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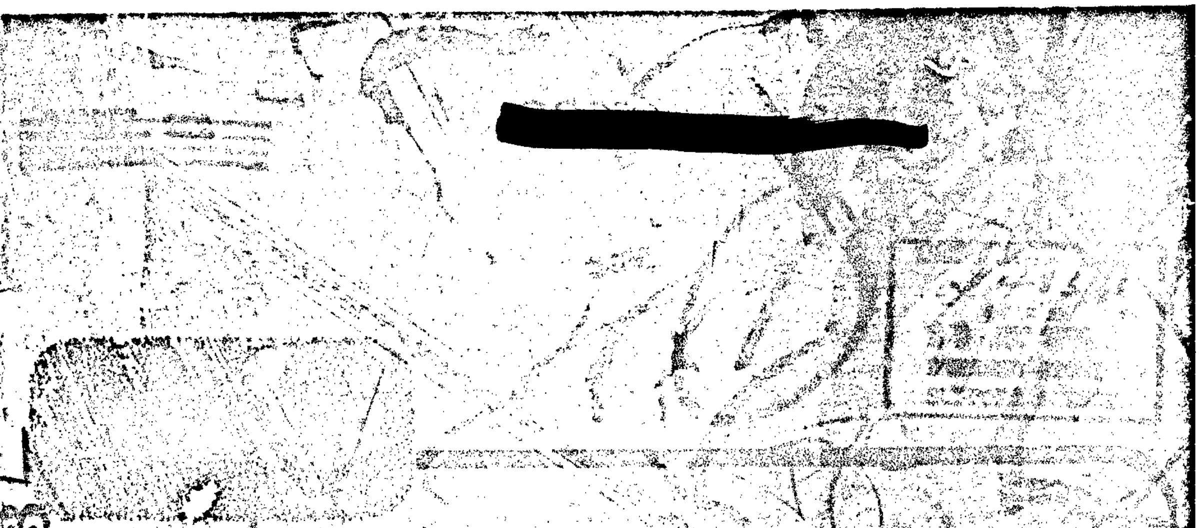

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Project 3.5

MINEFIELD CLEARANCE

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㉑ Report on

OPERATION BUSTER,

PROJECT 3.5.

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by

⑩ R. D. THURSTON

THOMAS BARDEEN.

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ABSTRACT

The methods for using Universal indicator mines to determine probabilities of detonation of anti-tank mines when subjected to blast are discussed. Scaling laws for normal bombs and atomic weapons are devised and methods for computing probabilities of detonation are given. An outline of the instrumentation and field procedure used in obtaining data during Operation BUSTER is given. The results show that, in addition to obtaining data for minefield clearance, estimates can be made of yield of the weapon and of peak pressure as a function of distance from ground zero. A rather poor radius of clearance was obtained in the BUSTER shots primarily because of a skip effect (abnormally low readings) occurring at a radius about equal to the height of burst. It is recommended that the Universal indicator mines with closer control be used in future atomic tests to study in detail the skip effect due to ground shock, terrain, and obstructions and that further studies be made on the mine as a peak pressure gage.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The Universal indicator mine was developed by the Gulf Research & Development Company under Contract OEMsr-266 in 1944.* A study was made of various types of pressure actuated mines, and it was found that, when mines are subjected to shock impulses of various types, the energy absorbed by the given type of mine when actuated is approximately constant.* The Universal indicator mine was designed to measure the energy absorbed by the mine over pressure ranges from 3 to 330 lbs. per square inch. It was found that most types of anti-tank and beach mines have dynamic systems which behave enough like the indicator mine so that the probabilities of detonation of these mines can be computed from the measurements made by the indicator mine. The indicator mine can be used as a peak pressure gage for explosions with a yield of 1000 lbs. or more.

1.2 OBJECTIVES OF PROJECT 3.5

1. Determine radius of clearance for various types of mines when subjected to blast of atomic weapons by means of Universal indicator mine.
2. Determine scaling laws for minefield clearance as function of blast yield and height of burst.
3. Determine if skip zones occur in minefield clearance using air burst atomic weapons.
4. Determine blast yield in TNT of atomic weapons.
5. Determine effective surface peak overpressures of atomic weapons.

---

*Reference 1.

CHAPTER 2*

HISTORICAL AND THEORETICAL

2.1 UNIVERSAL INDICATOR MINE

The significant dynamic characteristic of a mine which is subjected to shock impulses is the energy required to give a given displacement. It has been found that the displacement-energy function is the same for various types of impulses.

The Universal indicator mine uses a standard mine case and a special indicator fuze. The Universal indicator fuze measures the maximum displacement of the pressure plate of the mine. The fuze has been designed in such a way that the energy required to give a given displacement is approximately linear with the displacement so that the mine essentially measures energy.

A phantom view of the fuze is shown in Fig. A.2,** (about twice size). It consists of a piston which receives the force from the pressure plate, a special design of Belleville springs, a fuze body which sets in a fuze well in the mine base, a measuring pin, and a chuck which holds the measuring pin. Initially, the measuring pin is set flush with the top of the piston. When a force is applied to the piston, the springs deflect, the piston and measuring pin move down and the pin is held by the chuck in the deflected position. A dial gage with a special adaptor is used to measure the deflection of the measuring pin. A gage reading of 300 is arbitrarily set as the zero reading, and the gage reading decreases as the pin displacement increases so that the net displacement of the pin is

$$D\,(\text{mils}) = 300 - (\text{gage reading}) \qquad (2.1)$$

Inserts from the piston into the hole in the top spring and from the body into the hole in the bottom spring act as stops. The maximum deflection of the measuring pin (or the piston) varies among different fuzes from a minimum of 155 to about 175. Since 155 is the maximum reading for some of the fuzes, it is considered to be the maximum of

---

*For a more complete discussion and derivation of the equation in this chapter see Reference 1.

**Appendix A "Instruction Manual for Universal Indicator Mine" the scale reading of the fuze and all readings greater than 155 are considered to be the maximum scale reading of 155.

In order to extend the range of the indicator mine, two different diameter pressure plates are used. (M-1 large diameter and M-2 small diameter.) The M-1 and M-2 mines have overlapping ranges with:

$$D_{M-2} = 20\, D_{M-1} \qquad (2.2)$$

where: D_{M-2} = reading (mils) M-2 mine
D_{M-1} = reading (mils) M-1 mine

Readings made with the M-2 mine are always converted to the M-1 scale, using Equation 2.2.

During calibration programs for the Universal indicator mine, sufficient data have been obtained from point charge tests to allow a statistical analysis to be made and an empirical formula to be derived, which predicts the behavior of the Universal indicator mine when subjected to the shock impulse from point charges for various charge weights (8 lbs. to more than 1000 lbs.) for various depths of burial (0 in. to more than 6 in.), for distances covered by combined ranges of the Universal mines (3 to 300 lbs/sq. in. peak press.), for a wide variety of moisture conditions, and for sand or sandy clay soil. A method is shown for determining the probability of detonation of a number of other types of mines using this empirical formula. This formula applies only to bare cylindrical charges of cast TNT detonated at a scaled height. However, additional empirical formulae are shown (based on available data on peak pressure and impulse from explosive devices), and a method given for predicting the probabilities of detonation of a number of types of mines for bombs and rockets detonated at any height above the ground. Computed probabilities of detonation are compared in Table 2.1 with those obtained in a large number of tests with bombs, and are found to be in very good agreement.

2.2 POINT CHARGE FORMULA

A large number of tests have been made with TNT charges and bombs using the Universal indicator mine. A typical sample of the data from these tests is shown in Fig. 2.1. It will be noted that straight lines give a good approximation to the data. The equation of these straight lines is given as follows:

Let

[illegible] (mils) = Mean indicator reading M-1 mines
D (mils) = 20 times mean indicator reading M-2 mines
D_o (mils) = Soil constant
h (in.) = Depth from surface to top of pressure plate
W_e (lbs.) = Weight of explosive expressed in equivalent pounds of TNT detonated at a height H (ft.) $= W_e^{1/3}$
R (ft.) = Distance from the center of the charge to the mine

Then

$$\left(\frac{D}{D_o}\right)^{\frac{1}{q}} = \frac{C}{R}\left(\frac{W_e^{2}}{A + W_e}\right)^{1/3} \qquad (2.3)$$

where

$$q = 2 + \frac{0.8\,W_e}{10 + 10h + 0.6\,W_e} \qquad (2.4)$$

$$A = 20 + 7.5h^2 \qquad (2.5)$$

$$C = 5.5 + \frac{1.8}{1 + h} \qquad (2.6)$$

The value of C given by Equation 2.6 applies to charges up to 10,000 lbs. Data taken in Operation BUSTER show that this equation is in error for atomic explosions. A further discussion of this is given in Chapter 4.

2.2.1 Soil Constant

Table 2.2 shows a list of the values of D_o, which should be used to compute the effect of blast under various ground conditions based on this departure. The following general conclusions can be reached as to the effect of ground conditions on the Universal indicator mine:

1. A change in the compactness of the ground below the mine from solid to loose decreases the value of D_o about 40%.
2. A change in the moisture in the ground above the mine from dry to wet decreases the value of D_o about 30%.
3. A change in the compactness of the ground above the mine from loose to solid (muddy to frozen) decreases the value of D_o about 40%.

4. The mean value of D_0 for sandy clay with average moisture and compactness above and below the mine as used in tests at A. P. Hill is 115. (Extreme values from 60 to 150.)

5. The mean value of D_0 for sand with average moisture and compactness above and below the mine as used in tests at Vero Beach, Florida, is 100. (Extreme values from 60 to 110.)

6. For weathered minefields in sandy clay, the expected range of D_0 is from 90 (frozen ground) to 150 (dry ground).

The effect of the change in ground conditions for point charges has been expressed as a function of D_0 or in per cent of the average readings, and these conclusions should apply qualitatively but not necessarily quantitatively to line charges and atomic explosives.

2.2.2 Impulse and Peak Pressure

In Equation (2.3), if $W_e \ll A$

$$D = D_0 \left(\frac{C}{A^{1/3}} \frac{W_e^{2/3}}{R}\right)^2$$

Impulse is given by

$$I = K_0 \frac{W^{2/3}}{R}$$

Hence

$$D = D_0 \left(\frac{C}{K_0} \frac{I}{A^{1/3}}\right)^2$$ and the mine measures impulse

In Equation (2.3) if $W_e \gg A$

$$D = D_0 \left(C \frac{W_e^{1/3}}{R}\right)^{3.33} \qquad (2.7)$$

and D depends on the peak pressure alone.

Measurements have been made with 1030 lbs. of TNT (where $W \gg A$) and the relationship between D/D_0 and peak pressure has been determined. This relationship is shown in Fig. 2.2.

2.3 METHODS FOR COMPUTING PROBABILITIES OF DETONATION

The purpose of any program using indicator mines is to be able to determine the probability of detonation of a given mine that is subjected to blast. It has been shown* that there is a correlation between the mean Universal indicator readings and the 50% probability of many types of mines. Methods are derived below which allow other values of the probability (e.g., 99% of the mines detonated) to be computed from the mean readings.

The individual Universal indicator mine readings have been analyzed, and the mean deviations for different values of mean readings have been computed. A close approximation to the observed data for the mean deviation (α) is

$$\alpha = \sigma D \tag{2.8}$$

$$\text{with } \sigma = 0.19 \tag{2.9}$$

D = mean Universal reading

Since the mean deviation due to the differences in the Universal mines themselves (for mean readings greater than about 25) is about 0.05D, the mean deviation ($\alpha = 0.19\ D$) obtained in the above tests is primarily due to differences in the ground conditions and the method of burial of the mines.

The data obtained with the Universal indicator mine can be used to determine how the variations in the conditions of the ground and in the method of burial of the mines affect the probability of detonation of a given type of mine.

2.3.1 Approximate Probability of Detonation

The approximate formula below gives the probability of detonation of a given mine in terms of the calibration constant for the mine (mean Universal reading which corresponds to the 50% probability of detonation), the mean Universal reading at a given distance from the charge for which the probability is being computed, and the mean deviations in the Universal readings.

---

*Reference 1.

Let

D_a = calibration constant for the mine
D_b = mean Universal reading at the distance R
p = probability of detonation of the given mine
θ = probability function (probability that a reading differs from D_b by less than $D_b - D_a$)
$\gamma = D_b - D_a$
K = measure of precision
$z = K\gamma$
M_p = probability multiplier

Then

$$p = \frac{1}{2} + \frac{1}{2}\,\theta\,(z) \qquad (2.10)$$

$$K = \frac{1}{\alpha\sqrt{\pi}} \qquad (2.11)$$

$$z = \frac{\gamma}{\alpha\sqrt{\pi}} = \frac{D_b - D_a}{\sigma D_b \sqrt{\pi}}$$

or

$$D_b = \frac{D_a}{1 - \sigma\sqrt{\pi}\,z} = M_p\,D_a \qquad (2.12)$$

Thus, to find the mean Universal reading, D_b, for which the probability of detonation of the given type of mine is p, multiply the calibration constant of the mine, D_a, by the multiplier, M_p. Below is a list of the multiplier for various values of p using $\sigma = 0.19$:

p	M_p
0.01	0.643
0.05	0.718
0.10	0.767
0.25	0.862
0.50	1.000
0.75	1.192
0.90	1.439
0.95	1.645
0.99	2.241

(2.13)

A sample computation is:

$D_a = 75$ for German TMi-43 mine

When the mean reading $D_b = 125$

$$M_p = D_b/D_a = 125/75 = 1.667$$

From the table $p = 0.95$ or 95% probability of detonation.

In this method for determining the probability of detonation, the assumption has been made that all the mines of a given type (e.g., the TMi-43) have the same calibration constant. This method will give an approximate value of the actual probabilities of detonation and is useful when there are insufficient data to determine the deviations from a mean calibration constant for a given type of mine, or when the mean deviations are small.

2.3.2 Probability of Detonation for Mines Not Alike

The formula below gives the probability of detonation of a given type of mine for which the individual mines do not have the same calibration constant. Assume that the individual mines differ in a random manner.

Let

D_a = mean value of calibration constant

α_m = mean deviation of D_a

The probability of detonation is given by

$$p = \frac{1}{2} + \frac{1}{2}\,\theta\left(\frac{z_a}{\sqrt{1 + c^2}}\right) \qquad (2.14)$$

where

$$c = \frac{\alpha_m}{\sigma D_b} \qquad (2.15)$$

$$z_a = \frac{D_b - D_a}{\sqrt{\pi}\,\sigma D_b} \qquad (2.16)$$

Thus c is a function of the mean deviation of the calibration constant and the reading of the Universal mine at the distance from the shot where the probability of detonation is being determined.

Let

$$\alpha_m = \Delta D_a \qquad (2.17)$$

$$r = \frac{\Delta}{\sigma} \qquad (2.18)$$

Then

$$c = \frac{r}{M_p} \qquad (2.19)$$

The value of the probability of detonation of a given type mine is found by Equation 2.14 using the constants given in Equations 2.15 to 2.19. A graphical solution of Equation 2.14 (when $\sigma = 0.19$) is given in Fig. 2.3. The procedure to follow when using Fig. 2.3 is illustrated below for the TMi-43 indicator mine. Assume for the TMi-43:

Mean calibration constant is $D_a = 75$
Mean deviation in D_a is $\alpha_m = 8.5$
Mean deviation in Universal readings is $\alpha = \sigma D$
$\sigma = 0.19$

Then

$$\Delta = \alpha_m / D_a = 8.5/75 = 0.113$$
$$r = \Delta/\sigma = 0.113/0.19 = 0.6$$

From Fig. 2.3, the values of M_p for various values for the per cent probability of detonation P corresponding to $r = 0.6$ are:

	%P =	5	10	25	50	75	90	95	99
For $r = 0.6$;	M_p =	0.66	0.72	0.84	1.00	1.22	1.50	1.71	2.34
$D_b = M_p\, D_a$	=	50	54	63	75	91	112	128	175

The Universal indicator mines have manufacturing tolerances such that all mines behave alike within a maximum limit of ±10% for mean readings greater than about 25. Thus, for the Universal indicator mine, an approximate upper limit for r is $0.05/0.19 = 0.26$. It can be seen in Fig. 2.3 that the value of the multipliers, M_p, for various probabilities are nearly the same for $r = 0.26$ as for $r = 0$. This means that very little error is introduced when using the Universal indicator mine by assuming that all mines are alike (i.e., that $r = 0$).

The Universal indicator mine readings which correspond to various per cent probability of detonation have been determined for several types of mines and are shown in Table 2.3.

2.3.3 Universal Scale for Point Charges

The ultimate aim in using an indicator mine is to determine the probabilities of detonation of various types of mines when the mines are buried in various types of soil.

The Point Charge Formula gives a convenient method for determining the probabilities of detonation of various mines for various soil conditions. This formula has been used to compute a Universal scale graph (Figs. 2.4 to 2.7) for 0 in., 2 in., 4 in., and 6 in. depths of burial. From these graphs, the distance from the charge at which any desired probability of detonation of any mine, which can be correlated with the Universal indicator mine (M-1 or M-2), can be determined for weights of charge from 10 to 1000 lbs. While these graphs apply only to cast TNT charges (cylindrical with the length twice the diameter) hung at a scaled height above the ground (height (feet) equals the cube root of the weight (pounds)), they may be applied to other types of demolition weapons (e.g., bombs or rockets) by using an equivalent weight of charge* for these weapons.

A general outline of the method employed to determine the distance from a given weapon, at which a given probability of detonation of a given type of mine buried in a given type of soil occurs, is as follows:

1. Find the mean calibration constant (D_a) and the mean deviation of the constant ($\sigma_m = \Delta D_a$). Compute the value of Δ. (Table 2.3)
2. Compute $r = \Delta/\sigma$ where σ is the mean deviation ratio for the Universal indicator mine readings. $\sigma = 0.19$ for the point charge tests conducted at Vero Beach, Florida, and A. P. Hill, Virginia, but may be different for different test conditions.
3. By means of Equations 2.14 to 2.19 compute the value of multiplier, M_p, for a given probability of detonation, P, and the value of r from step 2. The value of M_p may be obtained from Fig. 2.3 when $\sigma = 0.19$.
4. Compute the value $D_c = M_p D_a$. The values of D_c for some mines which have been studied are given in Table 2.3 for various per cent probabilities of detonation.
5. Find the soil calibration constant, D_o, which corresponds to the given type of soil, from Table 2.2. (This table is incomplete due to insufficient data.) The general ranges of values of D_o are discussed in Section 2.2.1.

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*A method for determining the equivalent weight of charge is discussed in Sections 2.4 and 2.5.

6. Compute the value, D_u, on the mean Universal scale corresponding to the given probability of detonation of the given type of mine in the given type of soil using D_c from step 4, and D_o from step 5 by means of the following equation:

$$D_u = 100\, D_c/D_o \qquad (2.20)$$

7. Find the equivalent weight of charge, W_e, for the given weapon. Sections 2.4 and 2.5 give a method for computing the value of W_e. When the weapon is at the height $H_o = W_o^{1/3}$, the value of W_e equals W_o where W_o is the weight of a cylinder of cast TNT which produces the same blast effect on mines. When the weapon is at a different height, the value of W_e is a function of W_o and R, where R is the distance from the center of the charge in the weapon to the mine.

8. Using the value D_u from step 6 and W_e from step 7, the distance, R, from the center of the charge to the mine can be found using the Universal scale graphs in Figs. 2.4 to 2.7 for 0 in., 2 in., 4 in., and 6 in. depths of burial. When W_e is changing appreciably with R, it is convenient to plot W_e as a function of R directly on the Universal scale graphs.

9. The radius of clearance, d, from the point on the ground below the charge to the mine at which the probability of detonation, P, occurs can be found from

$$d = \sqrt{R^2 - H^2}$$

where R is obtained in step 8.

H is the height of center of charge above the ground.

Examples of the use of this method for the determination of the distance from a given weapon for a given probability of detonation are given in Section 2.6.

2.4 EQUIVALENT WEIGHT OF CHARGE NORMAL BOMBS*

In order to use the data obtained with TNT charges and the

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*The data on charge-weight ratios for bombs are from Reference 2. The data from which the pressure-height formula was derived and the impulse formula are from Reference 3.

Universal indicator mine, to predict the effect on anti-tank mines of the shock impulse from the detonation of bombs or rockets, the weight of a cast TNT test charge, which will produce the same effects on the mines as do the bombs or rockets, must be determined. Measurements of the peak pressures and impulses obtained from bombs are known and can be used to determine the equivalent weight of charge for bombs or rockets.

2.4.1 Effect of Case and Type of Explosive

Let

I = Value of the impulse on the surface of the ground

E = Explosive factor for the of type of explosive.

e = Naperian base for logarithms = 2.718...

S = Case-Weight Factor. This is the charge-weight ratio of an equivalent cylinder bomb, having the same diameter as the bomb, a length to give the same volume, and a wall thickness (including end caps) equal to the wall thickness of the bomb case.

W_x = Weight of charge in the bomb (lbs.).

d = Horizontal distance from the bomb to the point for the impulse, I (ft.).

U = Bomb body diameter (in.).

t = Wall thickness of bomb case (in.).

λ_x = Density of explosive (lb./in.^{3})

λ_c = Density of bomb case material (lb./in.^{3})

W_o = Weight of charge in equivalent cylinder with center level with ground (lbs.)

Then

$$S = \frac{W_x}{W_x + \text{Weight of Equivalent Cylindrical Case}} \qquad (2.21)$$

$$= \frac{1}{1 + \frac{4t\,(U - t)\,\lambda_c}{(U - 2t)^2\,\lambda_x} + \frac{\pi\,U^2 t\,\lambda_c}{2W_x}} \qquad (2.22)$$

For a bomb detonated with the center of the charge level with the surface of the ground

$$I = 29\, e^{S-1} (EW_x)^{2/3}/d \qquad (2.23)$$

For the equivalent cylinder of TNT

$$I = 29\, W_o^{2/3}/d \qquad (2.24)$$

These impulses must be the same. Hence:

$$W_o/W_x = E\, e^{1.5\,(S-1)} \qquad (2.25)$$

The value of E for various types of explosives is:

Explosive	λ_x	E
Cast TNT	1.58	1.00
Amatol 50/50	1.55	0.83
Composition B	1.60	1.12
Torpex 2	1.71	1.27
HBX	1.65	1.23
Tritonal	1.70	1.17
Minol 2	1.64	1.20

The values of S have been determined for a number of bombs. Using these values of S and the values of E in the table above Equation 2.25 was used to compute W_o in the following table:

Bomb	Weight (lbs.)	Explosive Loading	S	W_x (lbs.)	W_o (lbs.)
AN M30 GP	100	TNT	0.67	57	35
AN M57 GP	250	TNT	0.61	135	75
AN M31 GP	300	TNT	0.62	162	92
AN MK 17 Depth	325	TNT	0.76	224	156
AN MK 47 Depth	350	Torpex	0.78	252	230
AN MK 54 Depth	350	Torpex	0.78	250	230
AN M64 GP	500	TNT	0.65	258	153
AN M64 GP	500	Comp. B	0.66	275	185
AN M64 GP	500	Tritonal	0.67	285	203
AN MK 37 Depth	650	TNT	0.78	465	335
AN M65 GP	1000	TNT	0.59	558	302
AN M65 GP	1000	Comp. B	0.61	595	370
AN M66 GP	2000	TNT	0.64	1100	640

2.4.2 Effect of Height of Burst

An empirical formula has been derived from data on the peak pressure (from the detonation of bare charges of TNT) as a function of height of burst and horizontal distance from the center of the charge, so that the equivalent weight of a charge with the center above the ground can be determined.

Let

R = Distance from the center of the charge to a point on the ground (ft.).

d = Horizontal distance from a point directly under the charge to the point on the ground (ft.).

H = Height of center of the charge above the ground (ft.).

W_e = Weight of charge at height $H_e = W_e^{1/3}$ which gives the same peak pressure at a distance R as W_o at the height H (lbs.)

W_g = Weight of charge at height $H_o = 0$ which gives the same peak pressure at a distance R as charge of weight W at a height H.

The peak pressure when $H = 0$ is given by

$$\text{Peak Pressure} = \frac{4810}{V^3} - \frac{428}{V^2} + \frac{58.1}{V} \qquad (2.26)$$

where $V = R/W^{1/3}$. Equation 2.26 may be used to give the peak pressure from a charge at a height H over the range of $R/W^{1/3}$, which is covered by the Universal scale if V is replaced by

$$V_g = V\left(1 - B_h\left(1 + \frac{H}{R}\right)\right) \qquad (2.27)$$

where B_h is a function of $\frac{H}{W^{1/3}}$ given by:

$H/W^{1/3}$	B_h
0	0.00
1	0.05
2	0.10
3	0.15
4	0.175
5	0.18
6	0.17

(2.28)

The peak-pressure data obtained from Reference 3 is shown in Fig. 2.8. It can be seen that Equation 2.26 with V replaced by V_g is a very good approximation to the observed data except at the high pressures where Equation 2.26 does not apply.

The Universal scale graphs (Figs. 2.4 to 2.7) apply to charges detonated at a height $H_e = W_e^{1/3}$ above the ground. Equation 2.27 can be used to find the weight of a charge, W_e, detonated at a height, H_e, which gives the same peak pressures as a charge of weight, W_o, detonated at a height, H, above the ground. Using Equation (2.27), the equivalent weight of charge, W_g, detonated at a height, H = 0, which gives the same peak pressures as the charges, W_e, detonated at a height, H_e, or W_o, detonated at a height, H, is found from

$$R/W_g^{1/3} = R/W_e^{1/3}\ (1 - 0.05\ (1 + H_e/R)\ )\ \text{for}\ W_e$$

$$= R/W_o^{1/3}\ (1 - B_H\ (1 + H/R)\ )\ \text{for}\ W_o$$

Hence

$$\frac{R}{W_e}{}^{1/3} = \frac{R}{W_o}{}^{1/3}\ \frac{1 - B_H\ (1 + H/R)}{1 - 0.05\ (1 + \frac{H_e}{R})} \qquad (2.29)$$

Table 2.4 and Fig. 2.9 show the effective weight of charge for several types of bombs.

For many uses $R > H_e$ and Equation 2.29 can be simplified to become

$$\frac{R}{W_e}{}^{1/3} = 1.05\ \frac{R}{W_o}{}^{1/3}\ (1 - B_H\ (1 + \frac{H}{R})\ ) \qquad (2.30)$$

2.5 EQUIVALENT WEIGHT OF CHARGE FOR ATOMIC EXPLOSIONS

The pressure data for Operation BUSTER have been analyzed and it has been found that Equations 2.26 to 2.30, Section 2.4.2, do not apply for calculating pressure (and hence Universal indicator readings) from $R/W_t^{1/3}$ where W_t is the actual yield given in the preliminary report for Operation BUSTER . The reason for this discrepancy is that the effective yield based on peak pressure varies with distance from the explosion. The emperical formulae derived below corrects the pressure data so that pressure and Universal indicator readings can be determined from the TNT yield of the bomb.

Let

R = distance from center of explosion to a point on the ground (ft.)

W_t = actual yield of explosion (lb.)

W_o = equivalent yield corrected for size of explosion (a function of R and W_t) (lb.)

W_g = equivalent yield corrected for size of explosion and height of burst (lb.)

H = height of burst (ft.)

$$V_t = R/W_t^{1/3} \qquad (2.31)$$

$$V_o = R/W_o^{1/3} \qquad (2.32)$$

$$V_g = R/W_g^{1/3} \qquad (2.33)$$

V_a = equivalent yield correction factor (emperical)

The pressure data for Operation BUSTER is a function of V_g if V_g is computed in the following manner:

Let

$$V_o = \frac{2V_a}{\sqrt{1 + \frac{4V_a}{V_t}} - 1} \qquad (2.34)$$

and

$$V_a = \frac{W_t^{.3}}{40} \qquad (2.35)$$

Correct for height of burst using Equation 2.27 for pressure or Equation 2.30 for Universal Indicator readings and B_H determined by $H/W_t^{1/3}$.

Equation 2.34 may be written

$$V_t = \frac{V_g}{1 + \frac{V_a}{V_g}} \qquad (2.36)$$

Equation 2.36 shows that V_g will always be bigger than V_t with $V_g \rightarrow V_t$ when V_t is large. This means that the equivalent TNT weight for atomic explosions is smaller than the actual yield, but approaches the actual yield at great distances from the explosion.

2.5.1 Peak Pressure for Atomic Explosions

The peak-pressure data for Baker, Charlie, and Easy have been corrected by means of Equations 2.34, 2.35 and 2.27 and are shown on Fig. 2.12. For comparison Equation 2.26 is also shown on Fig. 2.12. It may be seen that Equation 2.26 is a fair approximation to the pressure data for atomic explosions after the weight and height of burst corrections have been applied.

2.5.2 Point Charge Formula for Atomic Explosions

The Point Charge Formula discussed in Section 2.2 can be used to predict the behavior of the Universal indicator mine for atomic explosions if the equivalent weight of charge is determined in a manner similar to the pressure data. For large charges the point charge formula, Equation 2.3, becomes:

$$\left(\frac{D}{D_o}\right)^{.3} = C \frac{W_e^{1/3}}{R} \qquad (2.37)$$

where

W_e = equivalent weight of charge

C = function of depth of burial and charge weight

There are insufficient data to accurately determine the manner in which C varies with charge weight. Chapter 4 discusses the values of C as determined in atomic tests to date. For TNT charges of 10,000 lbs. or less, C is independent of charge weight and is given by Equation 2.6.

Combine Equations 2.30 and 2.37. Then

$$\left(\frac{D}{D_o}\right)^{.3} = C \frac{W_e^{1/3}}{R} = \frac{C}{FV_o} \qquad (2.38)$$

where

$$F = 1.05 \left(1 - B_H \left(1 + \frac{H}{R}\right)\right) \qquad (2.39)$$

Combine Equations 2.34 and 2.38. Then

$$\left(\frac{D}{D_o}\right)^{.3} = \frac{C}{2V_a F}\left(\sqrt{1 + 4\frac{V_a}{V_t}} - 1\right) \tag{2.40}$$

Let

$$\left(\frac{D'}{D}\right)^{.3} = \frac{1}{2}\left(\sqrt{1 + 4\frac{V_a}{V_t}} + 1\right) \tag{2.41}$$

Then Equation 2.40 becomes

$$\left(\frac{D'}{D_o}\right)^{.3} = \frac{C}{V_t F} \tag{2.42}$$

Let

$$\frac{B}{A} = \frac{B_H}{1 - B_H} \tag{2.43}$$

$$\frac{C}{A} = \frac{C\,W^{1/3}}{1.05\,H\,(1 - B_H)} \tag{2.44}$$

Then Equation 2.42 becomes

$$\frac{C}{A}\left(\frac{D_o}{D'}\right)^{.3} = \frac{R}{H} - \frac{B}{A} \tag{2.45}$$

Equation 2.43 and 2.44 are shown graphically in Fig. 2.13.

2.5.3 Determination of Yield in Atomic Explosions

When it is desirable to determine the yield of atomic explosions from data taken with the indicator mine, the following procedure may be used:

1. For indicator scale readings (M-1) less than 25 determine the true value of D from Fig. 2.14.
2. Make an estimate of the yield and compute V_a and V_t from Equations 2.31 and 2.35.

3. Compute D' from Equation 2.41 and measured values of D.

4. Compute D'/D_o where D_o are known values of the soil constant.

5. On log log graph paper plot D'/D_o as abscissae and $R/H - 0.2$ as ordinates and draw a mean straight line through the points.

6. Find the value of $R/H - 0.2$ for $D'/D_o = 1$. This value approximates the value of C/A.

7. Find the value of $H/W_t^{1/3}$ in Fig. 2.13 corresponding to the value of C/A from step 6. Compute the approximate yield W_t.

8. Repeat steps 3 to 7 if the value in step 7 differs materially from the estimated yield.

The method outlined in steps 1 to 8 above has been used on the data obtained in Operation BUSTER in Chapter 4.

2.6 RADIUS OF CLEARANCE WITH NORMAL BOMBS

In order to check the validity of the methods outlined in Sections 2.1 to 2.4, the probabilities of detonation of the German TMi-43 mine (4 in. depth of burial) when subjected to blast from the Mark 17,325-lb. depth bomb detonated at various heights above the ground have been computed and can be compared with observed probabilities. These calculations follow the method outlined in Section 2.3. A sample calculation for the 95% probability of detonation with mines buried in wet clay is as follows:

1. The calibration constants for the TMi-43 (from Table 2.3 are

$$D_a = 75$$

$$\alpha_m = 8.5$$

$$\Delta = 8.5/75 = 0.113$$

In order to correct for the nonsymmetrical pattern of the bombs (due to the axis of the bomb not being vertical) Δ is increased to

$$\Delta = 0.247$$

2. The value of r is

$$r = \Delta/\sigma = 0.247/0.19 = 1.3$$

3. Using Fig. 2.3, the value, M_p, for a 95% probability of detonation when $r = 1.3$ is:

$$M_p = 1.91$$

4. The value of D_c is:

$$D_c = M_p D_a = 1.91 (75) = 143$$

5. From Table 2.2, the value of D_o for wet clay is:

$$D_o = 100$$

6. The value of D_u is:

$$D_u = 100 D_c/D_o = 100 (143)/100 = 143$$

7. The values of W_e for various heights of burst and various values of R (distance from center of charge to the mine) are given in Fig. 2.9. These curves were computed from Equations 2.28 and 2.29 with $W_o = 156$.

8. The values of W_e for various values of R can be plotted on Fig. 2.5, and a curve drawn through the points (a convenient method when more than one value of the per cent probability is being found), and the value of R for the value of D_u can be read directly. A second method, when only one value of probability is to be found, is as follows:

   From Fig. 2.9, the value of W_e varies from a minimum of about 130 lbs. when the height of burst is 2 ft. to 450 lbs. when the height of burst is 30 ft. From Fig. 2.5, when $D_u = 143$, the value of the distance to the charge, R, is

$$R = 20.5 \text{ (when } W_e = 130)$$

$$R = 37 \text{ (when } W_e = 450)$$

From Fig. 2.9, an approximate value of $W_e = (W_e)_1$ for various heights of burst is:

R	H	$(W_e)_1$	$(R)_1$	$(W_e)_2$	$(R)_2 = R$
20.5	2	137	20.8	137	20.8
20.5	5	153	22.2	153	22.2
20.5	10	203	25.5	197	25.1
37	20	320	31.8	340	32.3
37	30	405	35.2	418	35.5

$(R)_1$ is obtained from Fig. 2.5 for the value $(W_e)_1$ and $D_u = 143$. $(W_e)_2$ is obtained from Fig. 2.9 for the values of H and $(R)_1$. $(R)_2$ is obtained from Fig. 2.5 for the value of $(W_e)_2$ and is a close approximation to the value of R.

9. The value of the radius for 95% probability of detonation, d, can be computed from

$$d = \sqrt{R^2 - H^2}\,.$$

H	R	R^2	H^2	R^2-H^2	d
2	20.8	433	4	429	20.7
5	22.2	493	25	468	21.6
10	25.1	630	100	530	23.0
20	32.3	1043	400	643	25.4
30	35.5	1260	900	360	19.0

The values of the radius of clearance, d, for the various per cent probabilities of detonation are shown graphically in Figs. 2.10 and 2.11. The circled points are observed per cent of mines detonated in actual tests*. In these tests, the number of mines for each radius was only 12 or 24, so that the observed per cent of mines detonated do not fall on smooth curves. The predicted and observed values are in very good agreement, both in the absolute values of the radii of clearance for various heights of burst and in the general shape of the curve for per cent probability as a function of horizontal distance to the charge.

As a further check on the formulae for the equivalent weight of charge and to further illustrate the use of the Universal scale, the

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*Reference 4.

radius of clearance for the 50% probability of detonation of several types of mines using different types of bombs (with different types of explosive) in different types of soil and depths of burial has been computed. The results of these computations are compared with the observed results obtained in field tests with bombs* in Table 2.1.

Since the references from which the observed results were obtained do not state in detail the nature of the soil, the values of the Soil Constant, D_o, (from Table 2.2) for the indicated type of soil were chosen as follows:

For dry clay the highest value	$D_o = 150$
For wet clay the normal value for mud	$D_o = 100$
For dry sand the highest value	$D_o = 100$
For wet sand the normal value for hard packed sand at the edge of the surf	$D_o = 70$
For very dry sand the lowest value	$D_o = 60$

In Table 2.1 when the radius of clearance, d_c, computed using these values of D_o did not check the observed radius, d_o, a second value of D_o was chosen, and a second radius computed. For example, with the AN MK 37, 650-lb. depth bomb detonated at a height of 2.5 ft. (nose approximately on the ground) tested with the Universal mines at 2 in. depth of burial, the table shows:

Dry Sand	$D_o = 100$	$d_c = 38.5$ ft.
Very Dry Sand	$D_o = 60$	$d_c = 33.0$ ft.
Observed Radius		$d_o = 35$ ft.

The true value of the Soil Constant in these tests probably was between the value 60 and 100 and is shown in that manner in the table. Out of 38 comparisons shown in the table, only one observed radius does not fall between the radii predicted using the high and low values of the Soil Constant.

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*References 4, 5.

This exception is the test with the AN M65,1000-lb. GP bomb (TNT) detonated at a height of 2.5 ft. (nose on the ground), where the observed radius was 34 ft. compared with a calculated radius of 36 ft. to 41 ft. Since this test was carried out under the same conditions as the other tests on the TMi-43, using the same type of bomb where the calculated and observed radii of clearance are in agreement, the error is probably due to a faulty bomb.

The comparison of the calculated and observed results for the effect of the shock impulse from bombs on anti-tank mines, which is discussed above and shown in Tables 2.1 and in Figs. 2.10 and 2.11 shows that the method of computations can predict the observed results within the experimental error.

TABLE 2.1*

Radius of Clearance for Bombs

Type of Bomb	Height of Burst (ft.)	Type of Mine	Depth of Burial (in.)	Type of Soil	Soil Constant D_o	Radius of Clearance d_c	d_o
AN MK 47 Depth Bomb 350 Lb. (Torpex)	2	TMi-43	4	Wet Clay	100	32.0	
	2	TMi-43	4	Dry Clay	150	36.8	--34.0
	10	TMi-43	4	Wet Clay	100	35.1	37
	10	TMi-43	4	Dry Clay	150	40.3	41
	2	J-16	0	Dry Sand	100	22.5	
	2	J-16	0	Very Dry Sand	60	19.0	--21
	2	Type 3	0	Dry Sand	100	14.5	15
AN MK 37 Depth Bomb 650 Lb. (TNT)	2.5	J-16	0	Dry Sand	100	26.5	27
	2.5	Universal	2	Dry Sand	100	38.5	
	2.5	Universal	2	Very Dry Sand	60	33.0	--35
	2.5	Universal	4	Wet Sand	70	30.5	31
	2.5	Universal	6	Dry Sand	100	30.5	30.5
AN M64 GP Bomb 500 Lb. (Tritonal)	2	Universal	2	Dry Sand	100	31.0	
	2	Universal	2	Very Dry Sand	60	26.0	--28.5
	2	J-16	0	Dry Sand	100	23.0	23
AN M64 GP Bomb 500 Lb. (TNT)	2	TMi-43	4	Wet Clay	100	26.0	
	2	TMi-43	4	Dry Clay	150	30.2	--28
	10	TMi-43	4	Dry Clay	150	34.4	34

(Continued)

*Definition of symbols at end of table

TABLE 2.1*(Continued)

Radius of Clearance for Bombs

Type of Bomb	Height of Burst (ft.)	Type of Mine	Depth of Burial (in.)	Type of Soil	Soil Constant D_o	Radius of Clearance	
						d_c	d_o
AN M64 GP Bomb 500 Lb. (Comp.B)	2	TMi-43	4	Wet Clay	100	29.0	
	2	TMi-43	4	Dry Clay	150	33.3	--30
	10	TMi-43	4	Dry Clay	150	35.5	36
AN M65 GP Bomb 1000 Lb. (TNT)	2.5	TMi-43	4	Wet Clay	100	36.0	
	2.5	TMi-43	4	Dry Clay	150	41.0	--34
	5	TMi-43	4	Wet Clay	100	36.4	
	5	TMi-43	4	Dry Clay	150	41.7	--38.5
	15	TMi-43	4	Dry Clay	150	46.5	47
	23	TMi-43	4	Wet Clay	100	43.0	43
	3.5	J-16	0	Dry Sand	100	25.5	26
AN M65 GP Bomb 1000 Lb. (Comp. B)	15	TMi-43	4	Wet Clay	100	44.0	
	15	TMi-43	4	Dry Clay	150	50.3	--48.5
AN M66 GP Bomb 2000 Lb. (TNT)	18	TMi-43	4	Dry Clay	150	62	62
	25	TMi-43	4	Wet Clay	100	56	
	25	TMi-43	4	Dry Clay	150	65	----59
	4	Universal	4	Very Dry Sand	60	38.5	38

* d_c computed and d_o observed for 50 per cent probability of detonation
Soil constant values are chosen for above table from Table 2.2

TABLE 2.2

Point Charge Formula Soil Constant

Type Soil	Moisture	Compactness	Depth	D_o
Sand	Wet	Hard Packed	2"	70
Sand	Moist	Loose	0 - 6"	110
Sand	Dry	Loose	0 - 6"	100
Sand	Very Dry	Loose	0 - 6"	60
Sandy Clay	Dry	Weathered	0 - 6"	150
Sandy Clay	Dry	Loose above Mines Solid below Mines	0 - 6"	130
Sandy Clay	Dry	Loose above and below Mines	0 - 4"	100
Sandy Clay	Moist	Solid below Mines	0 - 6"	130
Sandy Clay	Wet	Muddy	0 - 6"	100
Sandy Clay	Wet	0 - 2" Frost	0"	100 - 130
Sandy Clay	Wet	0 - 2" Frost	2"	80
Sandy Clay	Wet	2 - 4" Frost	0"	100 - 130
Sandy Clay	Wet	2 - 4" Frost	2"	80
Sandy Clay	Wet	2 - 4" Frost	4"	60
Loose Sand* and Caliche	Dry	Hard below Loose Above	0"	112

*Nevada Test Site, October, 1951

TABLE 2.3

Mine Calibration Constants

Mine	D_a	α_m	Δ	r		% Probability of Detonation (%P)						
						10	25	50	75	90	95	99
Dutch	30	10	0.33	1.75	M_p =	0.46	0.70	1.00	1.35	1.76	2.06	2.86
					D_c =	14	21	30	40	53	62	85
Ger.TMi-42	60	9	0.15	0.80	M_p =	0.69	0.82	1.00	1.24	1.54	1.76	2.40
					D_c =	41	49	60	74	92	106	144
Fr. Light	65	5	0.08	0.40	M_p =	0.74	0.85	1.00	1.21	1.48	1.68	2.30
					D_c =	48	55	65	79	96	109	150
Ger.TMi-43	75	8.5	0.11	0.60	M_p =	0.72	0.84	1.00	1.22	1.50	1.71	2.34
					D_c =	54	63	75	91	112	128	175
Jap. J-93	90	18	0.20	1.05	M_p =	0.63	0.79	1.00	1.27	1.58	1.83	2.50
					D_c =	57	71	90	114	142	165	225
Jap. Yard (one fuze)	300	60	0.20	1.05	M_p =	0.63	0.79	1.00	1.27	1.58	1.83	2.50
					D_c =	189	237	300	381	474	549	750
Jap J-16	700	280	0.40	2.10	M_p =	0.36	0.65	1.00	1.40	1.85	2.19	3.05
					D_c =	252	455	700	979	1300	1530	2130

D_a = Mean calibration value for mine (Indicator reading for a 50% probability of detonation)
α_m = Mean deviation in the value of D_a. $\Delta = \alpha_m/D_a$.
r = $\Delta/\delta = \Delta/0.19$ ($\delta = \alpha/D$, where α = mean deviation in the mean reading D on indicator mine)
M_p = Amount D_a is multiplied to give D_c for the given %P (obtained from Figure 2.2)
D_c = Mean reading on the Universal scale which corresponds to the given %P

TABLE 2.4

Effective Weight of Charge for Bombs*

	AN MK 47 350 Lb. Depth Bomb		AN MK 37 650 Lb. Depth Bomb
	H = 2	H = 10	H = 2.5
R	W_e	W_e	W_e
10	191	303	277
20	199	277	290
30	201	269	295
40	203	266	297

	AN M64 500 Lb. GP Bomb					
	258 Lbs. TNT		275 Lbs. Comp. B		285 Lbs. Tritonal	
	H = 2	H = 10	H = 2	H = 10	H = 2	H = 10
R	W_e	W_e	W_e	W_e	W_e	W_e
10	129	222	155	256	168	278
20	134	197	161	230	175	250
30	136	190	163	222	177	241
40	137	187	164	220	178	239

	AN M65 1000 Lb. GP Bomb						
	558 Lbs. TNT					595 Lbs. Comp. B	
	H = 2.5	H = 5	H = 15		H = 23		H = 15
R	W_e	W_e	W_e	R	W_e	R	W_e
10	252	277				15	594
20	264	284	471	23	810	20	550
30	266	286	434	30	695	30	510
40	268	287	415	40	555	40	494

	AN M66 2000 Lb. GP Bomb		
	H = 4	H = 18	H = 25
R	W_e	W_e	W_e
30	570	905	1310
40	573	866	1180
50	577	845	1110
60	578	834	1060

* The effective weight of charge is the weight, W_e, (lbs.) of a cylinder of bare TNT detonated at a height, $H_e = W_e^{1/3}$, which gives the same effect on a mine at a distance, R, (ft.) from the center of the charge to the mine as does a bomb detonated at a height, H, (ft.) above the ground at a distance, R, from the center of the bomb to the mine. $R^2 = H^2 - d^2$ where d is the horizontal radius of clearance.

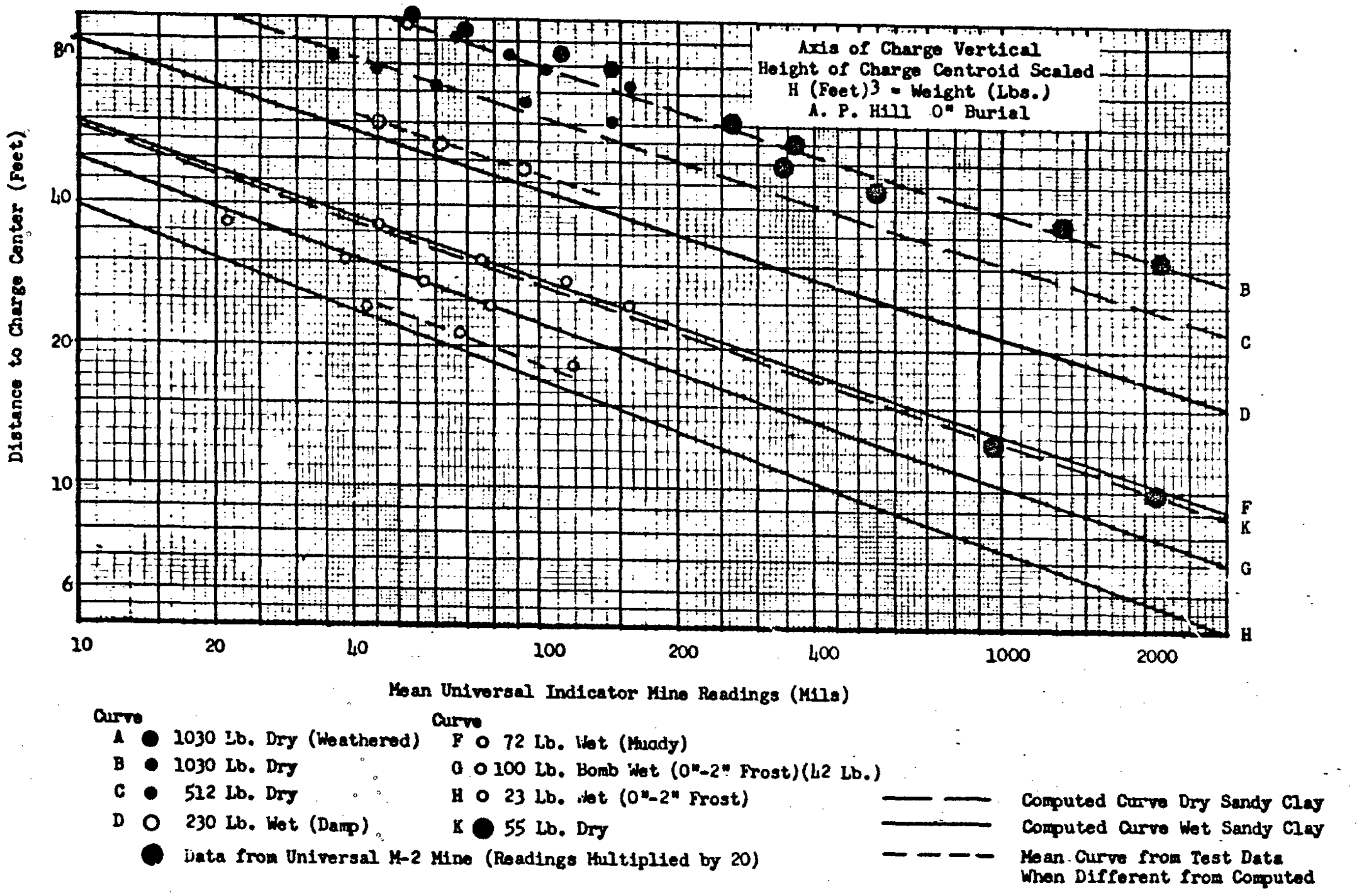

Figure 2.1 Universal Indicator Mine Effect of Point Charges

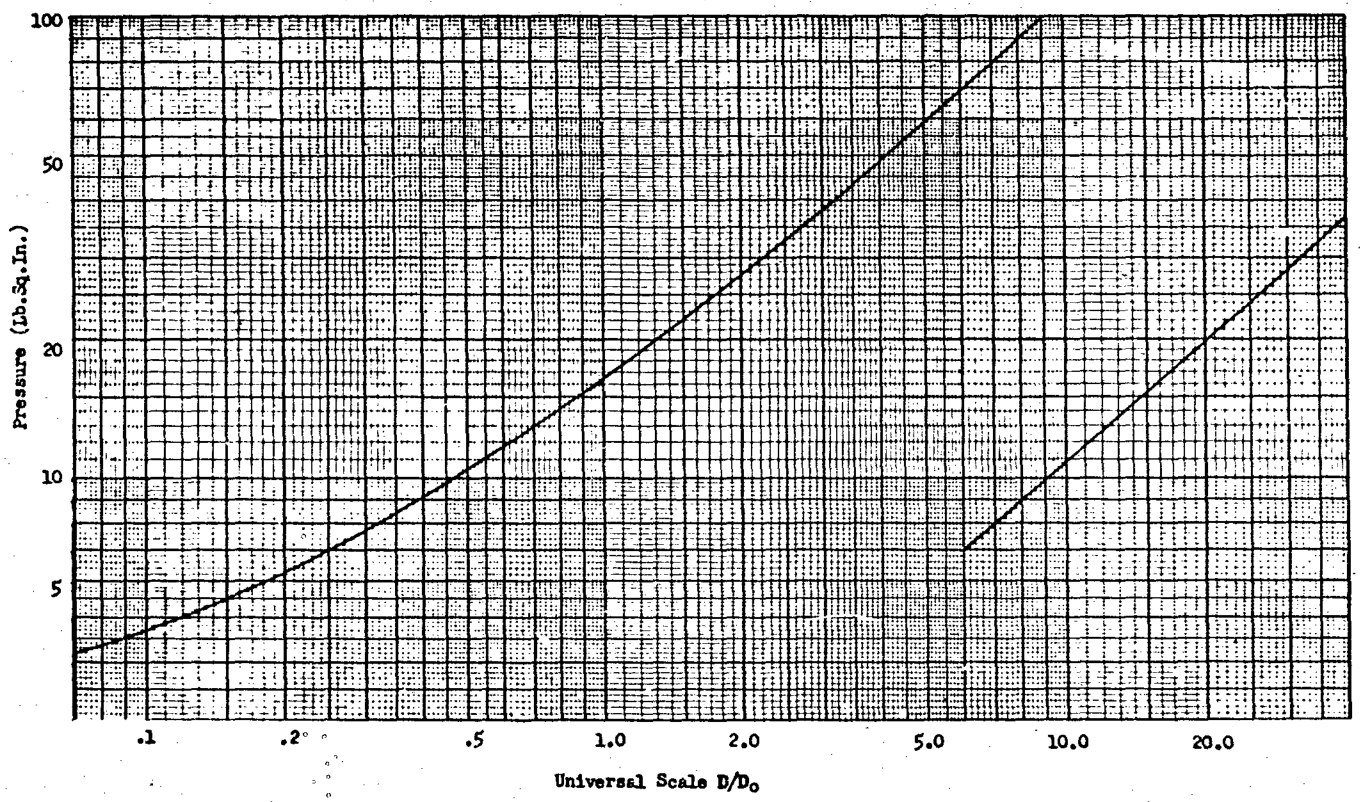

Figure 2.2 Universal Indicator Pressure Calibration

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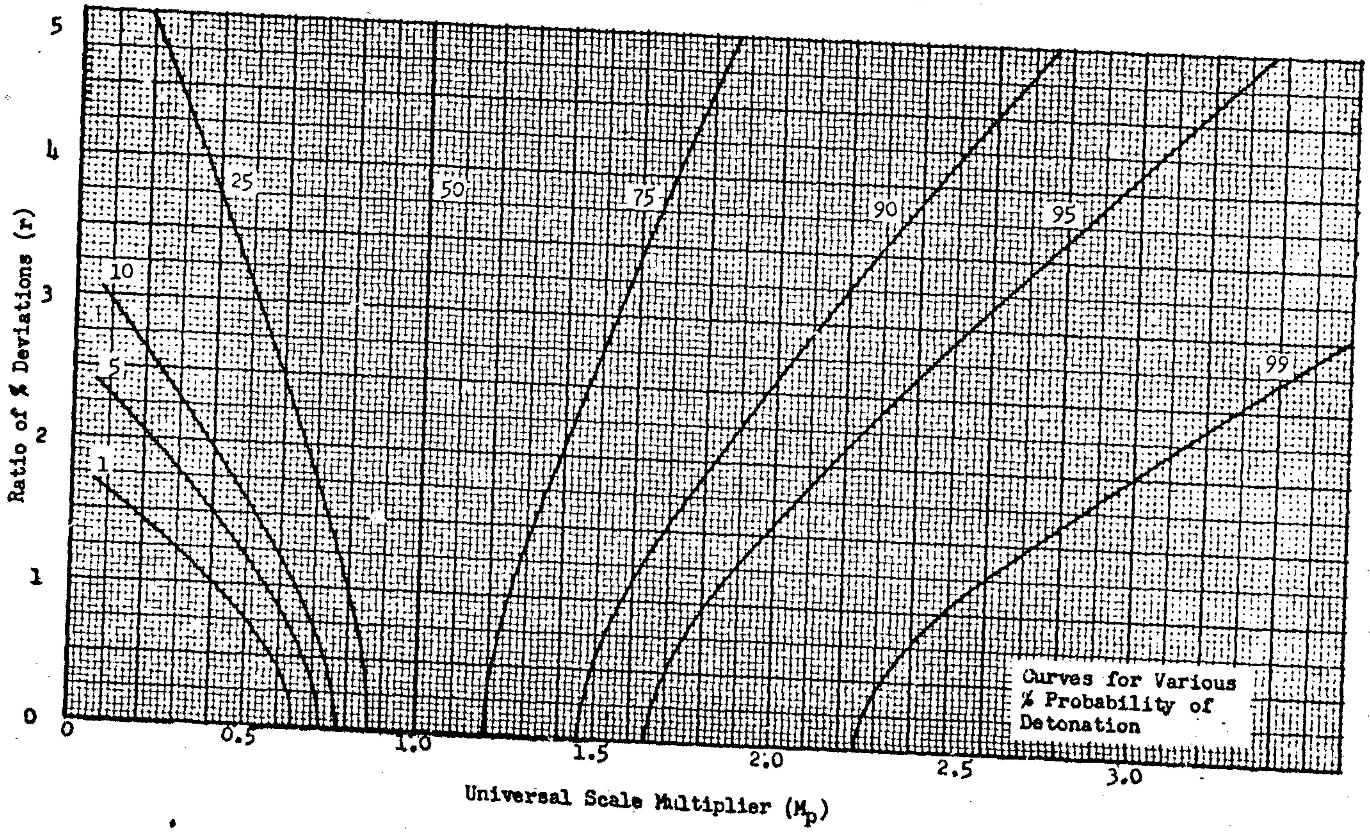


Figure 2.3 Probability Multiplier Graph

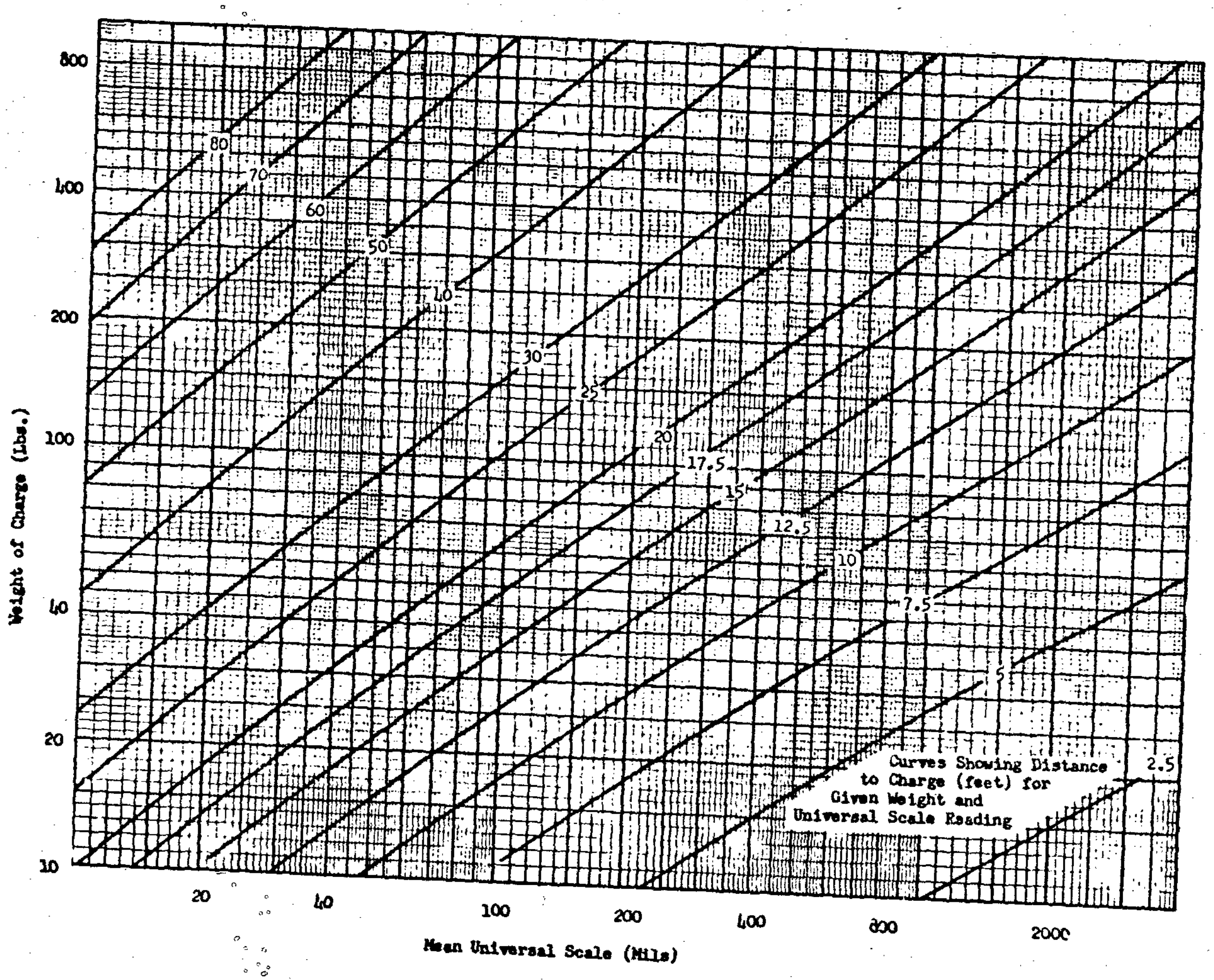


Figure 2.4 Radius of Clearance 2" Burial

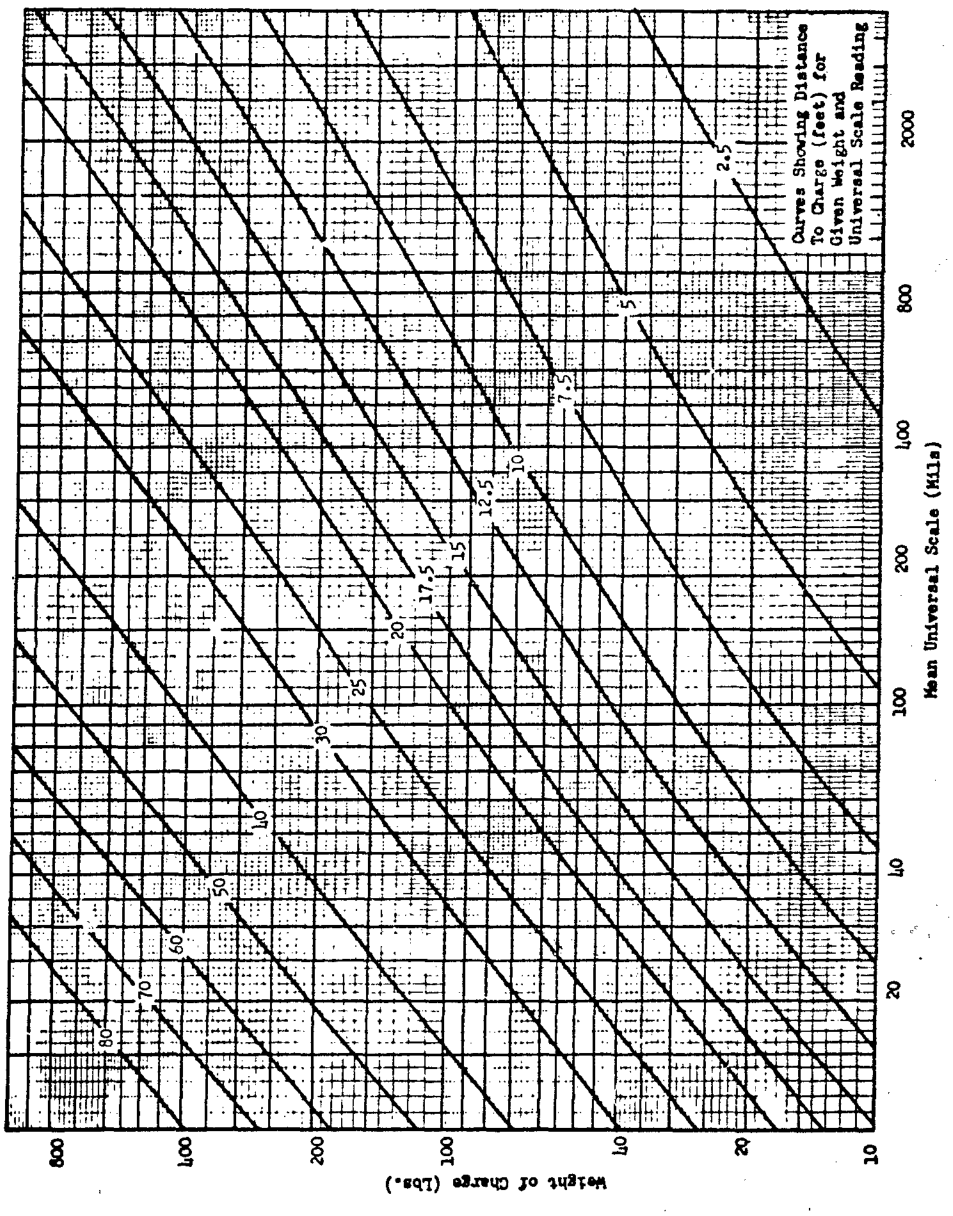


Figure 2.5 Radius of Clearance 4" Burial

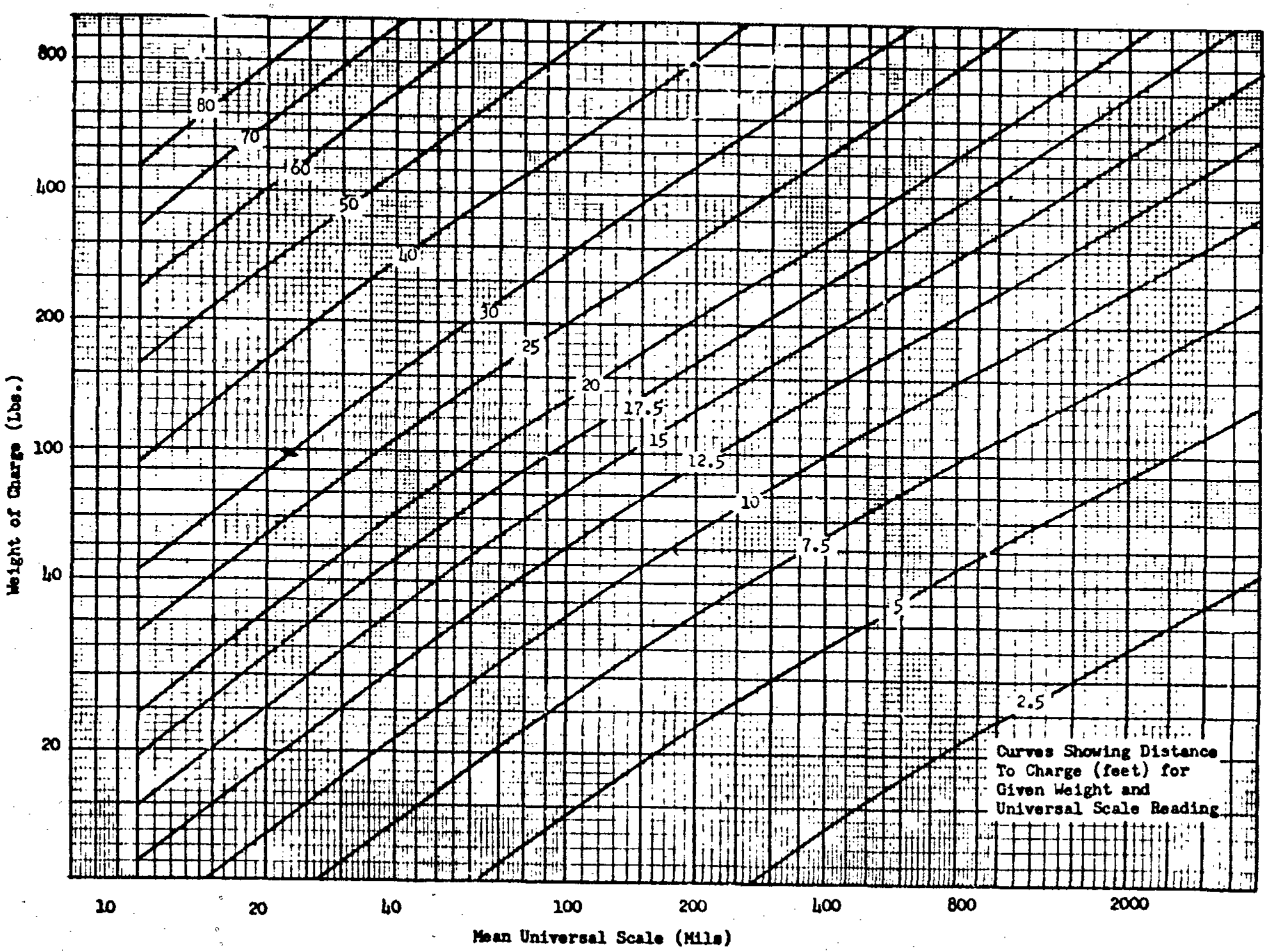


Figure 2.6 Radius of Clearance 6" Burial

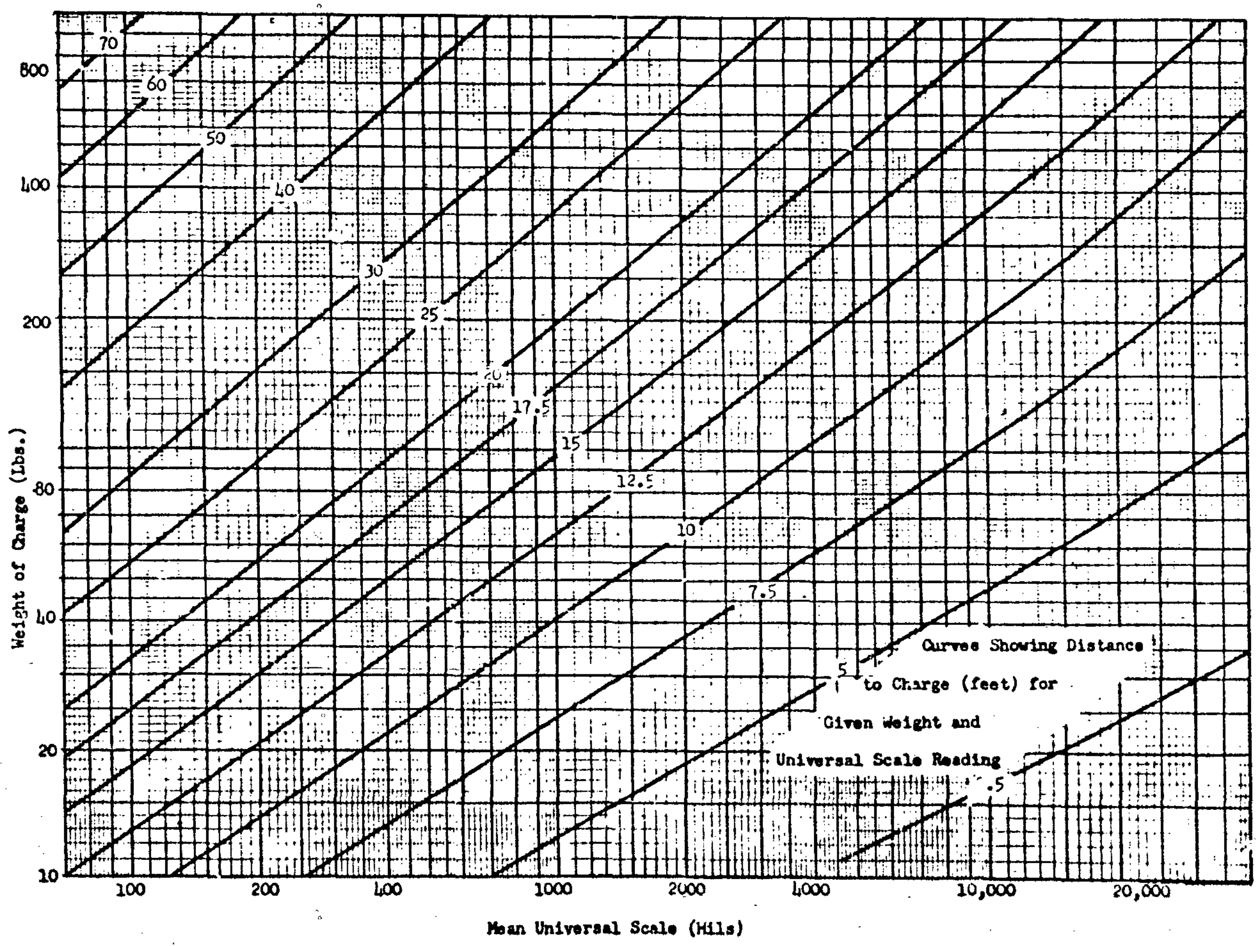


Figure 2.7 Radius of Clearance 0" Burial

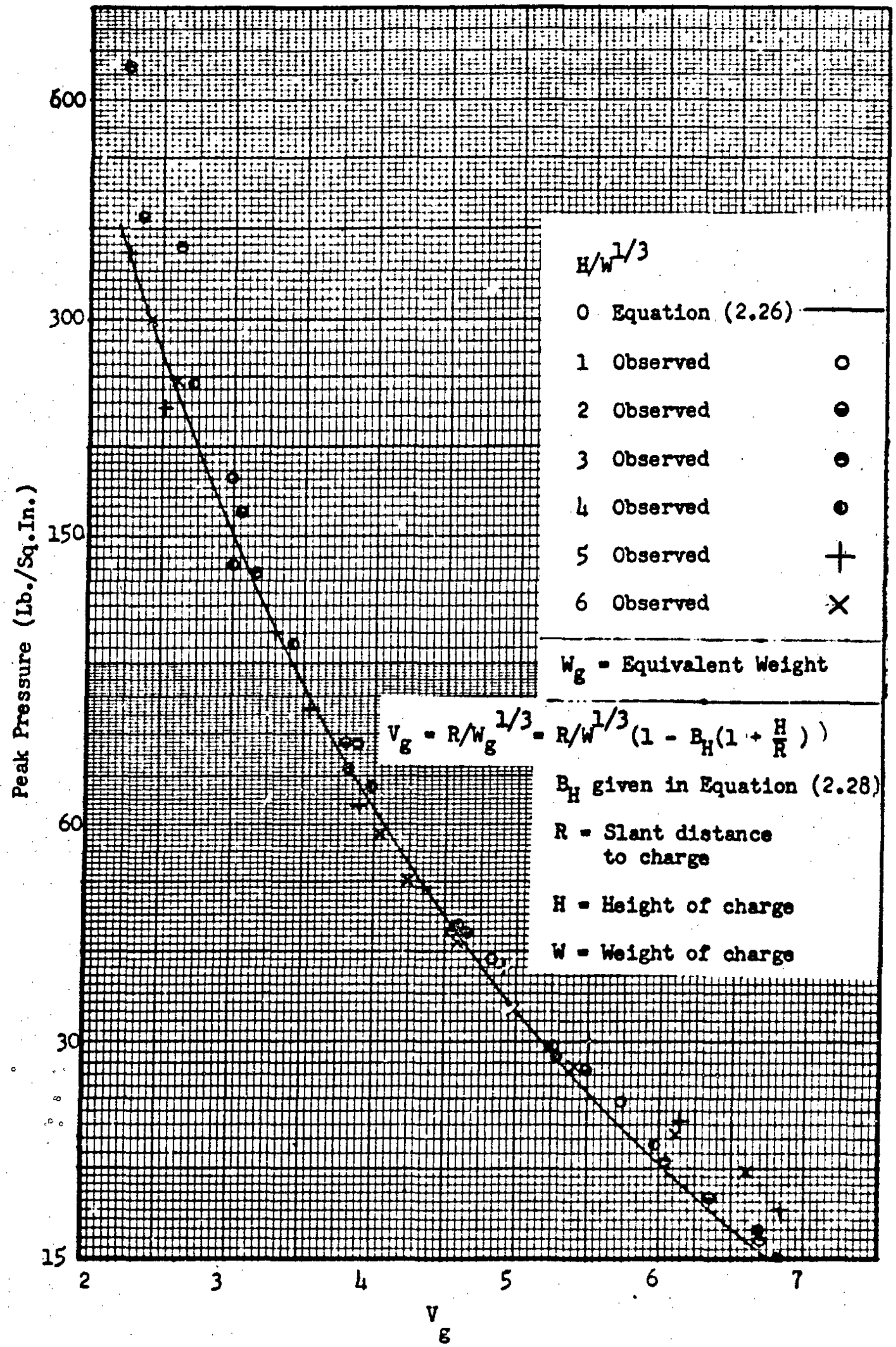


Figure 2.8 Peak Pressure for Airburst

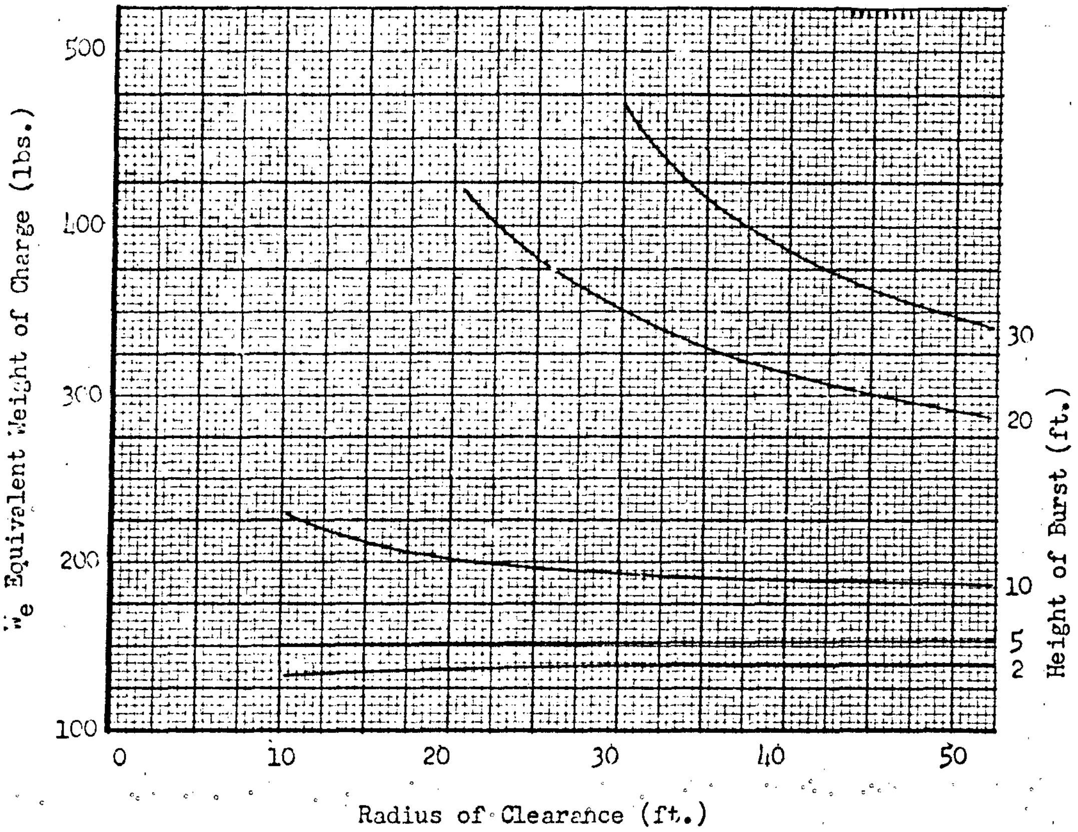


Figure 2.9 Equivalent Weight for Airburst MK 17 Depth Bomb

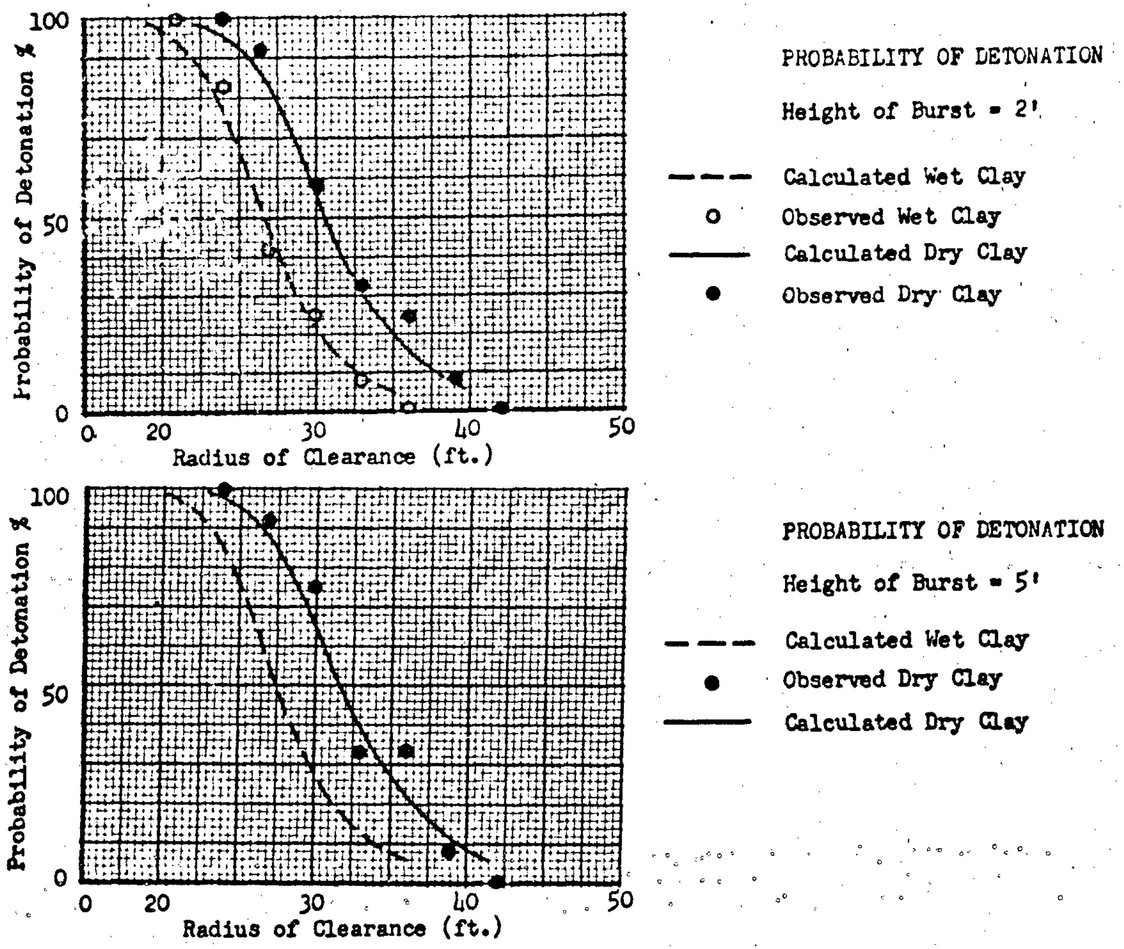


Figure 2.10 German TMI-43 and Mark 17 Depth Bomb

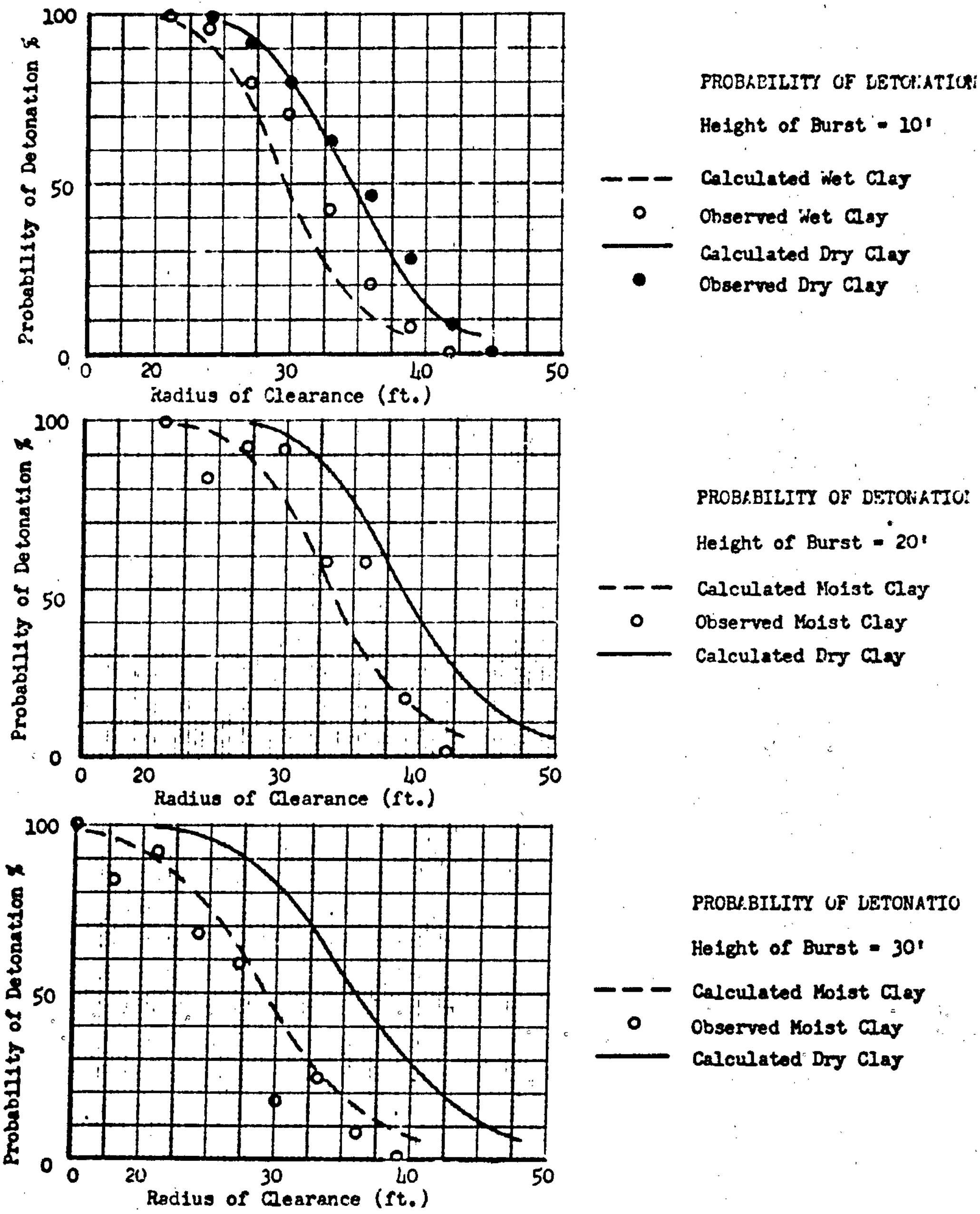


Figure 2.11 German TMI-43 and Mark 17 Depth Bomb

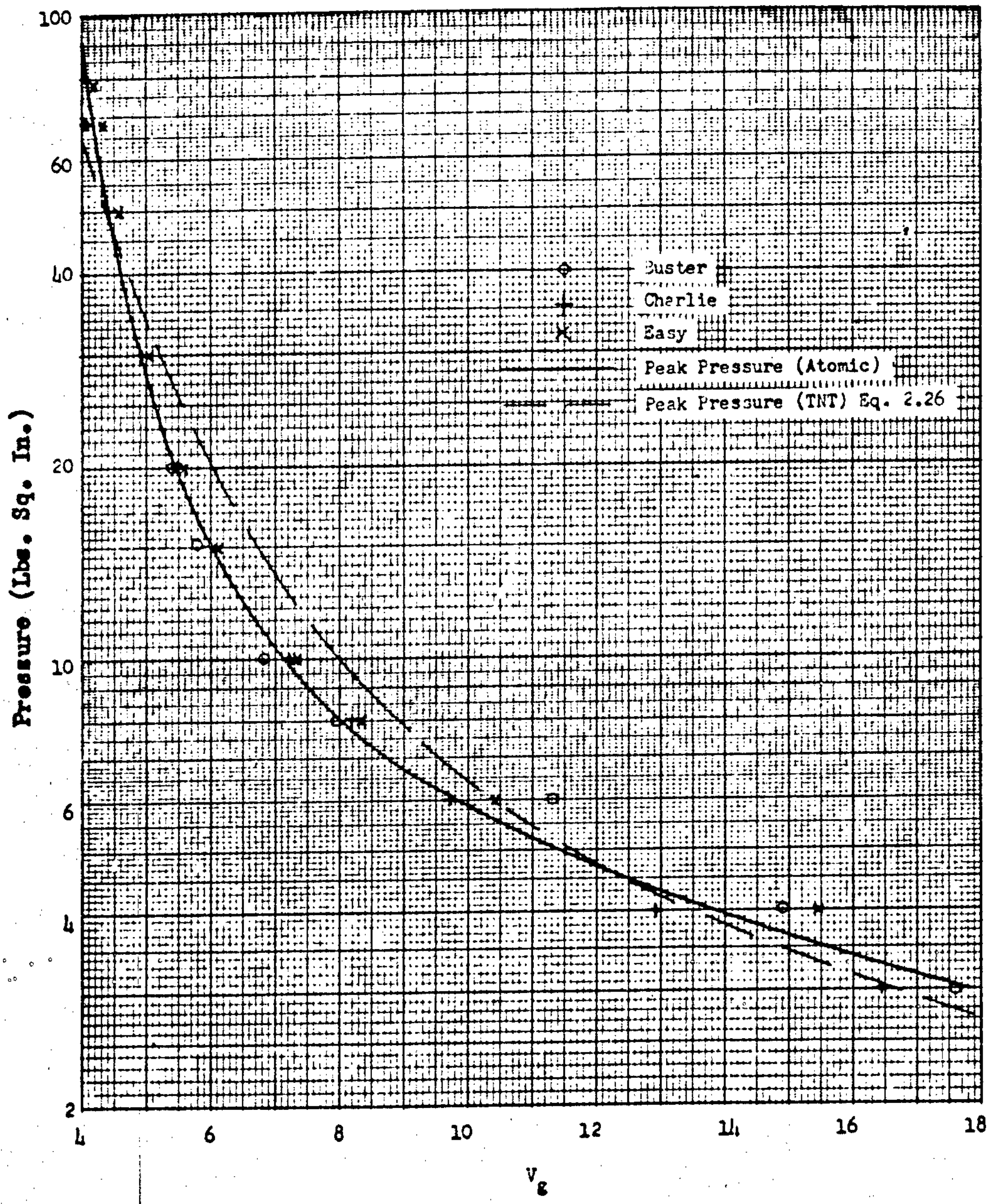
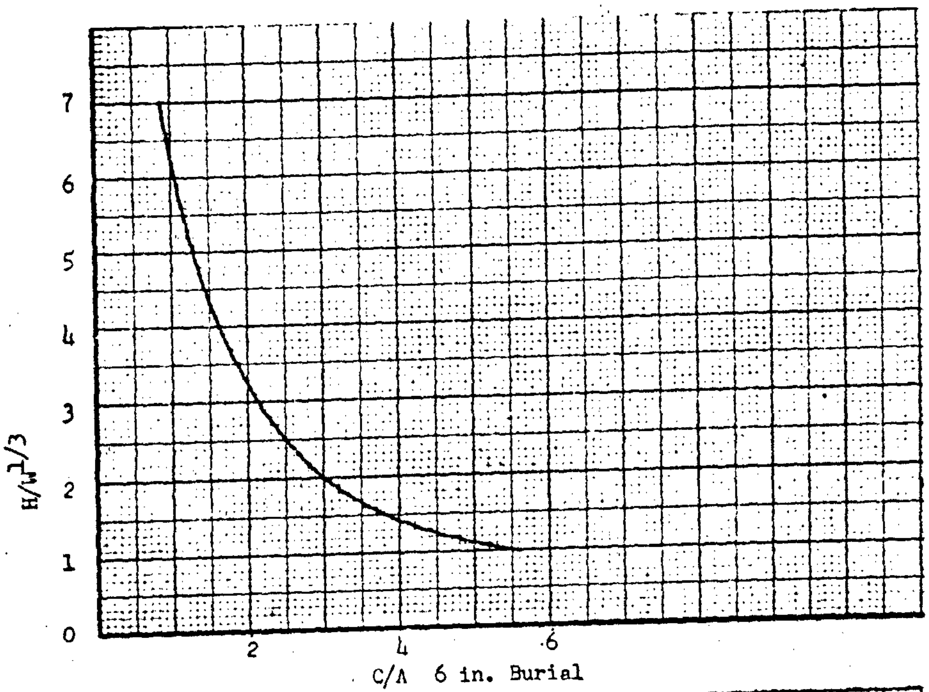


Figure 2.12 Peak Pressure for Atomic Explosions



6 in. Burial

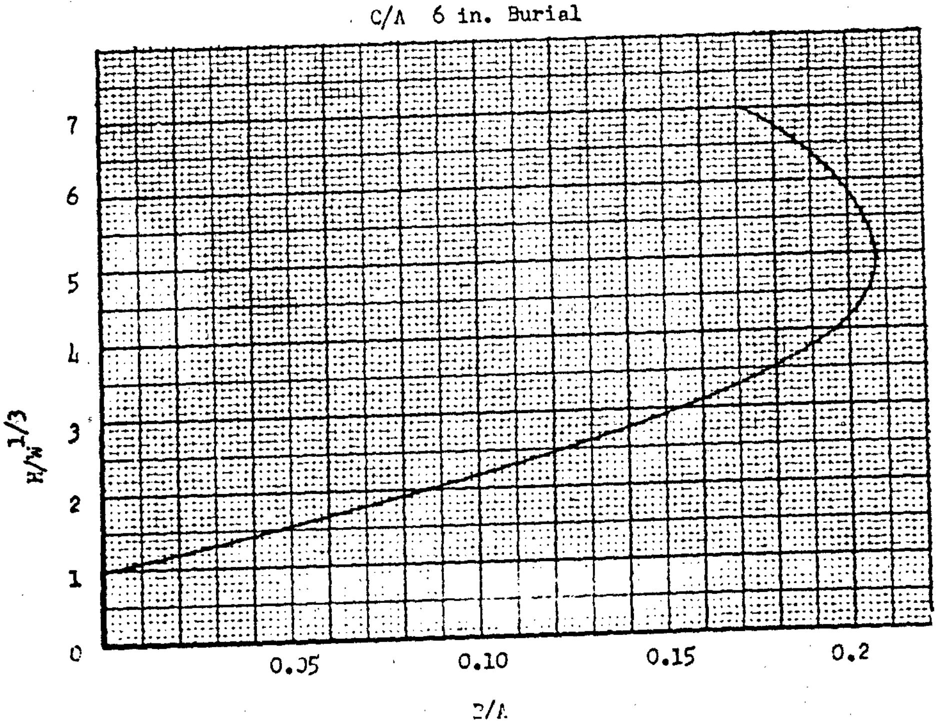


Figure 2.13 Height Weight Coefficients

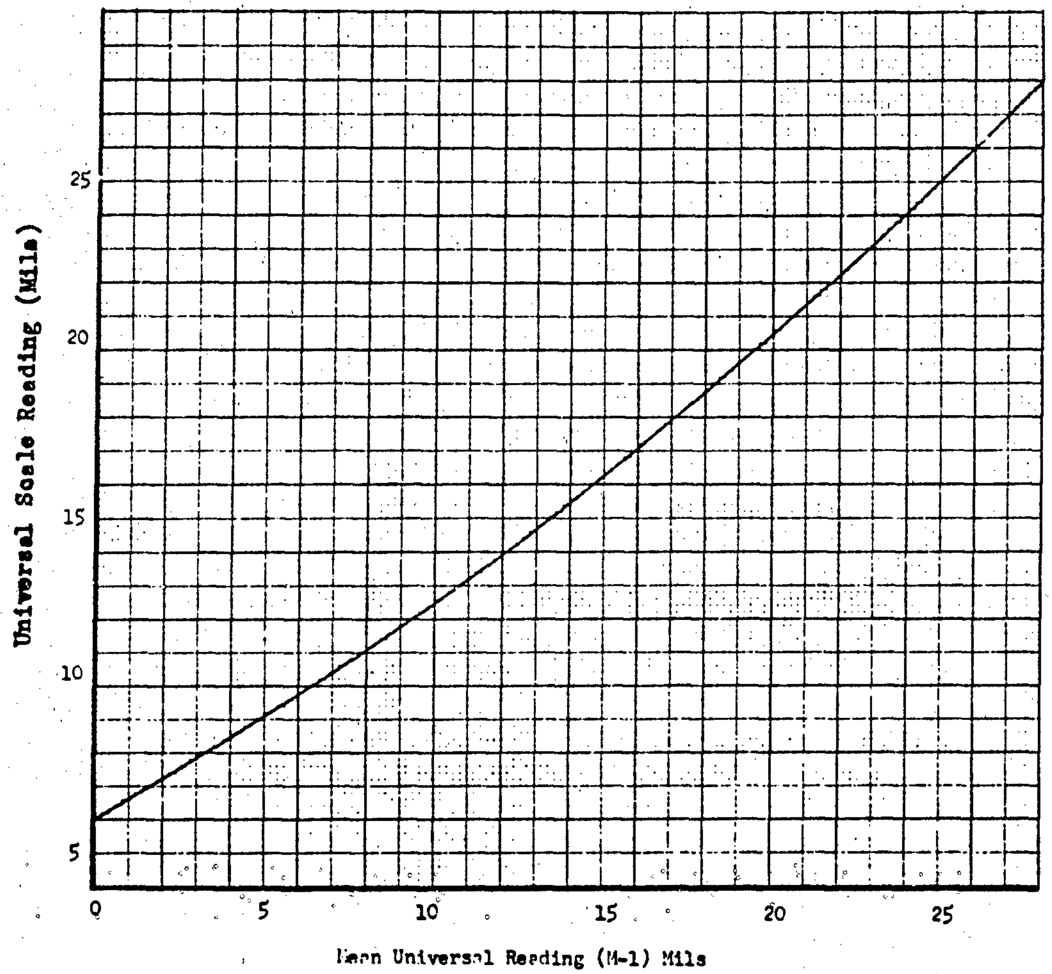


Figure 2.14 Universal Indicator Scale Corrections

CHAPTER 3

INSTRUMENTATION AND FIELD OPERATION

3.1 LAYOUT OF MINEFIELD

The Universal indicator mine was chosen as the most suitable device for studying the effects of atomic explosions for minefield clearance. The principles of operation of this indicator are discussed in Section 2.1 and Appendix A. There were 1600 Universal indicator mines, 1000 M-1 (large diameter) and 1000 M-2 (small diameter) pressure plates available for the tests.

A path 65 ft. wide was bulldozed on a line beginning at Point 3, Target Area 7, and extending 6000 ft. east. An elevation profile along the centerline of this path is shown on Fig. 3.2. The minefield pattern used is shown on Fig. 3.1. At each panel position A to T, 20 mines were placed using two rows of 10 mines and 5-ft. spacing between mines. The rows were placed at right angles to the profile line using 6 in. level burial for the mines in the row closest to Point 3, and 0 in. burial for the other row. (See Methods of Setting Out Mines, Fig. B.1.) Ten mines using 6 in. burial were used for panels TE to SE only for shot Easy. After each shot new fuzes and pressure plates were installed on the effected mines, and the exposed fuzes were returned to the laboratory for measurement.

No serious difficulties were experienced in placing or recovering the mines, and readings were obtained for shots Baker, Charlie, Dog and Easy. The detailed data and calculations for analyzing the results are in Appendix C.

3.2 CALIBRATION PROGRAMS

In order to adequately interpret the data with the indicator mine, it is necessary to know the soil constant. A calibration shot was taken at a point 5100 ft. east of Point 3 using the minefield pattern shown on Fig. 3.3. The results obtained were very good (details in Appendix C) and are shown graphically on Fig. 3.4. The value of the soil constant is 113.

Observations made during Operation BUSTER indicated that further data were needed as to the effect of tilt on indicator mines and about the behavior of the mines with very low indicator readings. A calibration program was conducted at Ft. Belvoir to determine these effects. The results obtained are shown in detail in Appendix B and are summarized on Fig. 3.5.

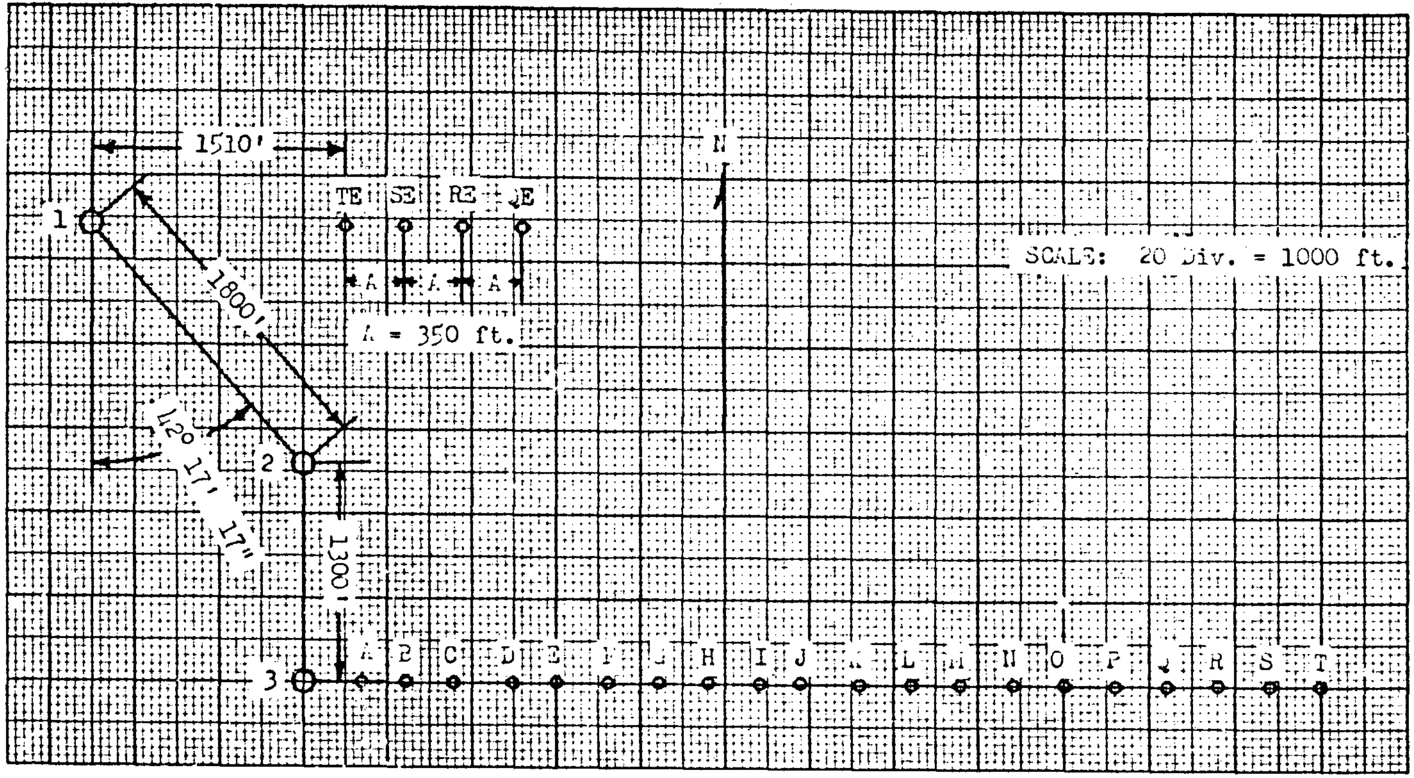


Figure 3.1 Blast Effects Line Layout

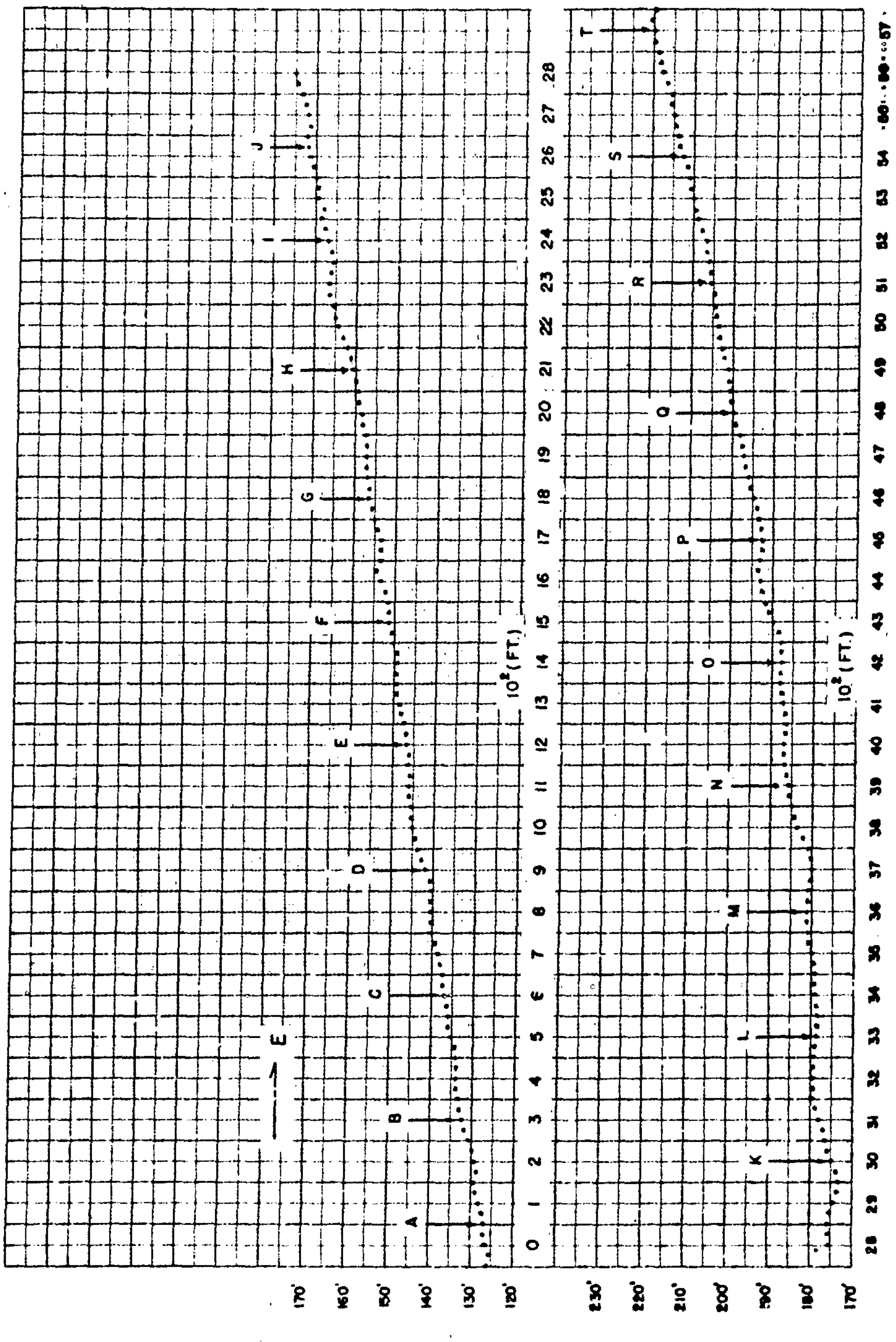
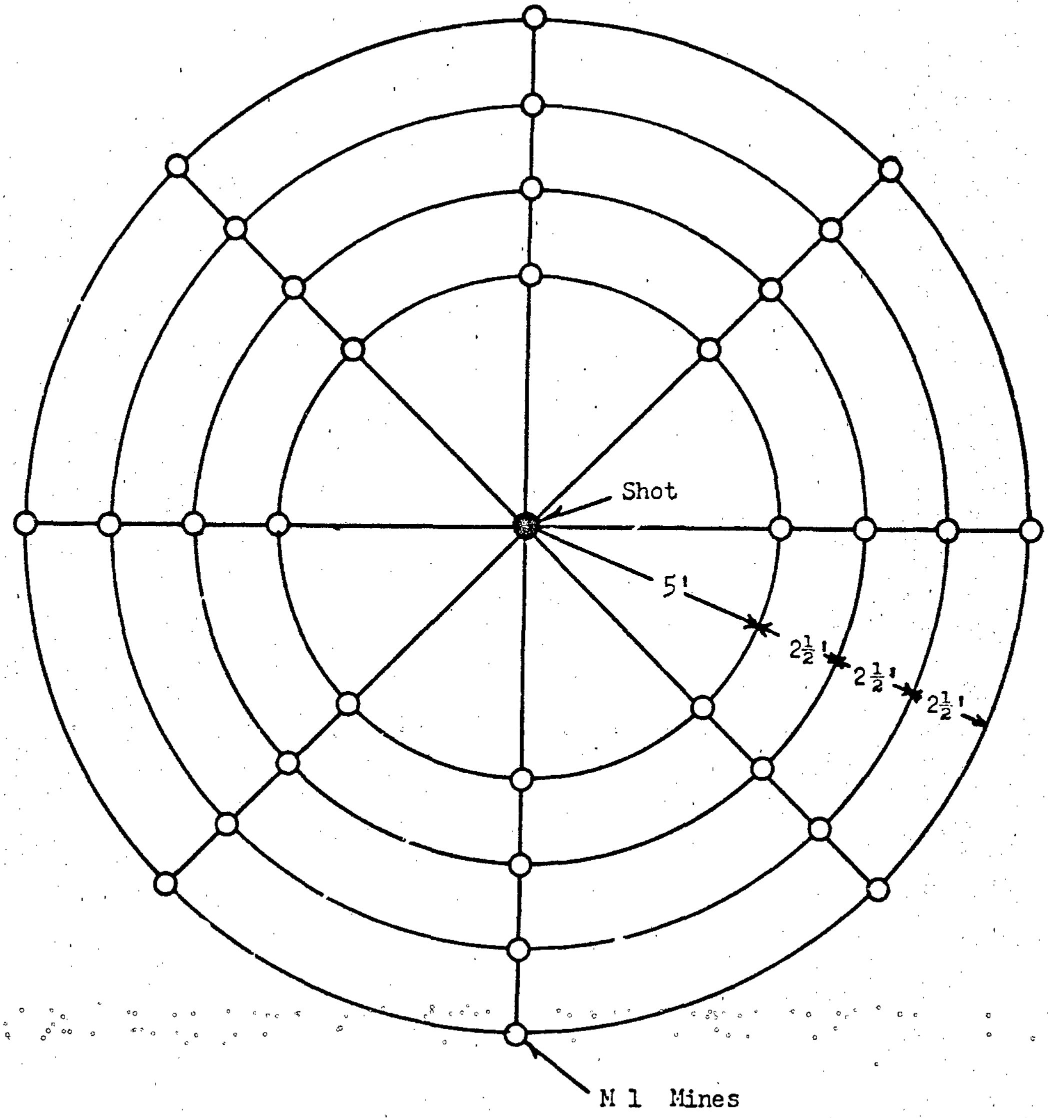


Figure 3.2 Elevation Profile Along Centerline of Mine Field



Shotpoint 5100' E Station 3

5.25 lb TNT at H = 1.74 ft

October 12, 1951

Figure 3.3 Calibration Pattern

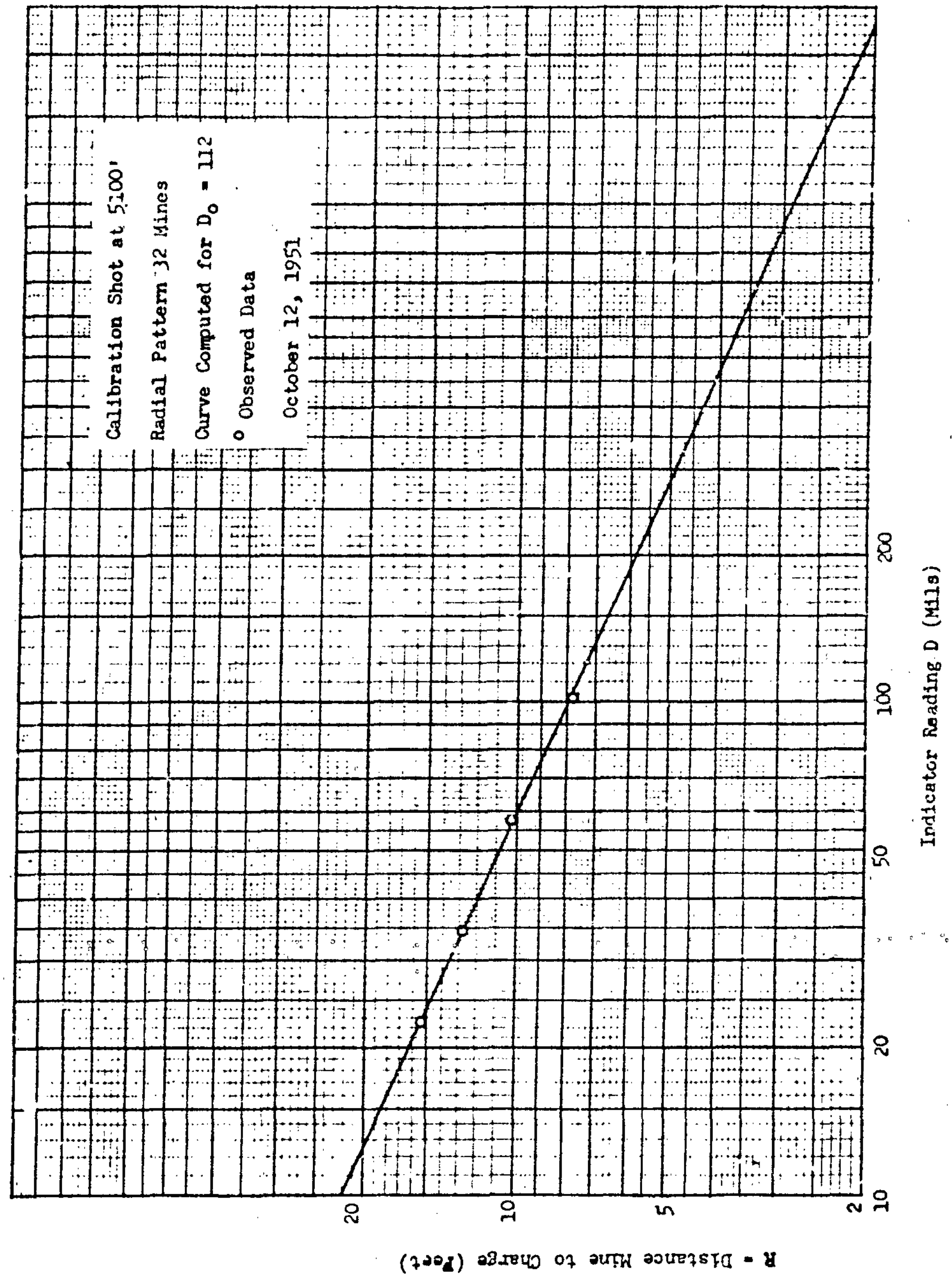


Figure 3.4 Calibration Data Nevada Test Site

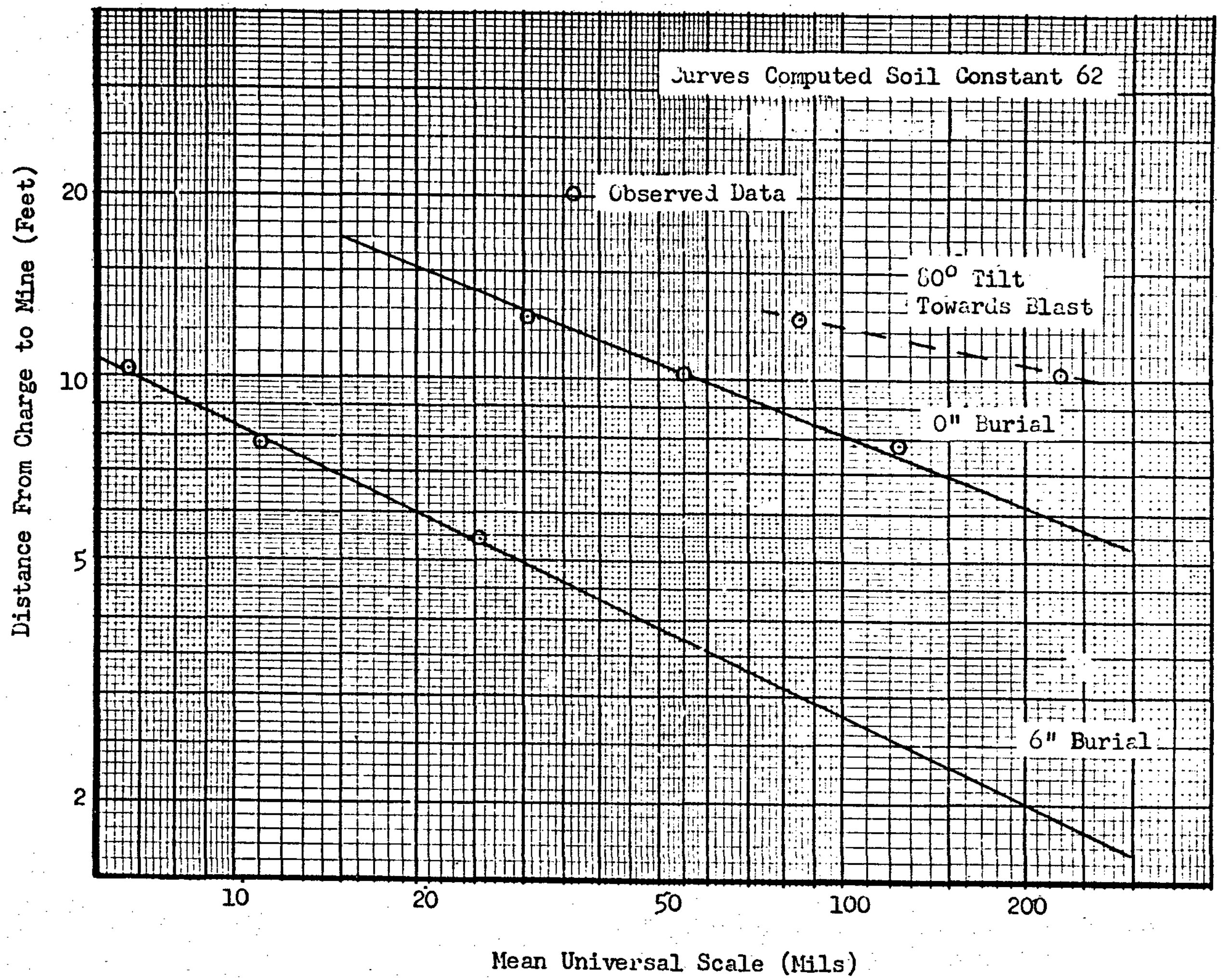


Figure 3.5 Calibration Data Fort Belvoir, Virginia

CHAPTER 4

ANALYSIS OF DATA

4.1 GENERAL

The pressure data for Operation BUSTER have been analyzed in Section 2.5 and scaling laws for indicator mine behavior when subject to blast for atomic weapons have been worked out. (Section 2.5.2.) Since these scaling laws are empirical, they are subject to revision as more data become available. The data obtained in Operation BUSTER show that the scaling law for depth of burial (the constant C in Equation 2.45 given by Equation 2.6), which applies for TNT yields of 10,000 lbs. or less, does not apply for Atomic Bombs. The value from Equation 2.6 for 6 in. depth of burial is about right, but the value for 0 in. burial is incorrect. There are insufficient data to determine the proper value for 0 in. burial so that all conclusions in this report are based on the data obtained with mines at 6 in. burial.

4.2 RADIUS OF CLEARANCE FOR MINES

The method for computing the probability of detonation for other types of mines from the Universal indicator readings is shown in Section 2.3. The indicator readings for Operation BUSTER are shown on Fig. 4.1. (The data obtained for Easy plot off scale on this graph because no mine was close enough to ground zero.) To find the radius of clearance for mines, compute the value of the indicator reading, D_b, which corresponds to the given probability of detonation as outlined in Section 2.3, divide D_b by the soil constant (varied from 60 to 112 at Nevada Test Site) and read the radius of clearance on Fig. 4.1. Considering the German TMi-43 mine, the radius for 99% probability for each shot is

Constants	Shot	Radius for 99% Prob.
$D_b = 175$	Baker	none
$D_o = 100$	Charlie	690 ft.
	Dog	620 ft.
	Easy	<1700 ft.

Thus, airburst atomic weapons where $H/Wt^{1/3}$ is greater than three are poor mine-clearing devices.

4.3 YIELD OF ATOMIC EXPLOSIONS

The data obtained in Operation BUSTER have been analyzed in

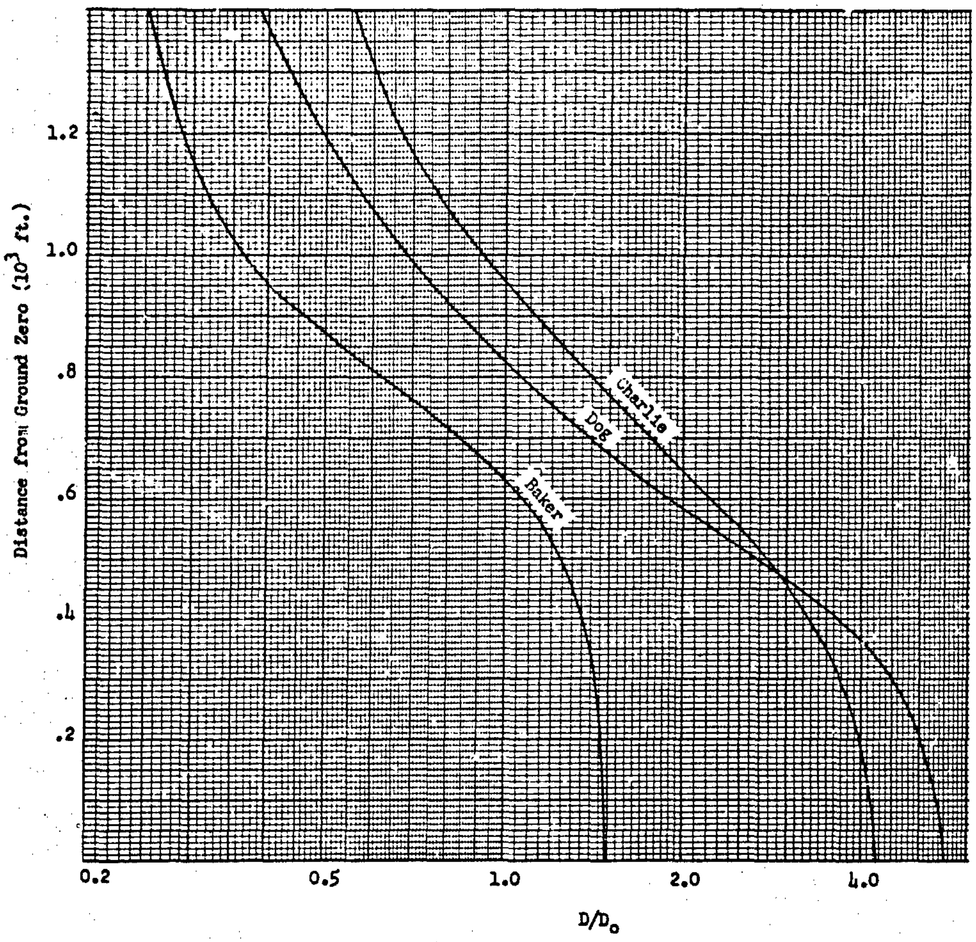


Figure 4.1 Indicator Readings Operation BUSTER

Appendix C by the method of Section 2.5.3 and the yields have been determined for shots Baker, Charlie, Dog and Easy. The results are shown graphically on Figs. 4.2 to 4.5. It will be noted in these figures that the observed values on the indicator scale are very low for all shots with a minimum at a distance from ground zero about equal to the height of burst where $R/H - 0.2 = 1.2$. This is called a skip effect and is the reason for the small radii of clearance noted above. The estimate of yield is obtained by ignoring the skip effect and drawing the line for determining C/A through the indicator readings that are maximum. A comparison of the yield as determined by indicator mines and that given in the Report for Operation BUSTER is as follows:

Shot	Yield Computed	Yield Stated
Baker	3.1	3.47
Charlie	16.1	14.1
Dog	24.8	20.9
Easy	34.5	31.25

The good agreement indicates that the scaling laws derived in Chapter 2 are approximately correct.

4.4 INDICATOR MINES AS PRESSURE GAGES

An empirical scaling law for peak-pressure as derived in Section 2.5 allows the pressure to be determined for any yield, height of burst and distance from ground zero. In applying this law, it is necessary to compute the value of the scaled $R/W_g^{1/3} = V_3$ where W_g is the equivalent weight of TNT. This was done for each panel position in the shots Baker, Charlie, Dog and Easy and the peak pressures were determined from Fig. 2.12.

The detailed computations are shown in Tables C.6 and C.7. These peak pressures were then plotted as a function of D/D_o (where D is the observed indicator reading and D_o is the soil constant) on Fig. 4.6. The solid curve, on Fig. 11, is the curve used for TNT peak-pressure measurements. The indicator readings in the skip zone have not been used as they are abnormally low. It may be seen that there is a fair agreement between the indicator readings and peak pressure. The relative readings on a single shot appear to be quite good.

In the calibration program at Ft. Belvoir indicator mines were placed with the normal of the pressure plate pointing toward the shot and the mine above the ground with solid sand-bag backing (see Fig. B.1). These mines gave considerably higher readings than mines buried with the pressure plate flush with the surface of the ground (see Fig. 3.5) and may be the proper way to use indicator mines as pressure gages and avoid the skip effect.

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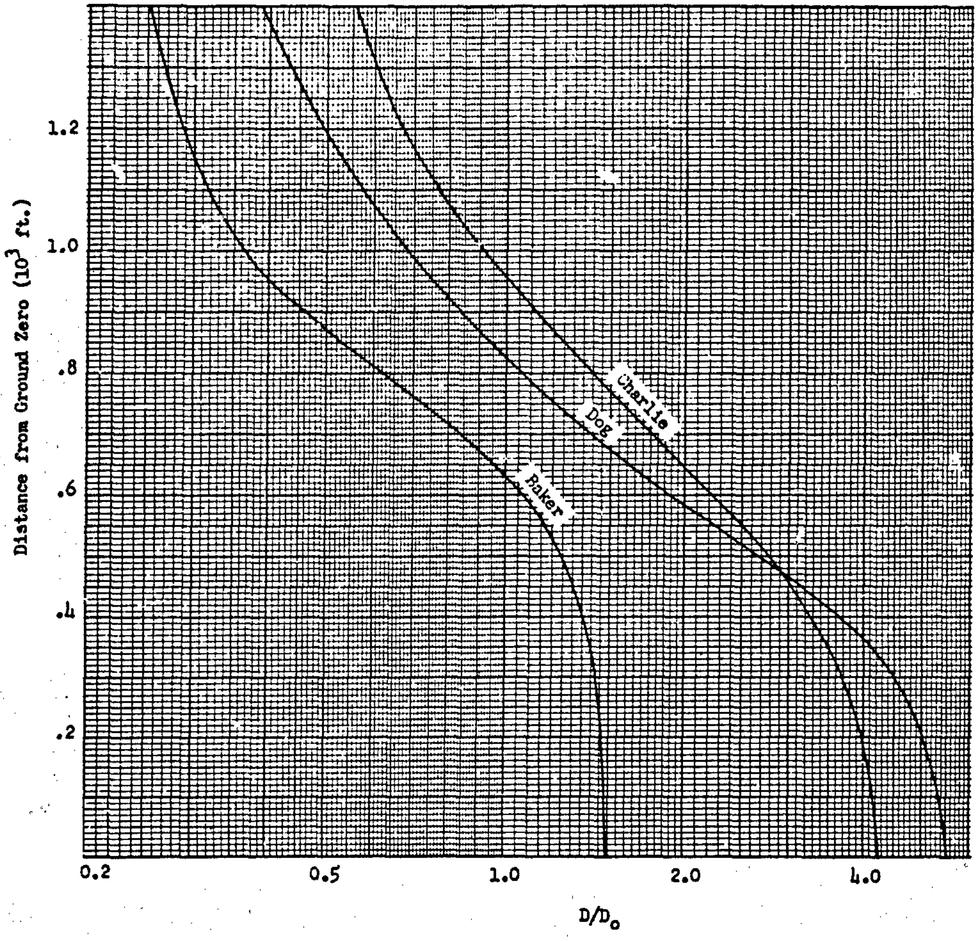

Figure 4.1 Indicator Readings Operation BUSTER

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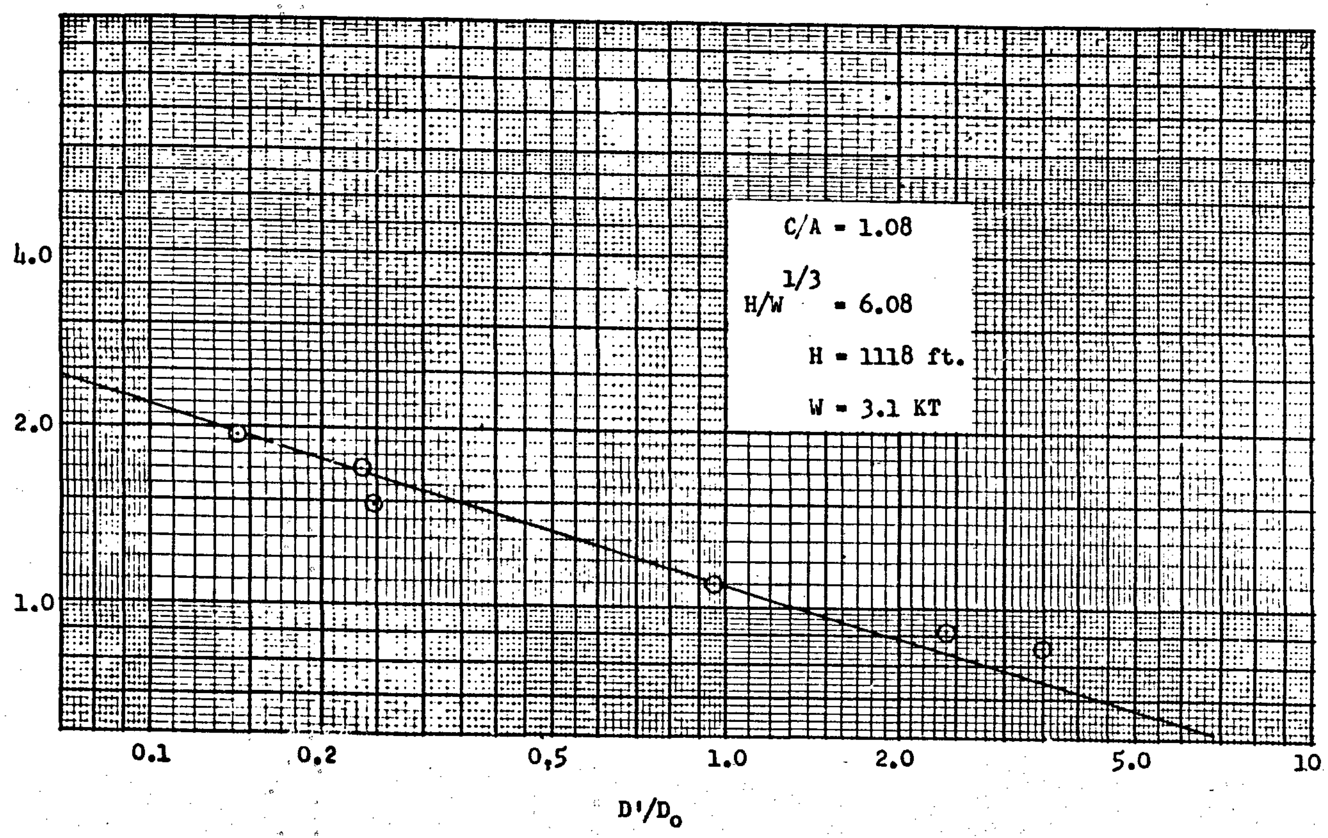

Figure 4.2 Equivalent Weight of Charge Baker

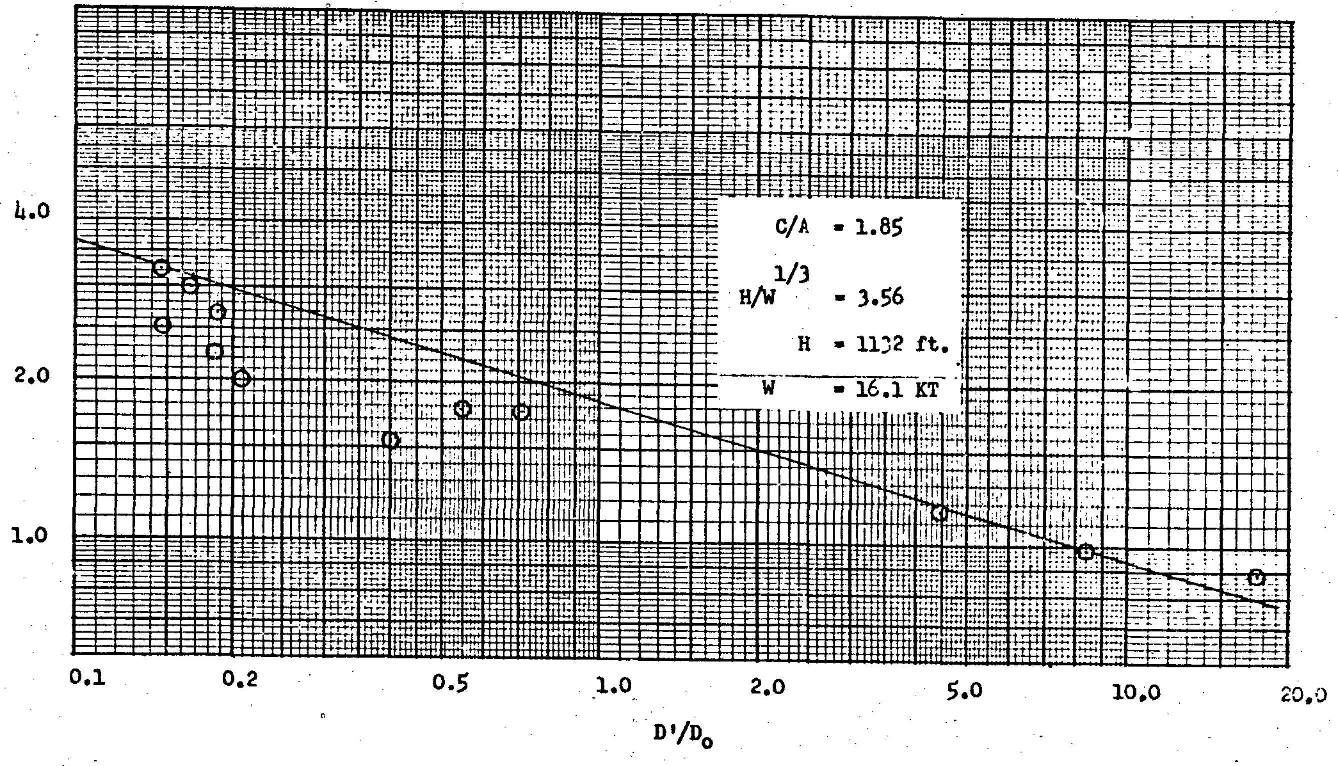

Figure 4.3 Equivalent Weight of Charge Charlie

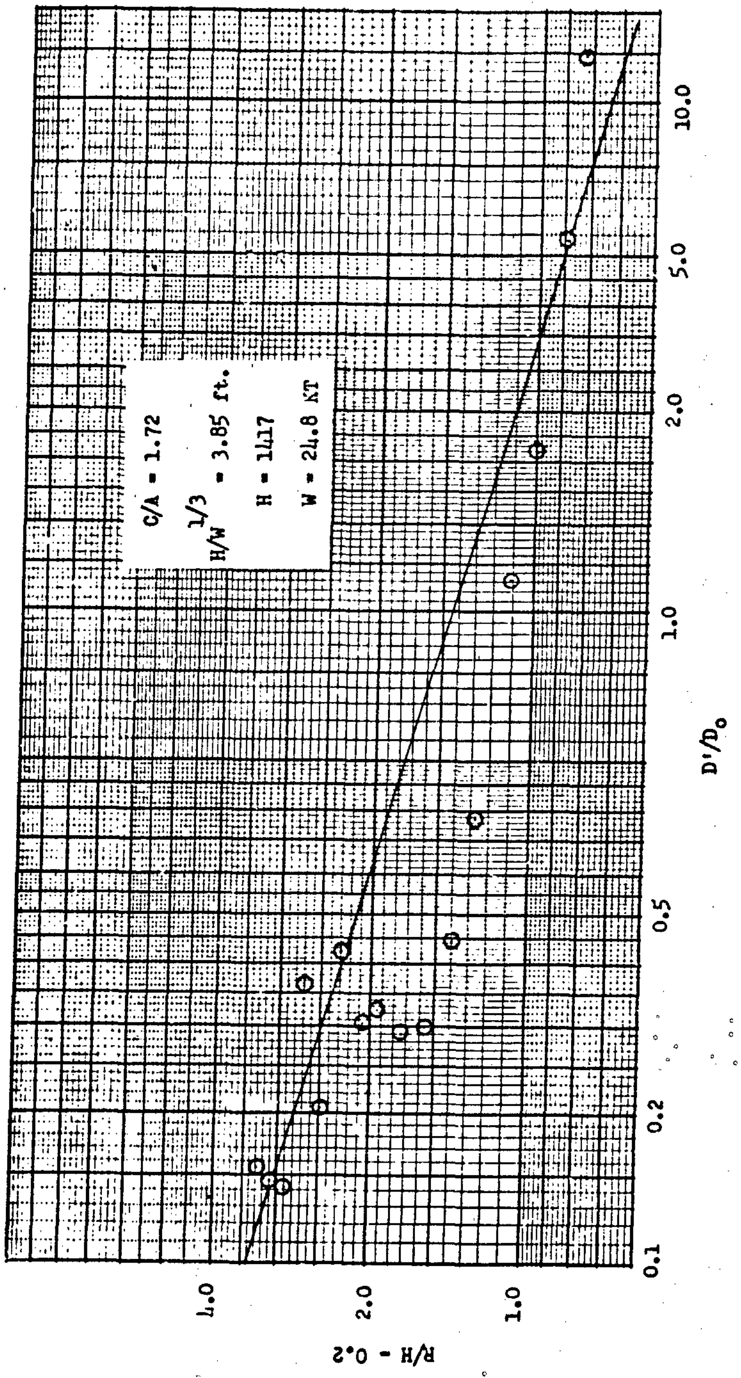

Figure 4.4 Equivalent Weight of Charge Dog

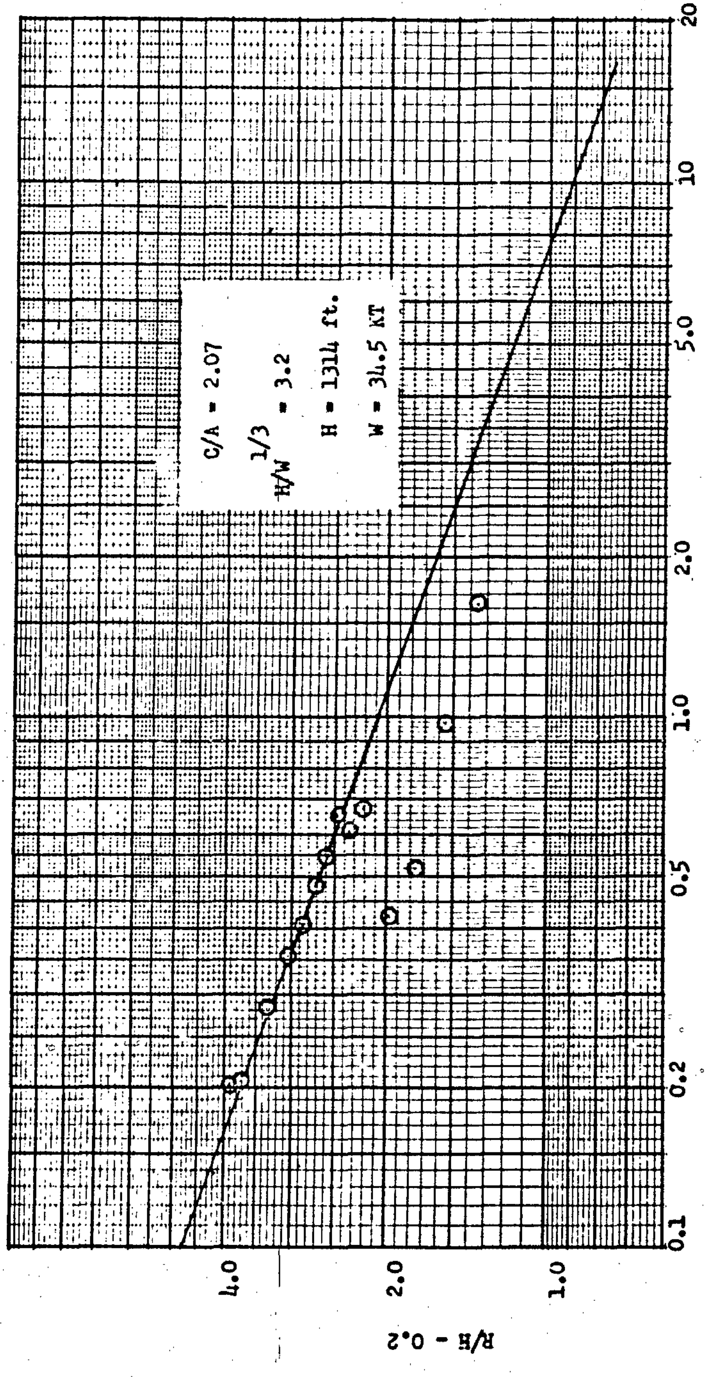

Figure 4.5 Equivalent Weight of Charge Easy

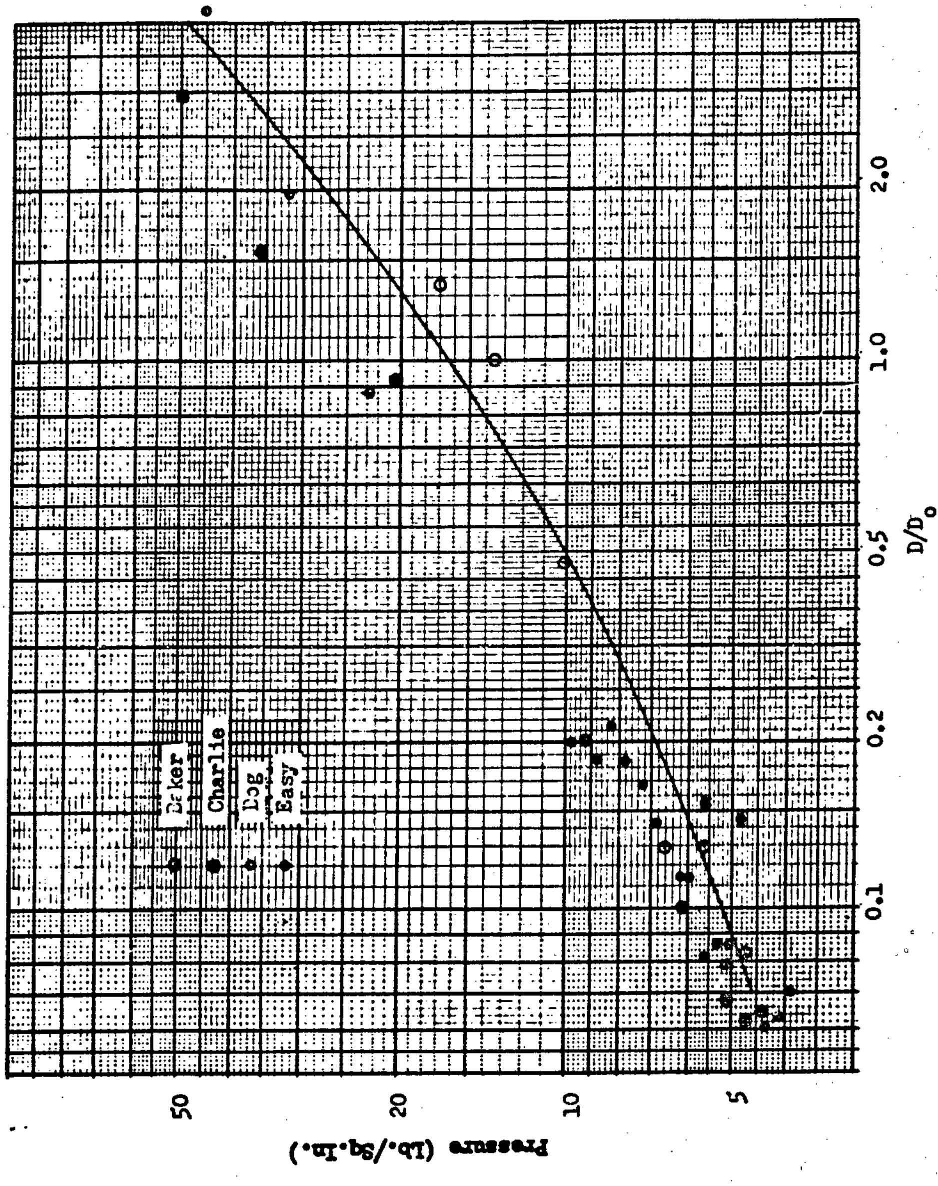

Figure 4.6 Pressure Calibration for Atomic Explosions

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The data taken in Project 3.5 during Operation BUSTER definitely show that atomic weapons detonated at a height (ft.) three or more times the cube root of the yield (lbs. of TNT) are not effective devices for minefield clearance. In Chapter 2 scaling laws have been devised which should be adequate to determine the effect of atomic explosions on mines as a function of yield, height of burst, and distance from ground zero.

There is definite evidence that a skip zone occurs, but more data are needed to determine scaling laws for the skip effect. A closer spacing of mine panels should be used (100 ft. instead of the 300 used in these tests). Studies should also be made as to the skip effect due to terrain, obstructions, etc.

The yield as determined by the revised scaling law (which allows for change in effective yield as a function of distance from ground zero) and the indicator mine readings are in substantial agreement on all shots.

The peak overpressures as determined by the indicator readings are in fair agreement with the observed values as reported for Operation BUSTER except in the skip zone where the pressures as determined by the mines are far too low. It is recommended that further studies on peak pressure and indicator readings be made using:

1. Closer spacing between mine panels.
2. Mines above ground facing the blast (similar to the 80° tilt in Fig. B.1).
3. Individual calibrations of soil constant at each panel and for each shot if any indication of variation occurs.

Additional data should be obtained so that a study can be made on the scaling laws for depth of burial. Mines using 0 in. burial gave lower readings than mines with 6 in. burial, while the reverse is true for TNT explosions.

APPENDIX A

INSTRUCTION MANUAL - UNIVERSAL INDICATOR MINE

A.1 INTRODUCTION

Anti-tank mines have been designed so that the weight of a tank, when running over the mines, will detonate the mines. Also, these mines may be detonated by shock impulses (from blast, flails, etc.). A series of tests made on various types of mines using various types of impulses show that the only measurable quantity which is independent of the type of impulse striking the mine is the energy absorbed by the mine, and that for any given type of mine there is a definite relationship between the energy and the maximum displacement of the pressure plate of the mine. Thus, any indicator mine should measure this displacement (or energy absorbed). The ability of a mine to absorb energy from a given type of impulse depends on the dynamic characteristics of the mine and differs for various types of mines. However, a relationship has been found* for various types of shear-pin mines which gives a method whereby the approximate behavior of one type can be predicted from the behavior of another type. The Universal indicator utilizes this relationship and has a range of measurement such that the behavior of the common types of shear-pin mines can be predicted from the results obtained using this mine in studying problems in minefield clearance.

A.2 DESCRIPTION AND OPERATION OF THE UNIVERSAL INDICATOR MINE

Figure A.1 shows a Universal indicator mine cut in half so that the relationship between the various parts may be seen. The mine consists of three parts: the pressure plate, the base, and the fuze. The fuze is inserted in the fuze well in the base, and the pressure plate is screwed on tight in the manner shown. The base is completely filled with an inert material of sufficient strength so that the top of the base does not yield appreciably with respect to the bottom when forces sufficient to collapse the springs of the fuze are applied to the pressure plate. The pressure plate acts as a spring with a spring constant of about 3000 lbs. per inch and an elastic limit of about 250

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*Reference 6.

lbs. (0.083 in. of motion). There is a gap (about 0.060 in.) between the under side of the top of the pressure plate and the top of the piston of the fuze (Fig. A.2). The measuring pin, which is held in place by the chuck, projects through a hole in the piston and is flush with the top of the piston. This piston is held in place by two Belleville springs which, although completely elastic, are designed to have a stiffness which approximates the elastic behavior of shear wire. When a force is applied to the pressure plate, the gap closes so that the force acts on the piston and Belleville springs. This force will deflect the springs so that the piston moves down with respect to the body. As the piston moves down (a maximum of about 0.175 in.), the measuring pin moves down. When the force is released, the piston returns to its original position (since the Belleville springs are completely elastic) but the measuring pin (held by the chuck) remains down with the top of the pin at the maximum displacement of the top of the piston. Thus, the displacement of the piston can be found by measuring the depth from the top of the piston to the top of the pin. This depth is a function of the energy absorbed by the mine. A method for obtaining this depth and a discussion for interpreting this measurement in terms of the behavior of shear-pin type mines are given below.

Two different diameter pressure plates are available for use with the indicator mine; the large diameter (M-1) and small diameter (M-2). These pressure plates have overlapping ranges.

A.3 PRESSURE PLATE RE-USE

The pressure plates have manufacturing tolerances such that the gap between the pressure plate and the fuze will be approximately 0.060 in. In field tests, the maximum deflection the pressure plate may have is about 0.235 in. which is well beyond the elastic limit (0.083 inch) so that a permanent set may occur. If this set is greater than 0.020 in., the pressure plate should be discarded. As an approximate rule, pressure plates may be re-used for depth measurements D_p of less than 30 and discarded when D_p is greater than 30 mils.

Figure A.3 shows the method which is recommended for determination of pressure plate re-use. The dial gage is designed to give a measure of the distance between the gasket seat and the under side of the top of the pressure plate. The movable dial is adjusted in a test jig to have a reading of 300 (3 on small scale and 0 on large scale). This setting gives a reading of 300 for standard pressure plates which give a 0.060 in. gap. The gage is placed on the bottom of the pressure plate being tested in the manner shown. If the reading of the gage is less than 280 or greater than 320, the plate should be discarded. (The rubber gasket should be removed before making this measurement.)

A.4 FUZE MEASUREMENTS

A dial gage with special attachments is recommended for measuring the displacement of the measuring pin of the fuze. The gage on the left in Fig. A.4 shows the gage assembly. When the protector cap on the bottom is removed, a 1/16 in. diameter pin, which is attached to the measuring arm of the gage, projects from the bottom. The zero position of the gage is adjusted by placing the gage, with the cap removed, on a firm level surface in the manner shown on the right in Fig. A.4, loosening the thumb screw (upper right side of gage), turning the dial until a reading of 269 is obtained, and fastening the thumb screw. The reading on the fuze is taken in the manner shown in Fig. A.5. The body of the fuze is held firmly in the hand with the gage centered on the top button of the piston and the 1/16 in. diameter pin projecting down to the top of the measuring pin of the fuze. Sufficient force (5 to 10 lbs.) should be used in holding the gage against the fuze to take up slack in the springs. Care should be taken that the hand does not touch the Belleville springs and that the fuze and gage surfaces are free from dirt. The reading obtained on the fuze subtracted from 300 gives the depth measurement D_p.

A.5 FUZE RESET

The Universal fuze has been designed so that it may be re-used repeatedly and reset in the field (unless hit by fragments or badly mishandled). Figure A.6 shows the reset jig in position for resetting the measuring pin of the fuze. This jig consists of a guide barrel and a plunger. One end of this plunger fits into a 1/8 in. diameter hole in the bottom of the fuze and rests against the bottom end of the measuring pin. When the outer end of the plunger (visible at the end of the jig in Fig. A.6) is struck lightly with a hammer, the measuring pin will be forced up until it projects slightly above the top of the piston. A force of 5 to 25 lbs. is required to move the pin. A convenient method in the field, when no hammer is available, is to press the plunger against a solid surface (e.g. the top surface of the mine) with sufficient force to move the pin. After pushing the pin up until it projects beyond the top of the piston, the reset jig is removed and the piston and pin of the fuze are pressed against a solid surface until the pin is flush with the top of the piston (e.g. a flat surface on the jig or the mine surface). The fuze is now ready for use again. Care should be taken to keep the fuze dry and free from dirt.

A.6 FIELD PROCEDURE

In order to obtain comparable results in the field with any indicator mine, it is necessary that all mines be buried in the same manner (i.e. the same depths of burial, the same compactness of soil below and above the mines, equal weights of soil on the pressure plates, equally level terrain, etc.).

The Universal indicator mine requires a hole approximate 13 in. in diameter. The height from the bottom of the base to the top of the pressure plate is approximately 3-3/4 in. so that the depth of the hole will be 3-3/4 in. plus the depth of burial. Before burial of the mine, the fuze (reset as described above) should be set in the fuze well (as in Fig. A.1) and a pressure plate (new or checked as described above) with a rubber gasket around the bushing on the under side should be screwed into the base until reasonably tight. The mine is then buried and ready for use.

After completion of the test on the mine, the pressure plate should be removed from the base and the fuze removed from the fuze well. The fuze, although inert, should be handled carefully until the fuze measurement with the dial gage (described above) has been recorded along with the position of the mine. (The gage is a delicate instrument and should be handled with care at all times.)

In observing tests in the field with indicator mines, two sources of experimental error have been found. Dirt or sand gets into the bottom of the fuze well and is not removed. The effect of this dirt is to raise the fuze towards the pressure plate, thus narrowing the gap between the top of the fuze and the underside of the pressure plate. With this condition the mine will give a reading which is too high. In some of the mines dirt or sand is left on the gasket seat when the pressure plate is screwed on. The effect of this dirt is to raise the pressure plate, increasing the gap between the top of the fuze and the underside of the pressure plate, in which case the mine will give a reading which is too low. From the above it is apparent that care should be taken to keep the fuze well and gasket seat free from dirt or sand. One method to remove dry dirt or sand is to blow it out with a tire pump (valves removed).

A.7 INTERPRETATION OF FIELD MEASUREMENTS

There are numerous methods for interpreting the data obtained using the Universal indicator mine. The calibration tests on Universal and several types of foreign mines, show that the wide variations in the data are primarily due to the conditions under which the tests were conducted (type of soil, moisture content of soil, type of terrain, method of burial of mine, etc.). In actual combat most of the variables will be present, so that it is necessary to include them when evaluating the effectiveness of a given method of clearance. Under these conditions no method will be 100% effective, and a study of how effective a given method is can only be made when there are sufficient data for a statistical analysis. Detail methods for interpreting the data are given in Chapter 2.

A.8 MINE CALIBRATION

The following method should be used to calibrate the behavior of a given foreign mine in terms of the Universal indicator mine readings:

1. Inert samples or replicas of the mine should be buried at the same distance from a charge and under identical conditions (depth of burial, type of soil, terrain, etc.) as Universal indicator mines.

2. The distance at which 50% of the mines are functioned by the effect of the blast wave from the charge should be found.

3. Determine the mean Universal indicator reading at the 50% distance. This average reading is the calibration value for the mine, since the Universal mines which give greater readings than the average correspond to the mines which function, and Universal mines which give smaller readings correspond to mines which fail to function.

4. Calibration values should be obtained in two types of soil (sand, clay) for two depths of burial (2 and 4 inches) using two weights of charges (e.g. 8 and 72 lbs.). If the calibration values under these various conditions agree, it is believed that the Universal indicator mine is a suitable instrument for determining the behavior of the foreign mine.

5. A shock tube* has been developed to assist in mine calibration. When only a few samples of an enemy mine are available, the shock tube is an ideal device for mine calibration.

A.9 UNIVERSAL FUZE LIMITATION

One limitation, which the Universal fuze has, is the failure to

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*Reference 1.

integrate the net effect of repeated shock impulses. Shear-pin type mines can be made to detonate by successive shock impulses, any one of which is not sufficient for detonation. For this reason the Universal indicator mine has been designed so that the TMi-43 fuze and Universal fuze are interchangeable. In tests in which repeated shock impulses are effective (e.g. flails, repeated small charges, etc.), it is recommended that the TMi-43 fuze be used.

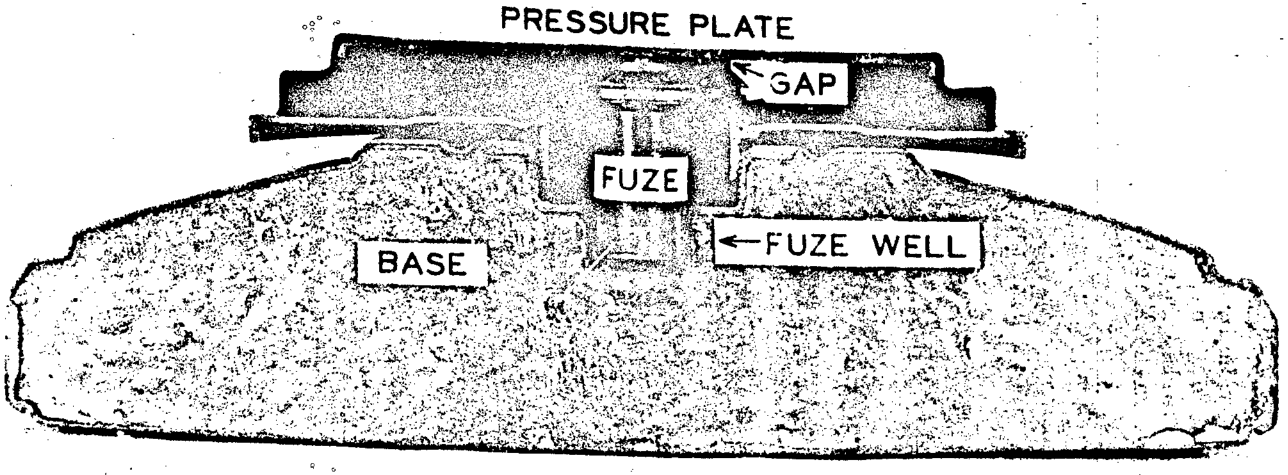

Figure A.1 Cross Section Universal Indicator Mine

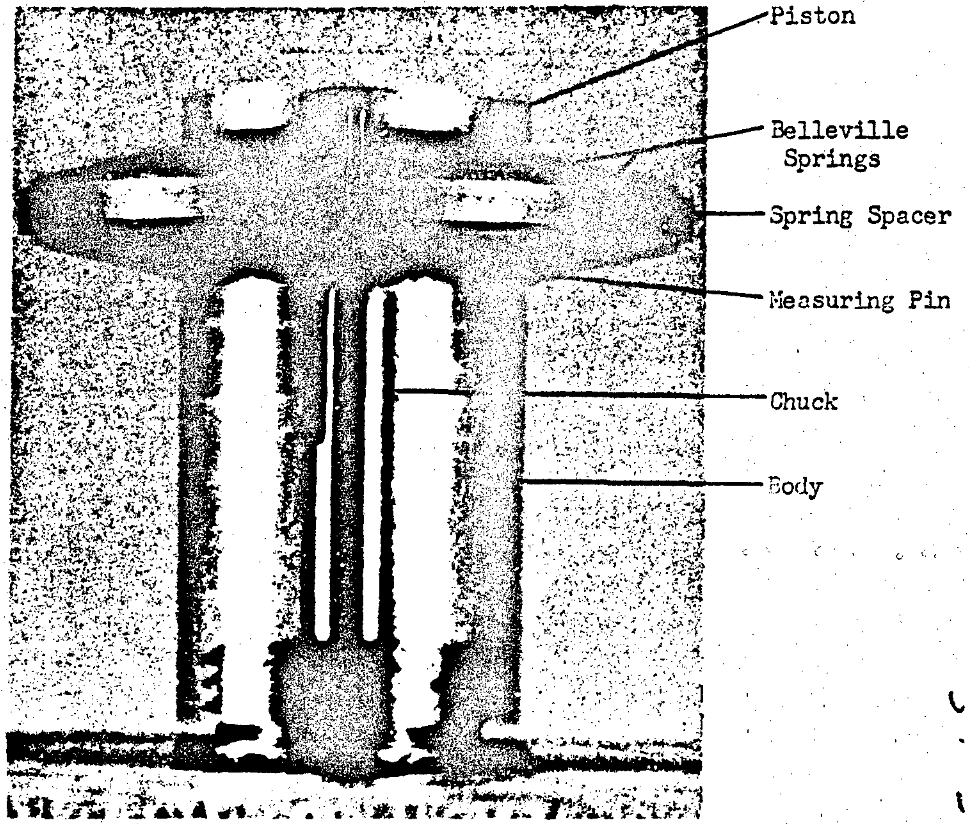

Figure A.2 Phantom View Indicator Fuze

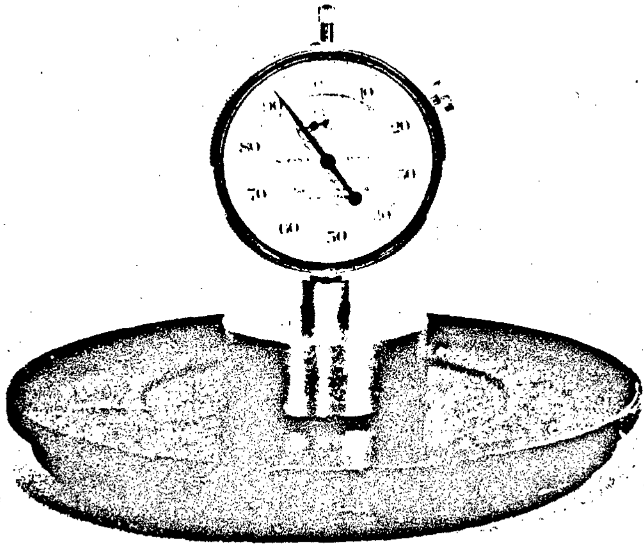

Figure A.3 Pressure Plate Calibration

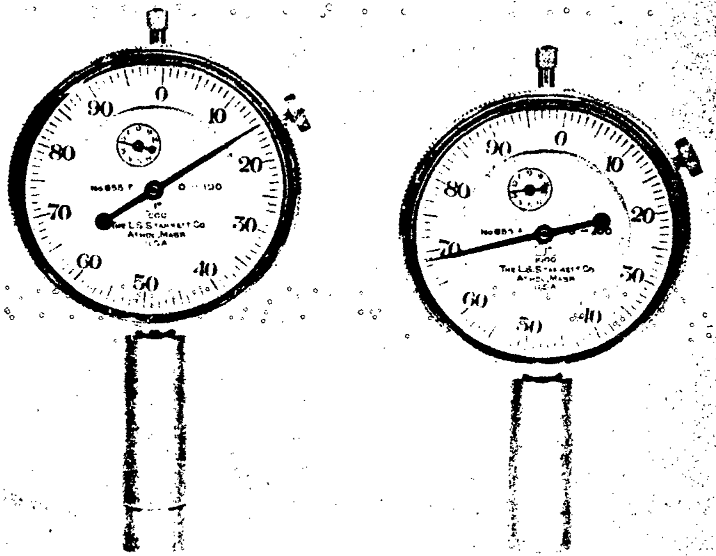

Figure A.4 Dial Gage Setting

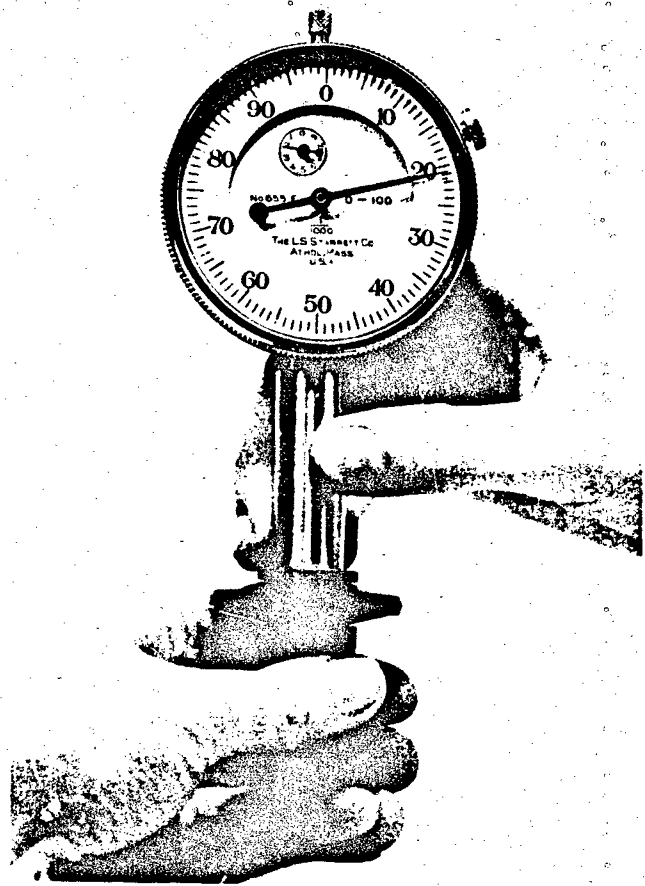

Figure A.5 Fuse Measurement

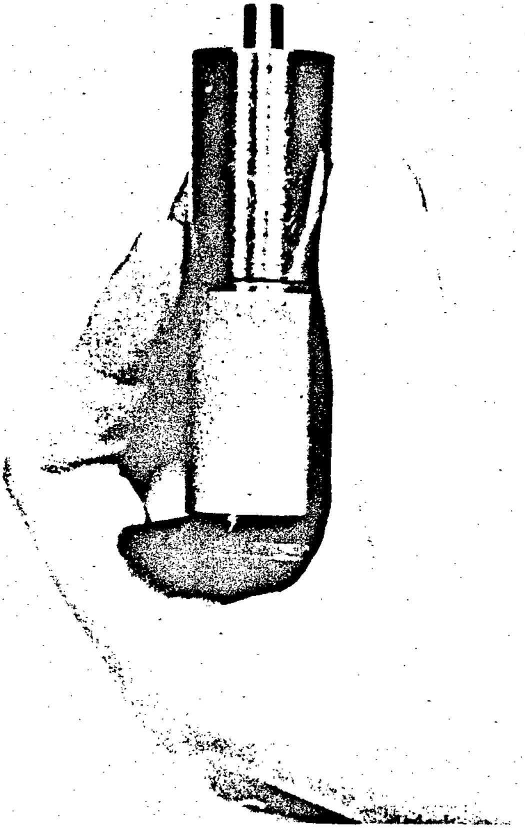

Figure A.6 Fuse Reset

APPENDIX B

CALIBRATION PROGRAM FT. BELVOIR, VA.

B.1 OBJECTIVES

Up until Operation BUSTER, all tests with the Universal indicator mine had been conducted at distances from the explosions which gave mean readings (M-1) of 20 mils or more. In addition, all mines were buried with the pressure plates on an average level with (0 in. burial) or parallel to (2, 4 or 6 in. burial) the surface of the ground.

It was observed in Operation BUSTER that the mines within 1000 ft. of ground zero had a pronounced tilt of the pressure plate so that the normal to the pressure plate pointed away from ground zero.

The objectives of the calibration program at Ft. Belvoir, Va. were as follows:

1. Determine the effect of tilt of the pressure plates.
2. Study the mine case behavior.
3. Determine the behavior of the mines when the mean readings (M-1) are 20 mils or less.

B.2 FIELD PROCEDURE

A radial minefield pattern similiar to that shown in Fig. 3.3 was used for all shots. Holes with vertical sidewalls and flat bottoms were dug so that mines could be placed as shown in Fig. B.1. A total of 36 mines were used for each shot and five shots, using 8-lb. charges with the charge center 2 ft. above the ground, were recorded. The procedure outlined in Appendix A was used in handling the mines and fuzes.

B.3 FIELD RESULTS

The data for the five shots is shown in Table B.1. A study of this table shows that there is no significant change in mine behavior when the normal to the mine pressure plate is tilted towards or away from the shot by 10° from being normal to the ground surface. The behavior of the mines was, in general, the same as was obtained in previous work* at Ft. Belvoir.

B.4 INTERPRETATION OF INDICATOR DATA

Since no appreciable difference was noted in the behavior of mines tilted 10° toward or away from the shot compared to level mines, the mean indicator readings for a given distance from the shot and for a given depth of burial were determined by averaging all the data. These mean values are indicated in Table B.1. The Point Charge formula Equation 2.3 can be used to compute the soil constant from the mean indicator readings at each distance and depth of burial. These values were computed and are shown in Table B.2. It can be seen that small mean indicator readings give a soil constant D_{o1} far too small. In order to extend the useful range of the Universal indicator mine below 20 mils, small readings must be corrected. These corrections can be obtained from Fig. 2.14 where the Universal scale reading can be found for small Universal indicator readings (M-1). The indicator readings for the 6 in. depth of burial have been corrected and D_o recomputed.

It will be observed that mines with the 80° tilt give considerably larger readings than do the 0 in. burial mines. There are insufficient data to determine the variation of indicator reading with distance for mines under these conditions. However, it is believed that mines placed in this manner receive the effect of total reflection of the shock wave rather than the partial reflection indicated by buried mines.

The calibration results are shown graphically on Fig. 3.5.

B.5 CONCLUSIONS

The following conclusions can be drawn from the data obtained in the calibration program:

1. With angles of tilt up to 10°, there is very little effect on the mean indicator readings.

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*Reference 1.

2. The new production of Universal indicator mines behaves like the World War II mines.

3. Data were obtained which allowed a correction curve (Fig. 2.14) to be made to convert small Universal (M-1) indicator readings to the Universal scale so that the point charge formula can be used.

TABLE B.1

Calibration Data, Fort Belvoir, Virginia, February 27-28, 1952

d =	7½ ft.	10 feet			12½ feet		
Tilt =	Level	Level	10° Away	80°* Toward	Level	10° Away	80° Toward
Indicator Reading Individual 0" Burial	100	60	52	400	23	47	95 49 135
	77	44	49	300	25	25	90 110 64
	109	47	44	160	32	37	92 135 59
	138	53	45	40	20	20	91 69 105
	OFF	65	65		38	30	80 81
	76	77	59		28	32	98 58
	148	56	40		19	36	100 54
		64	58		41	32	60 72
Mean	124	58	52	230	26	32	84.6
Mean	124	55		230	30.4		84.6

d =	5 feet			7½ feet			10 feet			12½ feet		
Tilt =	Level	10° Toward	10° Away	Level	10° Toward	10° Away	Level	10° Toward	10° Away	Level	10° Toward	10° Away
Indicator Reading Individual 6" Burial	29 25 15	32	34	6 11	10	10	2 -	1	6	1 0	0	2
	28 35 20	23	27	9 4	10	12	0 -	4	1	2 0	0	2
	23 19 33	28	25	10 12	10	9	0 4	1	5	0 -	1	
	27 23 20	18	30	5 7	1		3 3	5		0 1	1	
	26 22 28			5 3	16		0 1	2		0 1		
	18 27 25			10 3	5		- 1	0		0 1		
	20 21 22			7 6			0 3			- 2		
	30 23 22			12			0			- 2		
Mean	24.2	25	29	7.3	8.7	10	0	1.5	5	0	.5	2
Mean	24.9			8.0			1.0			0		

*Data Taken M-2 Plate (Reading x 20)

d = Horizontal distance mine to charge

TABLE B.2

Soil Constant Calculations

Fort Belvoir, Virginia, February 27-28, 1952

h(in.)	d(ft.)	R(ft.)	D(obs.)	D_{o1}	D_1	D_o
0	7.5	7.76	124.0	71	124.0	71.0
	10.0	10.20	55.0	63.5	55.0	63.5
	12.5	12.62	30.4	58.6	30.4	58.6
6	5.0	5.38	24.9	62.7	24.9	62.7
	7.5	7.76	8.0	43.3	11.0	59.6
	10.0	10.20	1.0	9.6	6.6	63.4

Mean D_o = 63.1

Nevada Test Site, October 12, 1951

h(in.)	d(ft.)	R(ft.)	D_1	D_o
0	7.5	7.71	102.2	108.3
	10.0	10.15	57.6	116.6
	12.5	12.62	34.3	113.9
	15.0	15.09	22.7	113.8

Mean D_o = 113.1

h = depth of burial
d = horizontal distance mine to charge
R = slant distance mine to charge
D = observed mean indicator reading
D_{o1} = soil constant computed for observed data
D_1 = corrected mean indicator reading
D_o = soil constant for Universal Scale

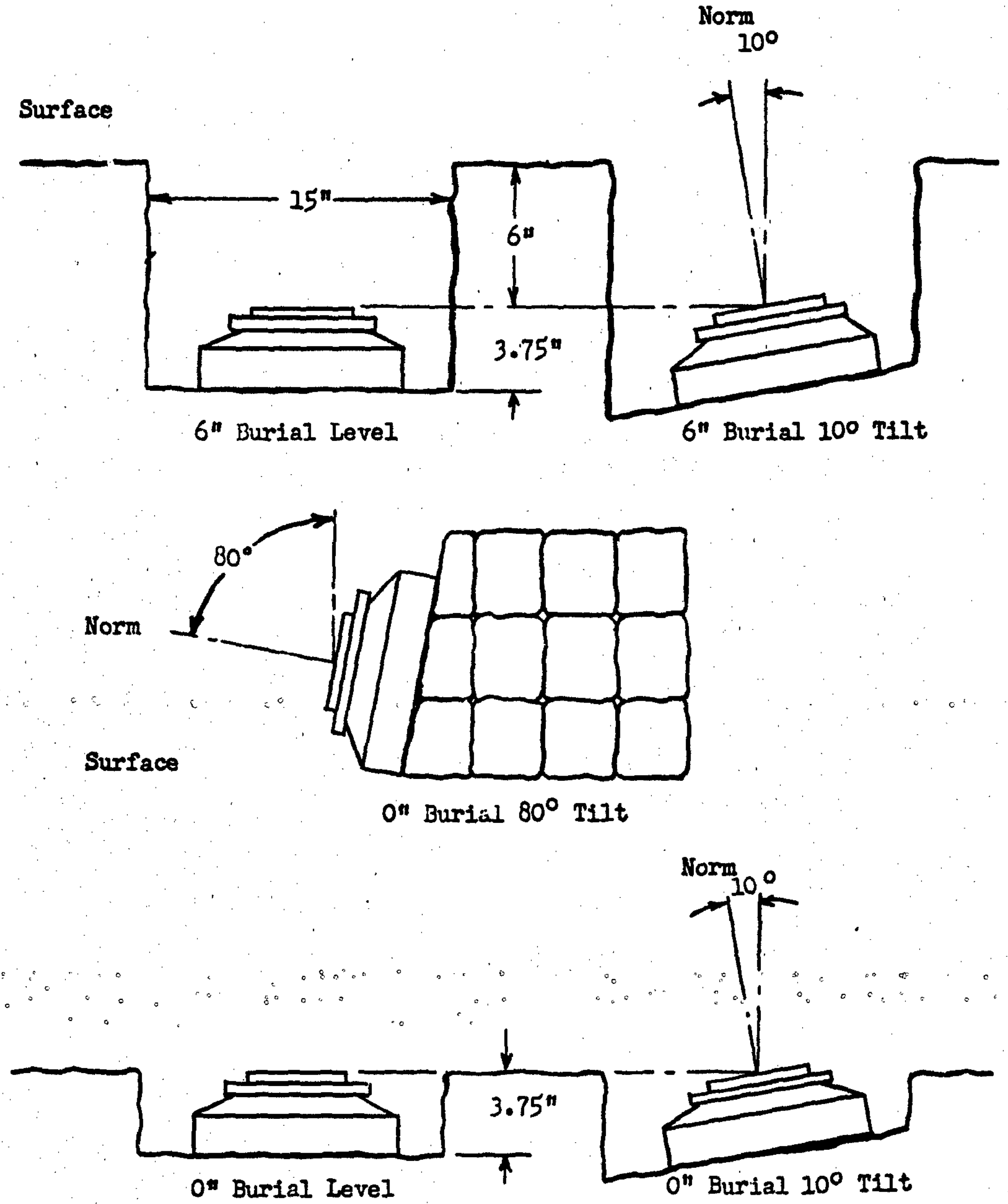

Figure B.1 Methods of Setting Out Mines

APPENDIX C

DETAILED DATA NEVADA TEST SITE

C.1 SOIL CONSTANT CALIBRATION

A soil constant calibration was made on the Nevada Test Site at a point 5100 ft. east of Point 3, Target Area No. 7. The minefield pattern used is shown in Fig. 3.3. Thirty-two mines were set out with 0 in. depth of burial (pressure plate flush with the surface). The individual and mean values of the indicator readings are shown in Table C.1. The values have also been corrected to fall on the Universal scale.

The soil constant was computed from the corrected mean values in Table C.1 for each radius and are shown in Table B.2. The results were very uniform and are shown graphically in Fig. 3.4.

C.2 MINEFIELD DATA FOR ATOMIC EXPLOSIONS

The layout of the various minefield panels is shown in Fig. 3.1. In each panel position A to T, 20 mines were buried using two rows of 10 mines and 5-ft. spacing between mines. These mines were placed at right angles to the profile line. The row closest to Point 3 used a 6 in. depth of burial to the top of the pressure plate and the other row a 0 in. depth of burial. After each shot the mines were uncovered and the fuzes read from the panels closest to Point 3 out from ground zero to the point where the readings were too small to be reliable. New pressure plates and fuzes were installed on the mines which were uncovered and the remainder were left undisturbed. The individual mine readings (after subtracting from the scale constant of the dial gage in accordance with instructions in Appendix A) were tabulated for each panel and each depth of burial. Mean values of the readings for mines the same distance and depth of burial were determined in the following manner:

1. If all readings were on scale a direct arithmetic mean was computed.
2. If one or more readings were not on scale the readings were tabulated in the order of their magnitude and an arithmetic mean was computed for the middle group of readings that were on scale.

3. The mean readings determined in steps 1 or 2 were converted to the Mean Universal Scale as follows:

   For M-2 (small pressure plate) mines multiply the observed mean by 20.

   For M-1 (large pressure plate) mine's mean readings between 25 and 155 record as read.

   For M-1 mine's mean reading between 0 and 25 the Mean Universal Scale value was determined graphically using Fig. 2.14.

The indicator mine readings for shots Baker, Charlie, Dog and Easy are shown in Tables C.2 to C.5.

In order to determine the radius of clearance of atomic weapons with indicator mines, the indicator readings for each of the shots are plotted as a function of the distance from ground zero. These curves are shown on Fig. 4.1 plotted from data given in Tables C.6 and C.7.

In order to determine the equivalent weight of explosive for each shot, it is necessary to convert the indicator readings to a scale which allows for the change in effective weight of TNT with height of burst and distance from the explosive. The method shown in Chapter 2, Section 2.5, was used on the data for shots Baker, Charlie, Dog and Easy. A summary of these calculations is shown in Tables C.6 and C.7. These data are plotted on Figs. 4.2 to 4.5.

In order to check the pressure calibration of the indicator readings, the value of V_g was computed for each of the 6 in. depth of burial readings and the indicated pressure was determined from Fig. 2.12. These values are plotted on the pressure calibration graph in Fig. 4.6.

TABLE C.1

Calibration Data Nevada Test Site, October 12, 1952

d=	7.5 ft.	10 ft.	12 ft.	15 ft.
Individual Mine Reading	99	63	40	33
	191	113	55	23
	81	45	28	33
	91	34	24	22
	78	39	32	22
	63	46	27	16
	138	47	31	23
	311	74	37	8
Mean	102.2	57.6	38.3	22.5
D_1	102.2	57.6	38.3	22.7

d = Horizontal distance charge to mine

D_1 = Mean Universal reading corrected by Figure 2.14

TABLE C.2

Indicator Mine Readings for Baker, October 26, 1951

Panel	A*	B*	C*	D*	E	F	G	H	I	J	K	L	M
Indicator Readings 0" Depth of Burial	13	7	1	1	-	8	13	7	-	-	0	1	-
	7	2	-	3	0	12	12	3	1	1	2	6	1
	7	5	0	-	2	7	13	6	3	-	0	-	0
	9	0	-	-	-	6	17	8	7	0	0	3	4
	-	0	-	-	5	10	7	4	-	-	0	-	-
	11	1	2	-	6	6	8	8	4	3	4	2	2
	-	10	0	-	-	6	13	2	7	-	4	-	-
	9	2	6	-	5	2	5	7	3	0	4	-	-
	2	2	0	-	-	6	12	12	1	1	6	2	0
	8	-	-	-	1	2	10	6	-	-	0	1	-
Mean	7.0	2.4	-	-	.5*	6.5	11.0	6.3	2.0	0	2.0	1.0	-
Un.Scale	140	48	-	-	10	10	13.2	9.3	7.2	6.0	7.2	6.5	-
Indicator Readings 6" Depth of Burial	12	10	4	2	10	13	9						
	11	6	4	-	11	13	8						
	6	7	6	-	11	13	2						
	-	-	9	16	14	14	5						
	8	6	-	2	10	22	2						
	8	-	0	2	10	14	5						
	8	8	3	-	18	2	2						
	6	7	1	-	16	12	4						
	13	7	1	-	17	14	3						
	3	1	-	3	9	4	10						
Mean	7.75	5.6	2.4	-	12.6	12.6	5.0						
Un.Scale	155	112	48	-	14.4	14.4	9.1						
R/H	1.06	1.15	1.30	1.51	1.09	1.91	2.14	2.38	2.63	2.84	3.13	3.38	3.64

* M-2 Mines Correct Value = 20 times Mean - Reading not on scale

TABLE C.3

Indicator Mine Readings for Charlie, October 30, 1951

Panel	A*	B*	C*	D*	E	F*	G	H	I	J	K	L	M
Indicator Readings 0" Depth of Burial	14	9	5	4	-	-	-	-	-	1	-	5	1
	11	7	2	1	7	7	-	4	-	2	3	4	8
	10	10	5	-	5	0	-	1	-	-	4	2	6
	12	8	5	-	1	3	-	-	-	8	4	2	2
	13	6	8	0	7	4	-	105	-	2	0	-	3
	10	11	2	-	0	7	-	-	-	2	1	-	3
	14	8	4	-	3	2	-	2	-	2	6	2	0
	11	5	1	1	3	-	-	-	-	4	9	0	0
	12		4	0	6	-	-	-	-	0	4	3	1
	13		4	1	2	0	-	-	-	-	2	2	-
Mean	12.0	8.0	4.0	-	3.4*	1.2	-*	-	-	1.5	3.0	1.8	2.0
Un.Scale	240	160	80	-	68	24	-	-	-	6.9	7.8	7.1	7.2
Indicator Readings 6" Depth of Burial	15	10	2	-	12	1	9	0	6	-	2	-	
	20	7	6	-	14	-	2	-	4	-	3	-	
	25	8	6	-	4	2	0	4	5	1	3		
	14	9	4	-	14	4	2	2	-	3	4	10	
	1	8	4	-	7	-	3	3	2	8	6	-	
	18	6	9	-	9	0	5	4	-	4	1	2	
	14	9	1	3	2	1	-	-	0	4	2	7	
	11	5	7	0	0	5	1	-	0	7	-	3	
	13	6	5	3	3	4	7	5	-	5	4	1	
	17	9	2	1	5	-	1	2	-	2	2	2	
Mean	14.8	7.7	4.6	-	7.0	1.0	2.1	1.8	0	3.2	2.6	1.7	
Un.Scale	296	154	92	-	10.4	20	7.2	7.0	6.0	8.0	7.6	7.0	
R/H	1.09	1.18	1.34	1.56	1.74	1.96	2.19	2.43	2.70	2.88	3.17	3.42	3.67

*M-2 Mines Correct value = 20 times Mean - Reading not on scale

TABLE C.4

Indicator Mine Readings for Dog, November 1, 1951

Panel	A*	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Indicator Readings 0" Depth of Burial	18	172	50	38	13	0	4	1	-	2	4	6	0	1	-	-	3
	14	168	128	18	11	1	-	2	5	1	5	11	4	1	4	-	-
	14	170	135	22	15	-	-	1	-	2	6	8	3	0	2	3	7
	11	169	58	25	5	2	0	2	4	1	7	3	7	3	0	-	-
	14	Inv.	130	25	13	3	-	2	-	1	6	7	3	4	5	-	-
	17	162	89	31	17	4	0	2	2	4	6	8	3	9	2	3	1
	13	178	70	30	17	-	-	0	2	8	8	0	0	2	2	0	-
	15	163	81	19	14	-	-	5	3	9	3	1	0	0	0	0	2
	7	167	66	31	10	-	4	3	-	6	-	7	1	1	2	-	3
	12	167	73	19	10	0	-	3	3	4	2	0	0	-	1	-	1
Mean	13.5	-	88	25.8	12.5	0	-	2.1	2.0	3.8	4.8	5.1	2.1	1.2	1.6	-	1.0
Un.Scale	270	-	88	25.8	14.3	6	-	7.3	7.4	8.3	9.0	9.1	7.3	5.7	7.0	-	6.6
Indicator Readings 6" Depth of Burial	18	52	49	36	18	0	1	6	4	5	17	3	9	5	4	-	-
	17	155	48	36	22	6	5	4	14	6	23	4	14	5	2	8	-
		116	42	39	21	3	0	0	11	5	22	9	14	4	3	3	-
	10	131		34	12	13	4	11	21	9	22	5	19	-	4	4	2
	13	85	43	39	23	13	9	11	11	9	28	4	18	1	0	4	-
	15	126	57	55	10	6	9	9	12	8	14	2	12	0	-	4	-
	16	148	39	35	3	10	7	11	8	7	10	6	18	3	5	5	-
	14	104	55	40	14	10	6	0	4	16	14	1	20	-	2	0	3
	12	135	73	33	15	15	5	7	3	17	10	7	11	-	-	1	1
	3	138	47	39	9	14	9	4	4	10	6	6	20	1	0	4	-
Mean	13.1	119	50.3	38.3	14.7	9.0	5.5	6.3	9.2	9.2	16.5	4.7	15.5	1.3	1.8	3.1	-
Un.Scale	262	119	50.3	38.3	16.0	11.7	9.4	9.9	11.9	11.9	17.5	8.9	16.5	6.8	7.1	7.9	-
R/H	1.03	1.10	1.17	1.31	1.47	1.59	1.76	1.94	2.13	2.28	2.50	2.69	2.89	3.09	3.29	3.49	3.59

* M-2 Mines   Correct values 20 times Mean   - Reading not on scale

TABLE C.5

Indicator Mine Readings for Easy, November 5, 1951

Panel	TE	SE	RE	QE	A	B	C	D	E	F	G	H	I	J	K	L	M
Indicator Readings 0" Depth of Burial					5	-	10		6	3	3	4	3	2	-	5	2
					1	2	5	0	-	4	3	1	1	0	3	-	7
					2	2	3	6	5	1	4	5	3	2	4	2	1
					3	2	2		5	1	0	2	2	0	4	0	5
					2	1		3	3	6	2	3	3	7	3	-	1
					3	4	3	2	0	4	2	1	3	1	2	6	-
					0	2	5	-	2	-	1	-	1	4	6	-	-
					3	7	1		2	2	0	2	2	1	2	1	1
					2	2	2		0	-	1	0	4	2	2	1	1
					2	2	5	2	5	3	2	0	1	-	3	0	0
Mean					2.2	2.1	4.0	2.3	2.7	2.3	1.8	1.6	2.3	1.5	2.9	1.0	1.0
Un. Scale					7.3	7.3	8.4	7.4	7.6	7.4	7.1	7.0	7.4	6.9	7.7	6.6	6.6
Indicator Readings 6" Depth of Burial	24	10	4	4	2		8		6	0	6	12	10	2	2	5	-
	18	12	6	3	19	8			7	3	8	10	11	6	2	3	2
	19	10	3	16	12	11	12	7	3	3	2	0	11	1	6		2
	15	14	4	2	8	9	5	7	10	6	5	3	9	0	3	7	0
	21	8	1	3	12	9	9	7	13	8	9	5	4	8	7	5	3
	18	17	2	0	9	13	8	10	7	7	6	9	7	8	10	12	0
	19	13	4	0	11	11	9	8	1	2	7	4	13	8	4	8	3
	18	10	0	-	11	4	20	13	11	4	4	7	2	3	6	2	1
	23	12	3	2	4	1	11	5	3	4	5	3	9	8	10	3	-
	22	9	3	-	6	8	12	7	4	4	9	5	5	6	9	8	3
Mean	19.7	11.5	3.0	1.7	9.4	8.2	10.4	8.0	6.5	4.1	6.1	5.8	8.1	5.0	5.9	5.8	1.3
Un.Scale	20.1	13.5	7.8	7.0	12.0	11.2	12.7	11.0	10.0	8.5	9.8	9.6	11.1	9.0	9.6	9.6	6.8
R/H	1.56	1.76	1.96	2.68	2.41	2.56	2.68	2.80	2.92	3.06	3.22	3.40	3.56	3.68	3.92	4.10	4.28

- Readings not on scale

TABLE C.6

Calculations for Baker and Charlie 6" Burial

Shot	Panel	$\frac{R}{1000}$	$\frac{Va}{Vt}$	$\frac{D'}{D_\theta}$	D	D'	$\frac{d}{1000}$	D_o	$\frac{D}{D_o}$	$\frac{D'}{D_\theta}$	$\frac{R}{H}$	P	V_g
Baker	A	1.19	0.424	2.52	155.0	391.0	0.39	112	1.38	3.49	1.06	17.0	5.75
	B	1.28	0.392	2.40	112.0	269.0	0.63	112	1.00	2.40	1.15	13.5	6.25
	C	1.45	0.347	2.25	48.0	108.0	0.92	112	0.43	0.96	1.30	10.2	7.10
	D	1.69	0.297	2.06	*	*	1.27	112	*	*	1.51	7.5	8.35
	E	1.89	0.266	1.92	14.4	27.7	1.52	112	0.129	0.247	1.69	6.6	9.15
	F	2.14	0.235	1.82	14.4	26.2	1.82	112	0.129	0.234	1.91	5.6	10.45
	G	2.39	0.210	1.75	9.1	15.9	2.12	112	0.81	0.142	2.14	4.8	11.7
	H	2.66	0.189	1.65			2.42	112			2.38		
	I	2.94	0.171	1.57			2.72	112			2.63		
	J	3.17	0.158	1.53			2.97	112			2.84		
	K	3.50	0.143	1.48			3.32	112			3.13		
	L	3.78	0.133	1.43			3.62	112			3.38		
	M	4.07	0.123	1.41			3.92	112			3.64		
Charlie	A	1.23	1.200	5.90	296.0	1748.0	0.48	100	2.96	17.48	1.09	50.0	4.40
	B	1.34	1.105	5.45	154.0	839.0	0.72	100	1.54	8.39	1.18	36.0	4.70
	C	1.52	0.975	4.85	92.0	446.0	1.01	100	0.92	4.46	1.34	20.5	5.40
	D	1.77	0.837	4.25	*	*	1.36	100	*	*	1.56	14.2	6.15
	E	1.97	0.753	3.85	10.4	40.0	1.61	100	0.104	0.40	1.74	11.3	6.75
	F	2.22	0.668	3.53	20.0	71.0	1.91	100	0.200	0.71	1.96	9.2	7.45
	G	2.48	0.597	3.22	7.2	23.2	2.21	112	0.064	0.207	2.19	7.7	8.20
	H	2.75	0.538	2.98	7.0	20.8	2.51	112	0.062	0.186	2.43	6.7	9.00
	I	3.05	0.485	2.76	6.0	16.6	2.81	112	0.053	0.148	2.70	6.1	9.70
	J	3.26	0.454	2.62	8.0	20.9	3.01	112	0.071	0.187	2.88	5.7	10.30
	K	3.59	0.413	2.48	7.6	18.9	3.40	112	0.068	0.169	3.17	5.1	11.25
	L	3.87	0.382	2.37	7.0	16.6	3.70	112	0.062	0.147	3.42	4.7	12.00
	M	4.16	0.356	2.27			4.00	112			3.67	4.3	12.9

TABLE C.7

Calculations for Dog and Easy 6" Burial

Shot	Panel	$\frac{R}{1000}$	$\frac{Va}{Vt}$	$\frac{D'}{D_o}$	D	D'	$\frac{d}{1000}$	D_o	$\frac{D}{D_o}$	$\frac{D'}{D_o}$	$\frac{R}{H}$	P	V_g
Dog	A	1.46	1.155	5.70	262.0	1490.0	0.32	60	4.36	24.80	1.03	45.0	4.52
	B	1.54	1.090	5.35	119.0	637.0	0.57	60	1.98	10.60	1.09	32.0	4.82
	C	1.67	1.010	5.00	50.3	252.0	0.87	60	0.84	4.20	1.18	23.0	5.25
	D	1.88	0.895	4.50	38.3	172.0	1.22	75	0.51	2.30	1.31	16.0	5.85
	E	2.09	0.805	4.10	16.0	66.0	1.46	85	0.188	0.775	1.47	12.5	6.45
	F	2.27	0.740	3.80	11.7	44.5	1.76	100	0.117	0.445	1.59	10.5	6.95
	G	2.51	0.670	3.55	9.4	33.5	2.06	112	0.084	0.300	1.76	8.8	7.60
	H	2.76	0.610	3.28	9.9	32.5	2.36	112	0.086	0.290	1.94	7.6	8.30
	I	3.04	0.554	3.04	11.9	36.2	2.66	112	0.106	0.323	2.13	6.6	9.05
	J	3.25	0.518	2.88	11.9	34.3	2.91	112	0.106	0.306	2.28	6.2	9.60
	K	3.57	0.472	2.72	17.5	47.5	3.26	112	0.156	0.425	2.50	5.6	10.40
	L	3.84	0.438	2.57	8.9	23.0	3.56	112	0.079	0.205	2.69	5.1	11.15
	M	4.12	0.409	2.48	16.5	41.0	3.86	112	0.147	0.365	2.89	4.8	11.90
	N	4.40	0.383	2.32	6.8	15.8	4.16	112	0.061	0.141	3.09	4.4	12.60
	O	4.69	0.359	2.28	7.1	16.2	4.46	112	0.063	0.145	3.29	4.1	13.40
	P	4.98	0.338	2.20	7.9	17.4	4.76	112	0.070	0.155	3.49	3.9	14.15
	T	6.13	0.275	1.97	7.7	15.2	5.96	112	0.069	0.136	4.30	3.2	16.95
Easy	TE	2.21	0.975	4.85	20.1	97.5	1.70	60	0.335	1.630	1.56	25.0	4.90
	SE	2.49	0.866	4.35	13.5	58.7	2.05	60	0.225	0.978	1.76	20.0	5.45
	RE	2.78	0.775	3.98	7.8	31.1	2.40	60	0.130	0.519	1.96	15.5	5.95
	QE	3.09	0.697	3.62	7.0	25.3	2.75	60	0.117	0.422	2.18	11.5	6.35
	A	3.42	0.630	3.36	12.0	40.3	3.12	60	0.200	0.672	2.41	9.8	7.15
	B	3.56	0.605	3.25	11.2	36.4	3.26	60	0.187	0.604	2.56	8.8	7.55
	C	3.80	0.567	3.10	12.7	39.4	3.52	60	0.212	0.654	2.68	8.2	7.90
	D	3.96	0.545	3.00	11.0	33.0	3.70	60	0.183	0.550	2.80	7.8	8.15
	E	4.13	0.522	2.92	10.0	29.2	3.88	60	0.167	0.487	2.92	7.3	8.40
	F	4.34	0.497	2.80	8.5	24.3	4.10	60	0.142	0.405	3.06	6.9	8.80
	G	4.56	0.473	2.72	9.8	26.7	4.34	75	0.129	0.355	3.22	6.5	9.20
	H	4.81	0.448	2.63	9.6	25.3	4.60	85	0.113	0.297	3.40	6.2	9.60
	I	5.04	0.428	2.54	11.1	28.2	4.84	100	0.111	0.282	3.56	5.9	10.00
	J	5.22	0.413	2.48	9.0	22.3	5.03	112	0.081	0.199	3.68	5.6	10.30
	K	5.55	0.389	2.40	9.6	23.0	5.36	112	0.086	0.205	3.92	5.3	10.90
	L	5.80	0.372	2.35	9.6	22.6	5.63	112	0.086	0.202	4.10	5.1	11.30
	M	6.07	0.355	2.28	6.8	15.5	5.90	112	0.060	0.138	4.28	4.8	11.75

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