reliability, RT, denotes the probability that the missile will successfully re-enter and detonate. In addition, we shall include the effect of the penetrability, P, the probability that the delivery vehicle will successfully penetrate any active defenses, and the survivability, Q, the probability that the delivery vehicle survives an enemy attack prior to its launch. Finally, we shall treat three degrees of reprogrammability for the weapon systems, "full" reprogrammability -- the case in which all failures prior to burn-out are detectable and correctable by the retargeting of subsequent missiles, partial reprogramming -- the case when only those failures which occur prior to lift-off are detectable and correctable by retargeting of backup weapons, and the case of no reprogramming where each missile is irrevocably committed to a single target from the beginning.

The determination of the measure of effectiveness, including these operation parameters, will now be considered. As before, let $\overline{S}$ denote the required damage criteria (the required minimum target survival probability). Let SSKP denote the single-shot kill probability for a successfully detonated weapon against the target class considered. The SSKP is, therefore, a function of the yield of the weapon, the delivery accuracy of the weapon, and the target vulnerability only and does not depend upon the other operational factors. Define the non-reprogrammable degradation factor, RN, as follows, depending upon the degree of reprogramming assumed:

$$RN = \begin{cases} Q \cdot RL \cdot RF \cdot RT \cdot P & \text{(no reprogramming)} \\ RF \cdot RT \cdot P & \text{(partial reprogramming)} \\ RT \cdot P & \text{("full" reprogramming)} \end{cases} \qquad (13)$$

RN, therefore, represents the fraction of the original force, for which no correctable failures have been detected, which will successfully detonate in the vicinity of the target. Let RR denote the reprogrammable degradation factor defined as follows:

$$RR = \begin{cases} 1 & \text{(no reprogramming)} \\ Q \cdot RL & \text{(partial reprogramming)} \\ Q \cdot RL \cdot RF & \text{("full" reprogramming)} \end{cases} \qquad (14)$$

The fraction of the original force which fails in such a way as to be detected, and for which standby weapons can be retargeted is, therefore, represented by $1 - RR$.

The effective single-shot survival probability of a target for a weapon whose failure is not detected or corrected is then given by

$$S = 1 - RN \cdot SSKP \qquad (15)$$

Having determined S, Equations (12) are then employed to determine[1] α, which is the average number of "successfully launched" missiles required to achieve the desired damage measures by $\overline{S}$. A "successfully launched" missile is any missile for which a failure has not been detected and corrected. The total number of missiles in inventory required to achieve this specified damage is then given by $\alpha' = \alpha/RR$, since RR represents the fraction of the total inventory which will be "successfully launched." Since the final measures of effectiveness desired are the reciprocal of α', the final result is:

$$MOE = RR/\alpha. \qquad (16)$$

In summary, the measure of effectiveness of any given weapon system against a particular target class is to be determined by the application, in the following order, of Equations (13), (14), (15), (12), and (16).

1. Note that α will depend upon which reprogramming case is pertinent.

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APPENDIX "C" TO ENCLOSURE "A"

PARAMETRIC STUDY OF SURVIVABILITY OF FIXED VS. MOBILE SYSTEMS

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APPENDIX "C" TO ENCLOSURE "A"

PARAMETRIC STUDY OF SURVIVABILITY OF FIXED VS. MOBILE SYSTEMS

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FIGURES

PARAMETRIC STUDY OF SURVIVABILITY OF FIXED VS. MOBILE SYSTEMS

PURPOSE

1. To investigate the conditions under which fixed or mobile systems are preferred on the basis of their relative costs and their survivability to enemy missile attack.[1/] Results of this Appendix will be integrated with other pertinent variables in the Main Paper of Enclosure "A".

METHOD

2. Analytic models are derived permitting parametric comparison of fixed versus mobile systems. The results are then applied to the MINUTEMAN and POLARIS systems.

ASSUMPTIONS

3. It is assumed that no missiles are launched during the enemy ballistic missile attack. They are compared on the basis of their survivability to the entire enemy attack.

4. The attacker is given credit for no intelligence on the precise location of mobile weapons at the time of his attack.

DISCUSSION

INTRODUCTION

5. The models developed here assume that one prefers either an all-fixed or an all-mobile system, and investigate the conditions under which each is preferred. It is usually true that if conditions are specified precisely then a single system rather than a mix is optimum, in the mathematical sense. There are some

1/ Consideration of cost and survivability alone are sufficient for comparison of two systems provided all other pertinent variables (such as yield, CEP and reliability) are equal. If they are not equal then the analysis is appropriate for evaluation only if cost is replaced by an appropriate cost/effectiveness index.

narrow ranges of conditions and special types of mobile systems for which the mathematical optimum is a mixture. Furthermore, if one is uncertain as to the characteristics of the enemy attack, he may assign weights to various enemy capabilities or attack levels and so arrive at a mixed system. However, as will become apparent shortly, there exist wide ranges of enemy capability and attack levels for which either the mobile or fixed system is always optimal.

6. Another line of reasoning can also lead to a mixed system. If different uses are to be made of surviving weapons--different target types, etc.--then different types of weapons may be needed, each designed for its specific task. Such a mixture is generally a cheaper alternative than the design of a universal all-purpose weapon. Similarly, if a superior system is available later than others, a mix may result.

7. In the following discussion, we shall restrict ourselves to essentially similar systems designed for the same objective, and consider the threats or ranges of threats under which fixed or mobile alternatives (but not both) are the best buy. This approach is adequate for discussing the relative merits of fixed and mobile systems, but does not answer the question of an optimum force program.

TYPES OF FIXED AND MOBILE SYSTEMS

8. From the attacker's point of view, the kill probability of his weapons might be thought to consist of:

1. The chance that his weapon destroy a given target at its aiming point, and

2. The chance that the desired target is sufficiently near the aiming point.

9. The fixed system usually uses hardening to reduce the first alternative probability. The mobile system, on the other hand, attains its "security" by lowering the second probability. That is, the multiplicity of points from which the mobile system can fire actually diffuses the enemy attack over a larger area, resulting in lower densities of attack and correspondingly higher survivability at any given point.

10. In the following discussion, then, we will consider fixed systems of relatively high survivability, due to hardening, and mobile systems of relatively low survivability when located near an aiming point for an enemy weapon. Such mobile systems will be divided into two types. The first type (called "point-to-point mobile") achieves its survivability by the multiplicity of firing sites that it can employ. The expected number of mobile missiles at a given firing site is simply the total number of mobile missiles divided by the total number of possible firing sites for the mobile system. As the number of firing sites per missile increases, of course, the survivability of the mobile systems increases. When more missiles are added to this system more firing sites are also prepared.

11. The second type of mobile system is constrained by the area in which it must operate. Within this area, the number of permissible firing points is assumed to be greater than the number of enemy aiming points for coverage of the entire area. As the area of the operation of the mobile system increases, its survivability correspondingly will gain. When more missiles are added to this system they are inserted into the constrained area. A subclass of the area-mobile system is the linear-mobile system. A rail or road-mobile system might be thought best approximated

by a line or series of lines along which the system possesses a fire-from-anywhere capability.[1/]

12. If the number of independent[2/] firing points could increase without bound in the first case, the mobile system would become essentially invulnerable since the enemy attack would be infinitely diluted. In the second case, if the area of operation approaches infinity the enemy attack is correspondingly diluted and the vulnerability of the mobile system reduced to zero.

METHOD OF COMPARISON

13. In each case mentioned above we have derived an index that permits comparison of mobile versus fixed systems. This index, which is a function of the number of enemy missiles to be used in a counterforce role against the fixed or mobile system, expresses the price ratio (mobile to fixed) at which it is indifferent which system is preferred. If the mobile system costs more than the index implies, then the fixed system is preferred. The mobile system is preferred if its cost is thought to be any lower value. Thus, in general the cost ratio index that is derived is some measure of the "goodness" of the mobile system relative to the fixed system that it is compared against. The higher this index the more the mobile system is to be preferred. If the index drops below the expected actual cost ratio for a pair of systems, then the fixed system is preferred. In the figures that follow, various factors that enter into the comparison of fixed versus mobile systems are explicitly illustrated. These factors are considered as principal ingredients that influence the survivability of either system. It should be noted that factors such as yield and CEP of enemy weapons are

1/ Results given for the area-mobile system may be applied directly to any linear-mobile system by considering the "area" as a total "length" of rail track or road. The lethal area of the enemy weapon then becomes a lethal length (about twice the kill radius).

2/ Two firing points are independent if they are spaced sufficiently far apart that both cannot be destroyed by a single enemy missile.

important only insofar as they combine to influence the survivability of individual points that might be targeted when hard weapons or soft mobile weapons are located at these points.

PRESENTATION OF RESULTS

14. The Annex to this Appendix derives equations for determining the index cost ratios as a function of type mobile system, hardness of fixed system, and enemy threat. A variety of special cases are presented in the figures below.

Point-to-Point Mobile Systems

15. Figures 1 to 3 show the effect of changes in the ratio γ of total mobile missiles to total number of possible independent firing points in a point-to-point mobile missile system. In all figures "survival probability" values are single-shot survivabilities. As the number of firing points increases, the ratio γ decreases and we are led to situations in which mobile systems appear more and more favorable. This is, of course, reasonable. The upper curve, where γ equals 0, applies to the case of an invulnerable mobile system. In this case, beyond certain low attacking levels, the index cost ratio quickly rises. It should be noted that the invulnerable mobile system is preferred to the fixed system for all Soviet force levels beyond the intersection of the curve with the horizontal line representing the estimated cost ratio. This intersection, of course, occurs at different attacking force levels depending on just what one estimates for the relative cost of mobile/fixed weapons. The various point-to-point mobile systems, characterized by values of γ greater than 0, exhibit maxima as may be seen in the figures. Thus, the estimated cost ratio may intersect the curve twice. At force levels of attacking weapons beyond the second intersection the fixed system becomes more attractive. If the estimated ratio is above the maximum the fixed system is preferred regardless of the enemy force level.

FIGURES 1, 2 AND 3

EFFECT OF VARIATIONS IN γ

EFFECT OF VARIATIONS IN γ OF POINT MOBILE SYSTEMS

MOBILE FORCES OF "POINT-TO-POINT" TYPE

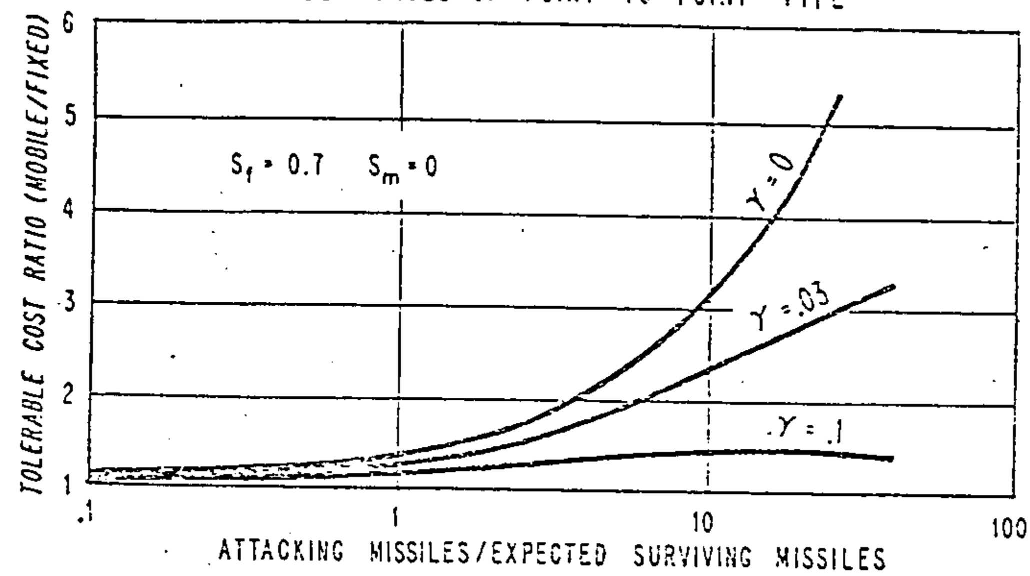

FIGURE 1

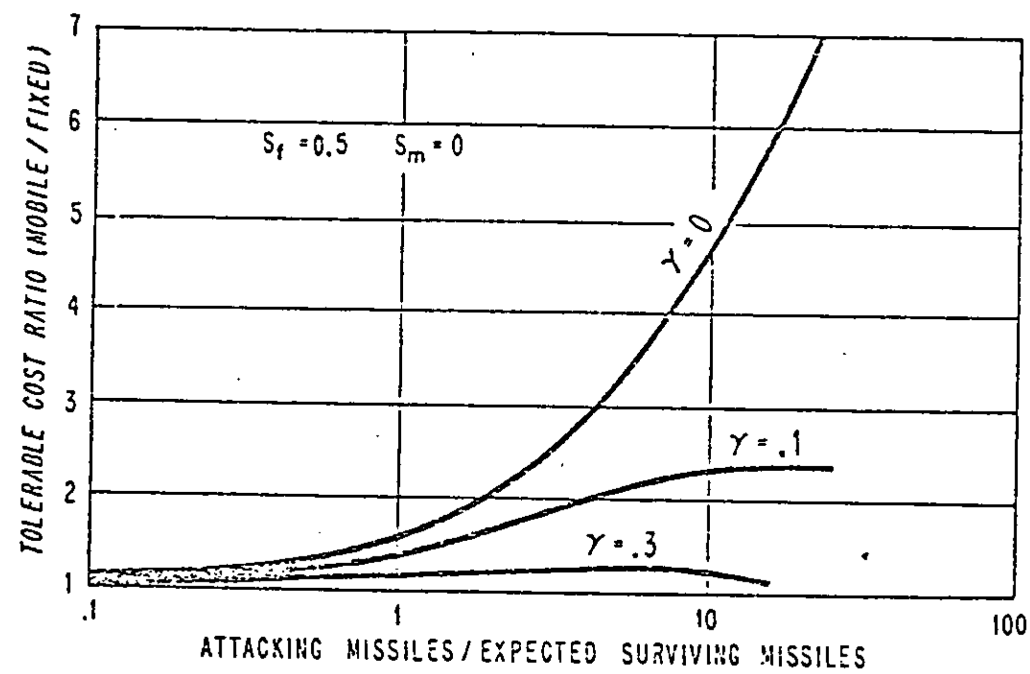

FIGURE 2

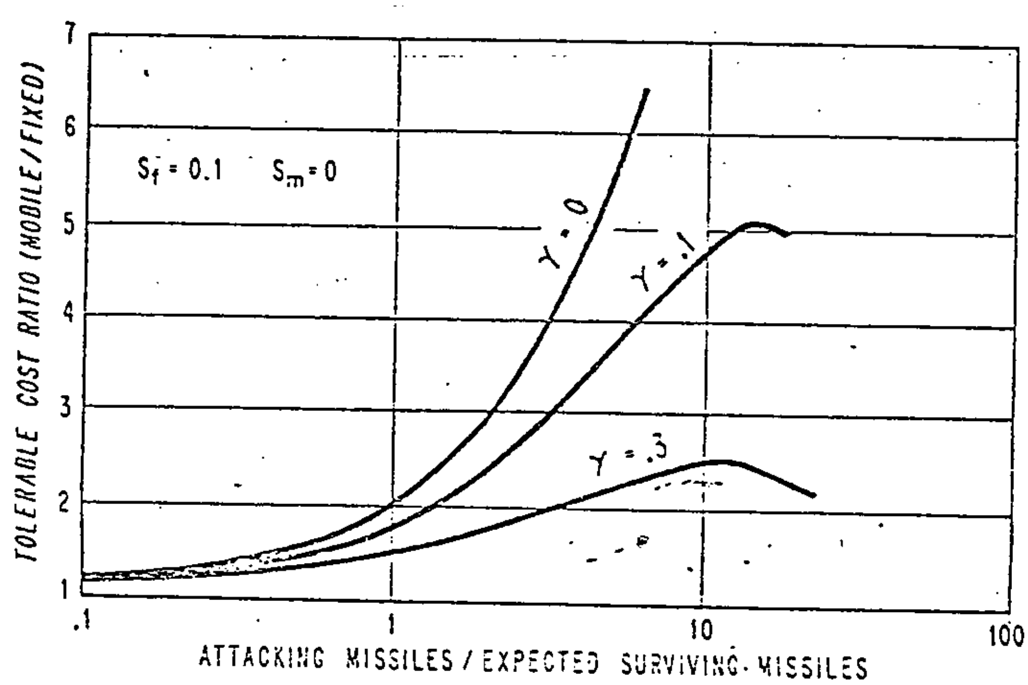

FIGURE 3

S_m = SURVIVABILITY OF MOBILE WEAPON AT A FIRING SITE

S_f = SURVIVABILITY OF FIXED SITE

$$\gamma = \frac{\text{TOTAL MOBILE MISSILES}}{\text{TOTAL POSSIBLE FIRING SITES}}$$

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FIGURES 1, 2 & 3
APPENDIX "C" TO
ENCLOSURE "A"
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16. The effect of variations in fixed-site survivability may also be seen in these first three figures. Index cost ratios always become more and more favorable for the fixed system as the survivability of the fixed system increases.

17. These figures also demonstrate that, for the invulnerable mobile system, the fewer the required number of survivors the higher the number of attacking missiles per survivor and hence the higher the cost ratio that can be tolerated for mobile weapons relative to fixed weapons. It is to be noted, however, that if the mobile system is truly invulnerable the enemy will allocate no weapons to it, but will transfer these weapons to other targets.

18. In all of the preceding discussion it is assumed that a mobile weapon, if located at a point where the attacker aims, is always destroyed. If the survivability of a mobile weapon be greater than zero, then, of course, the cost ratio that can be tolerated for the mobile system relative to the fixed system is higher. Figures 4 and 5 illustrate the manner in which this index cost ratio is dependent on the survivability of a mobile weapon when the weapon is located at one of the enemy aim points. It may be observed in these figures that the survivability can be quite influential in determining the cost ratio. The greater the survivability of the mobile weapon the higher the tolerable cost ratio becomes.

Area Mobile System

19. A second type of mobile system, the area (or linear) mobile system, presents certain aspects that differ from the point-to-point mobile system. The ratio of lethal area of the enemy weapon to the total area of operation of the mobile system is a parameter of primary interest. The optimal enemy tactic, in the absence of precise intelligence, is to attempt to blanket the area of operation of the mobile system. Since it is only the ratio of lethal area to total area that determines the cost ratio, only this ratio is shown in Figures 6, 7 and 8. The ratios may also be interpreted

FIGURES 4 AND 5

EFFECT OF CHANGES IN S_m

FIGURES 6 AND 7

EFFECT OF INCREASING THE AREA OF OPERATION OF A MOBILE SYSTEM

FIGURE 8

AREA MOBILE CASE FOR INCREASED FIXED SITE SURVIVABILITY

EFFECT OF CHANGES IN S_m

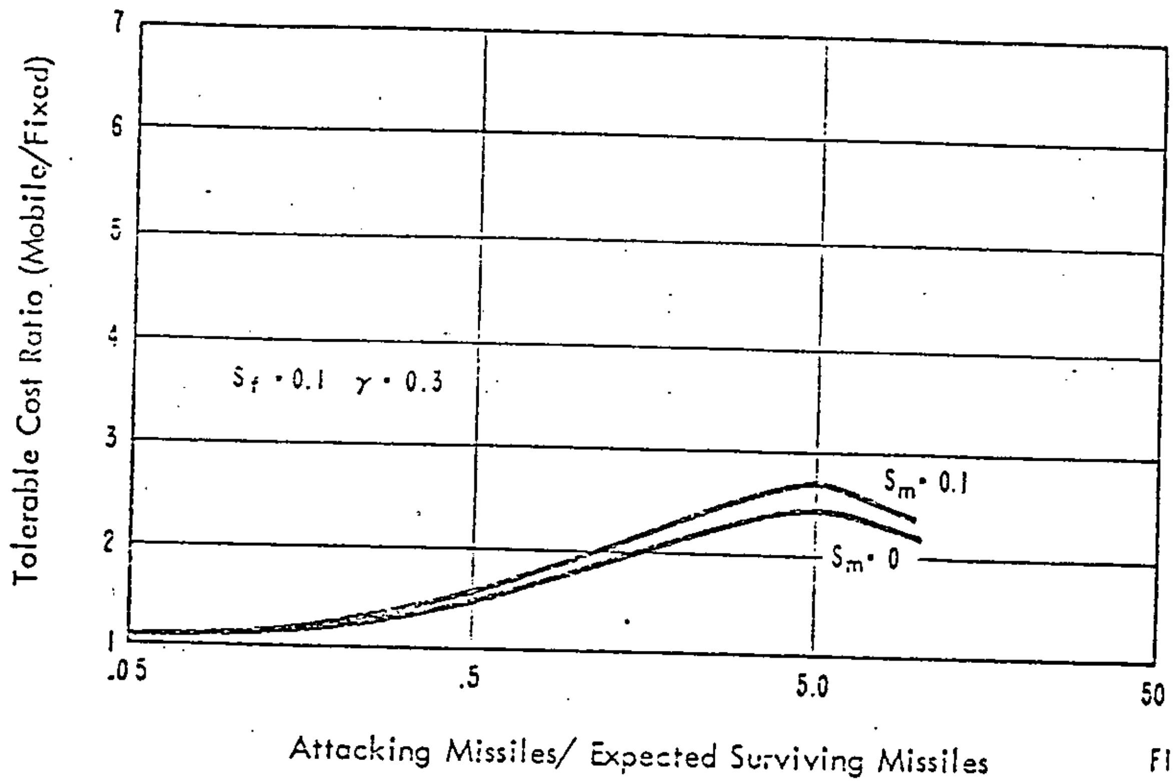

FIGURE 4

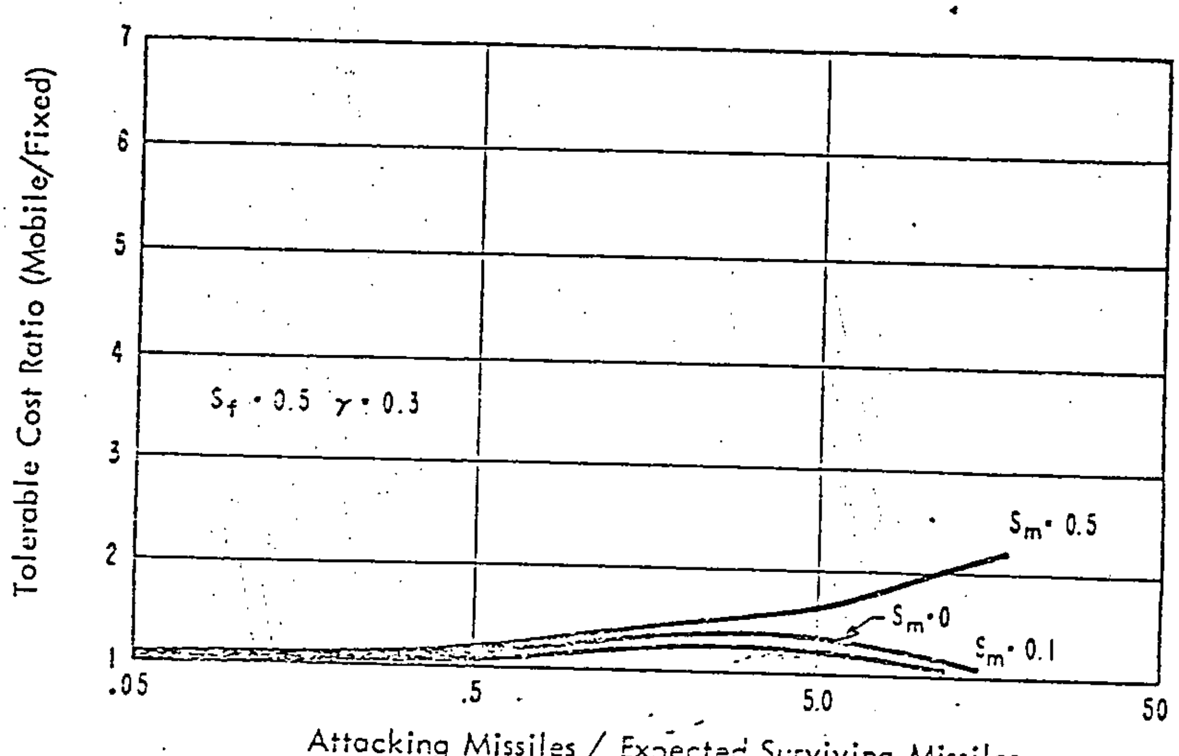

FIGURE 5

S_m = SURVIVABILITY OF MOBILE WEAPON AT A FIRING SITE

S_f = SURVIVABILITY OF FIXED SITE

$\gamma = \frac{\text{TOTAL MOBILE MISSILES}}{\text{TOTAL POSSIBLE FIRING SITES}}$

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FIGURES 4 & 5
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EFFECT OF INCREASING THE AREA OF OPERATION OF A MOBILE SYSTEM

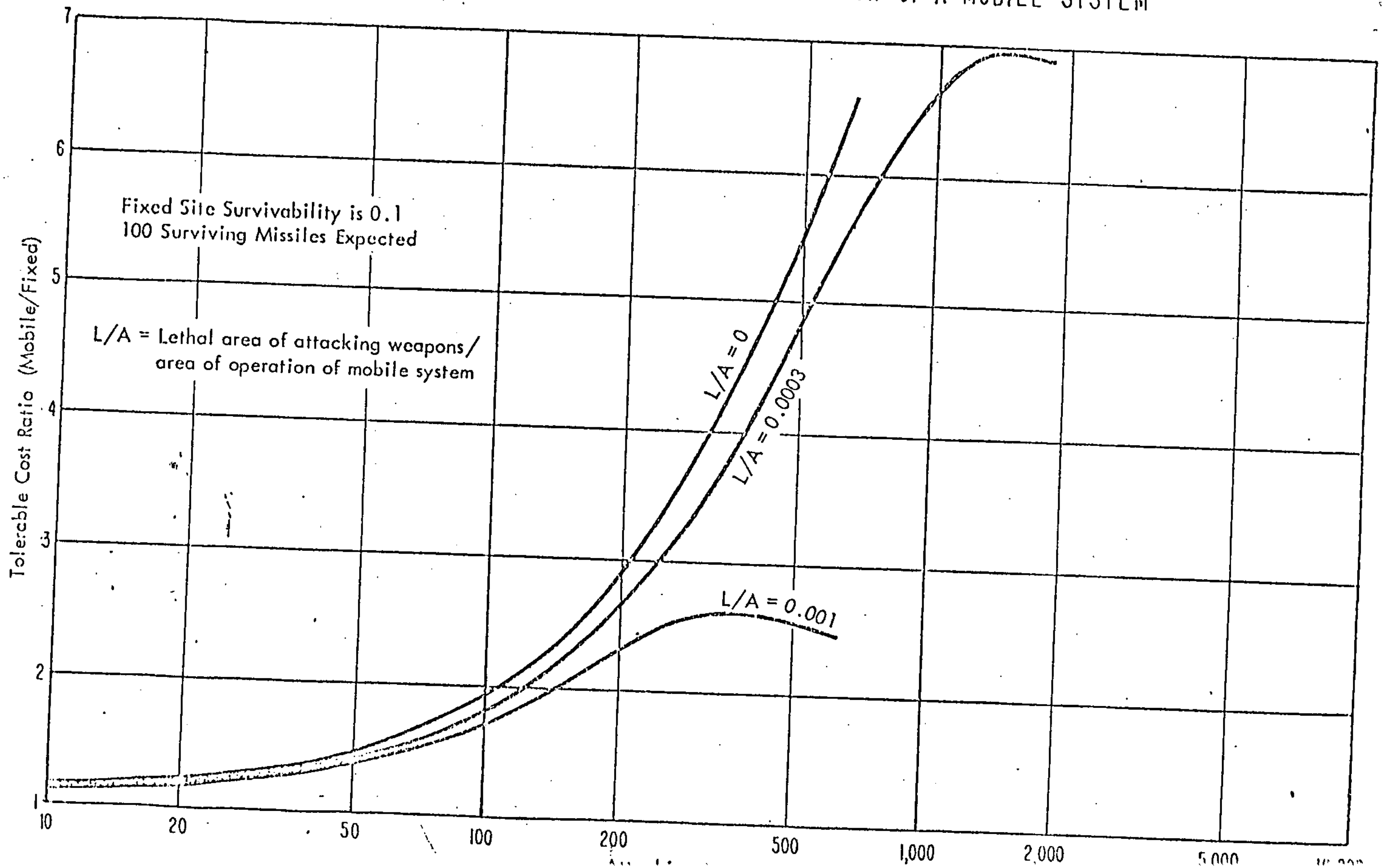

FIGURE 6
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EFFECT OF INCREASING THE AREA OF OPERATION OF A MOBILE SYSTEM

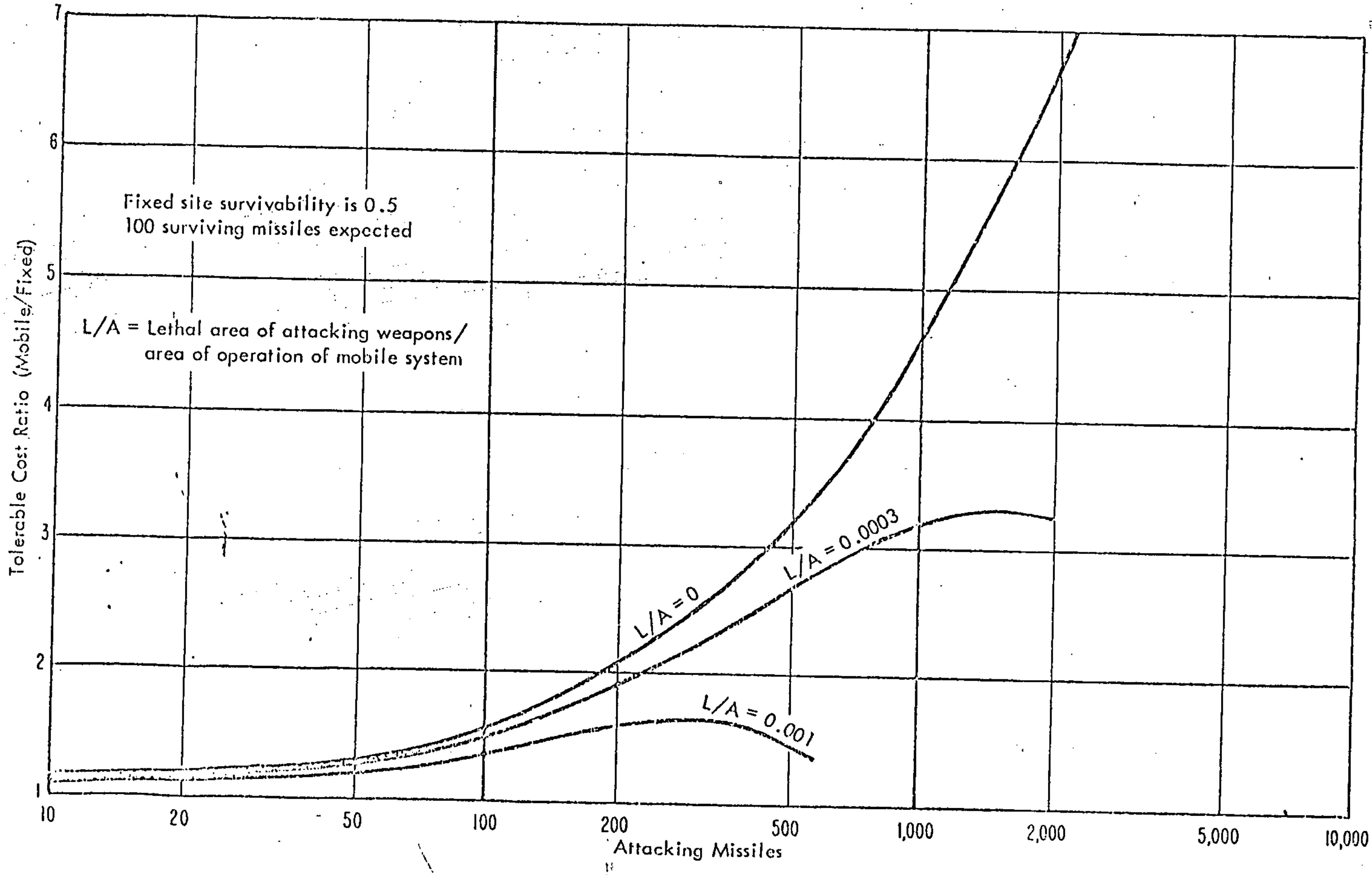

FIGURE 7
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AREA MOBILE CASE FOR INCREASED FIXED SITE SURVIVABILITY

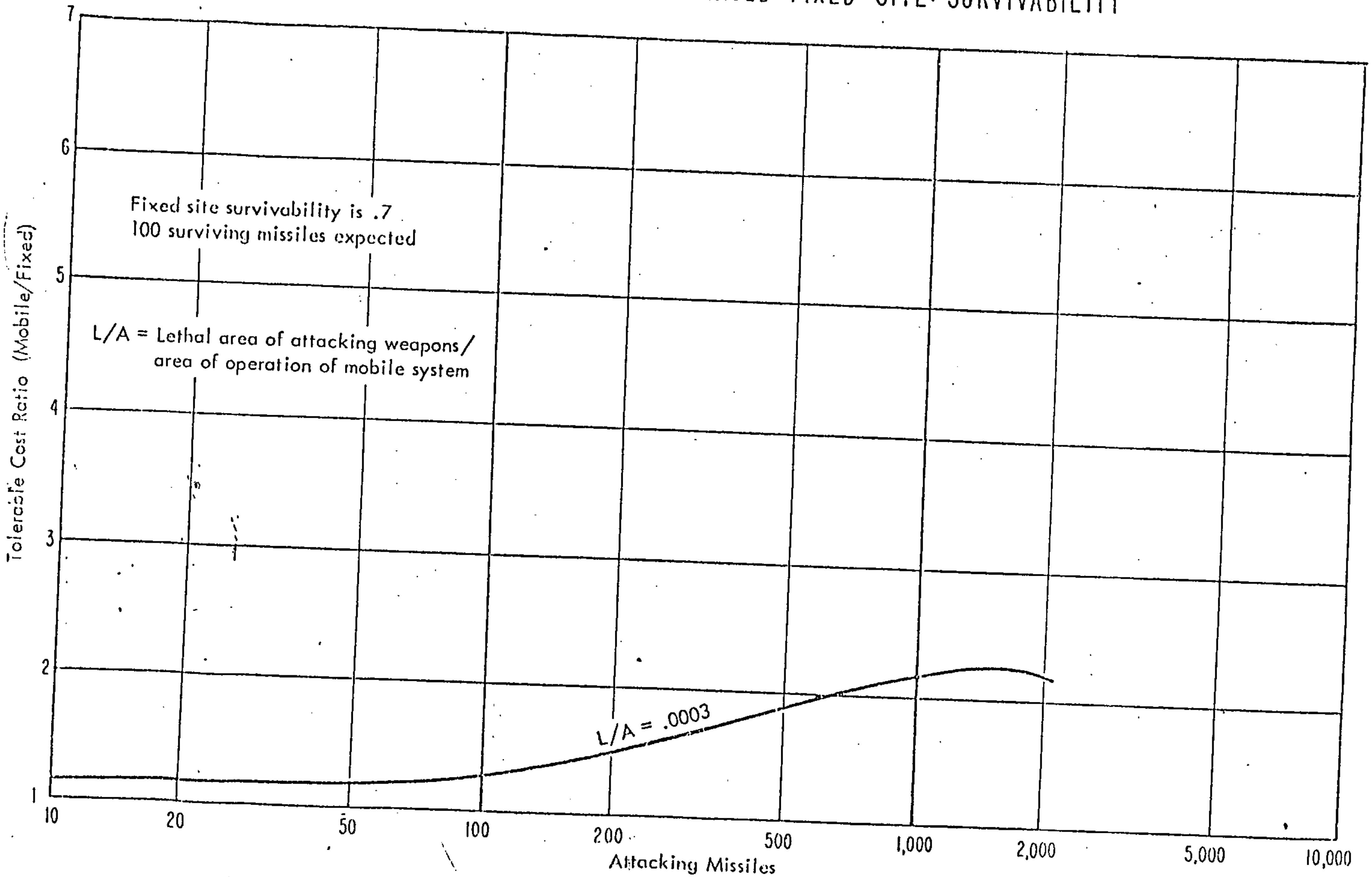

FIGURE 8
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as ratios of lethal lengths to total lengths of road or track for a linear mobile system. In the area mobile cases the dimensionless ratio of attacking missiles/expected surviving missiles cannot be used as before.

ANNEX TO APPENDIX "C"

DERIVATIONS OF INDEX COST RATIOS

ANNEX TO APPENDIX "C"

DERIVATION OF INDEX COST RATIOS

LIST OF SYMBOLS

NR = number of attacking missiles

NF = number of fixed missiles

NM = number of mobile missiles

SF = surviving fixed weapons expected

SM = surviving mobile weapons expected

β = NR/NF

δ = NR/SF

R_m = value of a single surviving mobile missile

R_f = value of a single surviving fixed missile

ρ = R_m/R_f

A = area within which a mobile system is known to operate

L = lethal area of enemy weapon

F = fraction of an area surviving an enemy attack (not covered to psi level desired

NS = number of possible firing sites for point-to-point mobile system

γ = NM/NS

β' = NR/NS

S_f = survivability of fixed site

S_m = survivability of mobile weapon at targeted launching site

C = index cost ratio.

DISCUSSION

1. If NR missiles are launched to cover as uniformly as possible a set of NF targets, then $NR - NF\left[\frac{NR}{NF}\right]$ 1/ of the targets receive an extra missile above the $\left[\frac{NR}{NF}\right]$ missiles assigned the other targets. The expected number of surviving targets, SF, is thus given by

$$SF = \left\{NR - NF\left[\frac{NR}{NF}\right]\right\} S_f^{\left[\frac{NR}{NF}\right]+1} + \left\{NF - NR + NF\left[\frac{NR}{NF}\right]\right\} S_f^{\left[\frac{NR}{NF}\right]} \quad (1.1)$$

1/ [ ] is used to indicate the largest integer contained in the bracketed expression.

where S_f is the single shot survivability of the target.[1]

To simplify notation, let $\beta = \frac{NR}{NF}$. If (1.1) is multiplied through by $\frac{NF}{NF}$, there is obtained

$$SF = NF\, S_f^{[\beta]} \left\{ (\beta - [\beta]) S_f + (1 - \beta + [\beta]) \right\} \qquad (1.2)$$

which can be rearranged to give

$$SF = NF\, S_f^{[\beta]} \left\{ 1 - (1 - S_f)(\beta - [\beta]) \right\} \qquad (1.3)$$

2. At this juncture a number of paths is possible. We have chosen to emphasize the surviving numbers of fixed or mobile missiles, deriving the cost ratio that must exist at parity--that is, as nearly equal as possible expected numbers of surviving missiles from either a fixed or a mobile force. This ratio, designated C, is given by NF/NM. C expresses the number of fixed missiles that must be purchasable at the price of one mobile missile. Alternatively, C expresses the maximum cost of mobile missiles relative to fixed missiles that can be tolerated (since mobile and fixed systems are being compared at parity in survivability). The higher the value of C, then, the more favorable appears the mobile system, since, by implication, the mobile system is sufficiently worthy in its survivability that the weapon buyer can stand higher and higher relative cost before switching his preference to the fixed system.

CASE 1 - INVULNERABLE MOBILE SYSTEM

3. If Equation (1.3) be divided by NR and the quotient $\frac{NR}{SF}$ be designated δ, there is obtained

$$\frac{1}{\delta} = \frac{1}{\beta} S_f^{[\beta]} \left\{ 1 - (1 - S_f)(\beta - [\beta]) \right\} \qquad (3.1)$$

which can be rearranged to give δ/β as a function of δ, that is

$$\frac{\delta}{\beta} = \frac{1 + \delta S_f^{[\beta]} (1 - S_f)}{S_f^{[\beta]} + [\beta] S_f^{[\beta]} (1 - S_f)} \qquad (3.2)$$

1/ S_f may include a measure of the nonreprogrammable reliability of the enemy missile, R, i.e., $S_f = (1 - RP_K)$ where P_K is the kill probability.

Since $\frac{\delta}{\beta}$ equals $\left(\frac{NR}{NF}\right)\left(\frac{NF}{NR}\right)$ or $\frac{NF}{SF}$, since $SF = SM$ by the parity constraint, and since $SM = NM$ for an invulnerable mobile weapon system, $\frac{\delta}{\beta}$ is the desired ratio, $\frac{NF}{NM}$.

4. If it is considered that surviving fixed and mobile weapons may not be of identical characteristics, differing, perhaps, in reliability, a further parameter, ρ, may be introduced at this point.

5. ρ expresses the relative values of surviving mobile to surviving fixed weapons. The final expression for the cost ratio, which we will denote C1, is then

$$C1 = \rho \frac{1 + \delta S_f^{[\beta]}(1 - S_f)}{S_f^{[\beta]} + [\beta] S_f^{[\beta]}(1 - S_f)} \qquad (5.1)$$

6. This equation is susceptible to single computer solution for various values of δ and S_f, given the proper integral value for $[\beta]$. $[\beta]$ itself is rather easily determined. Recall Equation (3.1)

$$\frac{1}{\delta} = \frac{1}{\beta} S_f^{[\beta]} \left\{1 - (1 - S_f)(\beta - [\beta])\right\}$$

7. The right-hand side of this equation is a monotone decreasing function of β and reduces to $\frac{1}{J^{\beta}} S_f^{[\beta]}$ at integral values of β. If then, the function $\frac{1}{J} S_f - \frac{1}{\delta}$ changes sign, becoming negative, between integral values J and $J + 1$, the exact value of $[\beta]$ is given by J.

8. Since $[\beta]$, as shown above, is a function of (S_f, δ), then $C1 = F(S_f, \delta)$ only.1/

1/ ρ is merely a multiplicative factor throughout and is carried for completeness.

CASE 2 - AREA-MOBILE SYSTEM

9. If the precise locations of elements of a mobile system are unknown except within a relatively large area, the optimal enemy tactic is to attempt uniform coverage of the large area to the extent that his weapon stockpile permits (granting that he desires to attack the mobile system). The expected fraction of the mobile system destroyed is then the fraction of the area covered. Since a mobile system is generally somewhat soft, the lethal radius of an enemy weapon will usually far exceed its CEP. For this reason, it appears likely that an enemy could essentially pattern his weapons in a large area, achieving additive coverage for each weapon until his total coverage exceeded some 50 or 60 percent (one layer of rather conservatively spaced weapons to eliminate any appreciable overlap). We can express the fraction, P, of an area, A, surviving under this rule as

$$P = 1 - \frac{L \cdot NR}{A} \quad (1 - P < 0.6) \qquad (9.1)$$

where L is the lethal area of a single weapon.[1] As a worst possible case, the enemy might be considered to resort to random attack in the area, leaving a fraction surviving that can be approximated by

$$P = \left(1 - \frac{L}{A}\right)^{NR} \qquad (9.2)$$

10. In the main section of this paper we have presented results only for the former case (Equation (9.1)) which seems much more realistic for the general problem.

11. Recalling that $C1 = \rho\ddot{u}/\beta = \rho \cdot NF/SF = \rho \cdot NF/SM$, and that $SM = NM \cdot P$, we obtain

$$C2 \equiv \rho \frac{NF}{NM} = C1 \cdot P \qquad (11.1)$$

where P is (preferably) given by Equation (9.1).

[1] In cases investigated, the constraint of about 50 to 60 percent total coverage did not occur at sufficiently low levels to prohibit interesting results.

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12. C2 is now dependent on the explicit enemy force level, NR, in addition to the dimensionless parameter $\delta = \frac{NR}{SF}$. Hence, $C2 = F(\delta, S_f, NR, L/A) = F(SF, NR, S_f, L/A)$.

CASE 2A - LINEAR MOBILE SYSTEM

13. Certain types of mobile systems may operate in a manner that precludes the conceptual use of the area mobile model just described (Case 2). Rail or some road mobile systems may be treated as linear, rather than area mobile systems. The attacker attempts to blanket the track or road network employed by the mobile system achieving a portion of the system destroyed given by $1 - \frac{LL \cdot NR}{TL}$, where LL is a "lethal length" and TL the total length of road or rail upon which the system is known to operate. The "lethal length" LL, is a function of yield and CEP, but for reasonably low CEP's may be approximated by twice the lethal radius.

14. It is apparent that we can write a new formula for a linear mobile system patterned after Equation (11.1) for the area mobile system:

$$C2A = C1 \cdot P' \qquad (14.1)$$

where $$P' = 1 - \frac{LL \cdot NR}{TL}.$$

15. The identication of L with LL and A with TL is obvious. There is one additional feature of an attack on a linear mobile system. The constraint of less than about 60 percent coverage for validity of Equation (9.1) no longer applies. Blanketing of a line target does not involve the necessary overlapping of circular weapon effect patterns required to blanket an area target beyond about 60 percent. Hence, the upper limit of validity for formula (14.1) is well beyond $1 - P' = 60\%$.

CASE 3 - POINT-TO-POINT MOBILE SYSTEM ($S_m = 0$)

16. If a mobile system utilizes presurveyed firing sites, moving more or less randomly among a number of such sites, the enemy, lacking precise intelligence on the instantaneous location of weapons, can only associate with each site a probability that a mobile weapon will be there. This probability is given simply as $\gamma = \frac{NM}{NS}$, where NS is the total number of firing sites the mobile system may employ. If the system can "fire from anywhere" but is restricted to a known area, Case 2 applies. If the area is unknown or too large for attack, Case 1 applies.

17. If a mobile weapon (with its associated mode of transport) be located at a targeted site, the mobile weapon might still survive an enemy weapon with probability S_m. Since, in general, portions of a mobile system will be in transit at any time, that fraction of the force is guaranteed to survive (barring a concommitant area attack). Such a system is really a mixed system of invulnerable and vulnerable mobile elements and therefore the higher the fraction in transit the better appears the mobile system against any attack.[1]

18. For Case 3, we shall consider a particularly soft mobile weapons system and correspondingly high enemy missile post-launch reliability and kill probability, combining to give a value of S_m essentially negligible.

19. If we recall again that $\beta/\delta = \left(\frac{NR}{NF}\right)\left(\frac{SF}{NR}\right) = \frac{SF}{NF} = \frac{SM}{NF}$, we can write

$$NF = \frac{\delta}{\beta} SM; \qquad (19.1)$$

[1] In no case can the index C exceed that for the invulnerable mobile system. If the mobile system is constrained to fire only from presurveyed sites, then destruction of all sites will insure the neutralization (at least for some time) of even the portion of the system in transit at the time of attack.

SM can be expressed in a manner analogous to Equation (1.3) for SF, that is

$$SM = NM\, S_m^{[\beta']} \left\{ 1 - (1 - S_m)(\beta' - [\beta']) \right\} \qquad (19.2)$$

but β' is now NR/NS. In terms of $\frac{C3}{\rho}$ $\frac{NF}{NM}$, $\beta = \frac{NR}{NF}$, and $\gamma = \frac{NM}{NS}$, β' becomes $\frac{C3\,\beta\gamma}{\rho}$.

20. Case 4 (treated in the following section) utilizes the complete Equation (19.2), ($S_m \neq 0$), Case 3 considers the reduced equation when S_m is set equal to zero and the enemy utilizes at most, therefore, only a single layer of weapons ($[\beta'] = 0$).

$$SM = NM(1 - \frac{C3}{\rho} \cdot \beta\gamma) \qquad (20.1)$$

21. Substituting in Equation (19.1) and multiplying by ρ, we obtain

$$\rho\, NF = \rho \frac{\delta}{\beta} NM(1 - \beta\gamma \cdot \frac{C3}{\rho}) \qquad (21.1)$$

which can be rearranged, noting that $\rho \frac{NF}{NM} = C3$ and $\rho \cdot \frac{\delta}{\beta} = C1$, to yield

$$C3 = C1(1 - \frac{C3}{\rho} \cdot \beta\gamma) \qquad (21.2)$$

or

$$C3 = \frac{C1}{1 + \frac{C1 \cdot \beta\gamma}{\rho}} \qquad (21.3)$$

which can be simplified further, since $C1 = \rho \frac{\delta}{\beta}$, to give the final expression

$$C3 = \frac{C1}{1 + \delta\gamma} \qquad (21.4)$$

Therefore, $C3 = F(S_f, \delta, \gamma)$ only.

CASE 4 - POINT-TO-POINT MOBILE SYSTEM ($S_m \neq 0$)

22. As in Case 3, we proceed from Equation (19.2), retaining all terms,

$$SM = NM\, S_m^{[\beta']} \left\{ 1 - (1 - S_m)(\beta' - [\beta']) \right\}$$

23. As in Case 1, we may solve for the cost ratio in terms of other parameters obtaining finally

$$C4 = C1 \cdot \frac{S_m^{[\beta']} + [\beta'] S_m^{[\beta']} (1 - S_m)}{1 + \gamma\delta S_m^{[\beta']} (1 - S_m)} \qquad (23.1)$$

This equation was solved for C4 by calculating trial values of C4, say $\overline{C4}$, by substitution of successive integral values of $[\beta']$, say J, until $\left[\overline{C4}\,\beta\gamma\right] = j$. Then $C4 = \overline{C4}$. It might be noted that $C4 = F(S_m, S_f, \delta, \gamma)$ since $\beta = F(C1, \delta) = F(S_f, \delta)$ as shown previously.

SUMMARY

24. In Case 2 only (Area-Mobile System) does the functional relation for the cost ratio demand a specification of the attacking force level, NR (and in addition, L/A). In all other situations, the dimensionless ratio, $\delta = \frac{NR}{SF} = \frac{NR}{SM}$ specifies the case. Secondary variations are obtained by choice of γ, S_f, and S_m. If ρ is felt to differ from 1, the indicated cost ratio C should be adjusted to ρC.

25. For convenience, the basic equations are summarized below.

$$C1 = \rho \cdot \frac{1 + \delta S_f^{[\beta]} (1 - S_f)}{S_f^{[\beta]} + [\beta] S_f^{[\beta]} (1 - S_f)} \qquad \text{Invulnerable Mobile} \qquad (25.1)$$

$$C2 = C1 \cdot P \qquad \text{Area-Mobile} \qquad (25.2)$$

$$C3 = \frac{C1}{1 + \delta\gamma} \qquad \text{Point-Mobile } S_m = 0 \qquad (25.3)$$

$$C4 = C1 \cdot \frac{S_m^{[\beta']} + [\beta'] S_m^{[\beta']} (1 - S_m)}{1 + \gamma\delta S_m^{[\beta']} (1 - S_m)} \qquad \text{Point-Mobile } S_m > 0. \qquad (25.4)$$

CASE 5 - INVULNERABLE MOBILE VS. LINEAR MOBILE SYSTEMS

25. Since all previous cost ratios derived are similar in relating various mobile systems to the fixed system, there exist. further cost ratios not yet explicitly derived which relate the various types of mobile systems to each other. The present case derives the tolerable cost ratio that must obtain for equal numbers of surviving missiles from an invulnerable mobile system compared to a linear mobile system.

26. If Equation (14.1) for the linear mobile system be recalled

$$C2A = C1 \cdot P', \qquad (26.1)$$

and explicit relations for C2A and C1 be substituted, there is obtained

$$\frac{NF}{NM} = \rho \frac{NF}{SM} \cdot P' \qquad (26.2)$$

The comparison base can now be changed from the fixed system to the invulnerable mobile system simply by changing NF to NM', where NM' refers to the invulnerable mobile system

$$\frac{NM'}{NM} = \rho \frac{NM'}{SM} \cdot P' \qquad (26.3)$$

27. As usual NM' = SM' for the invulnerable system, where SM' is the surviving mobile weapons from the invulnerable system.

$$\frac{NM'}{NM} = \rho \frac{SM'}{SM} \cdot P' \qquad (27.1)$$

If C5 be taken as NM/NM', we thus obtain for the usual condition SM' = SM.

$$C5 = \frac{1}{\rho \cdot P'}, \qquad (27.2)$$

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ODDR&E
Washington 25, D. C.

THIRD VOLUME OF

ENCLOSURE "A"

EVALUATION OF PROGRAMMED STRATEGIC OFFENSIVE SYSTEMS
1964-1967

WSEG REPORT NO. 50

27 December 1960

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APPENDICES "D", "E" AND "F" TO

ENCLOSURE "A"

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ANNEX TO APPENDIX "D"

FALLOUT METHODOLOGY

STATEMENT OF THE PROBLEM

1. To describe the method used to calculate fallout casualties, and the rationale for the selection of radiation shielding factors for use in the examples.

DISCUSSION

2. The model used to compute fallout near ground zero for use in the WSEG city fatality model is based directly on the model of WSEG Research Memorandum No. 10, and is identical with that used in the calculations of the Joint Atomic Weapons Planning Manual.

3. The area fallout model is the same as that described in WSEG Research Memorandum No. 5, but uses somewhat more up-to-date values for the parameters, and will be described in more detail.

THE AREA FALLOUT MODEL

4. This model makes use of the fact that fallout wind conditions cannot be predicted in advance of an attack. Therefore (except for the small percentage of fallout which is deposited in the immediate vicinity of ground zero), the areas hazarded by fallout from any given burst point cannot be predicted in advance. It is only known that most of the fallout will come down somewhere in the general vicinity of the burst point (usually within a few hundred miles). The model, therefore, makes the simplifying assumption that the actual location of the fallout is randomly located somewhere in the general vicinity of the burst point. For purposes of the calculation the total national area is divided into a number of regional sub-areas and the expected fallout casualties in each sub-area are computed as if the fallout from each detonation were randomly located within the sub-area. This method of calculation together with some simplifying mathematical

formulas is described in WSEG Research Memorandum No. 5. The results of this computational technique have been checked on several occasions against detailed calculations done both inside and outside WSEG, and have been found to be in good agreement with the results obtained from the more detailed analysis.

5. However, since the publication of RM-5, a number of refinements have occurred in the state of the art in fallout calculation, so that it is no longer appropriate to make use of exactly the same dose vs. area relations to describe fallout areas from a single detonation. For this reason the basic input data for the model have been revised. The basic dose vs. area data used in the present calculation are no longer based on the old RAND Memorandum RM-1969, but are based on the more recent estimates in WSEG Research Memorandum No. 10.

6. The dose vs. area results in Memorandum No. 10 depend not only on yield, but on wind velocity, and wind shear as well. In order to obtain a typical or reasonable estimate of this relation the dose vs. area relation was based on an expected value analysis in which the expected area of each dose contour was computed using a mixture of weapon yields from 1 to 20 megatons and a mixture of wind velocities and wind shear conditions. Actually the results in terms of percent casualties for a given number of megatons are not very sensitive to the differences involved in the mixture. The mixture was used only to give as typical an estimate of casualties as possible.

7. The doses used in the calculation are based on the maximum biological dose contours of RM-10, which are essentially equivalent to 96-hour cumulative doses integrated from the time of arrival of the fallout. The yield mixture chosen contained equal amounts by megatonage of 1, 3, 10, and 30 megaton weapons. The wind conditions used contained 0, 10, 20, 40, and 60 knot winds

with appropriate probabilities and appropriate wind shear distribution to correspond to the spring or fall season in the U.S.

8. The resulting dose vs. area relation per megaton for 100 percent fission yield at random in a very large area is:

AREA WITH DOSE GREATER THAN	
Square Miles	Roentgen
37,600	1
26,000	3
16,000	10
9,700	30
4,900	100
2,200	300
900	1,000
230	3,000
32.5	10,000
1.5	30,000

To get corresponding results for other fission yields, all doses are multiplied by fraction of fission yield.

9. These figures ignore additional effects due to induced activity

On the other hand, the figures are based on the DASA estimate of hypothetical h + 1 total area x dose rate per megaton fission which is about 2.6 x 10^6 roentgen per hour x square miles/MT. According to a recent preliminary calculation of fractionation of radioactive gases by NRDL this estimate could be a little high.

10. A smooth curve based on the data in the preceding table has been used to calculate the expected distribution of dose vs. area when a large number of weapons are dropped at random in the same area. The calculation was carried out by machine computation in the following way. Let $P_y(D)$ be the probability distribution of dose, D , at a random point for y megatons

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per unit area. Then the probability distribution for 2y megatons, $P_{2y}(D)$, is given by:

$$P_{2y}(D) = \int_0^\infty P_y(D_1)\, P_y(D - D_1)\, dD_1 .$$

This formula was evaluated in an iterative procedure which began with the dose area relation given above and built up by successive factors of two to the realistic attack densities.

11. Figure 1 shows the results of this integration, in heavy lines plotted on log normal graph paper for comparison with the log normal approximation of RM-5. The parameters of the simplified formula of RM-5 were adjusted to give a good fit to the results of the integration for 1.2 tons fission/mi.^{2}. The light lines in Figure 1 show how this approximation as used in the analysis compares with the results of the detailed calculation. While the accuracy of the fit is inevitably not perfect, it seems sufficiently good for the purpose of the analysis.

12. The calculation of area casualties by the method of RM-5 depends on breaking the area to be attacked into more or less homogeneous, contiguous sub-areas. In order for valid answers to be obtained it is necessary that the sub-areas be sufficiently large that they exceed the size of individual fallout patterns yet small enough that they can properly allow for major differences in attack density from one area to another. Sample calculations for the United States were carried out using individual states as the sub-areas. The calculations were then repeated using only twelve major regional areas in the country. Even for optimized attacks the differences in results were not more than 1 to 2 percent in the estimated population casualties. Consequently it was concluded that the use of sub-areas as small as states did not lead to serious errors in the results, and these areas were used in all the calculations of this report.

FIGURE 1

PERCENT AREA FREE OF DOSES IN EXCESS OF INDICATED VALUE

PERCENT AREA FREE OF DOSES IN EXCESS OF INDICATED VALUE

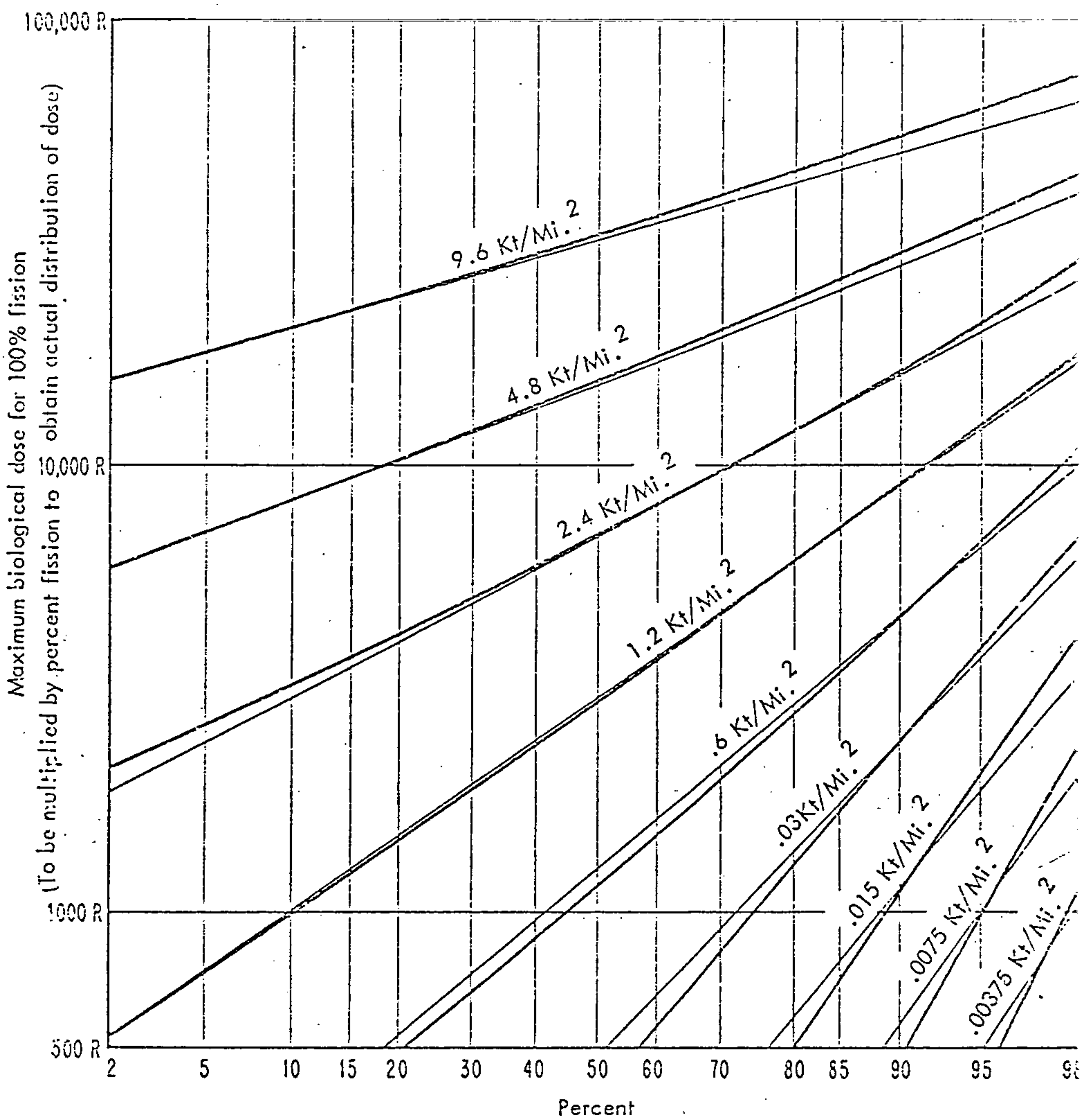

FIGURE 1
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13. There are a large number of large cities on or near the eastern coast of the United States. Because the prevailing wind from these cities would often carry fallout from these targets out over the Atlantic Ocean, it was decided not to include area fallout from weapons on these cities in the calculation. However, the omission of fallout from these targets as it turns out did not significantly reduce estimated casualties.

SELECTION OF SHIELDING FACTORS

14. The selection of shielding factors for calculations of this type is always somewhat arbitrary, since the actual factors which should be applied depend not only on the available shelter, but also on the behavior patterns of the population. The specific distribution of shielding factors used in this calculation for the unsheltered population has a median residual number of .34 with a maximum of .50 and a minimum of about .05. This is intended to correspond to the performance of a relatively undisciplined population, making reasonable use of readily available shelter. Best available residential shielding factors estimated for OCDM by DASA correspond to slightly better shielding factors, giving residual numbers about 30 to 50 percent lower than these. The difference between these two sets of numbers is intended to reflect the failure of a real population to find and remain in the areas of best available shelter. The uncertainties concerning the shielding factors for this unsheltered case, even though they are quite large, are not enough to introduce major errors in the estimated casualties.

15. However, the shielding factors used for the sheltered case are much more uncertain. Since the purpose of the analysis of a sheltered case in the United States is to compare the effectiveness of shelters with active air defense and offensive counterforce systems, it was decided to use a conservative estimate of

the effectiveness of a shelter program. In this way, if the result of the comparison proves unfavorable to offensive counterforce systems the result cannot be attributed to an overestimate of the effectiveness of shelters.

16. The shelter program considered provides shelters which give radiation shielding factors in excess of 500, corresponding to residual numbers less than .002. However, it would be unrealistic to use such a residual number as a single time averaged result because the population cannot remain permanently in the shelter. The specific time average residual number of .03 used as the median in the sheltered case can be obtained by continuous occupancy of the shelter for about one month with little or no shelter thereafter. The same residual number can also be achieved in a large number of other ways which are probably considerably more likely. For instance, continuous occupancy of the shelter for ten days followed by intermittant exposure outside the shelter equivalent to about eight hours a day with normal environmental shielding, for about the next three months, produces about the same time averaged residual number. If shelters are available, and are adequately stocked, as they can be, with provisions for about one month of continuous occupancy, then it is clear that residual numbers considerably better than .03 can be obtained. Thus the use of a median residual number of .03 for the sheltered case seems to represent a clearly conservative estimate of the effectiveness of shelters. That is, the effectiveness of the shelters should actually be considerably better than this.

17. On the other hand, it is not at all clear how much better the shelter performance might actually be. If one carries out a simple calculation of dosage that might be received by a really well-disciplined population, very large improvements appear to be possible. For instance, if very good shelters, RN .0005 or better, were occupied continuously for one month followed by

intermittent daily exposure of not more than eight hours a day for several months in an area with normal environmental shielding where effective decontamination had reduced doses by about a factor of three, then a time averaged residual number of about .0015 which is twenty times better than the .03 could be obtained in principle. While such behavior might be very realistic for a select group, it is not at all clear that such well-disciplined behavior could ever be obtained by the bulk of the national population. Consequently, the use of such shielding numbers might result in a gross overestimate of the effectiveness of shelters.

18. Moreover, the calculations indicated above are based only on the effects of external gamma radiation in the production of fatalities within a month or so. As a shelter program becomes more effective in protecting the population against this primary hazard (which for an unsheltered population is by far the most serious problem), other hazards which previously were of lesser importance begin to create a comparable threat.

19. While it is not easy to estimate quantitatively the importance of these factors they do create problems which tend to reduce the effectiveness of a shelter program in achieving what otherwise might be its ultimate capability. Two of these problems, specifically leukemia and sterility, merit special consideration.

20. There is an indication that even if the human exposure to radiation is kept low enough to avoid serious radiation sickness, the cumulative result of lower doses over a longer period of time can produce sterility. This concept is based on a well-controlled and documented sequence of experiments with male Beagle dogs, which demonstrated that a total cumulative dose in excess of 350 roentgens produced permanent sterility in the dogs, regardless of the exposure rate so long as the dose per week exceeded 15 roentgens. Since the other biological responses of Beagles to

radiation seem to parallel quite closely the human response it seems likely that such a sterilization would also occur in humans. This effect would be most important in a well-disciplined society where exposure was kept sufficiently low to avoid sickness, but where the total cumulative dose could be as high as 1000 roentgens.

21. A second problem which is important where protection from the external gamma radiation is quite good, results from the ingestion of Sr^{90}. Sr^{90} is chemically quite similar to calcium, so this radioactive contaminant enters the food cycle and tends to lodge in the bones. The resulting radiation of the bone marrow can produce leukemia.

22. An average attack density of about 1 MT per thousand square miles, which would be about 3000 MT total in the United States, would be estimated to produce Sr^{90} per square mile. Using data from the United Nations Scientific Committee on Effects of Atomic Radiation this density of Sr^{90} would be expected to produce leukemia after many years in about 1/2 percent of the population. However, if the attack tended to be more concentrated in the heavily populated areas of the country the incidence of leukemia would probably be greater by about a factor of two. These estimates assume that survivors of the attack are able to maintain a diet in which calcium is obtained primarily through milk. On the other hand, if the attack density were much higher, perhaps as high as 5000 MT total, then the percentage of livestock surviving the early gamma radiation would probably be so small that the basic diet after the attack would have to be a vegetarian diet with emphasis on grains, potatoes, and vegetables. In this case the Sr^{90} to calcium ratio in the diet would be higher by about a factor of 2 due to the heavier attack and by an additional factor of 6 because of the absence of the cows which otherwise would impose a selective filtering against the Sr^{90}. In this case

the percentage of leukemia in the population might be as high as 5 percent. Of course, these effects can be somewhat reduced by appropriate countermeasures. Deep plowing of the soil might decrease the Sr^{90} content of the food produced by a factor of 2 to 6. But this is an expensive operation requiring special equipment, and it is likely to seriously decrease productivity. Addition of calcium to the soil might also help, but this would require many tons per acre.

23. Clearly the problems of health and survival for the population become progressively more difficult as the attack density is increased even if one ignores entirely the effects of early gamma rays in producing direct casualties. Thus, while it is possible in principle to obtain very high shielding factors against early gamma radiation, it is not at all clear that the increase in the number of survivors would be nearly as large as one might estimate where only the effect of the early gamma radiation is considered.

24. The shielding factors selected for the sheltered case were chosen to be sufficiently conservative that it is almost certain that a well-organized shelter program could achieve them, and probably do considerably better. However, it is by no means clear how much better performance could actually be achieved because of the compounding of other factors which complicate the problems of health and survival for those who escape excessive exposure to the early radiation.

25. The casualty figures computed for the Soviet Union in this study are done in two ways, one using the shielding distribution for the unprepared case and one using a shielding distribution in which 40 percent of the urban population and 20 percent of the rural population are credited with a shelter posture, like that used in the sheltered case for the U.S. This second posture may

may well correspond closely to the present Soviet posture, and is used in Enclosure "A" to illustrate effects in the Soviet Union. If at some future date the Soviets adopt a more extensive shelter program, casualties would, of course, be considerably less than estimated here.

26. In the limit of a perfect shelter and civil defense program, the potential damage which might contribute to the deterrence of Soviet hostilities, might have to be measured primarily in terms of the damage to urban industrial floorspace (which is also shown). However, destruction of livestock, denial of farm land by radioactive contamination (and the inconvenience of prolonged occupancy of crowded shelters) would also be pertinent factors.

27. The level of attack required to produce heavy casualties in sheltered rural population as a result of blast or direct effects of nuclear weapons is extremely high, probably more than a hundred times that required for similar fatality levels in the urban population. On the other hand, it is not generally believed that potentially heavy casualties in the rural population are necessary for deterrence.

28. Since only about 30 percent of the population of the USSR resides in urban areas, population casualties much above the 30 percent level are very difficult to achieve if radiation effects are not considered. On the other hand, heavy casualties in the urban population can be achieved at relatively low force levels even when only the effects of blast are considered. Sheltering of the urban population in blast hardened shelters of about 100 psi might increase the force level required to obtain heavy casualties in this group by perhaps a factor of 4. However, since the force level required to obtain 30 percent casualties is not very high this would not greatly increase the requirements for deterrence.

29. Only if the urban population were evacuated and sheltered in high quality, long occupancy, shelters, or if a high level of casualties were required in a well-sheltered rural population does the force level needed to produce the required casualties become really large. In these cases the force levels become so large that it seems more appropriate to measure the damage required for deterrence in terms other than direct human casualties. Under these circumstances other measures of damage such as urban industrial floorspace appear more appropriate.

APPENDIX "E" TO ENCLOSURE "A"

THE FEASIBILITY OF ACHIEVEMENT OF COUNTERFORCE OBJECTIVES

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APPENDIX "E" TO ENCLOSURE "A"

THE FEASIBILITY OF ACHIEVEMENT OF COUNTERFORCE OBJECTIVES

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APPENDIX "E" TO ENCLOSURE "A"

THE FEASIBILITY OF ACHIEVEMENT OF COUNTERFORCE OBJECTIVES

INTRODUCTION

1. The purpose of this Appendix is to explore the potential value and the limitations of employment of U.S. systems for the purpose of blunting the effect of nuclear attacks on the United States.

2. The fact that delivery of a very small fraction of the Soviet nuclear forces estimated for the time period of this study is sufficient to inflict unprecedented levels of devastation in the U.S. has been demonstrated in Appendix "D". This fact raises the question of whether it will be possible for the U.S. to prevent unacceptable destruction to the U.S. through the employment of counterforce systems.

3. There are two main contexts which must be considered: the case of U.S. initiative in which U.S. offensive forces may be able to attack most enemy forces prior to their launching; and the case of Soviet initiative in which only a residual part of the Soviet force is subject to attack by U.S. weapons.

4. In addition to U.S. offensive forces, passive civilian defense measures such as fallout shelters, as well as active defenses against manned aircraft and ballistic missiles, must also be considered since they contribute to the same objective of blunting the effectiveness of attacks on the United States.

5. In order to assess the value of various methods of reducing the effect of Soviet attacks on the United States, we shall concentrate primarily on U.S. population fatalities as an indicator of U.S. national damage produced by Soviet attacks. Other

indicators of national damage such as destruction of industry, transportation, communications, or government, while also worthy of consideration, are largely correlated with population fatalities. In any event these other measures, if included, would only serve to increase the estimates of total national damage above the estimate based on population fatalities alone so that the use of population fatalities can be justified as giving a lower limit to the actual total national damage however it might be measured.

DISCUSSION OF AN EXAMPLE

6. In order to give the reader some appreciation of the contribution of U.S. counterforce which can be expected, the discussion will begin with the treatment of a particular example. While it must be recognized any single example is necessarily based upon many assumptions which are open to debate, it is felt that the present example is not unrealistic for the time period of this study. In any event, the subsequent discussion will treat many variations of assumptions, the sensitivity to the assumptions, as well as ultimate limits.

7. The example chosen is a case in which the Soviets take the initiative. The assumed Soviet force posture is given in Table I, which presents numbers of long-range strategic weapons in inventory, the configuration of the forces, the fractions of bases of each weapon whose locations are assumed known to U.S. with sufficient accuracy to permit targeting, the fraction of each force for which launching can be commenced in the first half to three-quarters of an hour assuming preparation commensurate with a Soviet initiative situation (i.e., the fraction which can be launched without any interference from a U.S. counterforce response), the fraction of each force for which launch is ordered which is actually delivered to the target, and finally the yield of the weapons.

TABLE I

SOVIET FORCE POSTURE EXAMPLE

Weapon System	Configuration	Number in Commission	Fraction of Bases Whose Location Known Well Enough to Target	Fraction of Force Ready for Launch in First 1/2-3/4 Hour in Initiative Situation	Deliverable Fraction Reliability x Penetrability
ICBM	Soft, 3 per aim point	200	60%	70%	.7 x 1.0 = .7
	100 psi, 1 per aim point	200	50%	80%	
	Land mobile	200	10%	50%	
SLBM	30% in port among 17 sub bases	300	100%	70% of subs not in port	.7 x 1.0 = .7
Bombers	Distributed among 100 airfields	400	90%	40%	.9 x .4 = .36

8. To illustrate what might be accomplished by a U.S. counterforce strike subsequent to Soviet initiation of hostilities, it is assumed that the U.S. immediately executes a counterforce strike against the residual target system.

9. The residual target system -- the expected numbers of weapons remaining from the initial wave of the Soviet attack distributed among the known bases -- is shown in Table II, together with the vulnerability assumptions and overall single-shot kill probabilities for the postulated U.S. counterforce weapon.

TABLE II

RESIDUAL TARGET SYSTEM OF EXAMPLE

Soviet Weapon		Expected Remaining Targetable Weapons	Known Aim Points	Assumed Vulnerability
ICBM:	Soft 3/aim point	36	40	VN 11-Q-6
	100 psi 1/aim point	20	100	100 psi
	Land mobile	10	20	VN 11-Q-6
SLBM		90	17	VN 17-P-0
Bombers		216	90	VN 11-Q-6

11. The first wave of the Soviet attack, however, leads to an expectation of about 1600 fission megatons delivered, and the non-targetable residue of Soviet forces is expected to ultimately deliver another 430 megatons. Thus, while the U.S. counterforce strike effected a dramatic reduction in the targetable residue of Soviet forces, the overall effect was only a reduction from about 3000 MT to about 2100 MT total delivered against the U.S.

12. To indicate the significance of these numbers for U.S. population fatalities, Table III summarizes the results, and presents expected U.S. population fatalities under several assumptions concerning Soviet targeting doctrine. The first doctrine is a pure military targeting doctrine, the second commits 80 percent of the Soviet force to military targets in the U.S. and 20 percent to population targeting, while the third case allocates one-third of the Soviet force to population targeting. The population fatalities for these cases are obtained from Figure 4 of Appendix "D".

TABLE III

SUMMARY OF RESULTS OF EXAMPLE

		PERCENT U.S. FATALITIES Soviet Attack Doctrine		
	Fission Megatons	Pure Military	20% Against Population	One-third Against Population
Expected Total Deliverable Yield From All Soviet Forces	3000	91%	95%	96%
Expected Total Deliverable Yield From Non-Targetable and First Wave Soviet Forces	2030	78%	88%	89%
Expected Total Deliverable Yield Surviving U.S. Counterforce Attack (Including Non-Targetable and First Wave Forces)	2120	80%	89%	90%

13. It is clear from these results that, for this example at least, the effect of the U.S. counterforce strike, while perceptible, cannot be regarded as a dramatic improvement for the U.S.

14. It is furthermore clear that no significant improvement in this situation would be effected by improving the quality or number of U.S. counterforce weapons over the weapons assumed in this example, since the ultimate limit is set by the non-targetable Soviet forces which by themselves produce U.S. fatalities within one or two percent of the results for the counterforce capability assumed in the example.

15. Even if the United States were to take the initiative in the present example, it would not fare much better. In the present example, the non-targetable Soviet forces alone contain a total expected delivery capability of megatons, so that execution of even a hypothetically perfect U.S. initiative attack which completely destroyed all targetable Soviet forces would leave a surviving Soviet force capable of delivering over a thousand megatons fission. Furthermore, under these circumstances (U.S. initiative attack), it seems reasonable to suppose that the Soviets might retaliate against our population, in which case they could exact a toll of more than 80 percent U.S. fatalities with their surviving force. Even a Soviet retaliatory attack with this surviving force which devoted only 50 percent to population would cause 75 percent fatalities, and if as little as one-third of their surviving force were targeted against population, 70 percent U.S. fatalities would result.

16. The remainder of this Appendix will attempt to demonstrate that the situation which obtains for the preceding example is not an isolated one, but is rather the general case.

17. A number of different illustrative Soviet postures have been chosen for the evaluation. In addition, in order to produce a convincing appraisal of the limitations of counterforce, the conditions upon which the following discussion is based have been deliberately biased in a direction which favors the success of U.S. counterforce efforts. As a result, the success of U.S. counterforce in a realistic situation can confidently be expected to be lower than indicated here, provided the Soviets can launch their surviving weapons against the U.S. (It is, of course, conceivable that U.S. counterforce might sufficiently disrupt the Soviet command and control system as to prevent the launch of any surviving Soviet weapons. The following evaluation is solely concerned with the effectiveness of counterforce directed against enemy weapons, and consequently is based upon the assumption that no such failure of Soviet command and control occurs.)

REPRESENTATIVE SOVIET FORCE POSTURES

18. In order to study the counterforce employment of U.S. weapon systems, it is necessary to postulate the Soviet offensive force posture against which the U.S. systems are to be employed. Because of present uncertainties concerning future Soviet strategic force postures, a number of different postures have been chosen for the Soviet Union to be representative of the possibilities in the time period of 1963-1967.

20. In addition to simply the number of Soviet weapons, it is necessary to delineate various postures that the Soviets might adopt for the basing of these weapons. The figures in Table IV are not intended, therefore, to be accurate intelligence estimates of future Soviet postures, but rather to present illustrative figures for purposes of analysis.

21. Six different missile postures are shown for each time period. These six postures are:

a. I - Soft. The majority of land-based missiles in this case are deployed in a soft configuration with three missiles per aim point.

b. II - Hard. The majority of the land-based missiles in this case are in hardened sites.

c. III - Mobile. Mobile land-based missiles are introduced in the 1965 and 1967 time periods. It is assumed that 10 percent of these mobile missiles can be targeted in a counterforce strike.

d. IV - Dispersed. Dispersed (one per aim point) but still soft missiles are included in the inventory.

e. V - Fast Reaction. In this case it is assumed that 50 percent of the missiles and 25 percent of the bombers can be launched prior to the impact of our counterforce missiles.

f. VI - Accelerated. Larger numbers of land-based missiles are included and all types of siting are also included.

TABLE IV

REPRESENTATIVE SOVIET STRATEGIC OFFENSIVE FORCE POSTURES 1963-1967

WEAPON SYSTEM	CONFIGURATION	(I) SOFT			(II) HARD			(III) MOBILE		(IV) DISPERSED		(V) FAST REACTION			(VI) ACCELERATED		
		1963	1965	1967	1963	1965	1967	1965	1967	1965	1967	1963	1965	1967	1963	1965	1967
ICBM	Soft, 3 per Aim Point	300	600	900	100	100	100	300	300	300	300	300	500	700	200	200	200
	Soft, 1 per Aim Point	---	---	---	---	---	---	---	---	200	400	---	---	---	---	200	400
	100 psi	100	100	100	300	500	500	100	100	100	100	100	100	100	200	400	400
	300 psi	---	---	---	---	---	200	---	---	---	---	---	---	---	---	---	200
	Land Mobile	---	---	---	---	---	---	200	400	---	---	---	---	---	---	200	400
SLBM	50% in Port Among 17 Submarine Bases	210	330	450	210	330	450	330	450	330	450	210	330	450	210	330	450
Bombers	Distributed Among 100 Airfields	600	500	400	600	500	400	500	400	500	400	600	500	400	600	500	400

TABLE IV (Continued)

	(I) SOFT			(II) HARD			(III) MOBILE		(IV) DISPERSED		(V) FAST REACTION			(VI) ACCELERATED		
	1963	1965	1967	1963	1965	1967	1965	1967	1965	1967	1963	1965	1967	1963	1965	1967
ICBM Detectability (%)a/	90	90	90	90	90	90	90/10	90/10	90	90	90	90	90	90/10	90/10	90/10
Reaction (%Missiles/%Bombers)b/	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	50/25	50/25	50/25	0/5	0/5	0/5
Expected Total Delivered Fission Yield if Unattacked (MT)																
Expected Total Delivered Fission Yield from Non-Targetable Elements (MT)																

a/ Percent of Soviet land-based missile sites whose location is known with sufficient accuracy to permit targeting prior to hostilities. 90/10 refers to capability of targeting 90 percent of fixed sites and 10 percent of mobile sites.

b/ Percent of Soviet missiles and bombers that could be launched prior to destruction by U.S. missiles.

22. It has been assumed in these cases that 90 percent of the fixed enemy land-based missiles have locations which are known to the United States with sufficient accuracy so that they may be targeted. This is a somewhat optimistic assumption and has been made in order to determine the limit of the greatest degree of success which one could hope for, for counterforce strikes. In the event that we are not, in fact, able to detect this large a fraction of Soviet missile sites, the effectiveness of U.S. counterforce strikes will, of course, be reduced.

23.

TABLE V

U.S. INITIATIVE CASE

24. In order to explore the potential value as well as the limitations of U.S. initiative counterforce attacks, calculations for a number of hypothetical attacks on the preceding representative Soviet force postures have been performed. In order to simplify the calculations each attack was performed entirely by a single idealized U.S. weapon system rather than by a mixture of U.S. systems. Although any actual case would, of course, involve a mixture of many U.S. weapons of diverse characteristics, the present procedure of considering only ideal pure systems serves adequately for investigation of the possibilities and limitations of U.S. initiative attacks.

25. For each particular case calculated (consisting of a particular number of U.S. weapons against a particular Soviet posture), the U.S. weapons were optimally targeted against the Soviet force to minimize the U.S. fatalities which could be produced by the surviving Soviet force. The U.S. fatalities which then result from retaliatory employment of the surviving Soviet force against U.S. population serve to measure the accomplishment of the U.S. initiative counterforce attack.

26. The fatality calculations are based on the methods and results of Appendix "D" to this Enclosure, and are estimates of direct fatalities due to blast and fallout only. Because of the additional effects of firestorms, and indirect effects caused by disorganization of society, destruction of communications, genetic damage, destruction of livestock, etc., these fatality estimates should be regarded as underestimates of the ultimate toll.

28. Figures 1 through 3 present the consequences, in terms of U.S. fatalities produced by surviving Soviet forces, of these hypothetical U.S. initiative attacks on the representative Soviet force postures given in Table IV for the years 1963, 1965, and 1967.

29. The general behavior of the curves of Figures 1 through 3 consists of a fairly rapid initial reduction in U.S. population fatalities with increasing numbers of U.S. weapons employed in the initiative attack, followed by decreasing effectiveness as the numbers increase further, and finally flattening out at a constant level of casualties which is not diminished with further increases in U.S. weapons. This lower limit to the population fatalities corresponds to the residue of non-targetable Soviet forces -- the on-station submarine-launched ballistic missiles, the alert or non-targetable fraction of manned bombers (5 percent), the assumed 10 percent of fixed-based missiles of unknown location, and the forces which escape prior to impact of the U.S. weapons in the fast reaction case and 90 percent of the mobile force in the mobile case.

30. In order to illustrate the variation of results with assumed U.S. weapons characteristics, Figure 4 presents the results for the year 1965 for the same yield, CEP, and reliability, but for the case where the weapon is not assumed to be reprogrammable. The ultimate limits for this case are, of course, the same as if the weapon were reprogrammable, since the limits correspond

FIGURE 1

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES (CASE: YEAR 1963)

FIGURE 2

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES (CASE: YEAR 1965)

FIGURE 3

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES (CASE: YEAR 1967)

FIGURE 4

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES (CASE: YEAR 1965)

FIGURE 5

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES (CASE: YEAR 1965) [redacted] 7-S-60-8A

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES

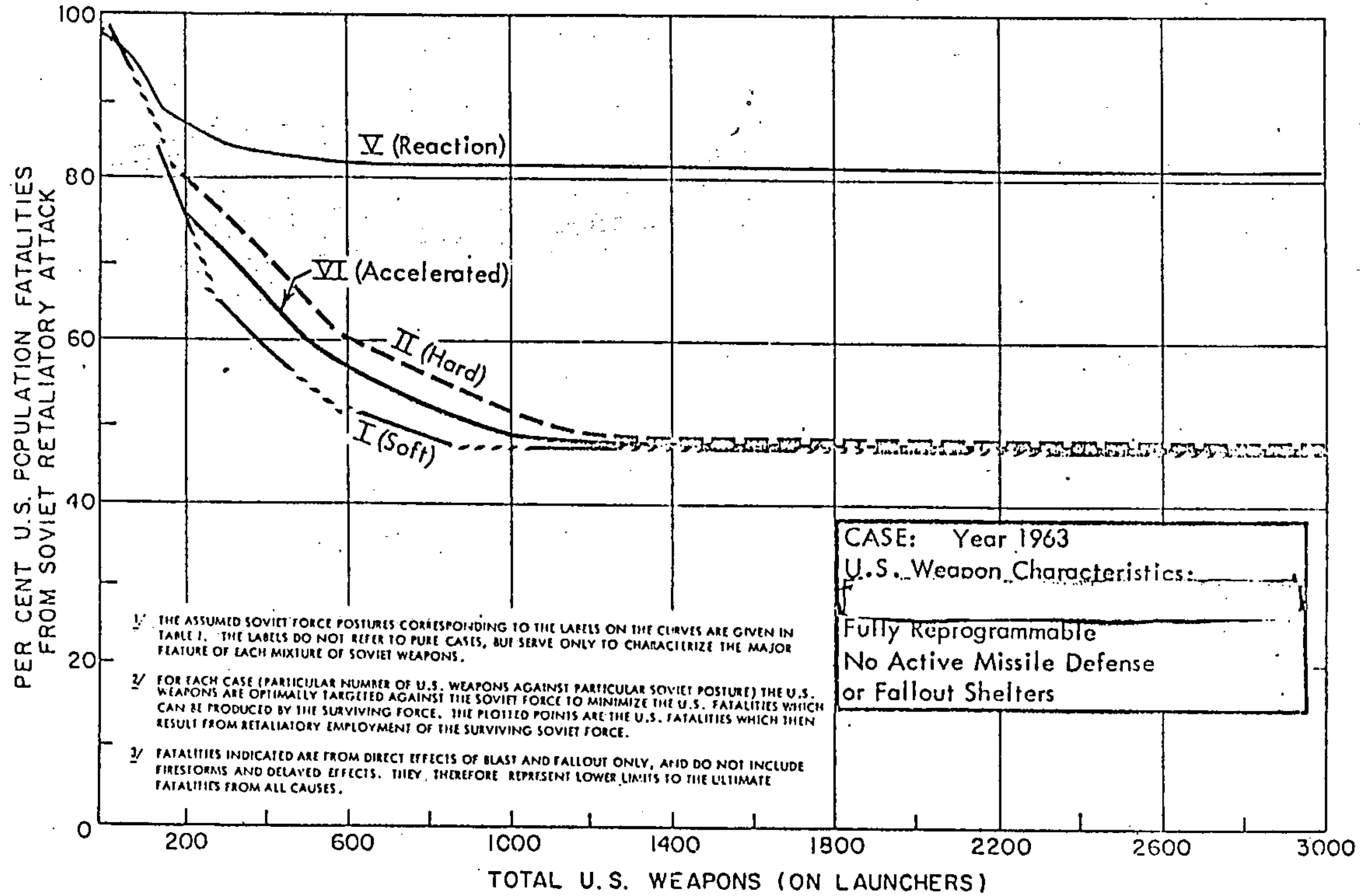

FIGURE I
APPENDIX "E" TO
ENCLOSURE "A"
WSEG REPORT NO. 5?

7-6-60-9A

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES

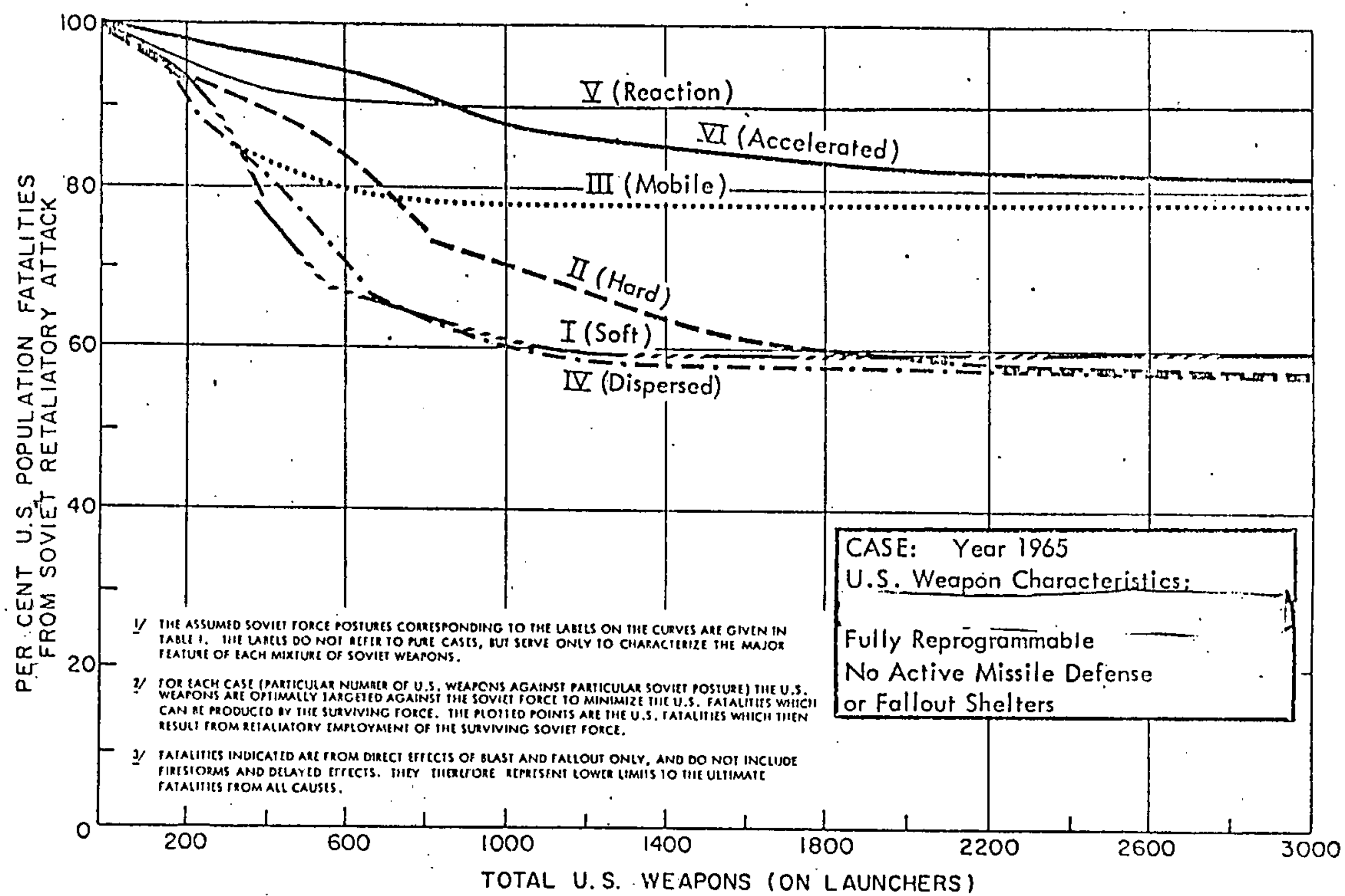

FIGURE 2
APPENDIX "E" TO
ENCLOSURE "A"
WSEG REPORT NO. 50

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES

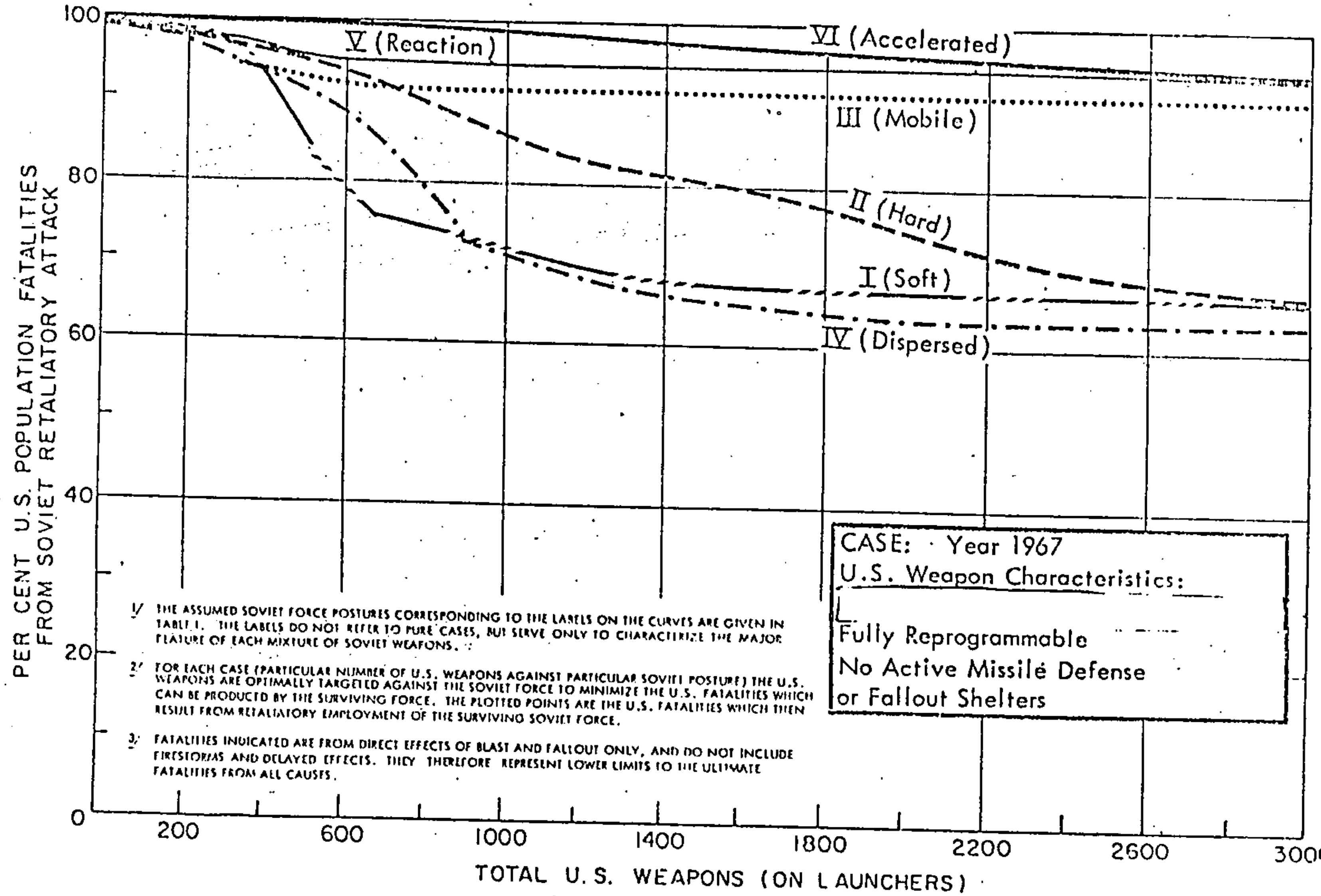

FIGURE 5
APPENDIX "F" TO
ENCLOSURE "A"
WSEG REPORT

7-6-60-11A

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES

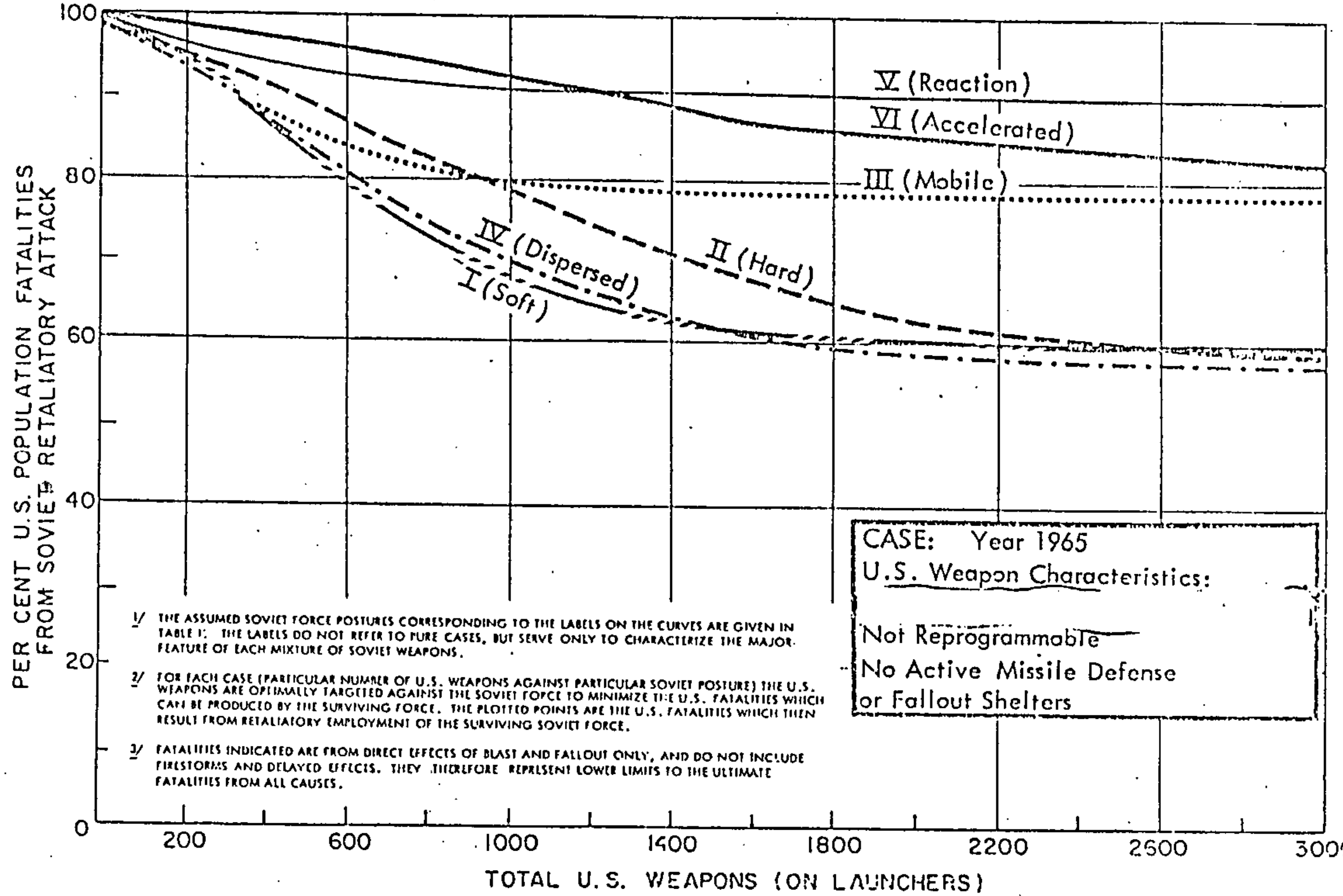

FIGURE 4
APPENDIX "E" TO
ENCLOSURE "A"
WSEG REPORT NO. [illegible]

7-6-60-12A

EFFECTIVENESS IN PREVENTING U.S. FATALITIES OF HYPOTHETICAL U.S. INITIATIVE ATTACKS ON REPRESENTATIVE SOVIET FORCE POSTURES

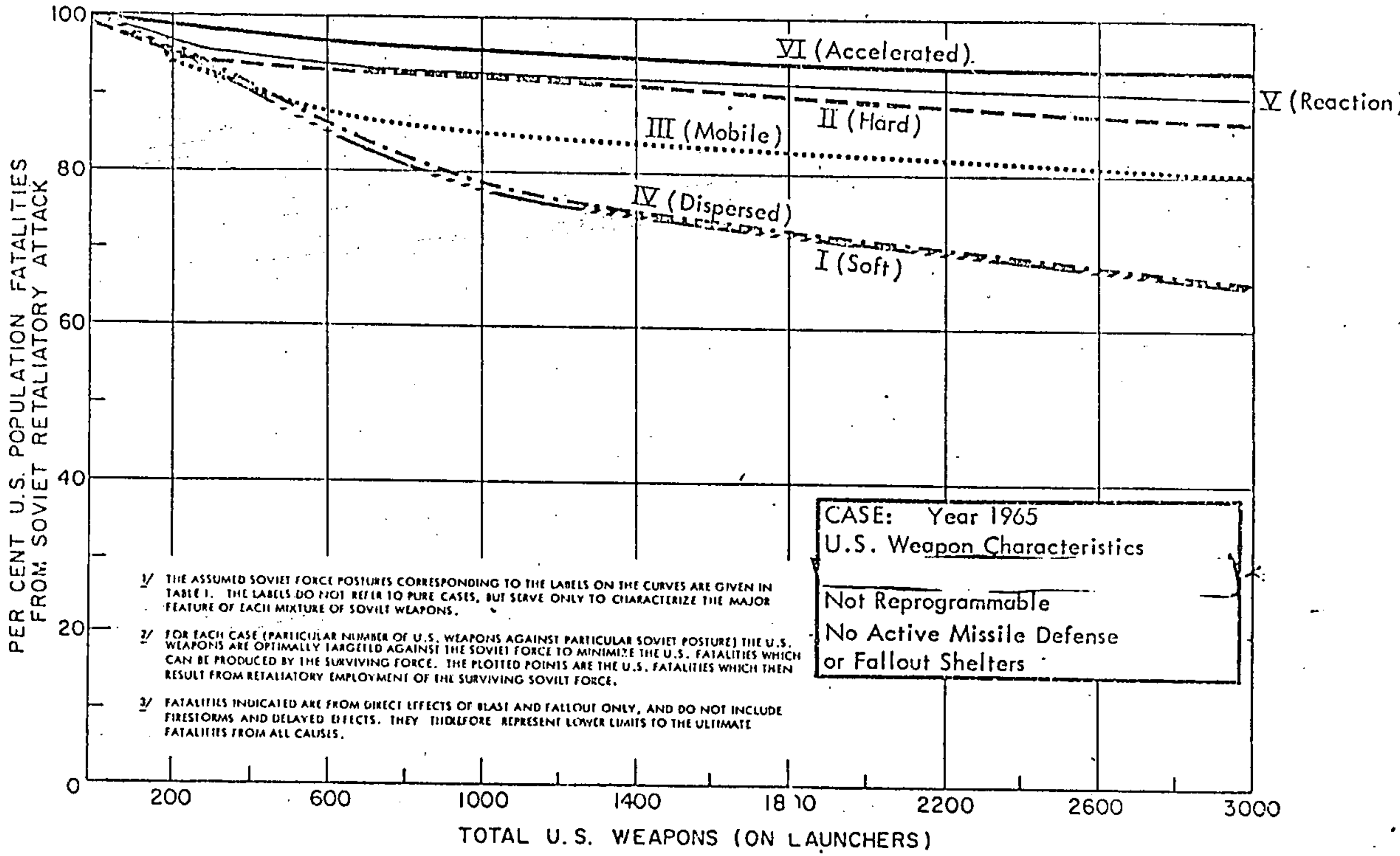

FIGURE 5
APPENDIX "E" TO
ENCLOSURE "A"
WSEG REPORT No. 50

34. It is clear from these results that (in the absence of an effective civil defense program and/or ballistic missile active defense) the prospects of a satisfactory outcome from a U.S. initiative attack are not good. The next section investigates the potential contribution of active and passive defense.

CONTRIBUTION OF PASSIVE AND ACTIVE DEFENSE MEASURES

35. In order to illustrate the potential contribution of fall-out shelters to blunting the effectiveness of a Soviet retaliatory attack, the calculations of Table VI have been repeated for the case of the U.S. population fully sheltered according to the assumptions of Appendix "D". The results of this calculation are presented in Table VII. Table VII thus presents percentage of U.S. population fatalities which might be expected from the retaliatory employment of the non-targetable residue of Soviet forces against a sheltered U.S. population, but without any active ballistic missile defense.

TABLE VII

PERCENT U.S. POPULATION FATALITIES FROM RETALIATORY EMPLOYMENT OF THE NON-TARGETABLE RESIDUE OF SOVIET FORCES FOR THE CASE OF FULLY SHELTERED a/ U.S. POPULATION (NO AICBM)

SOVIET POSTURE		YEAR		
		1963 (Percent)	1965 (Percent)	1967 (Percent)
I	(SOFT)	26	33	39
II	(HARD)	25	32	36
III	(MOBILE)	--	48	59
IV	(DISPERSED)	--	32	36
V	(FAST REACTION)	50	57	62
VI	(ACCELERATED)	26	50	62

a/ For shelter assumptions, see Appendix "D".

36. It is clear from Table VII that provision of fallout shelters to the U.S. population causes a further reduction in the casualties (beyond the reduction due to the U.S. counter-force attack) to be expected from the employment of the residual

Soviet forces. The reduction in fatalities ranges from 22 percent to 33 percent of the entire U.S. population, which represents a saving of about 40 million to 60 million lives.

37. In order to properly assess the significance of this calculation, it is necessary to bear in mind certain features of the assumed shelter program. In the first place, the effectiveness of the shelters was deliberately chosen conservatively in order to approximate a lower bound to the effectiveness which might be realized by a fallout shelter program. No provision was made for the employment of decontamination procedures upon exit from the shelters, nor were sufficient stocks of food and water supplied to last for more than a month or so. These measures could significantly increase the effectiveness of the shelter program.

38. In addition, no allowance has been made for the possibility of a fallout shelter program designed to shelter only a part of the entire U.S. population. By optimally choosing the geographic regions of the United States in which to apply sheltering, the number of lives potentially saved for a given cost could be considerably greater than for the case in which the entire U.S. population is sheltered. With these considerations the costs of saving lives by fallout sheltering implied by Table VII ($900 to $1400 per life saved based on a conservative estimate of $300 per person sheltered) may properly be regarded as overestimates. For the optimal deployment of a partial shelter program, the cost per life saved might approach the basic cost per person sheltered.

39. For purposes of assessing the potential contribution of active ballistic missile defense to blunting the effectiveness of a Soviet retaliatory strike, it is only necessary to observe that active missile defenses perform the same function in this respect

[redacted]

simply to the non-targetable residues of the Soviet forces. These limits are, however, approached somewhat more slowly in this case. Figure 5 shows the effect of a further reduction in the quality of the U.S. offensive missile by assuming [redacted] and also no reprogramming.

31. Since the asymptotes of the figures do not depend upon the U.S. weapon characteristics, and also serve to measure the ultimate possibilities, the subsequent discussion will be concerned only with these limits. Table VI summarizes these ultimate limits for the various Soviet postures and the three time periods considered.

TABLE VI

PERCENT U.S. POPULATION FATALITIES FROM RETALIATORY EMPLOYMENT OF THE NON-TARGETABLE RESIDUE OF SOVIET FORCES (NO SHELTERS OR AICBM)

SOVIET POSTURE		YEAR 1963 (Percent)	1965 (Percent)	1967 (Percent)
I	(SOFT)	47	59	67
II	(HARD)	47	57	63
III	(MOBILE)	--	78	91
IV	(DISPERSED)	--	57	63
V	(FAST REACTION)	82	90	94
VI	(ACCELERATED)	47	81	94

32. From Table VI it is seen that in the most favorable case the U.S. could suffer 47 percent population fatalities while in the fast reaction, mobile, or accelerated cases in which a larger fraction of the Soviet force is not targetable, the U.S. fatalities range from nearly 80 percent to 94 percent of the total population.

33. Since the assumptions upon which Table VI are based have been deliberately chosen favorable to U.S. initiative counterforce -- the fatality estimates are lower bounds, 90 percent of fixed Soviet ICBM bases were assumed to be targetable, and complete destruction of all targetable forces was assumed -- the outcome of any realistic case is likely to be a good deal worse.

as strategic offensive weapons employed in the counterforce role; namely, the reduction in the number of weapons impacting in the United States. Since this is the case, offensive weapon systems and active defenses can be considered to be direct competitors for purposes of blunting enemy attacks and may be compared on a basis of cost per enemy weapon killed independently of the assumptions of fallout sheltering and of the actual fatality level produced.

40. In order to gain some appreciation for the order of magnitude of the costs per unit enemy warhead killed by offensive missile systems, Tables VIII and IX present these costs for two different exemplary U.S. missile systems. Table VIII presents the cost per expected deliverable warhead kill for a hypothetical U.S. ICBM

Since the returns progressively diminish as more than one weapon is assigned to the same target, these costs are presented as the costs associated with each successive weapon assigned to the target. The costs are presented for each major type of target considered in the representative Soviet force posture.

TABLE VIII

COST ($ MILLION) PER EXPECTED DELIVERABLE WARHEAD KILL FOR A FULLY REPROGRAMMABLE ICBM COSTING 10 MILLION DOLLARS a/b/

Counterforce Weapon Assigned to Target	TARGET			
	Soft 3/Aim Point Soviet ICBM ($ Millions)	Soft 1/Aim Point Soviet ICBM ($ Millions)	100 psi Soviet ICBM ($ Millions)	300 psi Soviet ICBM ($ Millions)
1st Weapon	6.4	19.0	22.4	35.6
2nd Weapon	158.0	475.0	121.0	73.1
3rd Weapon	3,960.0	11,900.0	655.0	150.0

a/ Assumptions:

Soviet ICBM reliability 0.75.

b/ In the "fast reaction" case, all costs should be doubled to reflect the fact that 50 percent of the Soviet force is launched prior to impact of U.S. ICBM's.