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MEMORANDUM REPORT NO. 1409
JUNE 1962

ESTIMATED INCAPACITATION PROBABILITIES OF CALIBER .14 BULLETS (U)

Chester Grabarek
Anthony Ricchiazzi
Dennis Dunn

Department of the Army Project No. 503-04-010
Ordnance Management Structure Code No. 5010.11.817

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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[illegible]arek /AJRicchiazzi/DDunn/ic
Aberdeen Proving Ground, Md.
June 1962

ESTIMATED INCAPACITATION PROBABILITIES OF CALIBER .14 BULLETS (U)

(UNCLASSIFIED) ABSTRACT

Caliber .14 spin-stabilized projectiles were fired into gelatin and measurements of the loss in velocity of the projectiles were obtained. The yaw angle at impact and the striking velocity were varied; ~~and~~ the were related to the energy absorbed by the gelatin. The probability of incapacitation as a function of range was computed. The effect of two different nose shapes on the probability of incapacitation was studied.

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LIST OF SYMBOLS

[illegible] = energy loss of bullet in traversing the first 6" of gelatin.

ΔV = velocity loss of bullet in traversing the first 6" of gelatin.

δ = angle of yaw.

δ_s = angle of yaw at impact.

V = velocity of bullet.

V_s = striking velocity of bullet.

R = range.

ρ = density of gelatin.

d = diameter of bullet.

K_{Dg} = drag coefficient, based on d^2, in gelatin.

$\bar{K}_{Dg}$ = mean value of K_{Dg} averaged over 6" of travel in gelatin.

K_{Da} = drag coefficient, based on d^2, in air.

m = mass of bullet.

x = distance penetrated in gelatin.

P_{hk} = probability that a hit incapacitates.

(CONFIDENTIAL) INTRODUCTION

Recent advances in barrel fabrication at the Springifeld Armory have made feasible the production of a few test rifle barrels of 0.14-inch bore. Theoretically, the anti-personnel effectiveness of a small bullet is attractive[1]. Consequently, the Springfield Armory requested BRL to investigate the capabilities of caliber .14 bullets against personnel targets. A preliminary investigation was made using gelatin targets. The results are given in this report.

(SECRET) PROCEDURE FOR ESTIMATING THE VALUE OF P_{hk}

The anti-personnel effectiveness of a bullet depends on its kill probability at various ranges. The kill probability is the product of its hit probability, which is determined by its accuracy, and the probability that a hit incapacitates. In this report we are not considering accuracy. We are concerned with the conditional probability that a hit incapacitates, P_{hk}.

In a first approximation, the value of P_{hk} for a bullet is related to its energy loss in penetrating gelatin. This relation, given by Sperrazza and Dziemian[1], states that the only region of interest is the region between 1 to 15 cm in gelatin. For our bullets, which tumble after entering gelatin, the energy loss over the first centimeter, where the yaw is small, is negligible. Consequently, we have assumed that the energy loss over the first six inches is equal to the energy loss between 1 to 15 cm.

Kent has proposed theoretically[1] that the yaw angle at impact plays a major role in determining the rapidity of tumbling in a dense media. To test this proposal, some preliminary tests were made. Bullets of 0.14-inch diameter were shot into gelatin. The yaw angle at impact was measured and the damage in the gelatin perpendicular to the path was observed. The results, shown on Figures 1 and 2, show the great importance of the initial yaw angle, δ_s. We conclude that the yaw angle at impact affects the energy loss in gelatin.

In order to obtain the relationship between energy loss and range, $\Delta E(R)$, four intermediate relationships are needed. These are:

1. The energy loss of the bullet over the first 6" of gelatin as a function of the striking velocity, $\Delta E(V_s)$.

2. The energy loss in gelatin as a function of the yaw angle at impact, $\Delta E(\delta_s)$.

3. The yaw angle at impact as a function of range, $\delta_s(R)$.

4. The bullet striking velocity as a function of range, $V_s(R)$.

The dependence of energy loss on striking velocity and impact yaw angle, $\Delta E(V_s,\delta_s)$, was determined experimentally. The third relationship was computed from data for larger projectiles. The loss in bullet velocity with range was obtained by combining experimental data from three sources.

(CONFIDENTIAL) EXPERIMENTAL CONDITIONS

Caliber .14 Barrel and Cartridge Case

A special barrel, 24" long, with a twist of 1 turn in 4.2" was supplied by Springfield. The barrel was designed to launch a 17-grain bullet at a muzzle velocity of 4400 ft/sec. The cartridge case was a modified Remington Caliber .222 case, Figure 3.

Caliber .14 Projectiles

The caliber .14 projectiles, Figure 4, were fabricated from 1020 mild steel. Core weight was about 14.5 grains. Copper plating, about .004 inches thick, on the steel core increased the projectile weight to about 17 grains.

For comparison of results, two 7.62mm NATO bullets were used. These were the 147-grain M80 (lead core) and the M59 (steel core) bullets.

Range Setup

At short ranges, multiple spark shadowgraph photography was used to obtain photographs of the projectiles in free flight before and after impacting a 5 x 6 x 6 inch gelatin block, Figure 5. From the orthogonal sprange shadowgraphs immediately before impact, the angle of yaw at impact was obtained. The residual velocity of the projectile was determined from the measured time interval and the measured flight coordinates of the bullet in space immediately behind the gelatin. Projectile velocities were computed from the measured times of flight over the 5' and 10' base lines, Figure 5, and were corrected for air drag to obtain striking velocities.

At ranges of 100 meters or more, three lumiline screens were used to obtain the velocity before impact. The striking velocity was determined by applying the drag correction. Behind the gelatin, three large foil screens were used to obtain the path coordinates, bullet velocity and the velocity loss per foot of air travel in the yawed orientation. The experimental value of loss in velocity per foot of travel was then used to determine the residual velocity.

(CONFIDENTIAL) MEAN DRAG COEFFICIENT IN GELATIN

The drag coefficient, K_{Dg}, is defined by the equation

$$\text{drag force} = m V \frac{dV}{dx} = - K_{Dg} \rho d^2 V^2$$

where m, V and d are the mass, velocity and diameter, respectively, of the bullet; ρ is the density of gelatin; and x is the distance penetrated. Integrating the above equation we obtain

$$V(x) = V_s \exp \left(- \frac{\rho d^2}{m} \int_0^X K_{Dg} \, dx\right) \tag{1}$$

where X is the thickness of the gelatin and equals six inches.

For a given shape of projectile, the value of K_{Dg} depends on the angle of yaw and on the velocity and Reynolds number during penetration. Because our bullets tumble, the value of K_{Dg} will vary widely during penetration. The mean value is defined by the equation

$$\overline{K}_{Dg} = \frac{1}{X} \int_0^X K_{Dg} \, dx$$

Inserting this definition in equation (1), we obtain

$$V(x) = V_s \exp \left(- \frac{\rho d^2}{m} \overline{K}_{Dg} X\right) . \tag{1A}$$

The velocity and energy losses are

$$\Delta V = V_s \left[1 - \exp \left(- \frac{\rho d^2}{m} \overline{K}_{Dg} X\right) \right] \tag{2}$$

and

$$\Delta E = \frac{1}{2} m V_s^2 \left[1 - \exp \left(- \frac{2\rho d^2}{m} \overline{K}_{Dg} X\right)\right] \tag{3}.$$

All quantities, except $\overline{K}_{Dg}$, in equation (1A) were experimentally determined. Solving (1A) for $\overline{K}_{Dg}$ by inserting experimental values of the remaining parameters, the value of $\overline{K}_{Dg}$ is determined. The value of $\overline{K}_{Dg}$ will depend on the impact angle of yaw, the relation between yaw angle and distance penetrated, the velocity and Reynolds number. However, two conditions which simplify the dependence of $\overline{K}_{Dg}$ are appropriate to the work of this report. In the first place, the effects of tumbling on $\overline{K}_{Dg}$ are expected to override the effects of velocity and Reynolds number. In the second place, the relation between yaw angle and distance penetrated depends theoretically[1] on the static bullet characteristics and the yaw angle at impact, but is independent of striking velocity. Experimental support of the latter simplification is given under RESULTS. Hence, in a first approximation, $\overline{K}_{Dg}$ for a given bullet over six inches of gelatin is assumed to depend only on the yaw angle at impact.

(SECRET) RESULTS FOR THE 7.5 CALIBER OGIVE BULLET

Energy Loss as a Function of Striking Velocity and Yaw Angle at Impact

A number of firings into six inches of gelatin were made with the 7.5 caliber tangent ogive projectile in order to measure the effect of the impact yaw angle δ_s, on the velocity lost, ΔV, by the projectile through the six-inch gelatin block. For these tests the striking velocity, V_s, was held at about 3930 ft/sec. A plot of ΔV as a function of δ_s is given by the upper curve of Figure 6. For V_s of about 3930 ft/sec., Figure 6 shows that the initial impact angle had a significant effect on ΔV when $\delta_s < 2^\circ$; but at $2^\circ < \delta_s < 5^\circ$ there was little change in ΔV.

Using the observed residual velocities at V_s = 3930 ft/sec., the mean drag coefficient was computed by means of equation (1A) for the tumbling bullet over its six-inch path in gelatin. The mean drag coefficient, $\overline{K}_{Dg}$, is shown on Figure 7. In Reference 1, Kent shows theoretically that the relation between yaw angle and distance penetrated is, in a first approximation, independent of the striking velocity. One infers that the curve of $\overline{K}_{Dg}$, Figure 7, holds for striking velocities other than 3930 ft/sec. To test this inference, measurements of ΔV were made at a striking velocity of 2080 ft/sec; a curve predicting values of ΔV based on Figure 7 was also computed. The agreement between the predicted curve and observed values of ΔV is shown by the lower curve of Figure 6. We conclude that the curve of $\overline{K}_{Dg}$, Figure 7, provides the basis from which one can compute, by means of Equations (2) and (3), the dependence of ΔV and ΔE on striking velocity and impact yaw angle for this bullet. The computed energy loss at two striking velocities is illustrated on Figure 8.

To extend the curve of Figure 7 down to $\delta_s = 0$, firings were conducted at a real range of 200 meters. The measured striking and residual velocities of the bullet over 6 inches of gelatin are given below for the average of 10 rounds.

Muzzle Velocity, ft/sec	4300
Striking Velocity, ft/sec	3230
Residual Velocity, ft/sec	2930
ΔV, ft/sec	300
ΔE, joules	93
$\overline{K}_{Dg}$	.052

Yaw as a Function of Range

Measurements of the yaw angle in air near the muzzle resulted in an average value of 5°. This average yaw was used as the initial condition in the subsequent yaw-range computation.

The amplitude of the yaw angle decreases with range. For some large projectiles, the damping coefficient is known. For the Caliber .14 bullet, Mr. Maynard Piddington of the Exterior Ballistics Laboratory, BRL, estimated the yaw angle-range function based upon data for larger projectiles. The estimated function is shown on Figure 9. It is estimated that δ damps to nearly zero degrees at 120 meters.

The Velocity-Range Relation

Partial information from three sources was used to obtain the bullet velocity as a function of range. One source, Reference 3, gave a curve of drag coefficient in air for a projectile model of approximately the same shape out to Mach 2.6. A second source was recent data obtained at Frankford Arsenal for the caliber .14 bullet. The Frankford data indicates a velocity of 2330 ft/sec at 1300 ft. for a muzzle velocity of 4410 ft/sec. The third source was an experimental value of drag coefficient obtained near the muzzle by the authors; this value was $K_{Da} = .125$ at Mach 3.83. A drag coefficient curve was constructed which was compatible with the experimental data and close to the curve of Reference 3. It is given on Figure 10.

Probability of Incapacitating Personnel

The incapacitation capability for a penetrating missile is expressed in BRL TN 1297 in terms of the conditional probability, P_{hk}, that a random hit on the human target will incapacitate within a certain time, under a particular condition of military stress. Partial incapacitations are included. For the analysis of this report, the 1/2-minute assault situation was considered.

The curve of estimated P_{hk} as a function of range, out to 400 meters, is given in Figure 11. For the caliber .14 bullet at 100 meters, $P_{hk} = .64$ and, at 400 meters, $P_{hk} = .40$. For comparison Figure 11 also shows curves for the M80 (lead core) and M59 (steel core) 147-grain 7.62mm NATO bullets which are over 8 times heavier than the caliber .14 bullet. Since the M80 deformed on impact, its results do not provide a fair comparison with the caliber .14 bullet. Comparing the M59 results with the caliber .14 results, Figure 11, we see that the 7.62mm projectile at 100 meters results in an estimated value of P_{hk} only 7 percent higher than P_{hk} for the caliber .14 bullet; at 400 meters the 7.62mm bullet's value of P_{hk} is 30 percent higher. Figure 11 indicates that at short ranges, less than 70 meters, the value of P_{hk} for the caliber .14 bullet is greater than .75. Hence, a caliber .14 weapon may be particularly suited to guerrilla and anti-guerrilla warfare or as a patrol weapon. Other considerations, not covered in this report, such as accuracy, weapon weight, ammunition weight, etc., are required in order to assess the military value of a caliber .14 weapon.

(SECRET) EFFECT OF NOSE SHAPE ON P_{hk}

A hemispherical nose projectile, Figure 4, was fired into gelatin for comparison with the 7.5-caliber ogive projectile. Design characteristics compare as follows:

Nose Shape	Center of Gravity From Base, Cal.	Moment of Inertia, $Grs\text{-}in^2$ Axial	Transverse
Hemisphere	1.90	.039	.399
7.5-Cal. Tangent Ogive	1.93	.036	.445

At an average striking velocity of 3930 ft/sec. the hemispherical nosed projectile went through the gelatin block without tumbling. Experimental results for δ_s 1° are given below.

Nose Shape	ΔV Ft/Sec	ΔV Joules	Estimated Value of P_{hk}
Hemisphere	870	[illegible]	.70
7.5-Cal. Tangent Ogive	[illegible]	559	.81

Because the hemispherical nose projectile is stable in gelatin, its drag coefficient in gelatin, $\overline{K}_{Dg}$, is independent of δ_s for all pertinent values of δ_s. From the above firing data for this projectile the value of $\overline{K}_{Dg}$ is found to be .14. By means of Equation (3) we can compute the function $\Delta E(V_s)$ for the hemispherical nose projectile and can compare it to the 7.5-caliber tangent ogive projectile at all ranges. The comparison for equal muzzle velocity is presented.

(SECRET) COMPARISON OF HEMISPHERICAL WITH OGIVAL NOSE SHAPE (U)

RANGE, METERS	BULLET TYPE			
	HEMISPHERICAL		7.5-CAL. TANGENT OGIVE	
	V_s, ft/sec	P_{hk} (1/2 min. assault)	V_s, ft/sec	P_{hk} (1/2 min. assault)
0	4400	.72	4400	.86
100	3000	.63	3770	.62
200	2040	.49	[illegible]	.59
300	1400	.36	[illegible]	.45
400	840	.24	2370	.40

At very short ranges the value of P_{hk} for the ogival projectile is higher because its value of δ_s is high and it tumbles rapidly. At ranges of 100 to 200 meters the value of P_{hk} for each bullet type is about the same. The higher striking velocity of the ogival projectile compensates for its slow tumbling. At ranges greater than 200 meters the value of P_{hk} for the ogive nose bullet is higher because of its appreciably higher striking velocity. We conclude that the 7.5-caliber ogive bullet is more lethal than the hemispherical nose bullet.

The last table emphasizes the importance of striking velocity as a contributor to the value of P_{hk}. It suggests that a long ogive projectile may be more lethal than the 7.5-caliber ogive projectile. Preliminary estimates support this suggestion. Thus at 300 meters, an 11-caliber ogive projectile would have a striking energy about 18 percent greater than a 7.5-caliber ogive projectile; values of δ_s would be nearly equal; and the transverse moment of the longer nosed projectile would be only 5 percent higher. Hence we recommend that the lethality of a long nosed, caliber .14 projectile be investigated.

Chester Grabarek   Anthony Ricchiazzi   W J Dunn

CHESTER GRABAREK   ANTHONY RICCHIAZZI   DENNIS DUNN

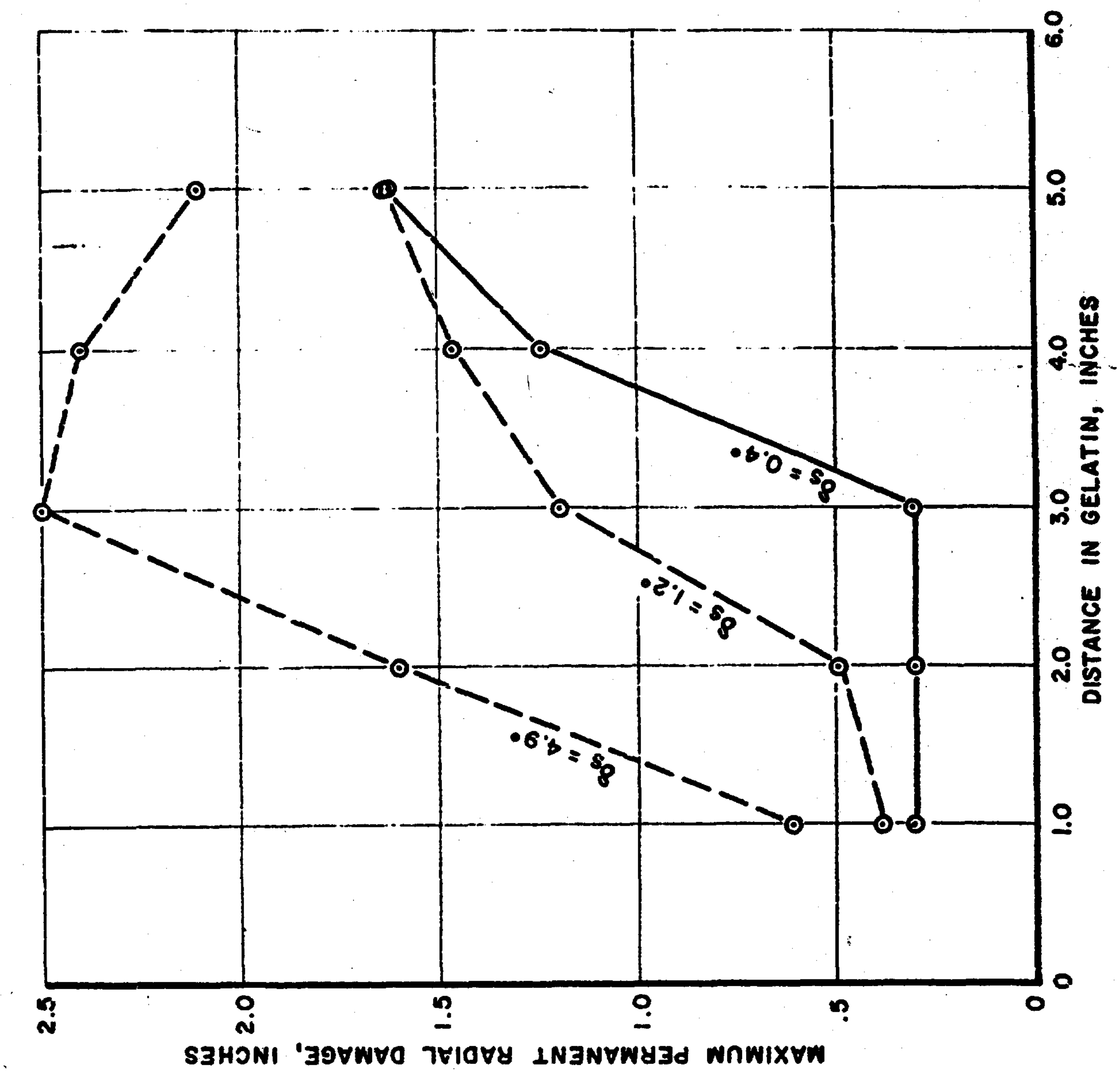
(UNCLASSIFIED) REFERENCES

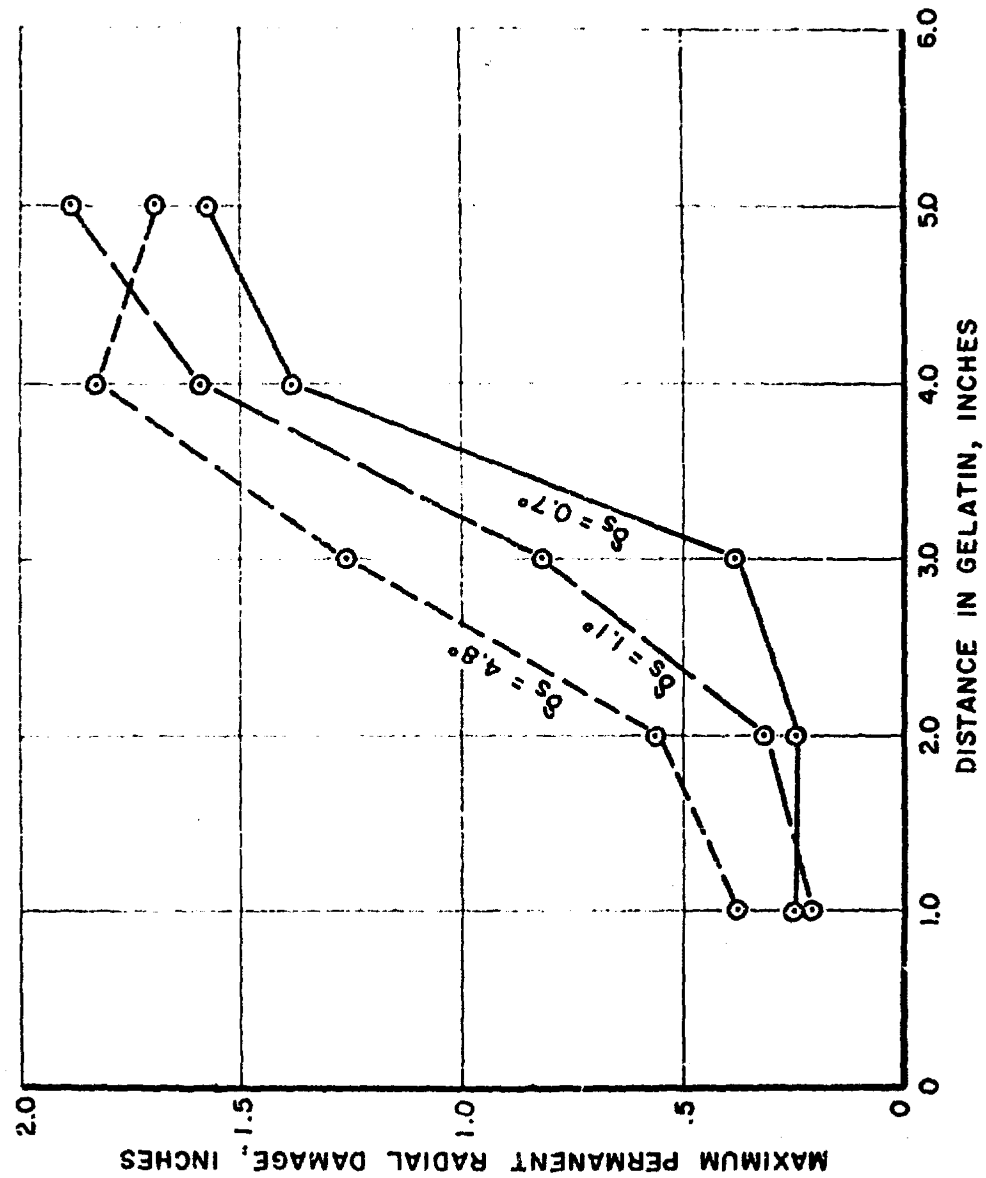
1. Kent, R. H. The Theory of the Motion of a Bullet About its Center of Gravity in Dense Media with Applications to Bullet Design, BRL Report X-65, January 1930.

2. Sperrazza, J. and Dziemain, A. Provisional Estimates of the Wounding Potential of Flechettes, BRL Technical Note No. 1297, Feb. 1960.

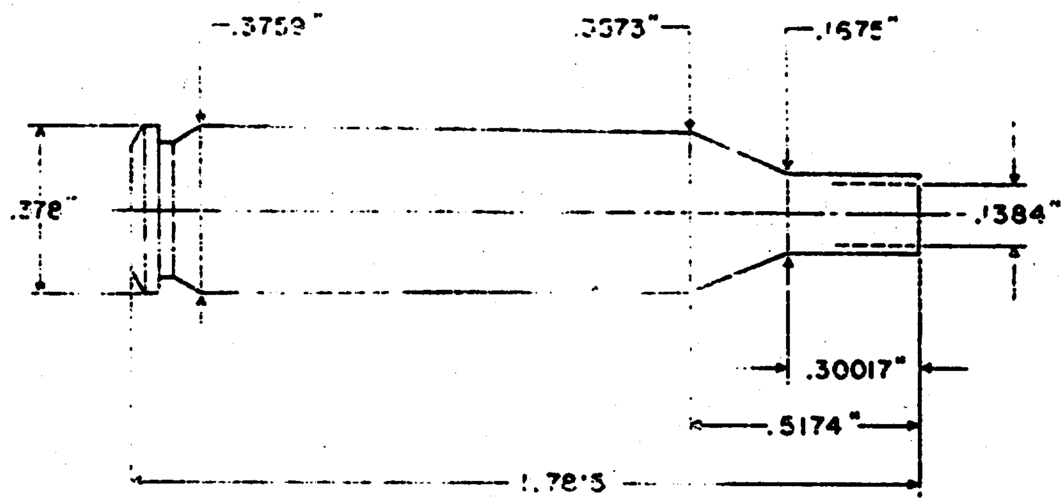
3. Murphy, C. H. and Schmidt, L. E. The Effect of Length on the Aerodynamic Characteristics of Bodies of Revolution in Supersonic Flight, BRL Report No. 876, Aug. 19

URE 1 -- GELATIN RADIAL DAMAGE FOR A CALIBER .14, 7.5 CAL.
TANGENT OGIVE PROJECTILE V_S = 3930 FT./SEC. (U)

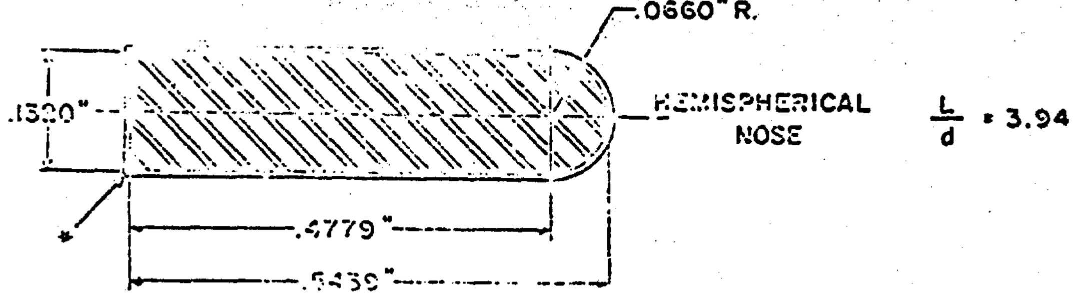


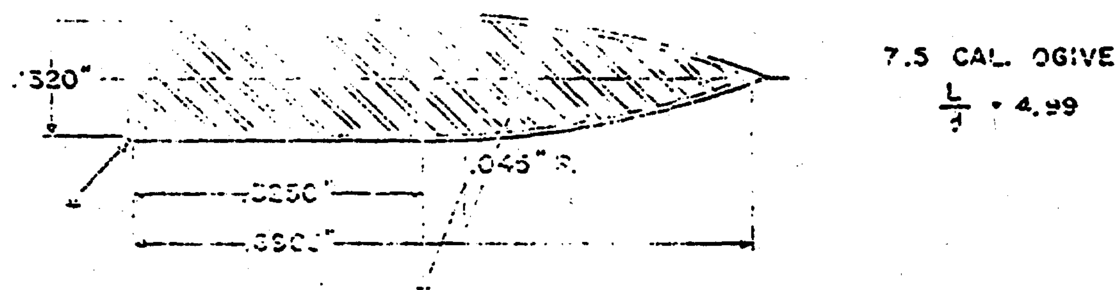


(CONFIDENTIAL) FIGURE 2 - GELATIN RADIAL DAMAGE FOR A CALIBER .14, 7.5 CAL TANGENT OGIVE PROJECTILE V_s = 2680 FT./SEC. (U)



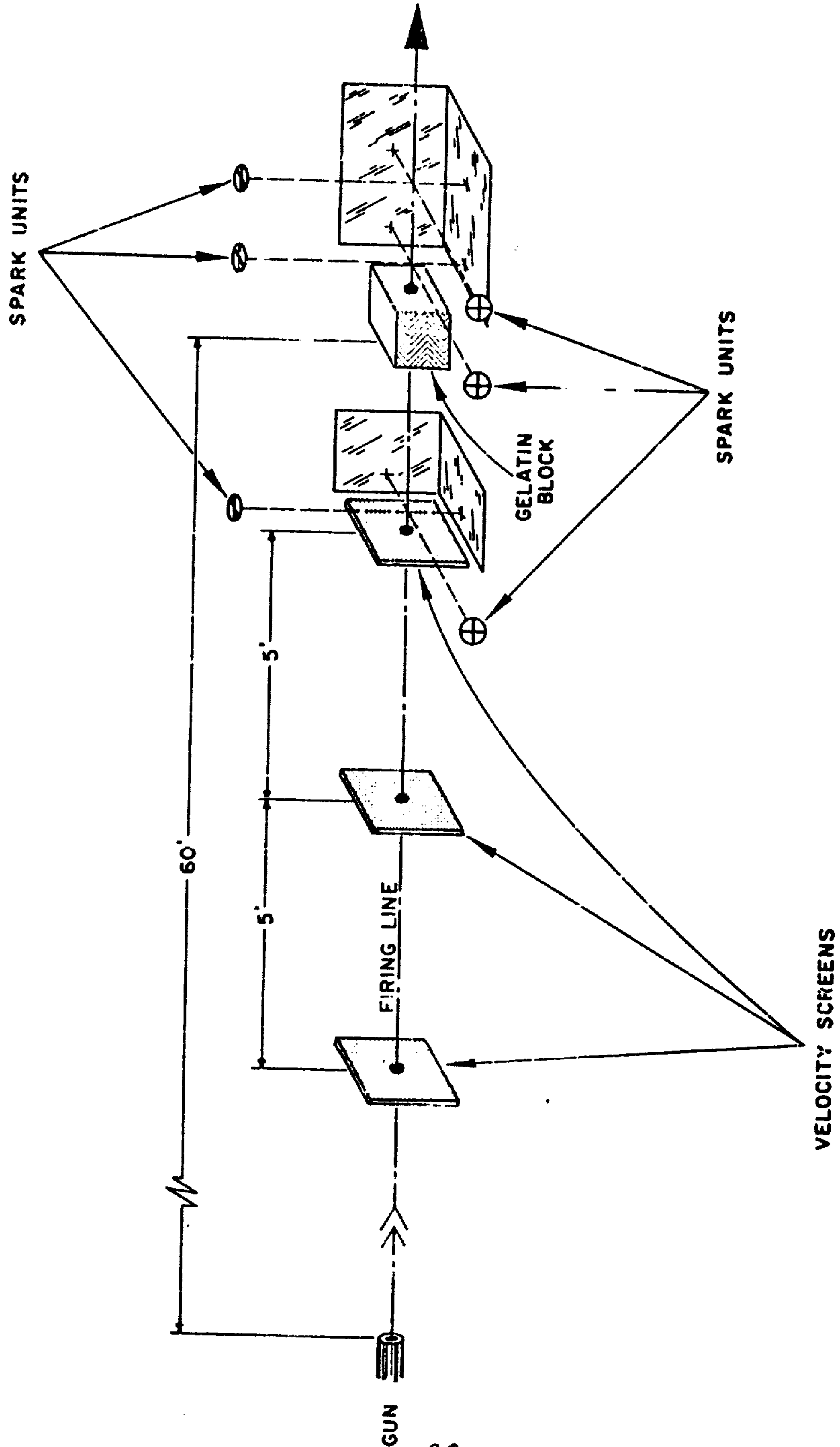
(CONF) FIG. 3 – CARTRIDGE CASE, CALIBER .140 (MODIFIED REMINGTON .222) (U)





ALL PROJECTILES COPPER PLATED
.004" THICK.

(CONFIDENTIAL) FIG. 4 - CALIBER .14 PROJECTILE
STEEL CORE, SAE 1020 STEEL (U)



(UNCLASSIFIED) FIG. 5 - RANGE SET-UP (U)

FIGURE 6.

(SECRET) VELOCITY LOSS FOR CALIBER .14, 7.5 CAL TANGENT OGIVE PROJECTILE THROUGH SIX INCHES OF GELATIN (U)

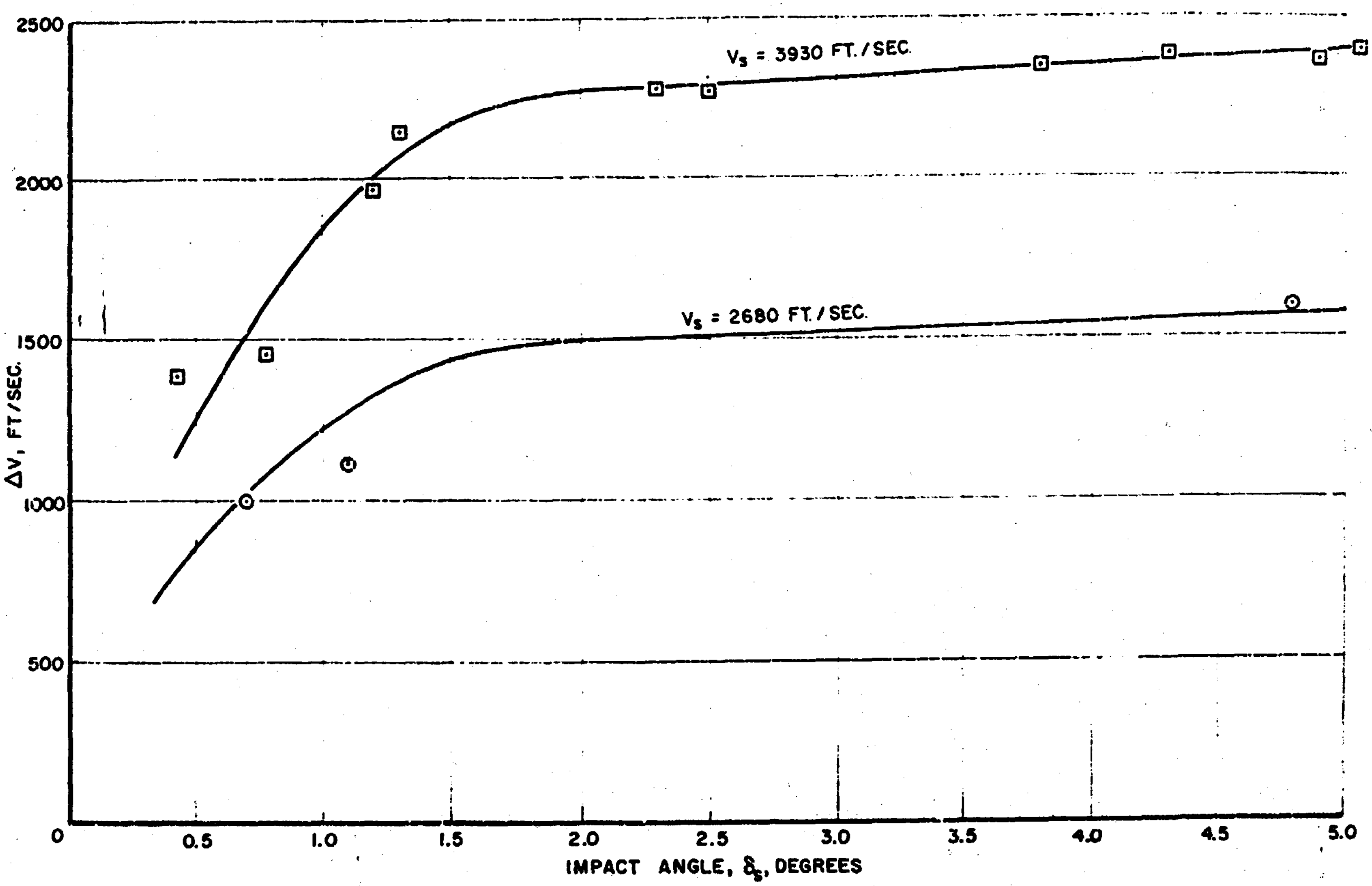


FIGURE 7.

(SECRET) $\overline{K}_{Dg}$ OVER SIX INCHES OF GELATIN
CALIBER .14 (7.5 CAL. TANGENT OGIVE) PROJECTILE (U)

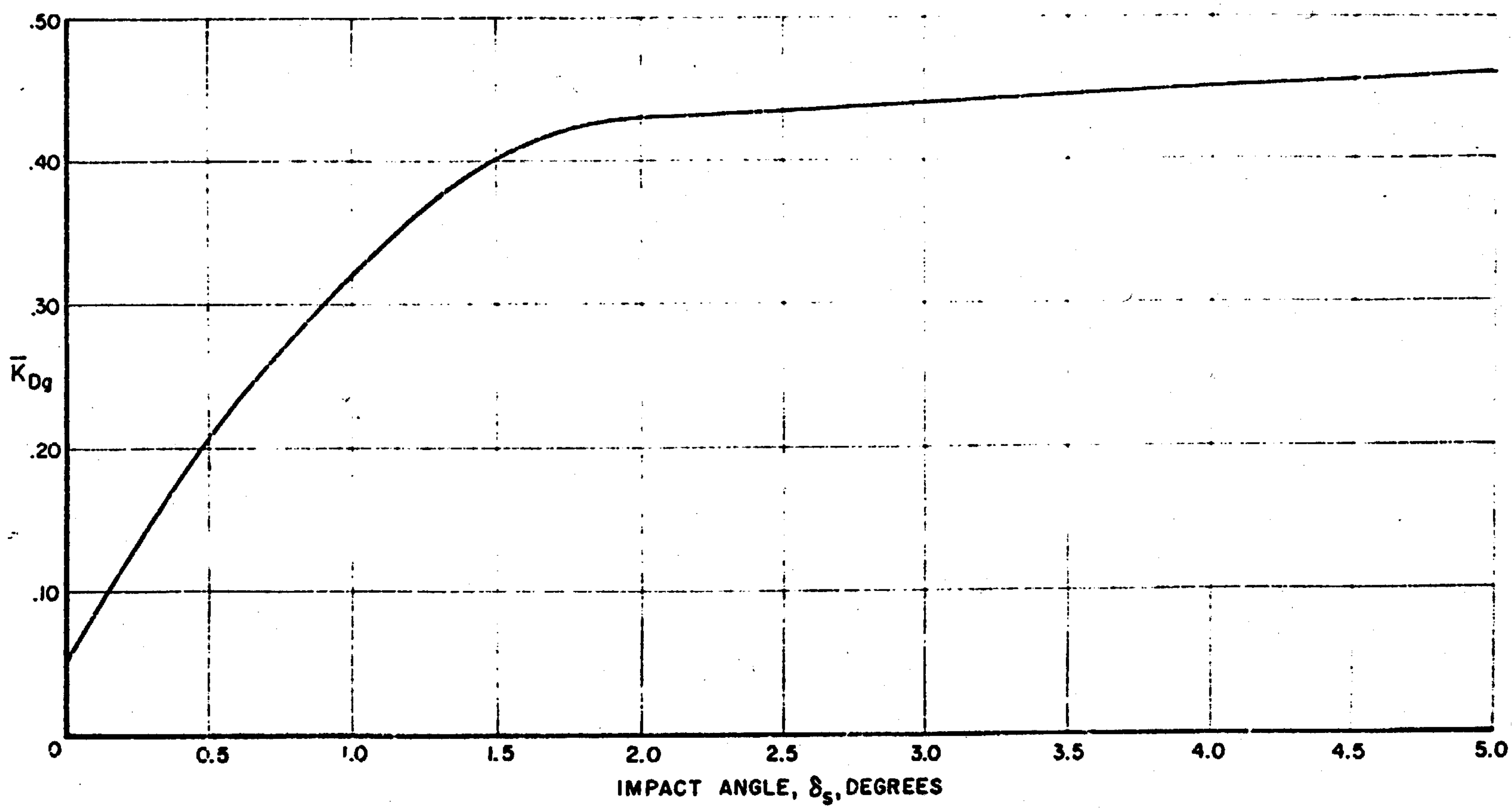
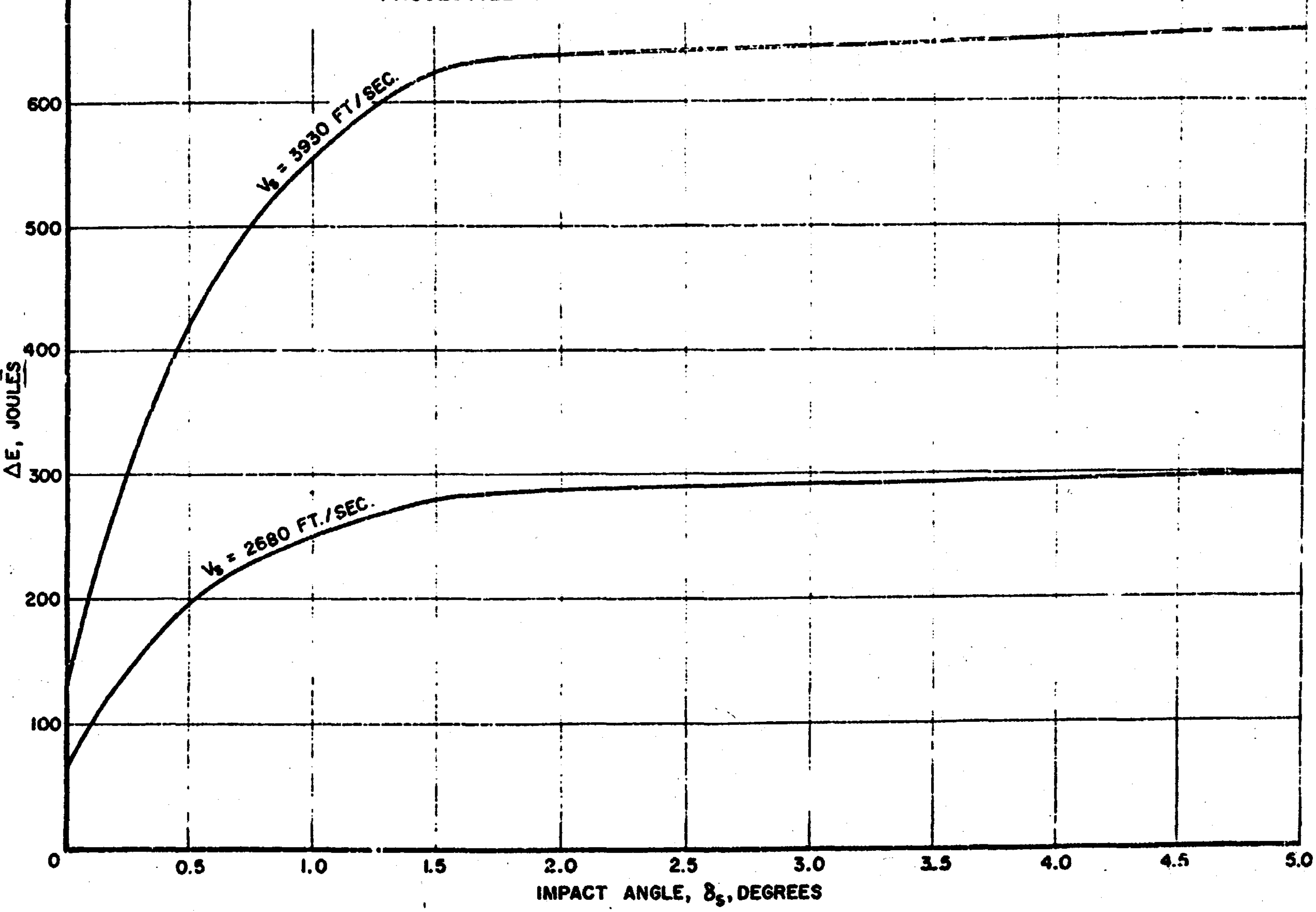
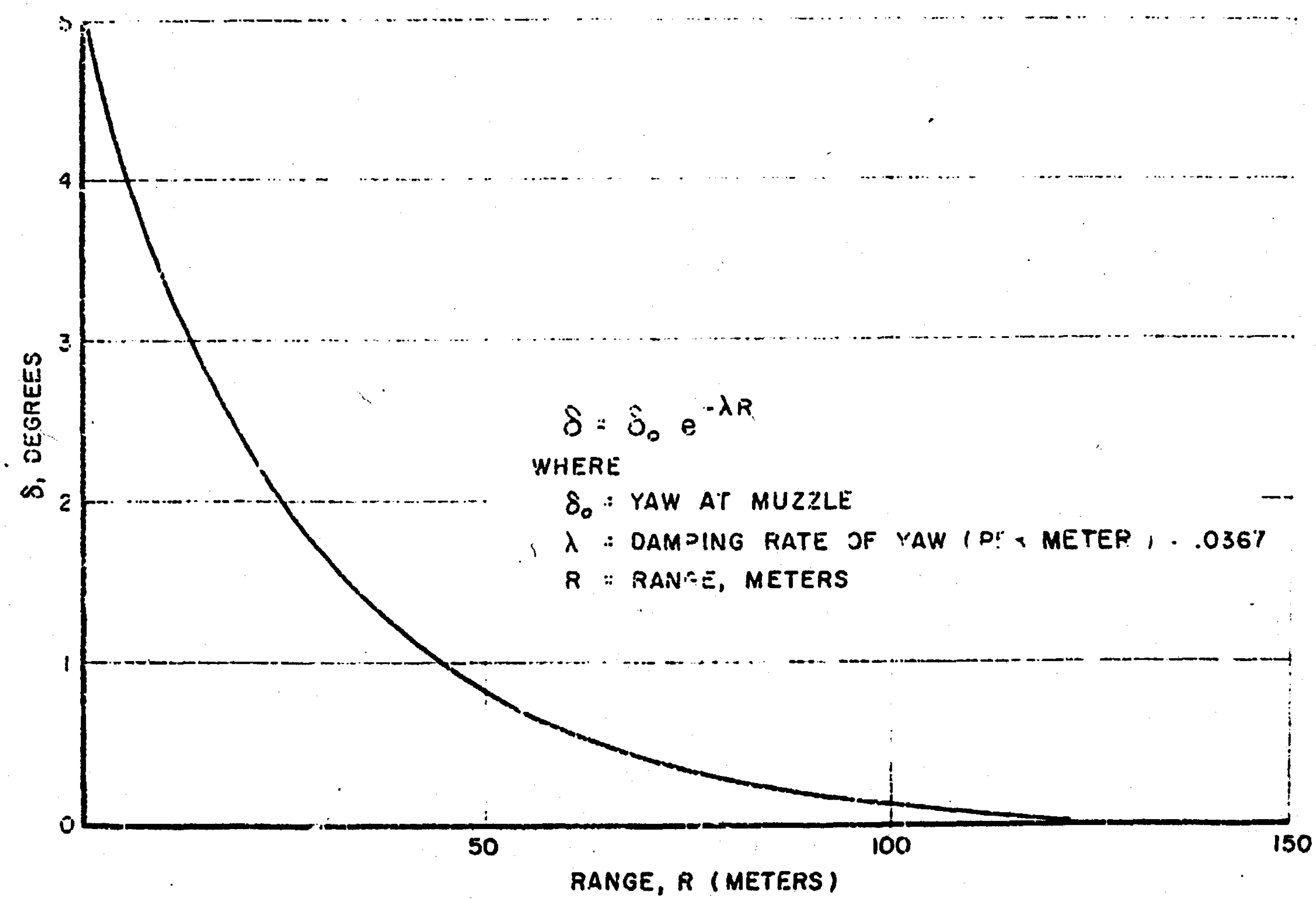


FIGURE 8.

(SECRET) KINETIC ENERGY LOSS FOR CALIBER .14 (7.5 CAL. TANGENT OGIVE) PROJECTILE THROUGH SIX INCHES OF GELATIN (U)



(SECRET) FIGURE 9 -- YAW ANGLE VERSUS RANGE
CALIBER .14 (7.5 CAL TANGENT OGIVE) PROJECTILE (U)



(SECRET) FIGURE 10 - DRAG COEFFICIENT IN AIR

CALIBER .14 (7.5 CAL. TANGENT OGIVE) PROJECTILE (U)

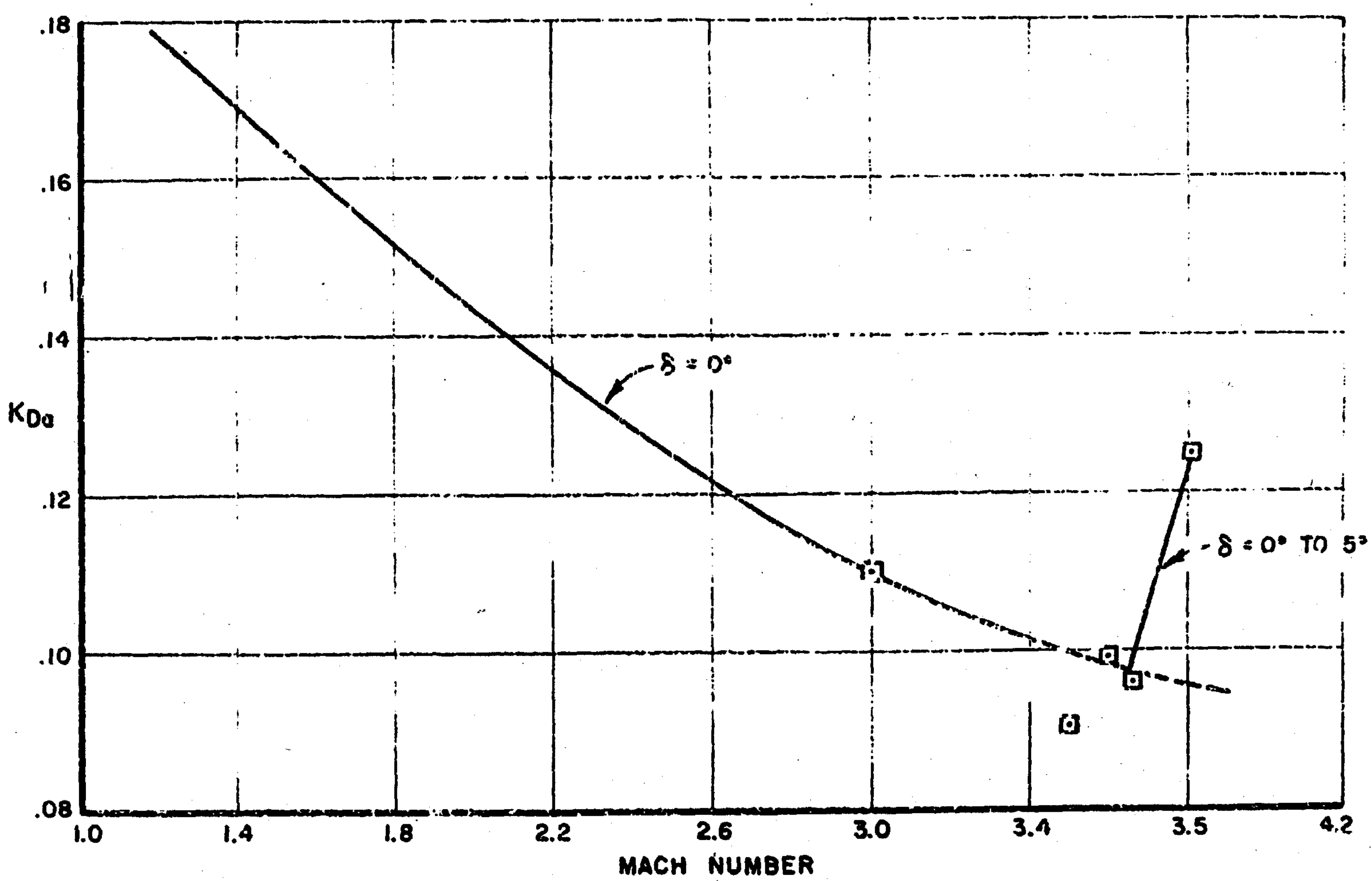
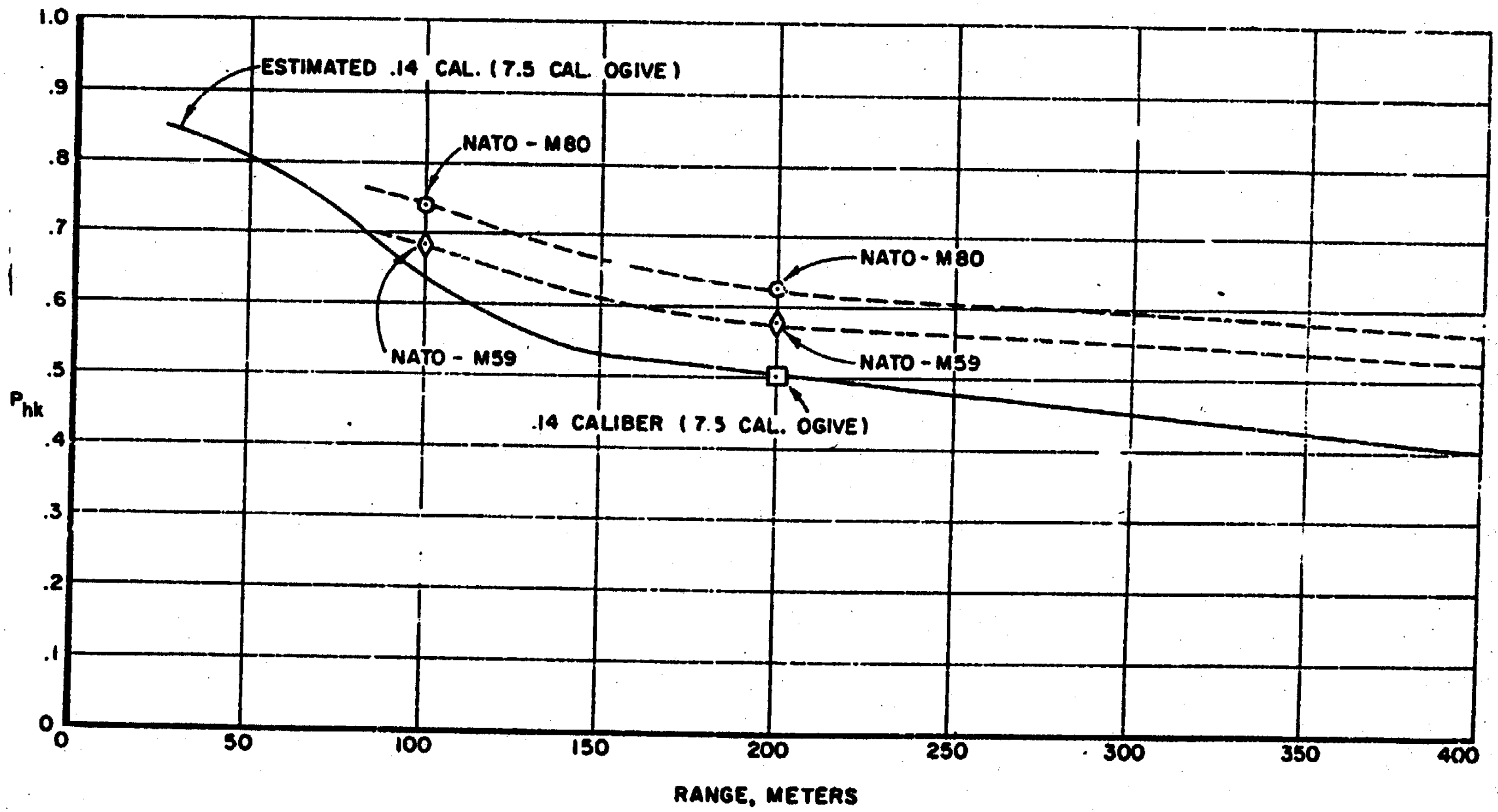


FIGURE 11

(SECRET) P_{hk} (1/2 MINUTE ASSAULT) CALIBER .14 (7.5 CAL OGIVE) BULLET AND 7.62 MM NATO BALL M80 AND M59. (U)



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Small arms ammunition - Terminal ballistics
Wound ballistics - Small arms

BRL Memorandum Report No. 1409 June 1962

DA Project No. 503-04-010, OMSC No. 5010.11.817
SECRET Report

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Caliber .14 spin-stabilized projectiles were fired into gelatin and measurements of the loss in velocity of the projectiles were obtained. The yaw angle at impact and the striking velocity were varied and were related to the energy absorbed by the gelatin. The probability of incapacitation as a function of range was computed. The effect of two different nose shapes on the probability of incapacitation was studied.

DEPARTMENT OF THE ARMY
US ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND
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Constance L. Berry
CONSTANCE L. BERRY
Team Leader
Security/CI Office