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IDA MEMORANDUM REPORT M-144

DUEL BETWEEN AN ASAT WITH MULTIPLE KILL VEHICLES AND A SPACE-BASED WEAPONS PLATFORM WITH KINETIC ENERGY WEAPONS

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A mathematical model is described for a duel between a ground-based anti-satellite (ASAT) and a space-based weapons platform defending itself with kinetic energy weapons. The ASAT carries one to six kill vehicles and the space platform may first attack the ASAT booster with one to three defense missiles. If the ASAT kill vehicles collectively survive the boost phase, they are each subject to a post-boost phase attack consisting of one to three defense missiles. A formula for the probability of killing the space platform with a single ASAT launch is derived as a function of the vehicle reliabilities, target detection probabilities, kill probabilities, and number of participating vehicles. Formulas are also given for the probability of kill if the space platform defends itself with a high-energy laser or with both high-energy laser and defense missiles. Illustrative examples are calculated for the case in which the space platform is defended by defense missiles only. It is assumed that all offense and defense reliabilities, detection probabilities, and kill probabilities are equal to 0.90. A sensitivity analysis (cont'd...)

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A mathematical model is described for a duel between a ground-based anti-satellite (ASAT) and a spaced-based weapons platform defending itself with kinetic energy weapons. The ASAT carries 1-6 ~~one to six~~ kill vehicles and the space platform may first attack the ASAT booster with 1-3 ~~one to three~~ defense missiles. If the ASAT kill vehicles collectively survive the boost phase, they are each subject to a post-boost phase attack consisting of 1-3 ~~one to three~~ defense missiles. A formula for the probability of killing the space platform with a single ASAT launch is derived as a function of the vehicle reliabilities, target detection probabilities, kill probabilities, and number of participating vehicles. Formulas are also given for ~~the~~ Kill probabilities ~~of kill~~ if the space platform defends itself with a high-energy laser or with both high-energy laser and defense missiles. Illustrative examples are calculated for the case in which the space platform is defended by defense missiles only. It is assumed that all offense and defense reliabilities, detection probabilities, and kill probabilities are equal to 0.90. A sensitivity analysis illustrates the effect of a variation in any one of the assumed parameters on the probability of killing the space platform when all other parameters are held equal to 0.90.

It is shown that the survivability of the space platform is crucially dependent on a capability to destroy the ASAT booster before it can deploy its miniature kill vehicles. Improvement in parameter values above the 0.9 level, if shared equally by both the ASAT offense and space platform defense, will favor the platform defense. This conclusion is based on the mathematical model developed, which does not consider countermeasures, costs, and defense missile inventory exhaustion effects.

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DUEL BETWEEN AN ASAT WITH MULTIPLE KILL VEHICLES AND A SPACE-BASED WEAPONS PLATFORM WITH KINETIC ENERGY WEAPONS

A. INTRODUCTION

The U.S. is currently testing a sophisticated air-launched anti-satellite (ASAT) which carries a miniature infrared homing vehicle capable of hitting and thereby killing a satellite. A heavier ground-launched ASAT booster could deploy a number of such kill vehicles dedicated to destroying a single satellite. A space-based weapons platform that defended itself against such an attack would be required to engage and kill each of the ASAT kill vehicles separately, unless the booster were to be engaged and destroyed before it could deploy its kill vehicles. The attacker, of course, could also launch more than one ASAT booster against the space platform.

Various scenarios might be postulated for the types of engagements considered here. A ground-based attack, for example, could be a prelude to a nuclear strike. For this case, commonly referred to as defense suppression, time considerations would preclude the use of a shoot-look-shoot firing doctrine by the attacker. In another case, the attack may be of a much more leisurely nature, designed to discourage deployment of such satellites or to disable them in a war of attrition. Here ample time would be available for the attacker to assess the results of each ASAT booster attack and decide whether or not another attack is required.

The purpose of this memorandum is to determine the degree of success an ASAT attack could have in killing a space platform defending itself with defense missiles. The measure of success is here measured by the probability P_{KL} of killing the space platform with a single ASAT booster carrying one or more

ASAT kill vehicles. The formula for the probability P_K of killing the space platform with a force of N ASAT booster launches is easily derived as a simple function of the complex expression derived for P_{KL}.

The outcome of a duel between a ground-launched ASAT and a space-based weapons platform will depend on many offense and defense system parameters. In the simple mathematical model described in this memorandum only the most basic parameters are considered, i.e., vehicle reliabilities, target detection probabilities, kill probabilities, and numbers of participating vehicles. No consideration is given here to cost factors or the use of countermeasures by either side.

The mathematical relationships are developed on the assumptions that (1) the number of defense missiles is sufficiently large to avoid exhaustion effects, and (2) the battle management system is sufficiently powerful to avoid saturation effects. The exhaustion case, however, is considered briefly in Section C.

Three cases are considered for the space-based platform defense: (1) kinetic energy weapons (KEW) only, (2) space-based high energy laser only, and (3) KEW weapons and space-based high energy laser. While equations are derived for all three cases, illustrative numerical results are presented only for case (1), followed by a sensitivity analysis of the key parameters.

B. MATHEMATICAL MODEL FOR THE DUEL

The basic parameters in the survivability of a space-based weapons platform attacked by a ground-launched direct ascent ASAT are defined in Table I. Many of these independent parameters can be combined to reduce the number of variables in the expression for the probability of killing the space platform with a single ASAT launch to 9 from the 15 in Table I.

If the space platform is to be able to defend itself, it must have sensor and fire control equipment which are reliable

TABLE I. PARAMETERS IN SPACE PLATFORM SURVIVABILITY AGAINST DIRECT ASCENT ASAT ATTACK FOR A KEW DEFENSE

• Reliabilities	
- ASAT Booster	R_B
- ASAT Kill Vehicle	R_V
- Space Platform	R_P
- Defense Missile	R_M
• Detection Probabilities†	
- Space Platform by ASAT Kill Vehicle	D_{PV}
- ASAT Booster by Space Platform*	D_{BP}
- ASAT Kill Vehicle by Space Platform	D_{VP}
- ASAT Booster by Defense Missile	D_{BM}
- ASAT Kill Vehicle by Defense Missile	D_{VM}
• Conditional Kill Probabilities**	
- Space Platform by ASAT Kill Vehicle	P_{PV}
- ASAT Booster by Defense Missile	P_{BM}
- ASAT Kill Vehicle by Defense Missile	P_{VM}
• Number of Vehicles	
- ASAT Kill Vehicles/Booster	N_V
- Defense Missiles Fired/Booster	N_B
- Defense Missiles Fired/ASAT Kill Vehicle	N_M
- ASAT Boosters/Space Platform	N

†Here defined to include acquisition and tracking. The probability of detection of the space platform by the ground-based surveillance system is assumed to be unity.

*Or by surveillance satellite(s).

**Assuming a reliable vehicle and successful target detection.

at the time of the ASAT attack. The probability that this will be the case is R_P. The sensor is here assumed to be located on the space platform.* It is also assumed that the sensor must detect the ASAT booster while it is burning. The probability that this will be the case is D_{BP}. If γ denotes the joint probability that the space platform is operable and the sensor detects the booster, then

$$\gamma = R_P D_{BP} \quad . \tag{1}$$

The parameter D_{BP} is a function of the earth IR background, booster IR signal strength, range, sensor characteristics, etc. It is assumed that if the space platform fails to detect the burning booster, it will be incapable of detecting any of the miniature kill vehicles subsequently deployed by the booster. The overall kill probability E_{PV} of a single ASAT kill vehicle against the space platform, assuming the booster survives the boost phase, is given by the product of the kill vehicle's reliability,† its probability of detecting the space platform, and its conditional probability of killing the space platform, or

$$E_{PV} = R_V D_{PV} P_{PV} \quad . \tag{2}$$

It is assumed that the mission of the ASAT kill vehicle is solely the destruction of the space platform and that it will be designed so as to preclude the possibility of engaging an attacking defense missile along its path.

The probability that a reliable ASAT booster launch kills the space platform is derived below as the sum of two probabilities, A and B. In probability A, the ASAT booster is undetected and the ASAT kill vehicles are unopposed by the space platform's defense missiles; in probability B, the ASAT

*The sensor could be located on a surveillance satellite(s).

†Not including the probability that the kill vehicle deployment is successful which is subsumed in the booster reliability R_B.

booster is detected and the ASAT kill vehicles must survive a boost phase attack and a post-boost phase attack by the space platform's defense missiles.

The probability A that a reliable ASAT booster goes undetected and kills the space platform with one of N_V kill vehicles is given by

$$A = (1 - \gamma)\left[1 - \left(1 - E_{PV}\right)^{N_V}\right] . \tag{3}$$

In order to kill a space platform which is ready and able to defend itself, the ASAT booster may first have to survive N_B missiles fired against it, each with an overall kill probability E_{BM} where, in analogy to Eq. (2),

$$E_{BM} = R_M \, D_{BM} \, P_{BM} \quad . \tag{4}$$

The probability α that the ASAT booster encounters an operational space platform, is detected, and survives a boost phase attack consisting of N_B defense missiles is therefore given by

$$\alpha = \gamma\left(1 - E_{BM}\right)^{N_B} . \tag{5}$$

The probability β that any one of the ASAT kill vehicles survives an attack of N_M defense missiles fired against it and then proceeds to kill the space platform is given by

$$\beta = E_{PV} \left\{1 - D_{VP}\left[1 - \left(1 - E_{VM}\right)^{N_M}\right]\right\} \tag{6}$$

where

$$E_{VM} = R_M \, D_{VM} \, P_{VM} \tag{7}$$

is the probability that a defensive missile is reliable, detects the ASAT kill vehicle, and kills it. The term in the interior brackets in Eq. (6) is the conditional probability that one ASAT kill vehicle is killed by one of N_M defense missiles. Before a defense missile can kill the ASAT kill vehicle, the space platform (or surveillance satellite) must first detect it, an event which has the probability defined as D_{VP}.

The probability B that the attacking ASAT encounters an operational space platform, is detected, survives a boost phase attack, and kills the space platform with one of its N_V kill vehicles is therefore given by

$$B = \alpha\left[1 - \left(1 - \beta\right)^{N_V}\right] . \tag{8}$$

The probability P_{KL} of a single ASAT killing the space platform is given by $R_B(A + B)$, or

$$P_{KL} = R_B \left\{(1 - \gamma)\left[1 - \left(1 - E_{PV}\right)^{N_V}\right] + \gamma\left(1 - E_{BM}\right)^{N_B}\left[1 - \left(1 - \beta\right)^{N_V}\right]\right\} . \tag{9}$$

The probability P_K of N ASAT booster launches killing the space platform, assuming that they are independent events, is given by

$$P_K = 1 - \left(1 - P_{KL}\right)^N . \tag{10}$$

The equation for P_{KL} in the case of a single ASAT launch against a space-based laser which relies only on its high energy laser to destroy the booster and its kill vehicles is similarly derived to be

$$P_{KL} = R_B \left\{\left(1 - \gamma_L\right) \left[1 - \left(1 - E_{PV}\right)\right]^{N_V} + \gamma_L \left(1 - E_{LB}\right) \left\{1 - \left[1 - E_{PV} \left(1 - D_{VP} E_{LA}\right)\right]^{N_V}\right\}\right. \tag{11}$$

where E_{LB} and E_{LA} are the probabilities of kill of the laser against the ASAT booster and ASAT kill vehicle respectively, and γ_L is the joint probability that the sensor detects the booster and the high energy laser is operational at the time it is called upon to defend itself.

The equation for P_{KL} in the case of a single ASAT launch against a space-based laser which depends on kinetic energy weapons and its high energy laser to defend itself is more complex. Four states of defense systems operability exist for this case: (1) both the laser and the missile system are inoperable, (2) the laser system is operable but not the missile system, (3) the missile system is operable but not the laser, and (4) both the laser and missile system are operable. Assuming both laser and missile systems are independent and have their own sensor system, the expression for P_{KL} is given by

$$P_{KL}/R_B = \left(1 - \gamma\right)\left(1 - \gamma_L\right)\left[1 - \left(1 - E_{PV}\right)^{N_V}\right] +$$

$$\left(1 - \gamma\right)\gamma_L\left(1 - E_{LB}\right)\left\{1 - \left[1 - E_{PV}\left(1 - D_{VP}\,E_{LA}\right)\right]^{N_V}\right\} +$$

$$\left(1 - \gamma_L\right)\gamma\left(1 - E_{BM}\right)^{N_B}\left[1 - \left(1 - \beta\right)^{N_V}\right] +$$

$$\gamma_L\gamma\left(1 - E_{LB}\right)\left(1 - E_{BM}\right)^{N_B}\left\{1 - \left[1 - \left(1 - D_{VP}\,E_{LA}\right)\beta\right]^{N_V}\right\} \quad (12)$$

where β is defined in Eq. (6). A space platform defended by two independent weapon systems obviously would be more highly survivable than it would be if it were defended by only one.

C. ILLUSTRATIVE EXAMPLES

1. Firing Doctrine

The probability of kill P_{KL} of a single ASAT launch against a defense consisting of only kinetic energy weapons, i.e., Eq. (9), is plotted in Figs. 1 through 6 for one to six kill vehicles per booster, respectively. The firing doctrine is represented by (N_B, N_M) where N_B is the number of defense missiles allocated per ASAT booster and N_M the number of defense missiles allocated per ASAT kill vehicle, for a total of ($N_B + N_V N_M$) defense missiles allocated per ASAT launch. The expected number of missiles fired per ASAT booster may be a smaller number as will be discussed later. It is assumed in this illustrative example that $R_B = R_V = R_P = R_M = D_{PV} = D_{BP} = D_{VP} = D_{BM} = D_{VM} = P_{PV} = P_{BM} = P_{VM} = 0.90$.

The need for an active defense is illustrated by the high values of P_{KL} with no active defense, i.e., the case (0, 0). If $N_V = 1$, $P_{KL} = 0.66$ (Fig. 1); if $N_V = 6$, $P_{KL} = 0.90$ (Fig. 6). Without an active defense, however, there would be little motivation for the offense to develop a capability of deploying more than two kill vehicles per booster. An active defense could more than halve the value of P_{KL} if a single missile attacks the booster, i.e., the case (1, 0) in Figs. 1 through 6.

For the case $N_V = 1$, one defense missile fired during boost (1, 0) reduces the value of P_{KL} from 0.65 to 0.27; two defense missiles (2, 0) would further reduce the value of P_{KL} to 0.16. However, firing more than two defense missiles at the ASAT booster rapidly encounters diminishing returns due to the limits imposed by the reliability and detection probability parameters assumed. Thus, for example, as the number of defense missiles fired during boost approaches infinity, i.e., (∞,0), the value of P_{KL} approaches an asymptotic value of 0.125 for $N_V = 1$ and 0.185 for $N_V = 6$. The limiting P_{KL} values for the case (∞,∞) are the same as for the case (∞,0).

It appears to be particularly advantageous for the offense to deploy more than one kill vehicle per booster if $N_B = 0$ (see Figs. 2 - 6). This corresponds to the case of an invulnerable booster, a condition that (for example) could arise if the ASAT booster burned so fast that the defense missile would be incapable of intercepting the booster. The (0, N_M) values of P_{KL} for $N_V = 3$ (Fig. 3) are approximately double the corresponding values for $N_V = 1$ (Fig. 1). If the ASAT booster can be attacked, the offense advantage of deploying multiple ASAT kill vehicles is lessened. With firing doctrine (2, 2), for example, the value of P_{KL} is only increased from a value of 0.13 for $N_V = 1$ to 0.19 for $N_V = 3$.

The expected number of defense missiles fired per ASAT launch will be smaller than the number of missiles ($N_B + N_V N_M$) required to implement a given firing doctrine provided the booster can be attacked and/or a shoot-look-shoot firing doctrine can be used against each ASAT kill vehicle.* This is illustrated in Table II for the case $E_{BM} = E_{VB} = 0.9^3 = 0.729$ and $N_M = 2$. The expected number E_F of missiles fired if salvos of 2 are fired at each ASAT kill vehicle is given by

$$E_F = N_B + \left(1 - E_{BM}\right)^{N_B} N_V \, N_M \tag{13}$$

$$= N_B + 2N_V \, (0.271)^{N_B} . \tag{14}$$

If a shoot-look-shoot firing doctrine can be used and damage assessment is perfect,

$$E_F = N_B + N_V \left(1 - E_{BM}\right)^{N_B} \left[1 + \left(1 - E_{VM}\right)\right] \tag{15}$$

$$= N_B + (1.271) \, N_V \, (0.271)^{N_B} . \tag{16}$$

*It is assumed that there would be insufficient time to use a shoot-look-shoot KEW firing doctrine against the booster.

TABLE II. EXPECTED NUMBER OF MISSILES FIRED

$N_M = 2;\ E_{BM} = E_{VM} = 0.729$

N_V	N_B	P_{KL}	$N_B + N_V N_M$	E_F SALVO	E_F S-L-S
3	0	0.40	6	6.0	3.8
3	1	0.24	7	2.6	2.0
3	2	0.18	8	2.4	2.3
6	0	0.56	12	12.0	7.6
6	1	0.27	13	4.3	3.1
6	2	0.20	14	2.9	2.6

If $N_B = 0$ the defense is confronted with a high value of P_{KL} and a severe missile inventory problem, particularly if shoot-look-shoot cannot be used, in which case $E_F = 2\ N_V$. However, if $N_B = 2$ and S-L-S can be used, then $E_F = 2.3$ for $N_V = 3$ and $E_F = 2.6$ for $N_V = 6$.

The space platform missile inventory I that would be required to cope with multiple ASAT booster attacks should be limited by the expected lifetime of the platform, which corresponds to $(P_{KL})^{-1}$ attacks. Thus, if k is a constant,

$$I = \frac{kE_F}{P_{KL}} \quad . \tag{17}$$

For the case $N_B = 2$, $N_M = 2$, $N_V = 6$ and assuming S-L-S and $k = 1$, $I = 13$. However, there is still a probability of $(1 - P_{KL})^5$ or 0.33 that the space station would still be functional after depleting its missile inventory defending against 5 ASAT attacks. Doubling the value of k to 2 would double the value of I to 26, which would enable the space platform to survive 10 ASAT booster attacks with a probability of 0.11. The space station survivability falls to nearly zero very rapidly after the expected point of defense missile exhaustion.

Thus, there is near zero space station survivability with 7 ASAT booster attacks for I = 13 and 13 ASAT booster attacks for I = 26.

2. Sensitivity of P_{KL} to Common Parameter Value

In the duel defined by Eq. (9) it is interesting to investigate the sensitivity of P_{KL} to the assumed equal value of 0.9 for each reliability, detection probability, and kill probability. If x is the common value of the parameters and $N_B = 0$, Eq. (9) reduces to the high order polynomial

$$P_{KL} = x \left\{ \left(1 - x^2\right) \left[1 - \left(1 - x^3\right)^{N_V} \right] + x^2 \left[1 - \left(1 - \beta\right)^{N_V} \right] \right\} \quad (18)$$

where

$$\beta = x^3 \left\{1 - x \left[1 - \left(1 - x^3\right)^{N_M} \right] \right\} \quad . \quad (19)$$

Eq. (18) is plotted in Fig. 7 for $N_V = 1, 3, 6$ and $N_M = 1, 3$. The peak value of P_{KL} for the 6 curves occurs in the region $0.80 < x < 0.87$ and is close to the assumed value of 0.90.

From the curves in Fig. 7 it is seen that if each of the offense and defense parameters were somehow to be equally increased to a value approaching unity, the value of P_{KL} would approach zero. Thus, for this model of the duel in which countermeasures, costs and exhaustion effects are not considered, it could be inferred that extremely high technology, even if exploited by both sides in the distant future, should favor the space platform defense over the ASAT offense.

3. Sensitivity of P_{KL} to γ

The parameter γ, the product of the space platform reliability and booster detection probability, is fundamental to the effectiveness of the defense. If γ were substantially increased from the value assumed in the example, i.e., $0.9^2 = 0.81$, to say 0.96, the impact on the value of P_{KL} would depend greatly on whether or not the booster could be attacked.

The plot of P_{KL} vs γ in Fig. 8 illustrates the case $N_B = 0$ with $N_V = 1$, 3, and 6, and $N_M = 1$ and 3. If $N_V = 6$ and $N_M = 3$, increasing γ from 0.81 to 0.96 would decrease P_{KL} from 0.48 to 0.40. The impact of this decrease is minor when compared to that for the case where the booster can be attacked, as illustrated in Fig. 9. Here, for the case $N_B = 2$, $N_V = 6$ and $N_M = 2$, it is seen that an increase in the value of γ from 0.81 to 0.96 would decrease the value of P_{KL} from 0.20 to 0.06. The expected number of ASAT booster launches required to destroy the space platform would increase correspondingly from 5 to 16. For the case $N_V = 1$ the number of ASAT launches required would increase from 8 to 29.

4. Sensitivity of P_{KL} to D_{VP}

The sensitivity of P_{KL} to D_{VP} for the most defense-stressing case $N_B = 0$ is illustrated in Fig. 10. Here it is seen that an increase in the value of D_{VP} from 0.90 to, say, 0.98 would decrease the value of P_{KL} from 0.48 to 0.29 for the case $N_V = 6$ and $N_M = 3$. The value of P_{KL} could be reduced further to 0.13 if, in addition to increasing D_{VP} from 0.90 to 0.98, γ could be increased from 0.81 to 0.96 (see Fig. 11). The sensitivity of P_{KL} to D_{VP} here is very high. If D_{VP} were only increased to 0.95 instead of to 0.98, the value of P_{KL} would be 0.25 instead of 0.13. Clearly it would require multiple significant improvements (above the 0.90 level) in the defense parameters to decrease P_{KL} to a level acceptable to the defense if the booster were invulnerable to attack.

If the booster could be attacked, then the sensitivity of P_{KL} to D_{VP} would not be as high. This is illustrated in Fig. 12 for the case $N_B = 2$, $N_M = 2$, and $N_V = 6$. If, as in the case discussed above, $\gamma = 0.96$ and $D_{VP} = 0.98$, $P_{KL} = 0.026$; if $D_{VP} = 0.95$, $P_{KL} = 0.032$. The expected number of ASAT booster launches that would be required to kill the space platform in either case would exceed 30, assuming a defense missile inventory large enough to avoid saturation.

5. Sensitivity of P_{KL} to E_{PV} and E_{VM}

The sensitivity of P_{KL} to E_{PV} is illustrated in Fig. 13 for the case $N_B = 0$. While there is an increase in P_{KL} as E_{PV} increases above the assumed value of $0.9^3 = 0.729$, the magnitude of the increase is not very large regardless of the values of N_V and N_M assumed. The value of E_{VM} in Fig. 13 was held constant at 0.729.

In Fig. 14 the value of E_{PV} is held constant at 0.729 and the sensitivity of P_{KL} to E_{VM} is shown, again for the case $N_B = 0$. There is appreciable sensitivity of P_{KL} with E_{VM} above its assumed 0.729 value for $N_M = 1$, but the value of P_{KL} remains essentially constant for $N_M = 3$ in this region.

It is interesting to examine the behavior of P_{KL} if $E_{PV} = E_{KV} = E$ and E is allowed to vary while all other parameters are equal to 0.9 (Fig. 15). The value of P_{KL} in the region above $E = 0.729$ decreases sharply with E if $N_V = 6$ or 3 for $N_M = 1$, but increases slightly for $N_M = 3$. The peak values of P_{KL} for the illustrated case ($E = 0.729$) are very close to the slightly higher peak values that they would have had if E had been assumed to be equal to a slightly lower value. The value of P_{KL} is not sensitive to the value of E if $N_M > 1$.

D. CONCLUSIONS

Based on the results of the illustrative examples discussed above, the following general conclusions can be drawn with respect to a duel between a ground-based ASAT and a space-based weapons platform defended by kinetic energy weapons.

1. The survivability of the space platform is crucially dependent on a capability to destroy the ASAT booster before it can deploy its miniature kill vehicles.
2. All of the defense reliability, probability of detection, and probability of kill parameters are important to survivability and all must be high ($> \sim 0.90$), but some are more important than others and should be very high ($> \sim 0.95$).
3. The reliability of the sensor and fire-control equipment of the space platform and the probability of detecting* the ASAT booster are crucial to survivability. If these two parameter values are not very high, improvements in any of the other defense parameters would be of little significance.
4. The most important defense parameter in the post-boost battle is the probability of detecting a miniature kill vehicle from the space platform or surveillance satellite. If this parameter is not very high, improvements in the defense missile characteristics will do little to compensate.
5. The requirement for overall defense missile effectiveness should be high ($> \sim 0.8$) but need not be very high since salvos of two can compensate.
6. If the ASAT booster can be reached with defense missiles, a salvo of at least two missiles should be fired, thereby significantly enhancing survivability and decreasing defense missile inventory requirements.
7. Use of a shoot-look-shoot firing doctrine against the ASAT kill vehicles, if time allows, would yield additional substantial savings in defense missile inventory requirements.

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*Including acquiring and tracking.

8. It appears that improvements in parameter values above the 0.9 level, if shared equally by both the ASAT offense and the space station defense, will favor the defense.* For an idealistic limiting case in which all offense and defense parameters approach unity, the model indicates that the probability of the ground-launched ASAT killing the space platform approaches zero.

9. The complexity of this duel, even without the presence of offense and defense countermeasures, is likely to lead to a highly uncertain prediction of an outcome since there is bound to be considerable uncertainty in the estimation of each of the many offense and defense parameters.

10. The deployment of two independent defense systems, e.g., high energy laser and kinetic energy weapons, would complement each other and greatly enhance the survivability of the space platform.

*This conclusion is based on the mathematical model developed which does not consider countermeasures, costs, and defense missile inventory exhaustion effects.

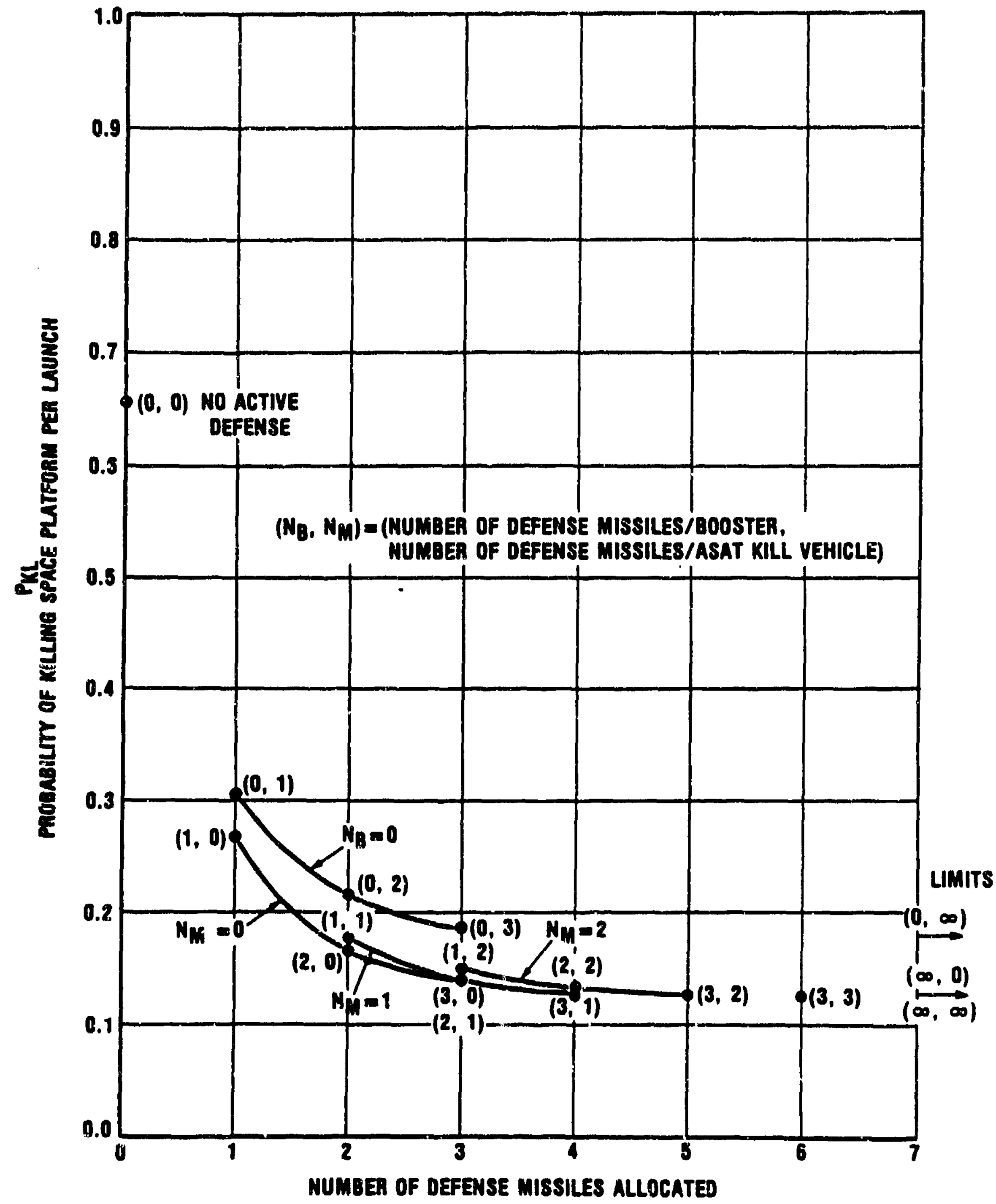

FIGURE 1. P_{KL} vs number of defense missiles allocated assuming all parameter values = 0.90 and N_V = 1

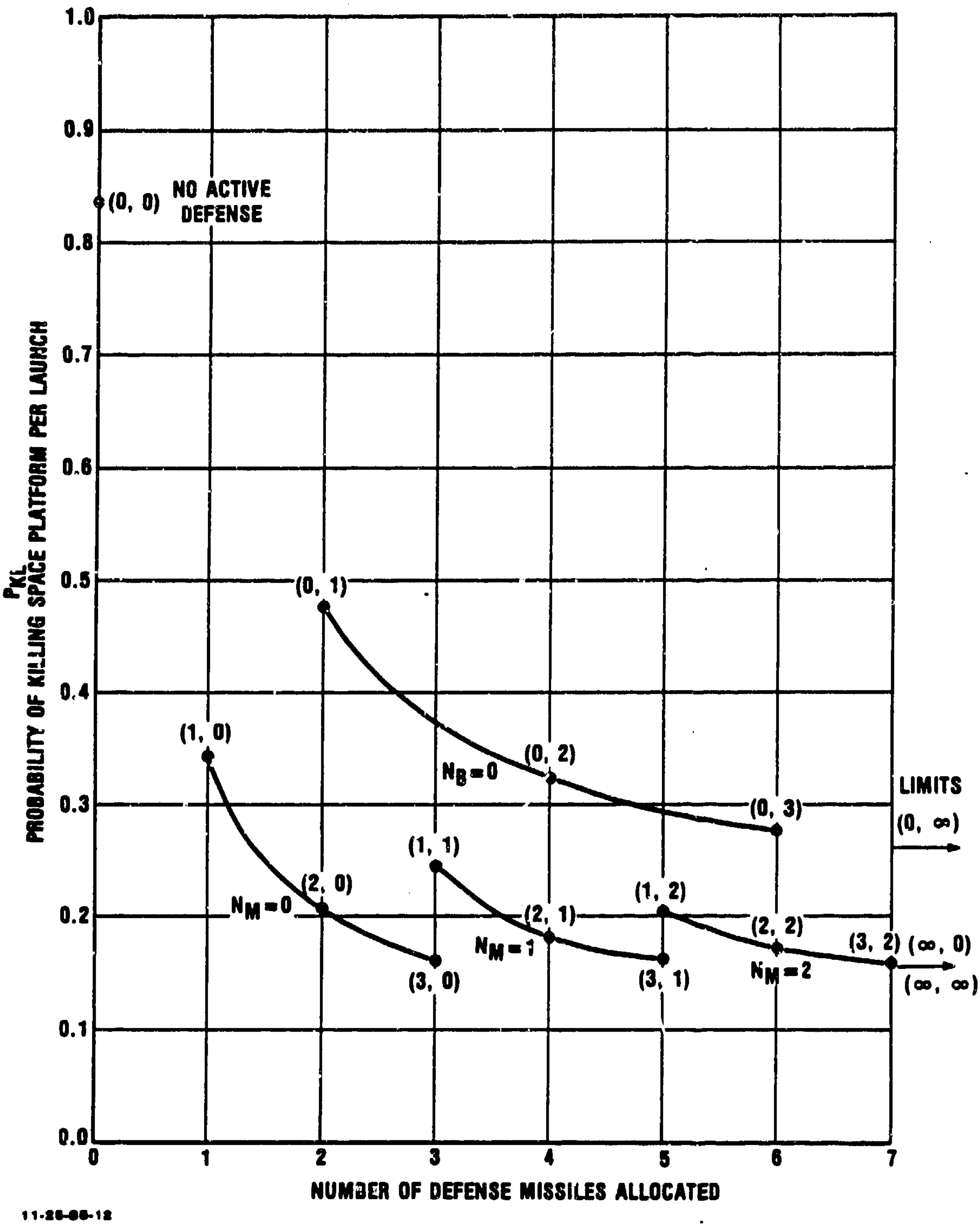

FIGURE 2. P_{KL} vs number of defense missiles allocated assuming all parameter values = 0.90
$N_V = 2$

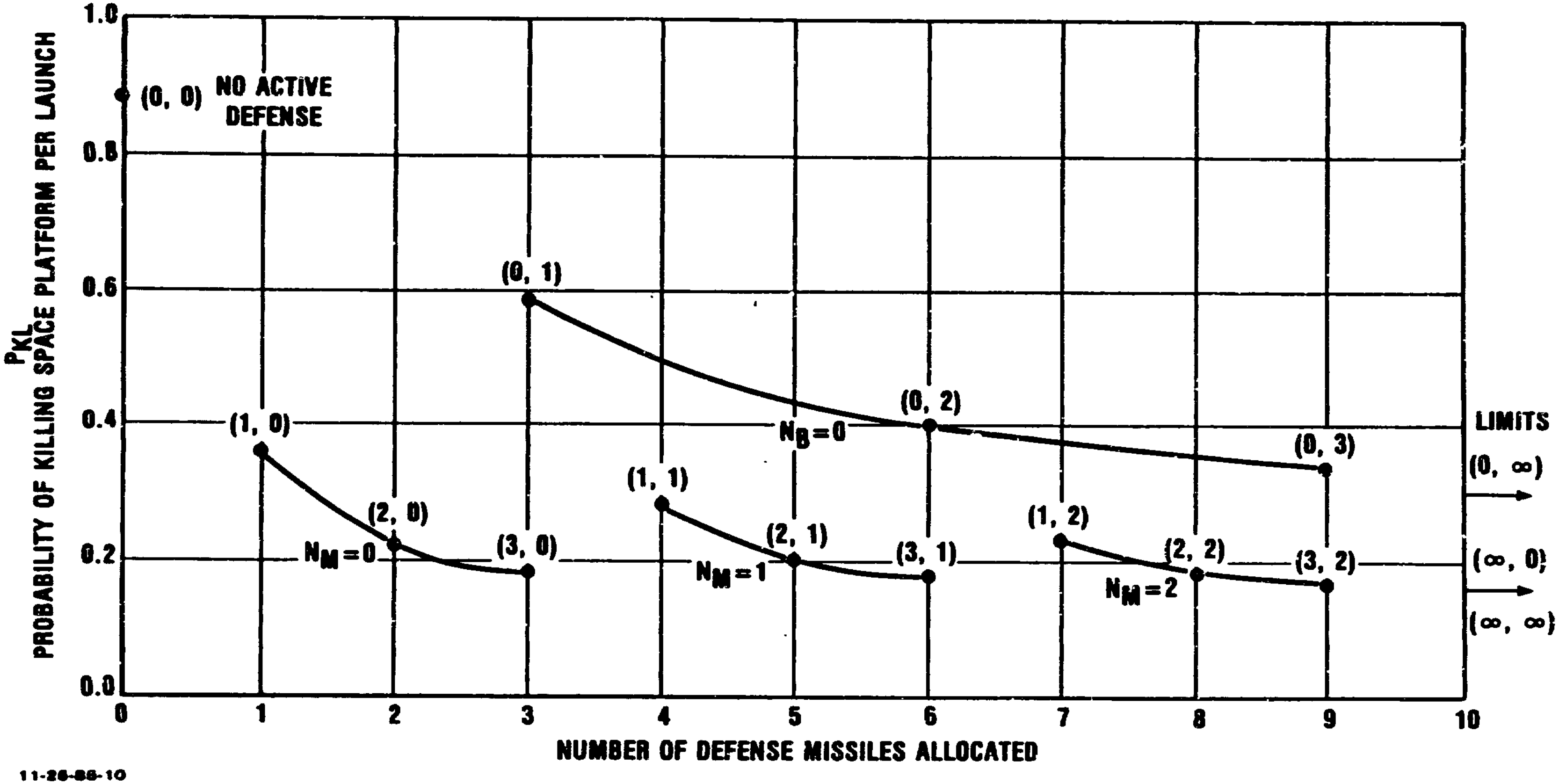

FIGURE 3. P_{KL} vs number of defense missiles allocated assuming all parameter values = 0.90 N_V
$N_V = 3$

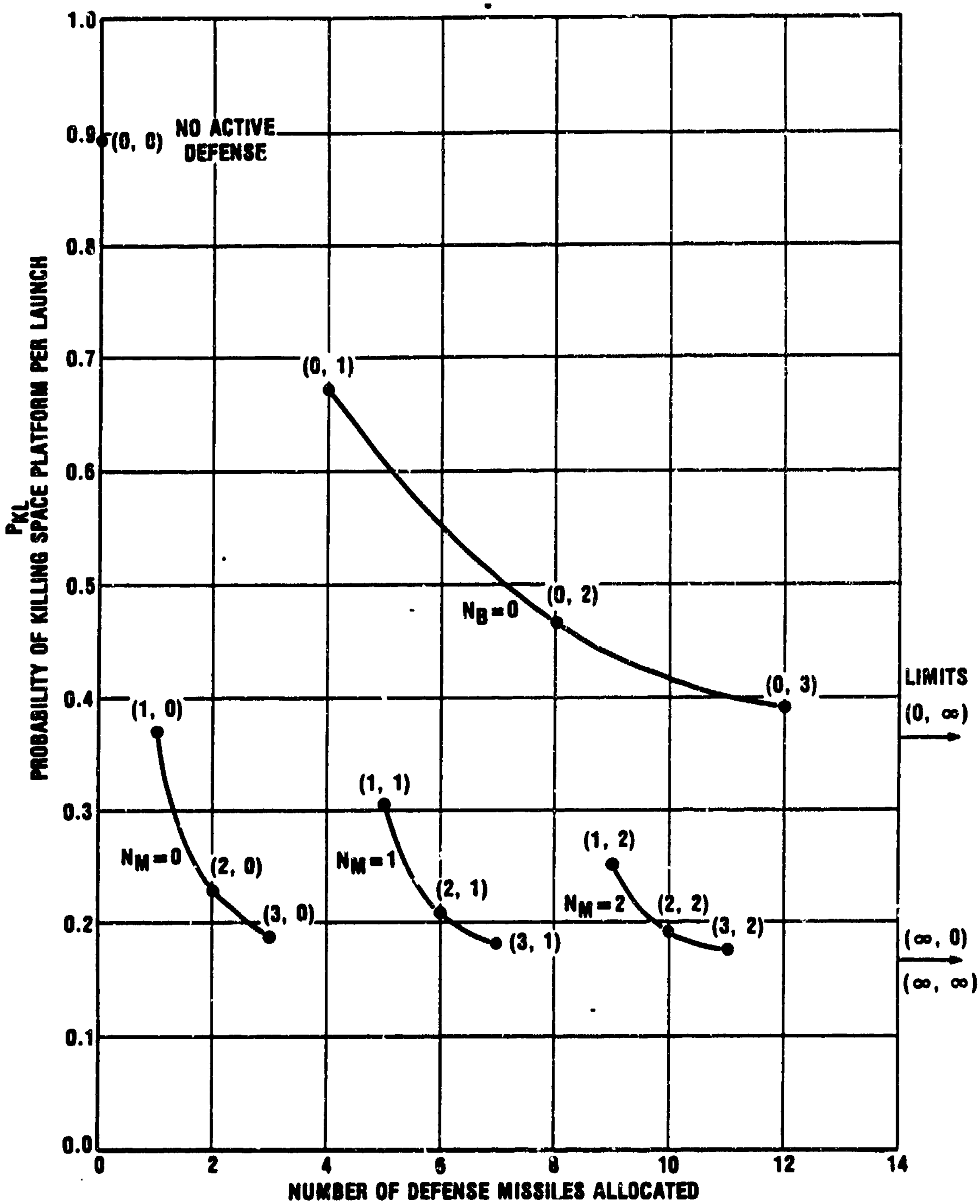

FIGURE 4. P_{KL} vs number of defense missiles allocated assuming all parameter values = 0.90 $N_V = 4$

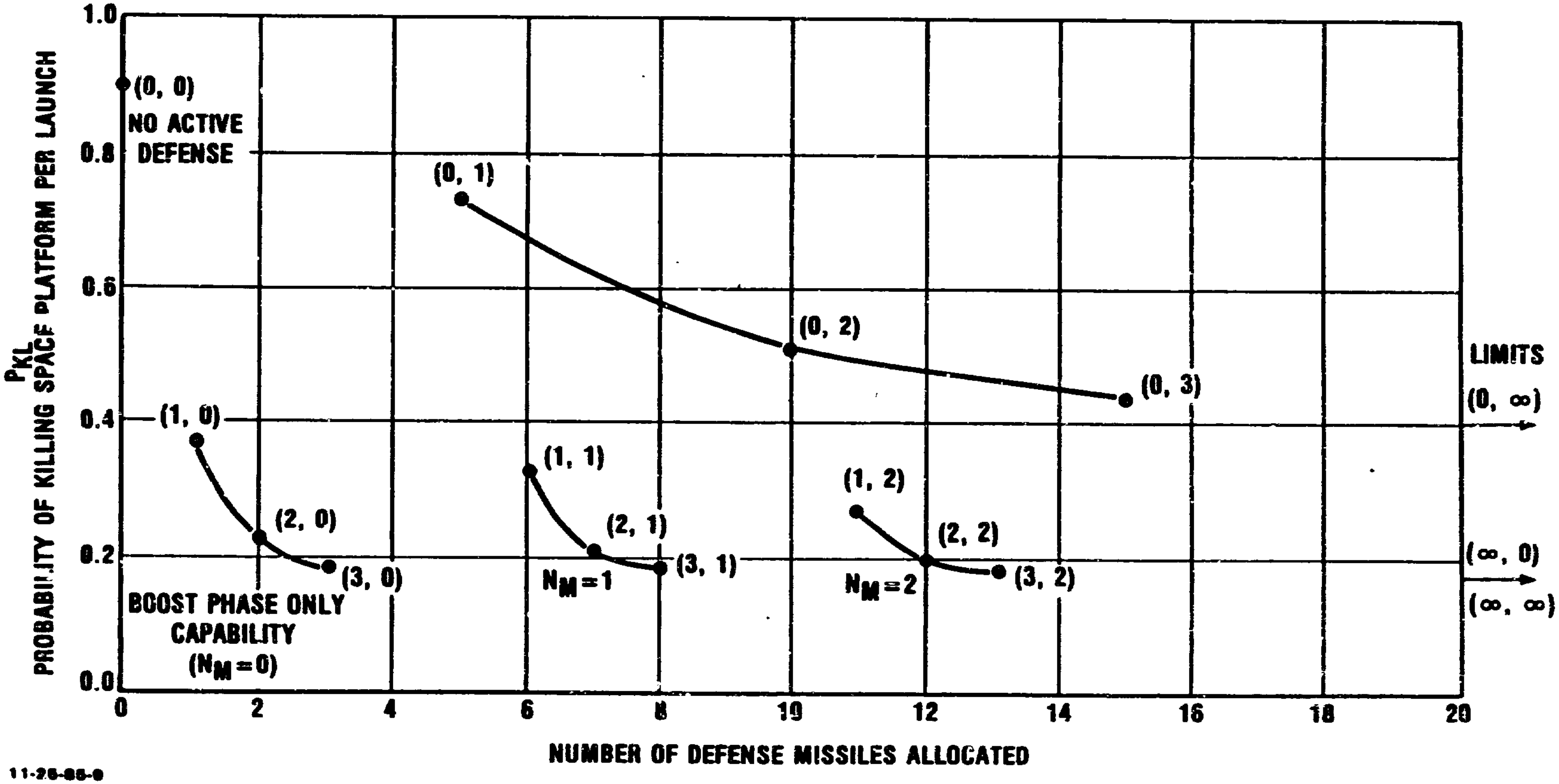

FIGURE 5. P_{KL} vs number of defense missiles allocated assuming all parameter values = 0.90
N_V = 5

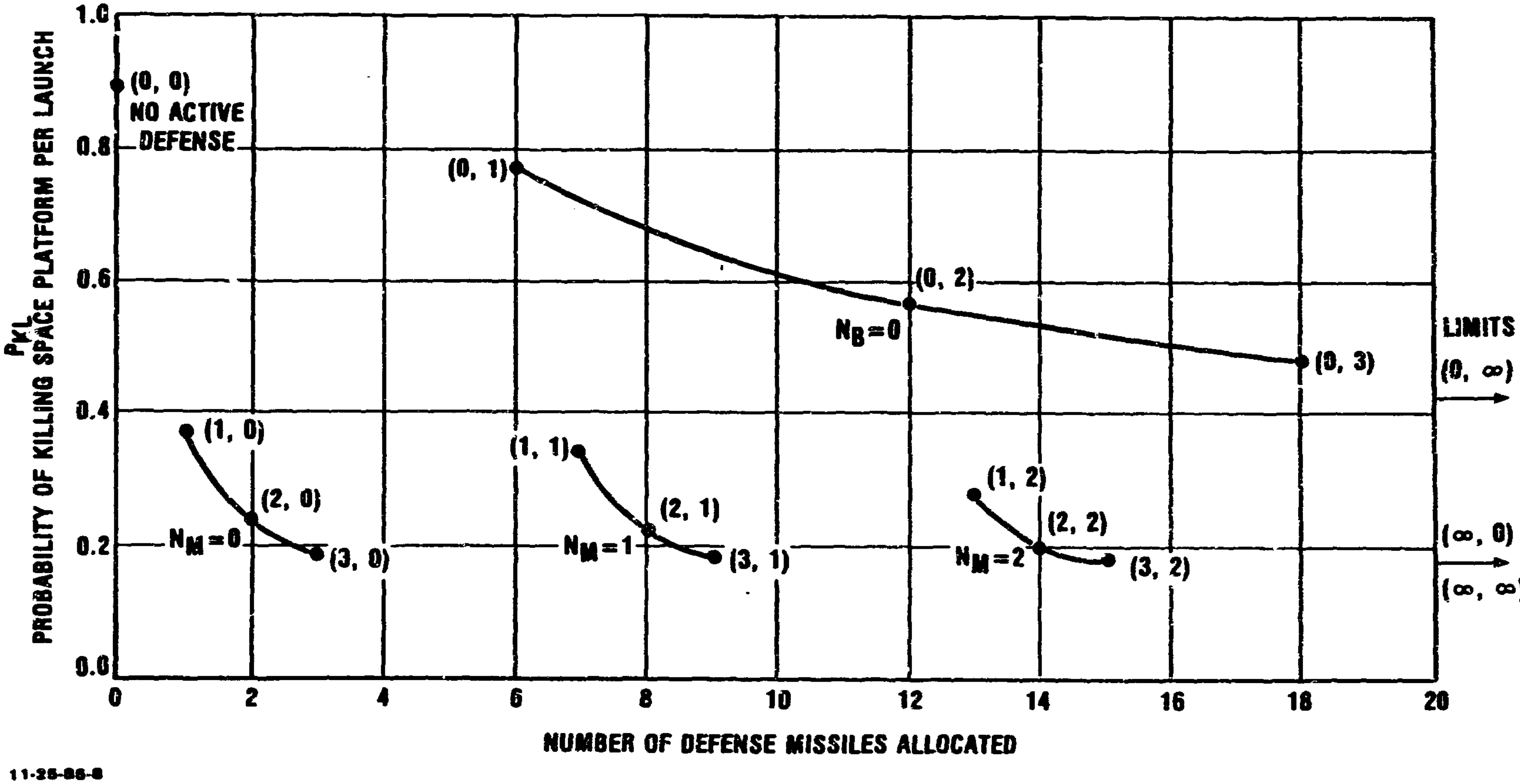

FIGURE 6. P_{KL} vs number of defense missiles allocated assuming all parameter values = 0.90
$N_V = 6$

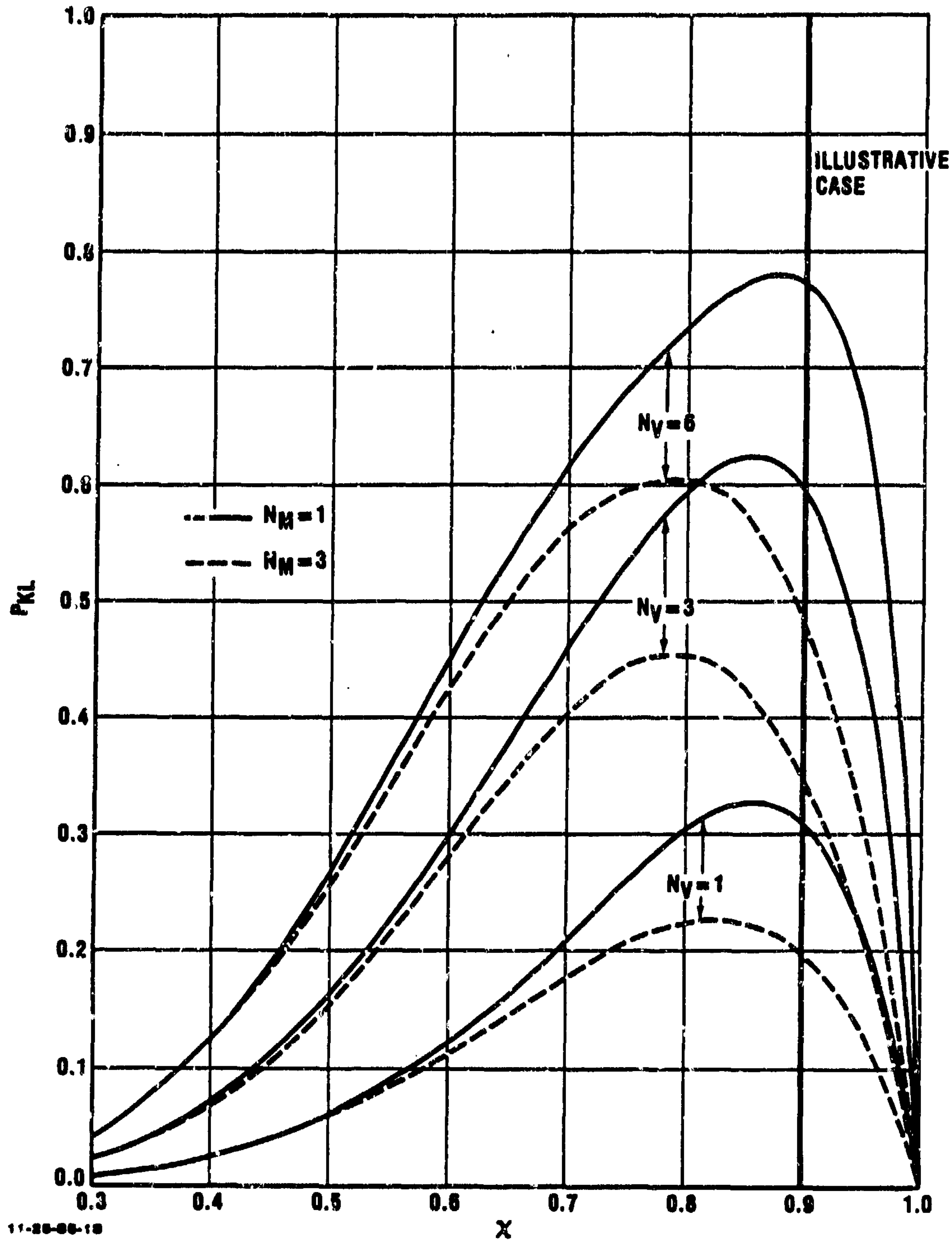

FIGURE 7. P_{KL} vs x, assumed to be the common parameter value for all reliability, detection and kill probability parameters
$N_B = 0$

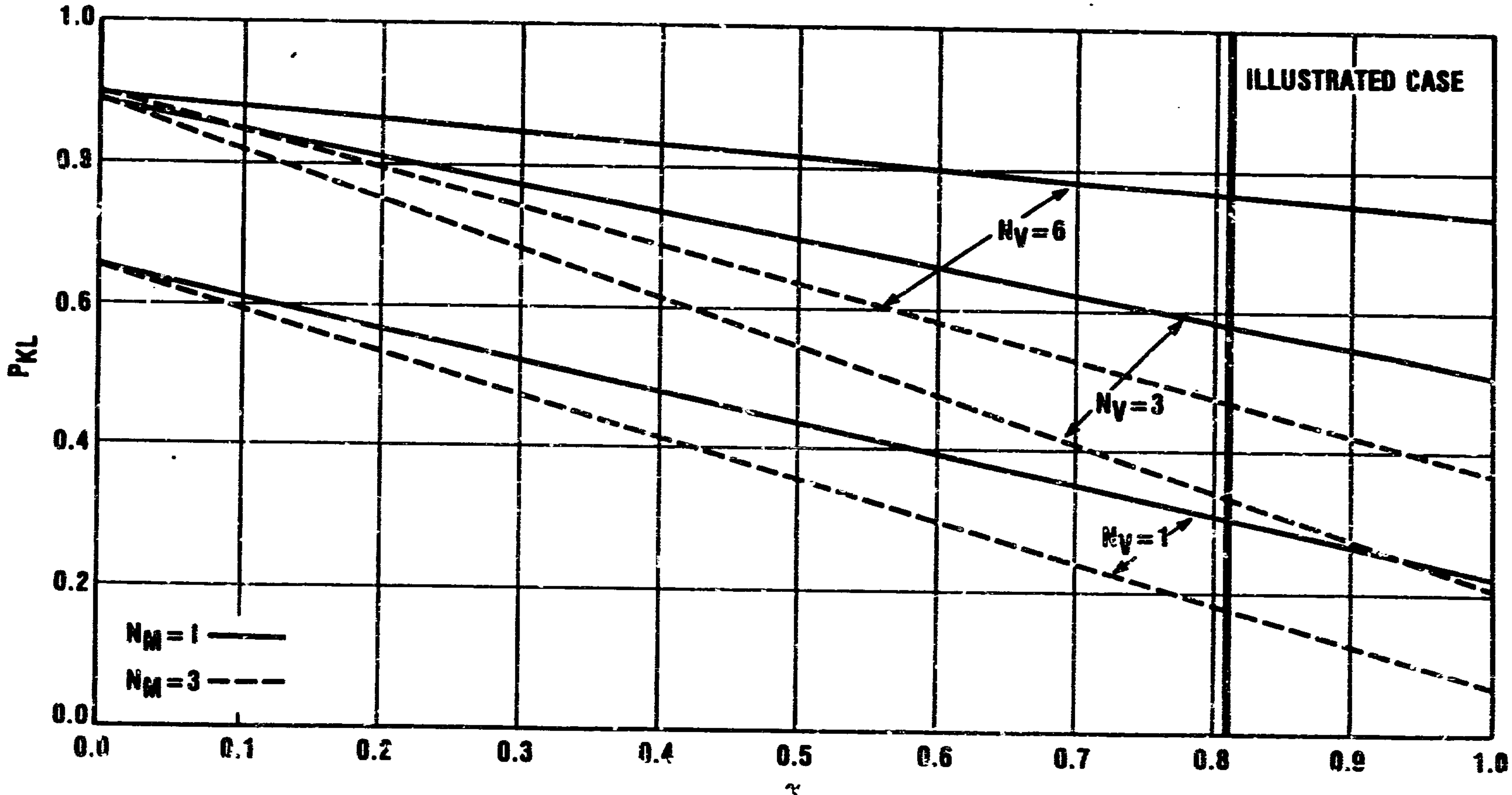

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FIGURE 8. P_{KL} vs γ assuming all other parameter values = 0.90
N_B = 0

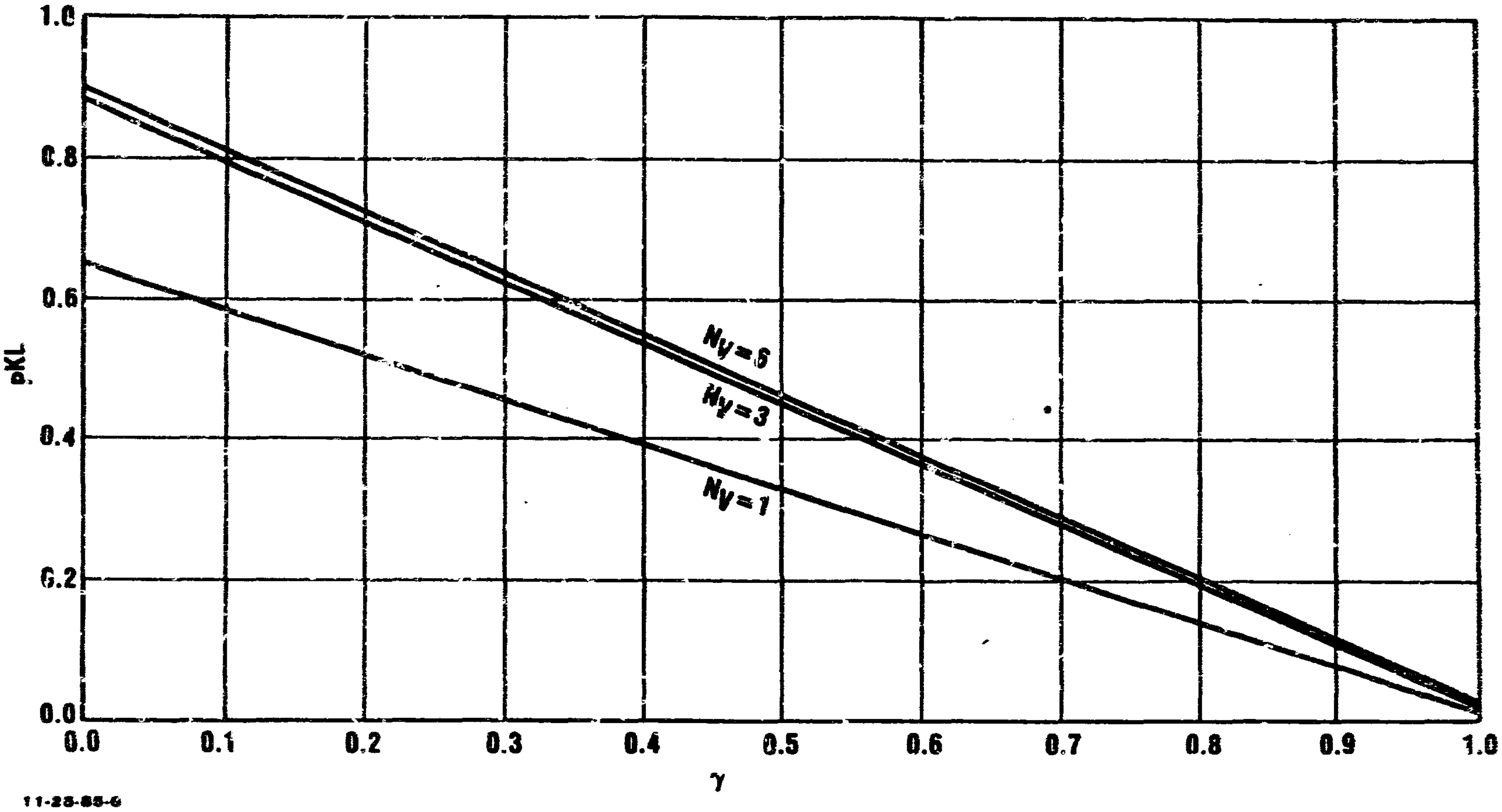

FIGURE 9. P_{KL} vs γ and D_{VP} assuming all other parameter values = 0.90
$N_B = 2$; $N_M = 2$

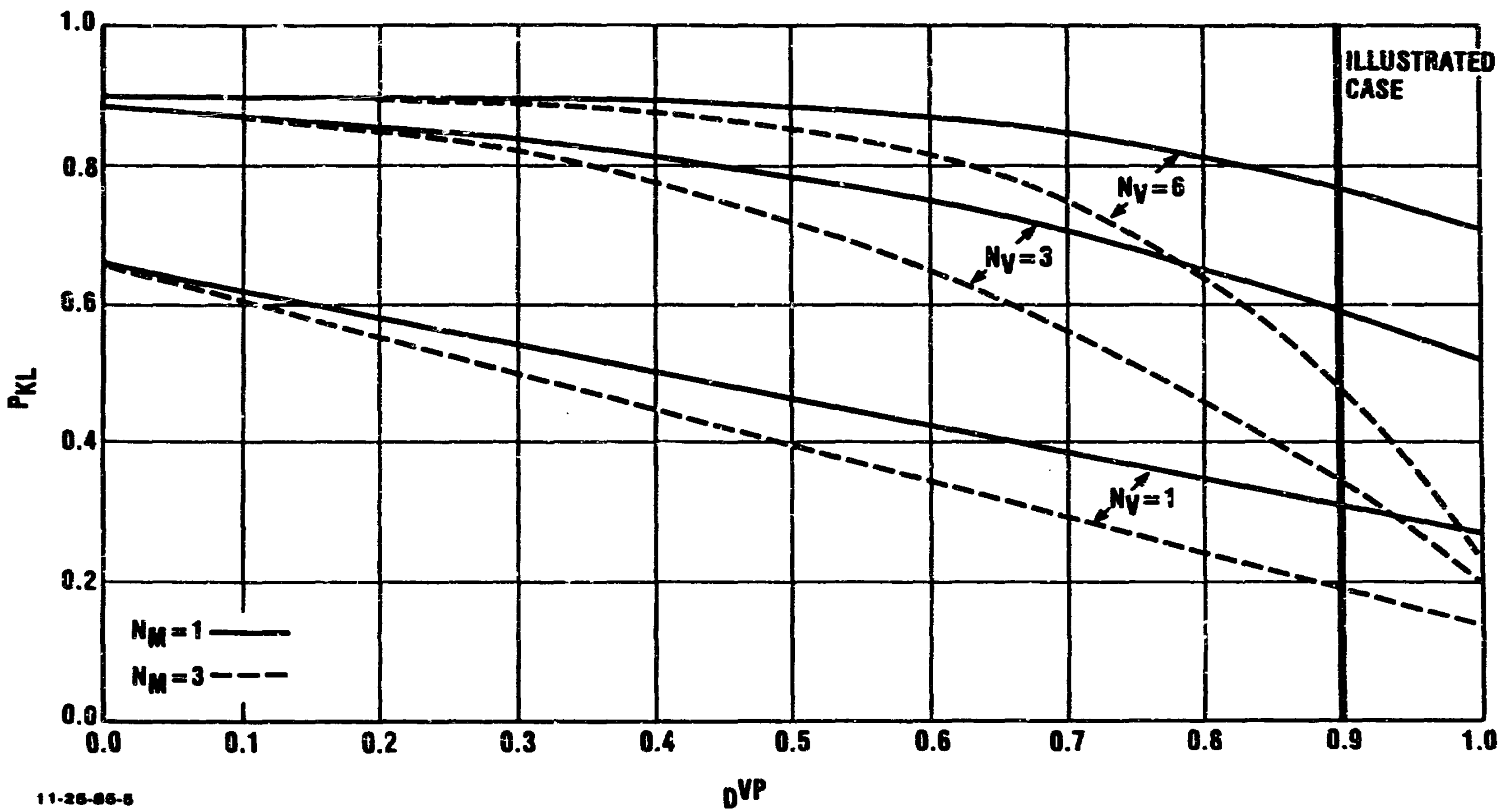

FIGURE 10. P_{KL} vs D_{VP} assuming all other parameter values = 0.90
$N_B = 0$

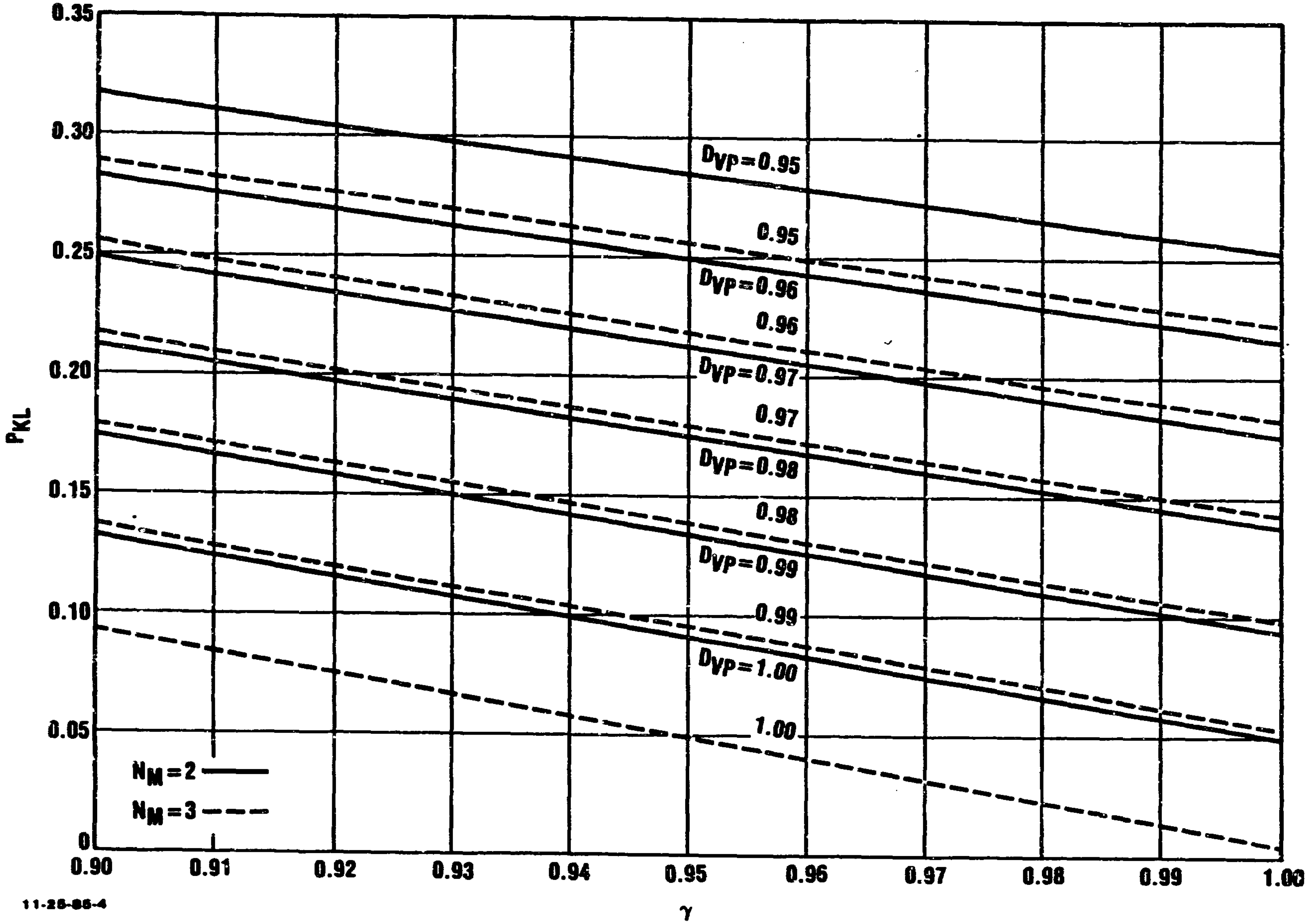

FIGURE 11. P_{KL} vs γ and D_{VP} assuming all other parameter values = 0.90
$N_B = 0$

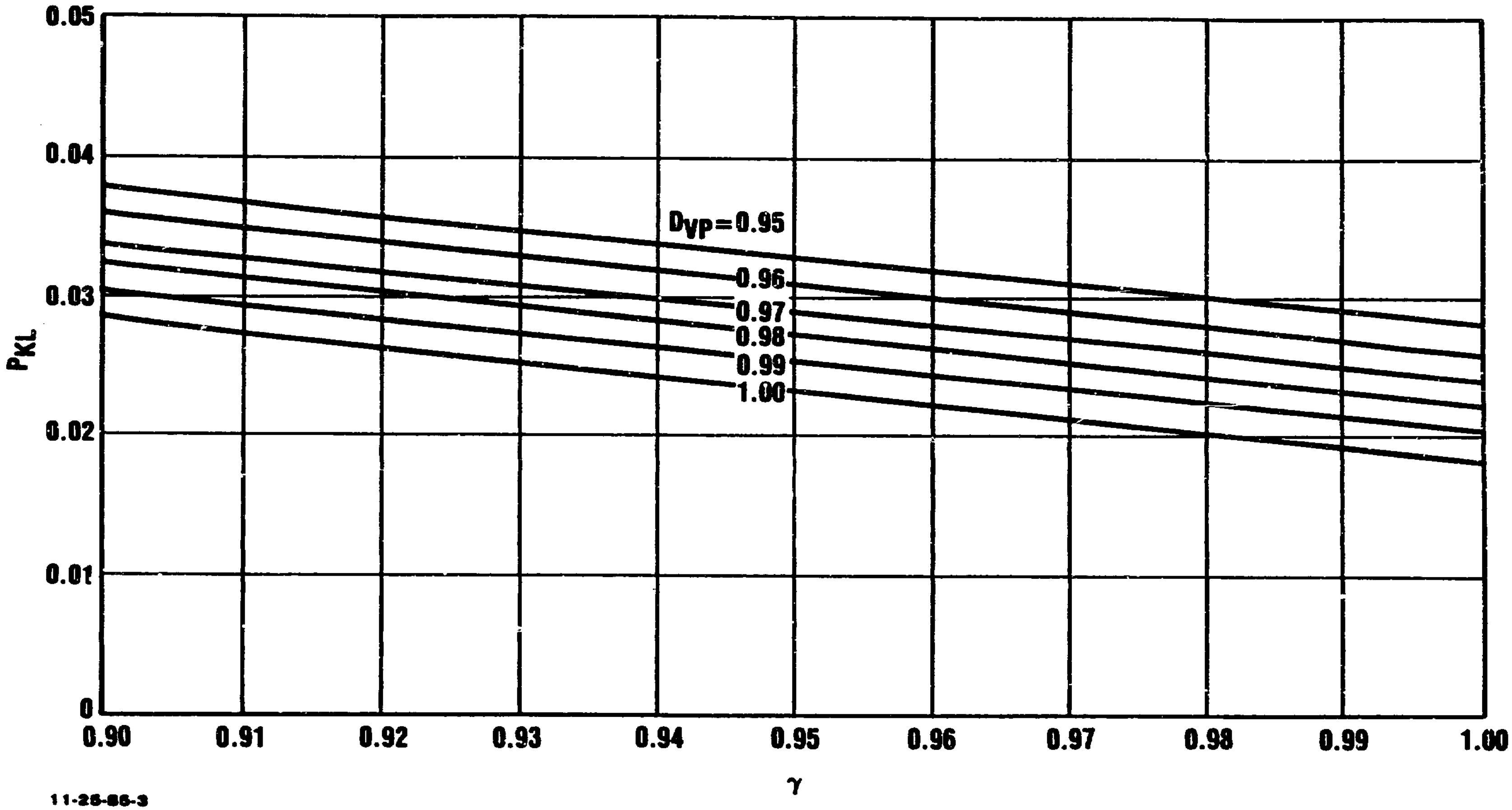

FIGURE 12. P_{KL} vs γ and D_{VP} assuming all other parameter values = 0.90
$N_B = 2$; $N_M = 2$; $N_V = 6$

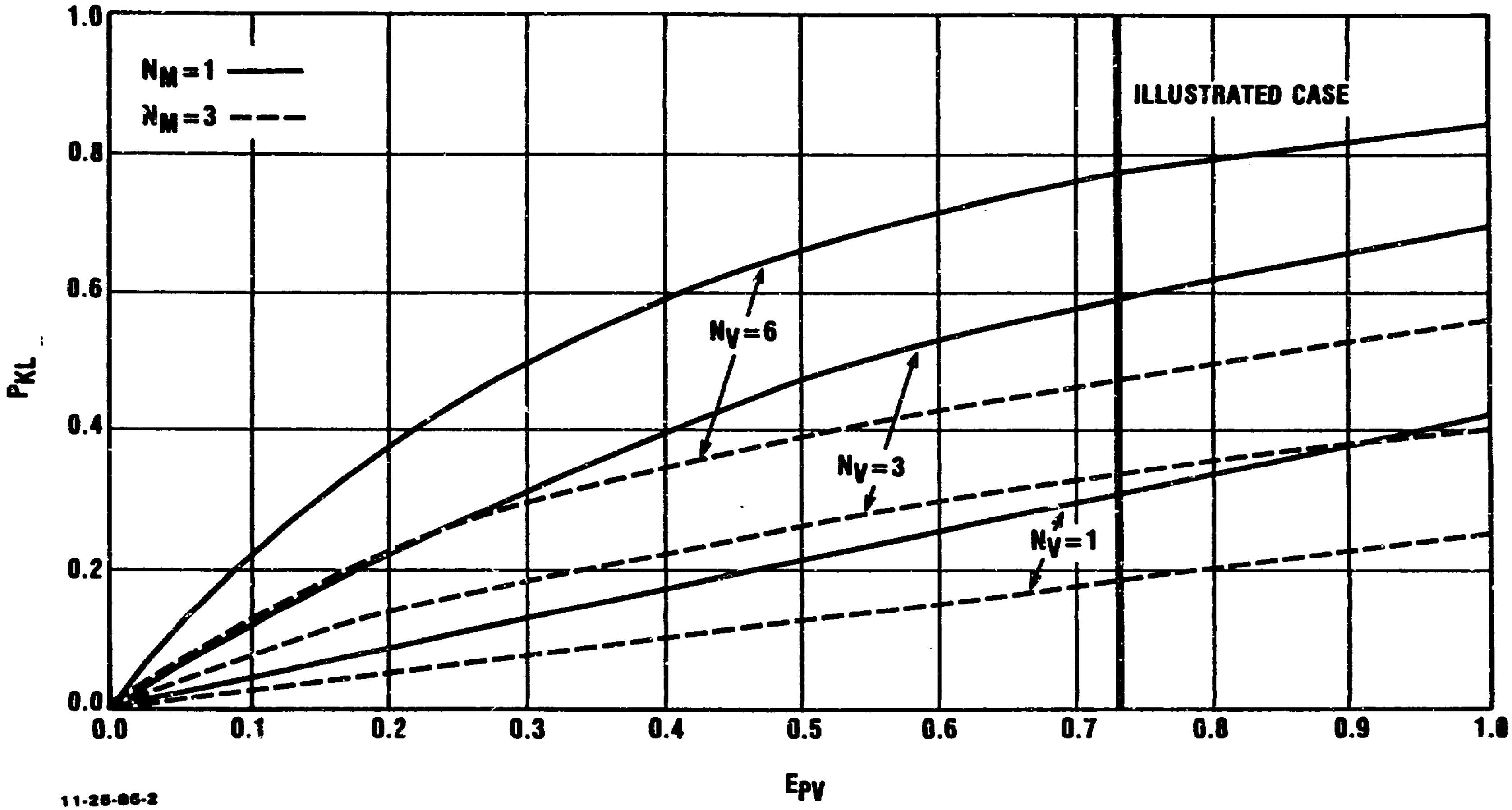

FIGURE 13. P_{KL} vs E_{PV} assuming all other parameter values = 0.90
$N_B = 0$

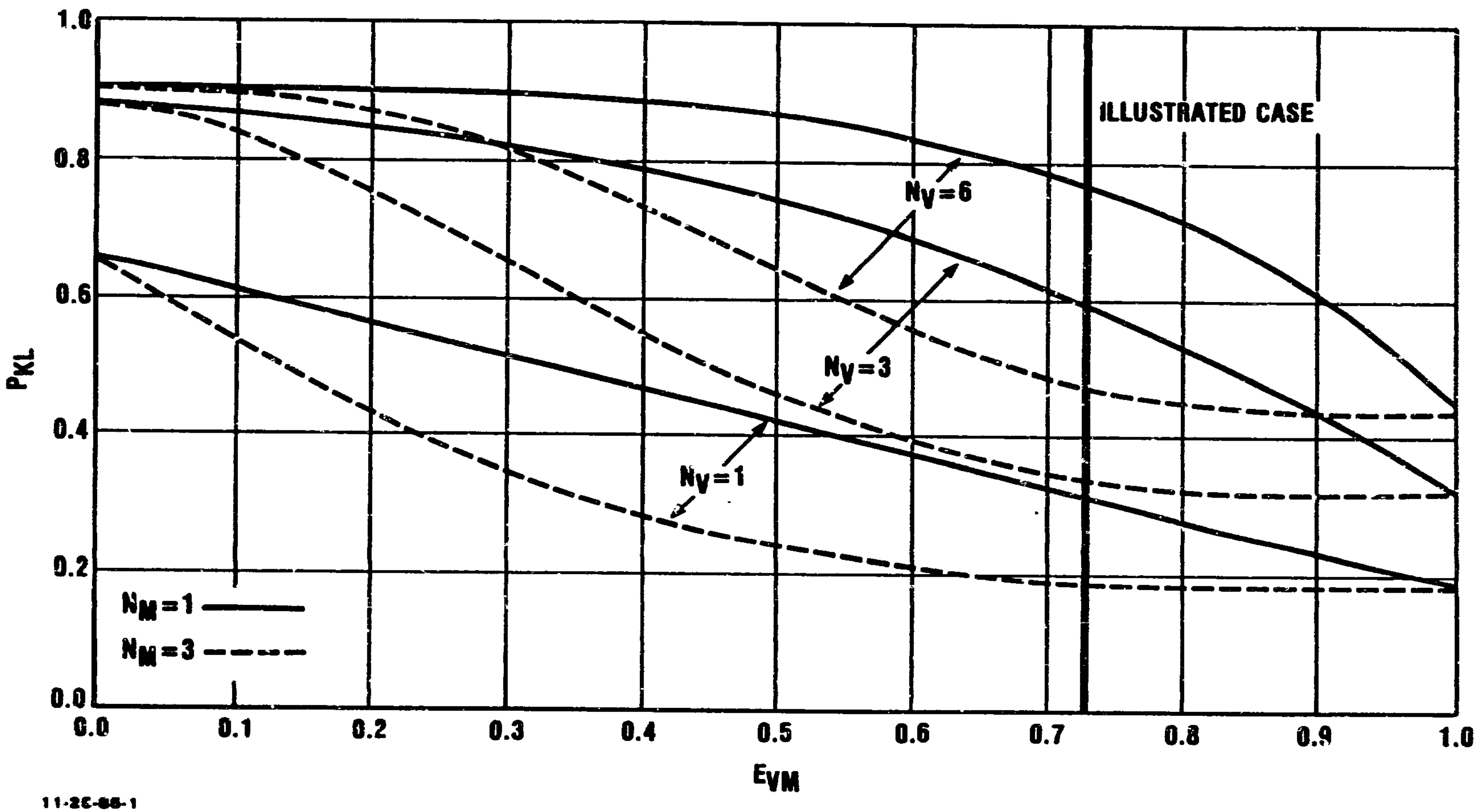

FIGURE 14. P_{KL} vs E_{VM} assuming all other parameter values = 0.90
N_B = 0

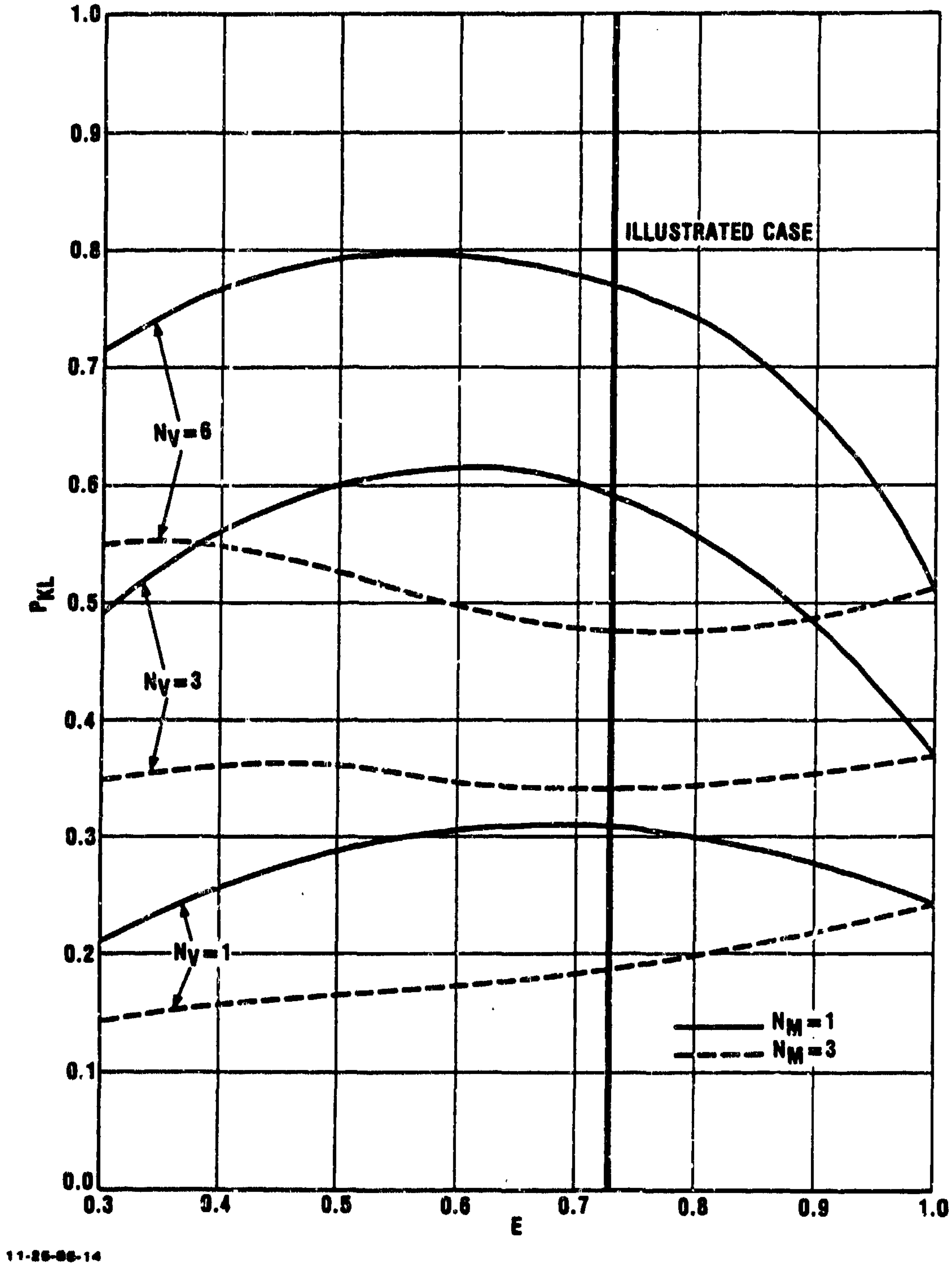

FIGURE 15. P_{KL} vs E assuming $E_{PV} = E_{VM} = E$ and all other parameter values = 0.90 $N_B = 0$