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(6) HEIGHT OF BURST FOR ATOMIC BOMBS
(AFTER UPSHOT-KNOTHOLE) (U), (8)

(10) by Harold L. Brode.

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HEIGHT OF BURST FOR ATOMIC BOMBS (AFTER UPSHOT-KNOTHOLE)

Harold L. Brode

I. INTRODUCTION

The "height of burst" or HOB effect, (referring to the increase in peak overpressures due to Mach reflection), has long been considered an important factor in atomic bomb blast damage.

The early Los Alamos Blast Wave volumes(1) (1947) included a chapter on Mach reflections and height of burst effects for atomic explosions. By 1949 the effect was predicted in more detail in the LA-743(2) Los Alamos report. But since little atomic bomb blast data existed prior to publication of the SANDSTONE (1948) test results,(3) the several assumptions about blast efficiency, TNT data, free air overpressure curves, and reflection coefficients underwent considerable change in such later papers as LA-743R(2) and the SANDIA reports SC-1516(tr)(4) and SC-1827(5).

Atomic test data from GREENHOUSE(6) (Spring 1951) and later from BUSTER-JANGLE(7) (Fall 1951) disclosed a serious discrepancy between predicted and measured overpressures and lead to a limited report by Porzel(8) which in turn preceded the planning of the effects program for the TUMBLER test series.

It is not the purpose of this report to present a detailed account of the HOB picture prior to the TUMBLER-SNAPPER test series, and it is recommended that those readers interested in such information consult the OPERATION TUMBLER report, Pressure-Distance-Height Study of 250-lb. TNT Spheres,(9) by J. D. Shreve, Jr., since it affords an excellent history and analysis of the HOB effect up to OPERATION TUMBLER. The same report also points out the lack of useful correspondence between TNT and nuclear explosion data. The Armour Research Foundation final report on IBDA(10) also gives considerable attention to the pre-TUMBLER HOB (or p-d-h) concepts.

The issuance of many reports on the HOB effect and the supplementing of and then the revision of the AFSWP Capabilities of Atomic Weapons(11) handbook should indicate the rapidity with which the HOB picture is still changing.

The TUMBLER series (Spring 1952) was designed with particular attention to the height-of-burst problem, and the data obtained(12,13,14,15,16,17) have served as the basis for most HOB curves drawn since then. The TUMBLER results, however, disclosed several blast wave features that required further study,(12,17,18) so the UPSHOT-KNOTHOLE (Spring 1953) effects program was designed with particular attention to investigations of thermal surface effects, possible pressure differences at heights above the ground, the correlation of dynamic pressure and peak overpressure, and the effect of a very high burst.

Section II of this report includes the HOB data of TUMBLER and UPSHOT-KNOTHOLE and some sets of corresponding curves. The free air peak overpressure curve as measured at TUMBLER and the deduced TNT equivalent blast energy are also discussed.

Section III considers in a very general way several factors which affect the applicability of these HOB curves to target damage from airburst atomic bombs.

II. FREE AIR AND HEIGHT OF BURST DATA

FREE AIR CURVE

The measured peak overpressure from an air burst atomic explosion in the absence of reflections or refractions is useful in estimating the blast wave energy or the partition of bomb energy. The blast efficiency of a nuclear bomb is the percentage ratio of its blast energy to its total or radio-chemical yield.

The blast energy is generally derived from a comparison of the free air peak overpressure curve with a correspondingly scaled TNT or pentolite overpressure curve.

In the past, atom bomb blast efficiencies have ranged from better than 75% for BIKINI-ABLE or 66% for GREENHOUSE shots to between 50 and 40% for the TUMBLER shots. This wide range may be as much due to the nature of the comparisons with TNT curves and to inaccurate data as to any real partition differences between various atomic bombs or tests.

Several reasons may be given for the variance in partition estimates, the primary reason being the initial spread in overpressure data. As a result of the cube root scaling with energy, a displacement of a pressure-range curve (usually fitted visually to a set of measured pressures with some unavoidable error) is reflected in the blast energy or efficiency as a discrepancy three times as large.

A second reason for differences in partition estimates stems from the lack of similarity in TNT and atomic blast curves leaving the analyst some freedom in fitting or comparing them. The differences in the free air peak overpressure curves is greatest near the explosion center since initial pressures for TNT are characterized by chemical reaction temperatures while atomic explosions involve temperatures and pressures many times larger. These excessive initial pressures in a nuclear explosion may be responsible for a later balance of energies and pressures somewhat different from that in an equivalent TNT explosion, since the loss through heating is more rapid at higher pressures.

Nuclear explosions are also accompanied by considerable thermal radiation which can affect both the early and late blast wave energies or pressures. At large distances the atomic blast may have gained energy through the late absorption of either direct or reflected radiation, while the early phases of a nuclear explosion are known to be intimately connected with and profoundly affected by the thermal radiation throughout the formation and growth of the fireball and nitrous oxide layers.[1]

Asymmetries and jetting in the fireball and early shock wave may also contribute to differences in partition estimates since the blast becomes a function of azimuth as well as distance. Asymmetries in tower shots at GREENHOUSE[6] and UPSHOT-KNOTHOLE[19] have been observed to be of significant magnitude. The asymmetries are closely associated with cable jets or large shielding masses near the bomb. The cable jets are responsible in part for increased damage and at the same time for the slow shock rise times and lowered peak overpressures observed in their vicinity. The large shielding masses have the opposite effect, leading to clean, sharp shock fronts. The total impulse and blast energy may not show such asymmetries, however, and it is postulated that the peak pressure asymmetries are a result of thermal radiation interactions with the materials and surrounding air of the same nature as are involved in the precursor action observed at recent low altitude shots.

Although instability and jetting are the rule in TNT detonations, nuclear blasts, dominated in the early phases by radiation diffusion, produce very isotropic blast waves if large non-concentric masses are not involved. Because of the early radiative phase symmetrical blasts are expected even for high velocity delivery, i.e., there should be little directional effect due to bomb or missile motion. In other words, air burst atomic bombs may safely be considered to have no significant asymmetric blast effects.

A fourth source of lesser differences in efficiency estimates is the continuing change in total yield figures in the months after a test is shot and during the time these reports are being written and published.

A fifth and relatively minor source of error is in the lack of agreement between the various TNT or pentolite theoretical (Kirkwood-Brinkley)[20],[21],[22] curves used. The effects of charge shape, and the variations in energy release per pound of different high explosives, and the amount of this energy not effective in blast are all contributory to the general lack of agreement.

In the face of these excuses for "disagreement", the Operation IVY tests may indicate that the partition of energy may really vary and that consequential deviations from the supposed constancy of energy partition do exist for large yield bombs, although the extent of this variation is masked by uncertain meteorological effects. The evidence for decreasing thermal energy (going from about 35 or 40 percent of the total yield for small bombs to about 15 or 20 percent for super bombs), does not necessarily substantiate the supposed increase in blast partition since much of the radiation escape occurs too late to affect the positive overpressures.

Calculations of blast energy based on the actual spatial distributions of pressure (P), density (ρ), and particle velocity (u) would be more reliable, particularly where wave forms of TNT and atomic blasts are known to differ or where the atomic blast includes precursor effects or any other deviations from the "ideal" case.

$$E_{Blast} = 4\pi \int_0^R \left(\frac{P}{\rho\,(\gamma - 1)} + \frac{1}{2} u^2 \right) \rho r^2 \, dr - \frac{4\pi}{3} \frac{P_1}{\gamma - 1} R^3$$

The free air peak overpressure curve of Figure 1 indicates very little of these ambiguities, but represents a visual fit to the data deduced from TUMBLER rocket-trail and fireball photography[12,14] and by parachute cannister gauges from TUMBLER-SNAPPER[23], IVY[24] and UPSHOT-KNOTHOLE[25] all scaled to one kiloton at sea level. Figure 1 also includes for comparison the Kirkwood-Brinkley

TNT curve[21] scaled to one-half kiloton (50 percent efficiency). Not shown in this figure is the fact that the bulk of UPSHOT-KNOTHOLE and GREENHOUSE data lies above the TUMBLER free air curve (shown) in the region between 300 psi and 10 psi.

TUMBLER and UPSHOT-KNOTHOLE HOB DATA

Several laboratories (NOL, SRI, SANDIA, LASL, DTMB, BRL) have engaged in ground-level measurements of blast pressure using a variety of gauges and methods. Measurements of particle velocity, sound velocity, air temperature, and density also have been instrumented.

Since each group analyzes and reports its findings in its own way and in separate reports, the final results suffer somewhat for lack of a standard form of presentation and comparison. Results cannot be reported as measured, since raw data are not usually of a form that can be directly read or quoted, and in the analysis of records some corrections and manipulations are necessarily made that cannot appear in detail in final reports. In some cases the final data has been scaled to sea level atmospheric conditions and to a one kiloton yield. The scaling constants used by each group do not always agree, nor do the methods.

In addition, peak pressure measurements quoted may be maximum pressures, shock pressures, initial rise pressures, or extrapolated shock pressures, and even when the detailed pressure-time traces are reported, it is difficult to properly evaluate and extract the data since wave forms vary from point to point and the significance of each feature depends to a considerable extent on how the derived results will be used.

The AFSWP preliminary TUMBLER report[12], which avoided some of these difficulties by using preliminary field data, affords an excellent early summary of the effects programs. The corresponding UPSHOT-KNOTHOLE report[26] is equally well done, and includes much of what was learned from that and earlier tests.

Peak overpressure versus ground range curves given in these reports together with each Laboratory's data are shown in Figures 2, 3, 4, 5, 6, 7*. Smooth curves are empirically drawn through the TUMBLER points and a 5 percent average mean deviation is claimed for the data of all groups.

It is important to note that these smoothed curves were scaled to one kiloton at sea level and used to plot the HOB points of Figure 8, and that a set of curves were again visually fitted to these points with the upper portions determined by the TUMBLER free air curve and the reflection factors from SC-1827(Tr)[5]. The ground level points were derived from JANGLE surface data.

For the purpose of indicating the initial spread of data it is desirable to plot HOB points as derived independently from each laboratory's report**. This is done in Figures 9, 10, and 11 using data as reported in references 13 through 16 (by SRI, NOL, BRL and DTMB respectively), references 27 through 30 (by NOL, SRI, SANDIA, BRL), and earlier test results as given by Porzel[17]. This data is compared with the AFSWP HOB curves from reference (12). Figure 10 also contains TNT curves (1/2 KT) scaled from SANDIA 250-lb. tests[9], indicating the lack of correspondence.

In the case of David Taylor Model Basin results, where several instruments were used at a single station and a number of points resulted, limit lines have been arbitrarily attached to indicate the extremes of this spread, but they should not be interpreted in any exact sense since the extrapolation was gross.

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*The results of BRL measurements as reported in reference (15) have been added to the TUMBLER plots, but the curves have not been changed.

**Porzel in his <u>Surface Effects</u> preliminary report (17) made such a plot using field data and some 250-lb. TNT sphere data from SANDIA which he then compares with several curves corresponding to "thermal," "mechanical," "ideal," and "free air" effects. Although later data does not entirely agree with points Porzel plots, the results are similar.

In these figures the AFSWP curves prove to be reasonable fits to the data (with the possible exception of the 12 psi curve), although any number of different curves would appear to be equally good fits. These curves can represent the HOB effect for atomic bombs only if it is valid to simplify the problem to such an extent that differences due to surface effects, deviations from cube-root scaling, height and type of target, and other influences are ignorable; that is, only to the extent that a single set of curves can be meaningful.

III. INTERPRETATION AND APPLICATION OF HOB CURVES

In finding optimum burst heights and in using the usual height of burst curves one should consider the following points:

1.) The reproducibility of these HOB curves, or the reliability with which such data can be applied to seemingly identical bombs and targets.

2.) The changes that can be reliably predicted for different target or surface types; i.e., the predictability of surface effects.

3.) The expected changes in these curves with the height of the target above the ground.

4.) The relation of the peak overpressure to the damage.

5.) The reliability of scaling procedures when thermal interaction with surfaces is important or where the precursor effects are present.

(1.) REPRODUCIBILITY OF BLAST PATTERNS

Both the multiple measurements at a single test shot and the corresponding measurements at two "similar" shots exhibit a natural and unpredictable spread;

consequently any study whose results may depend critically on either the shape or the absolute values of the HOB curves should include some consideration of this dispersion or variation between essentially identical circumstances.

It is not surprising that such an apparently random dispersion of results should exist when the nature of the measured pressure-time curves is considered. In nearly every case the traces show the superposition of high frequency and very irregular perturbations on a gross compression wave of predictable form (outside of the anomolous region of the precursor).

The peak overpressure may be unduly influenced by these rapid fluctuations, so it would seem unwise to accept the observed values as direct measures of the strength of an ideal shock wave since this would imply much larger fluctuations in the total damage capability of the blast than is warranted by the actual pressure-time record.

The effect of such variations must be considered in connection with the type of target and damage involved. For targets capable of responding to high frequency pressure pulses or to large local variations in the blast wave, the damage resulting may be expected to exhibit the greatest dispersion, while gross drag-type targets might be expected to show damage more nearly as predicted with little variation due to the short range and high frequency blast perturbations.

For nearly all types of targets, the nature of response to loading is such as to place the greatest importance on the initial forces, since subsequent forces encounter increasing resistance. As a consequence, structures whose fundamental periods are of the same order as the blast duration are more critically influenced by the initial pressure rise than by the total duration. That is, a degradation in peak overpressure may be more serious than a comparable reduction in positive duration.

It is suggested, therefore, that, whenever possible, specific consideration of the effect of such deviations from predicted overpressures on the conclusions or assumptions of a study be made a part of such a study. Some feeling for the magnitudes of these deviations may be gained from referring to the plots of measured overpressures, Figures 2, 3, 4, 5, 6, 7.

(2.) TARGET OR SURFACE EFFECTS ON BLAST

The HOB curves illustrate the primary surface effect, which is the effect of Mach reflection of shock waves, but secondary effects of various real, non-ideal surfaces are not as well known.

In both the TUMBLER and the UPSHOT-KNOTHOLE test series considerable effort was directed toward understanding the effects of the Nevada desert surfaces on the blast wave.

The Precursor, first noticed on TUMBLER-4 [17,18] and, on re-examination, on other low altitude bursts, and more recently found prominent on UPSHOT-KNOTHOLE-10, [26] is a shock wave that actually precedes the initial wave near the ground, causing a slower pressure rise and accompanying signs of considerable turbulence and irregular flow. Its origin seems to be closely associated with the interaction of the blast wave with the thermal radiation through the heating of the air near the ground. The phenomenon is discussed and partially analyzed in a recent Sandia Corporation publication.[31]

In regions of precursor action the pressure wave is generally erratic and frequently lacking in any sharp peak. The dynamic pressures are also very rough but are not much reduced from ideal predictions. As a consequence, pressure sensitive targets may be less damaged, while drag type targets may be damaged to the full extent of predictions. Some actual enhancement of damage may be achieved by the increased upward and horizontal components of the blast wind and this possibility will be subject to future atomic test study.

In built-up targets the peak overpressures may be reduced, especially in Mach reflection regions, as may also the dynamic pressures. In the "tree-stand" on UPSHOT-KNOTHOLE the pseudo-static and dynamic pressures fluctuated rapidly. The dynamic pressures were less reduced, however.

Outside of precursor regions and aside from built-up surfaces, the peak dynamic (q) and pseudo-static overpressures (Δp) at the ten-foot level agreed fairly well through the Hugoniot relation

$$q \approx \frac{5}{2} \frac{(\Delta p)^2}{7p_o + \Delta p}$$

in which p_o is the ambient, preshock pressure, and $q = 1/2 \, \rho u^2$ is the peak dynamic pressure. Some slight increase in dynamic pressures above prediction is observed near the Mach triple point, but this requires further confirmation.

Subject to close study of UPSHOT-KNOTHOLE data and further test results, current conclusions indicate that ground surfaces may with sufficient thermal radiation degrade the blast wave, affecting the pseudo-static pressure more seriously than it does the drag forces or general damage capability.

(3.) TARGET HEIGHT

Pressure profiles at ten and fifty feet above the desert surface were recorded at several stations on Operation TUMBLER, and both pseudo-static and dynamic pressures were measured on Operation UPSHOT-KNOTHOLE at various heights up to sixty feet.

In regions of regular reflection the overpressure above the surface arrives in an incident and a reflected shock separated in time and lower in peak value than the pressure on the ground. The peak dynamic pressures correspond well with those calculated from static peak overpressures in these regions.

In Mach reflection regions even after the triple point has risen to considerable height the peak pressure above the surface is generally lower than the surface pressures. The triple point pressure may be about fifteen percent lower than the ground level pressure.

The measured dynamic pressures at the farthest stations on UPSHOT-KNOTHOLE exceed the values calculated from peak pressures by more than instrument error. This excess in drag forces is consistent with the observation that the Mach stem is nearly vertical despite the decreasing overpressure above the ground. A decreasing pressure would ordinarily predict decreasing shock and particle velocities and an accompanying backwards bend to the Mach stem.

The slow rises and degraded peaks in the precursor region are less evident at heights above the surface. The turbulent nature is still present but the measured dynamic pressures exceed those calculated from measured overpressures by as much as a factor of two a few feet above the ground.

It should be evident, therefore, that a factor of considerable interest in predicting damage is the height of the target structure, since ground-level pressures do not represent well the blast parameters above the surface. Sets of height of burst curves optimizing pressures at the ten or twenty-foot levels would be useful.

(4.) PEAK PRESSURE VERSUS DAMAGE

For ordinary chemical explosive blasts the duration of blast wave is short relative to response times of targets and damage is caused by a short impulsive loading. For atomic explosions, however, the duration is comparable to the characteristic periods (fundamental modes) or target structures and the dynamic (wind) pressure becomes a more effective force.

For a shock wave in air the peak values of the dynamic pressure (q_s), the wind velocity (u_s) and the density (ρ_s) are related to the peak overpressure (Δp) by the following relations in which the ambient air pressure and density are indicated by P_o and ρ_o,

$$q_s = \frac{1}{2} \rho_s u_s^2 = \frac{5}{2} \frac{\Delta p^2}{7 P_o + \Delta p}$$

$$u_s = \sqrt{\frac{5}{\rho_o}} \frac{\Delta p}{\sqrt{7 P_o + 6\Delta p}}$$

$$\rho_s = \rho_o \frac{7 + 6\Delta p}{7 + \Delta p}$$

Since damage by dynamic forces is not linear in static overpressure, the significance of deviations in blast strengths may be obscured by reference only to the overpressure.

Furthermore, knowledge of these peak values alone is not sufficient for estimating the dynamic loading of a structure, since for longer durations lower overpressures are required to attain the same damage. The duration increases about like the cube root of the yield for equal overpressures, making it necessary to know, in addition to the overpressure, either the yield, or the duration (or the distance from the blast) before the dynamic impulse can be computed.

The dynamic impulse may not, however, accurately represent damage levels, since targets respond differently to impulses of equal total momentum and different durations and peak pressures. The most effective force is one in which the momentum is imparted to the structure in a very short time, and so the most effective part of a blast wave is that early part delivered before the target becomes appreciably deflected. As a result, one may only need to consider the peak or shock values and the rate of decay immediately after the peak in order to estimate the damage potential of a blast wave.

On recent tests some attempts have been successful in measuring the time dependence of various blast parameters (overpressure, dynamic pressure, wind velocity, temperature, and density)[19,26,30,32]. From some of this data it is evident that the rate of decay is not constant, being nearly linear for small overpressures, and sharper than exponential at high values. The time dependence of the overpressure and the dynamic pressure for an unreflected spherical blast is represented by the following forms. These expressions are approximately correct for reflected shocks except in the region of Mach stem formation where the shapes are considerably changed. Beyond the Mach formation region, however, the Mach reflected pressures return to this general form.

$$\Delta P = \Delta P_s (1 - z) \epsilon^{-\alpha z}, \quad \alpha = 0.50 + 0.068\, \Delta P_s$$

$$Q = Q_s (1 - z)^2 \epsilon^{-\beta z}, \quad \beta = 0.75 + 0.22\, \Delta P_s$$

$$\Delta P_s < 20 \text{ psi}$$

$$z = t/D$$

where P_s and Q_s are the peak overpressure and peak dynamic pressure, and D is the positive duration (see Figure 12). (The positive duration of dynamic and pseudo-static pressures in the regions of interest differ by only a few percent). The coefficients α and β range between $1\frac{1}{2}$ to $\frac{1}{2}$ and $4\frac{1}{2}$ to $\frac{1}{2}$ respectively in the range from 20 psi to zero for an unreflected spherical blast. Above 20 psi the simple exponential form is no longer suitable since the early decay requires a larger exponent than that which fits nearer the end of the positive phase.

For higher overpressures the forms can be modified satisfactorily:

$$\alpha = 0.5 + \Delta P_s \left[0.075 - z(0.088 - 0.0093\Delta P_s) \right]$$

$$\beta = - 0.09\Delta P_s + \frac{0.435\Delta P_s}{1 + 0.0493\Delta P_s}$$

for $15 < \Delta P_s \leq 45$

These approximate forms are derived from a detailed numerical calculation[33] and are not based on test data. They are, however, compatible with the published measurements of unreflected blast waves assuming 0.6 KT blast energy as in Fig. 1).

On Mach reflection both the coefficients (α) and (β) seem to increase, sometimes by more than a factor of two. This is obviously necessary if energy and momentum in a blast are to be conserved in reflection, since peak pressure becomes suddenly larger while the duration remains about the same.

Used in conjunction with empirical curves of peak overpressure (Figure 1) and duration (Figure 12) these expressions make possible the complete specification of the blast forces in the absence of reflections.

The impulse due to either overpressure or drag pressure may be calculated from these forms, and leads to the indicated approximate radial dependence.

$$I_p = \int_0^D \Delta P \, dt \sim 0.70 \, r^{-1} \text{ psi-sec}$$

r in Kft, 1KT

$$I_q = \int_0^D Q \, dt \sim 0.080 \, r^{-2.7} \text{ psi-sec}$$

These impulses are shown in Figure 13 as a function of the radius in kilofeet for a one-kiloton, free air burst.

Because of the different roles enjoyed by peak overpressure and by duration (or rate of decay) the analysis of a particular structure requires the specification of these parameters individually. However, when the aim is to predict general levels of damage to general classes of targets, some simple combination in a single damage parameter would be useful and perhaps valid.

We are less concerned here with the specific forms proposed for damage indices than we are with the relation between isobars on the HOB curves and iso-damage contours. There is no suggestion that Mach reflection does not enhance damage, but it is clear that the increase in overpressure may be of less importance than an increase in dynamic impulse. Durations do not increase in the Mach region, and total impulses are not far different from the sum of incident and reflected waves.

For diffraction type targets and for targets sensitive to duration the HOB increases will be fairly realistic, but for low frequency structures and targets sensitive only to total drag impulse, the enhancement due to Mach reflection will be negligible, and the zero height-of-burst values are more realistic. In the case of no HOB effect the curves shrink to arcs of circles with centers at ground zero and radii equal to the surface burst horizontal ranges, while the existing isobar HOB curves should represent a maximum possible Mach effect. It should be reasonable to draw between these limits appropriately interpolated curves corresponding to the expected degree of drag or diffraction response. Given the proper impulse or dynamic pressure-time data, it becomes a task for the target analyst to establish such intermediate curves.

This data does not exist in any profundity at present, but it is not clear that it would constitute a significant consideration to the analysis of damage or collapse of structures in the light of the greater unpredictable variations in structural responses.

In the precursor region, much of the preceding simplified picture no longer applies. Slow rises and very irregular pressure and wind waves make peak pressure and durations very erratic and unreliable damage guides. The effect of slow rise times for blast waves is discussed in detail in another recent Sandia Corporation publication.[33] The Hugoniot or shock relations no longer hold, and peak overpressures are much lower than would be predicted, while peak dynamic pressures are not diminished.

(5.) SCALING

In applying the HOB curves to other yields, the height and the horizontal distances are multiplied by the cube root of the kiloton yield. This scaling is well verified by atomic test results.

The HOB curves are not valid in the precursor region, however, and the precursor region does not scale in the same manner. This region is probably best defined by a critical thermal energy delivered per unit area which is nearly proportional to the yield and to the inverse square of the slant range. Accordingly, and ignoring such things as the angle of incidence and the deviation of thermal scaling from strict proportionality with yield, the range of thermal energies is greater than the cube root. For modest ranges in yield this difference may be neglected.

For targets above the surface, it is probably sufficient to assume the Mach stem height also scales by the cube root law, so that at the scaled range, for a scaled burst height, the Mach stem will be at a height increased by the cube root of the yield over the one kiloton height. Unfortunately Mach stem height is not well known, since it seems to vary radically from test to test and even on a single test at different ranges.

If the peak overpressure alone is used as a damage index for drag targets the scaling used should be greater than the cube root. Recent studies at RAND[35,36,37,38] and elsewhere[39] have considered in detail the effect of changing durations with yield for various target types. No simple rule involving peak overpressure has resulted, but always the bonus from longer durations is significant for larger yields.

IV. CONCLUSIONS

CHANGING CONCEPTS

The trend in blast prediction philosophy is toward aerodynamic and away from pseudo-static notions of target loading and response. Most militarily significant targets have proved vulnerable to dynamic or drag pressures and are destroyed not by squeezing or by the short impulse supplied by the shock overpressure, but by the winds which follow the shock.

The use of peak overpressure as a damage guide to such target groups is inconvenient and in many instances misleading, and in the past two years many analysts have modified their prediction methods to depend directly on dynamic or wind pressures, or to include other parameters such as the positive phase duration of the blast wave.

It is also a fact that structural engineers can never achieve great precision in predicting damage or destruction to individual structures or targets. This fact, coupled with the usually incomplete intelligence about the history and construction of particular targets, makes uncertainties in the blast loading a rather unimportant source of error. Thus, the lack of reproducibility in blast phenomena and the variations introduced into the blast by local surface or target effects need not be of great concern in operational planning, and should not invalidate the use of curves derived from scattered data.

NATURE OF TARGETS

An important fact that must be mentioned in connection with the height of burst problem is the "hard" nature of most targets of military significance. In both strategical and tactical situations the primary targets generally require much greater than hurricane forces to accomplish destruction. On the basis of the Hugoniot relations (mentioned in Section III), an overpressure of 20 psi produces a dynamic pressure of only 8 psi (200 mph wind) and values greater than these are frequently necessary to overturn bridges, reinforced concrete buildings, or armoured vehicles.

For such "hard" targets the HOB curves (Figures 4, 5, 6, 7) would always prescribe a surface burst (for overpressures greater than 15 psi).

FUZING

The requirement for precision fuzing with its concomitant complicated radar circuits does not exist for low or surface bursts. One can suggest many vital targets requiring near surface bursts but relatively few significant targets requiring high bursts. Weapons currently in stockpile already have precision fuzing capabilities, but one may expect future weapons to include less stringent fuzing, perhaps baro-fuzing and contact or proximity fuzing. This would allow some savings in weight and size, and would reduce radar jamming, as well as avoid some problems of predetonation, delivery, maintenance and logistics.

It is important to recognize that there exist situations where optimized burst heights will still be relatively high, however, and a capability for such delivery should not be lost. Any target with no "hard core", or need for increased nuclear or thermal radiation, any case where urban area destruction is of primary importance, any case where parked aircraft are the most important targets, might require high bursts.

In the light of the many factors mentioned which tend to ameliorate the effect of burst height, the precise height of burst would appear to enjoy only a minor role in planning operations or in assessing damaging for a majority of instances.

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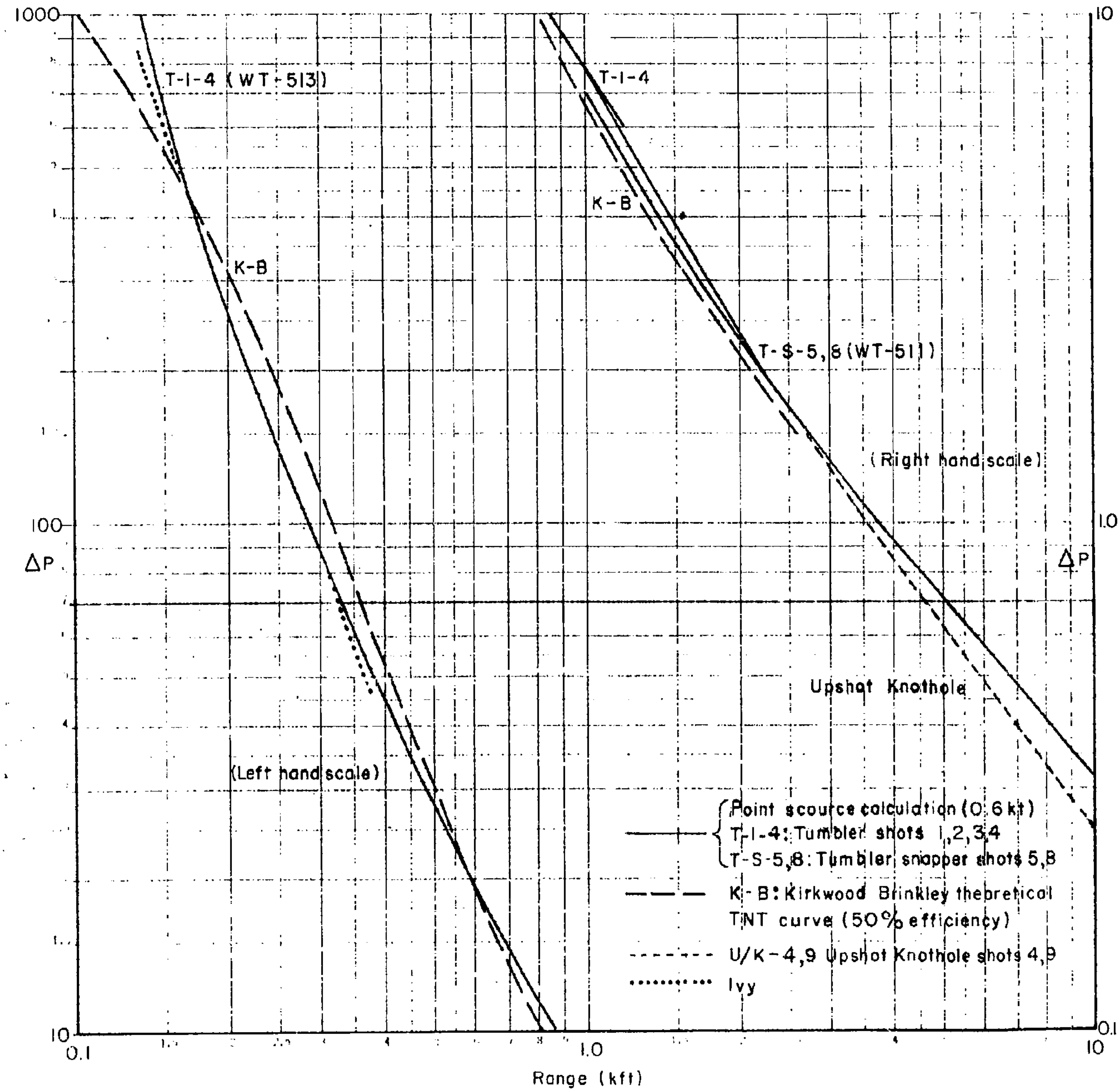

Fig. I — Free air peak overpressure (psi) vs range (kft)

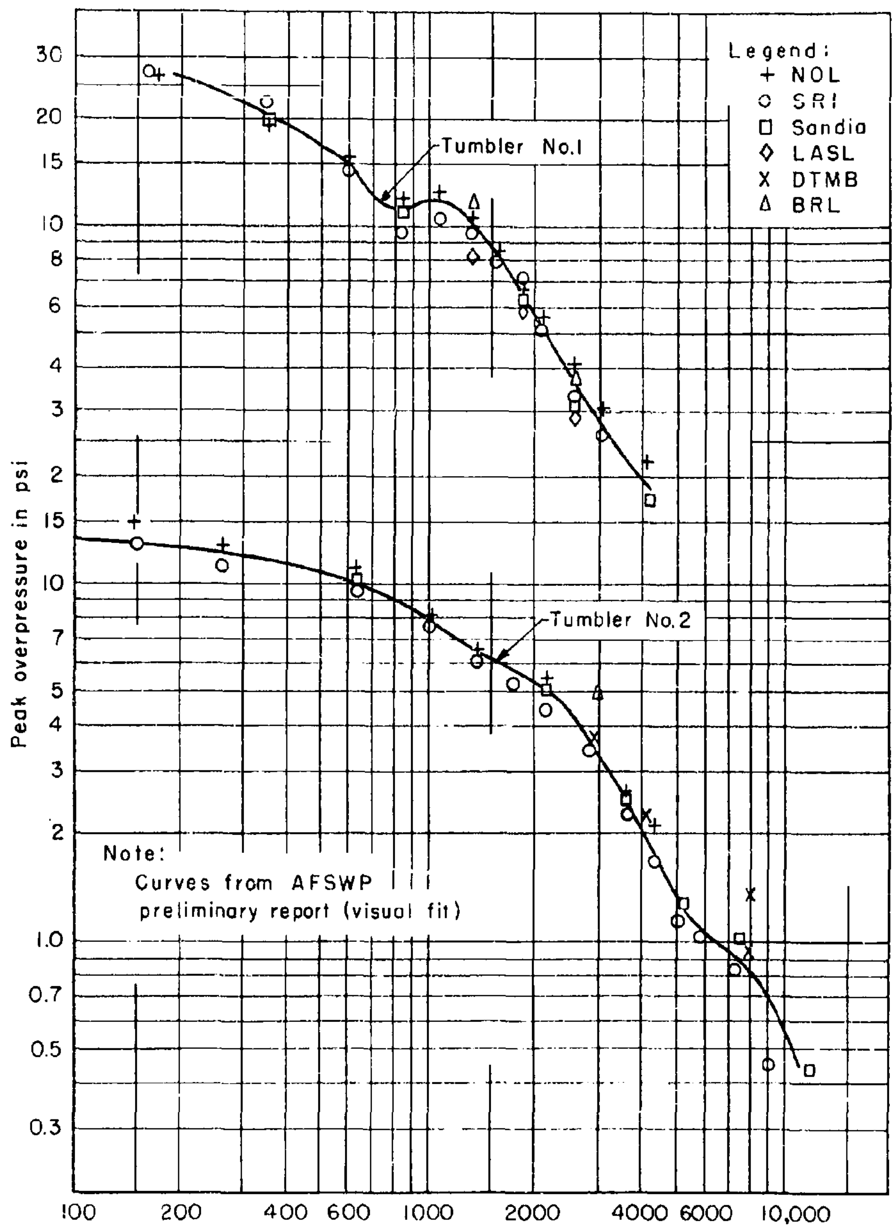

Fig. 2 — Peak overpressure data
Tumbler No. 1 and No. 2

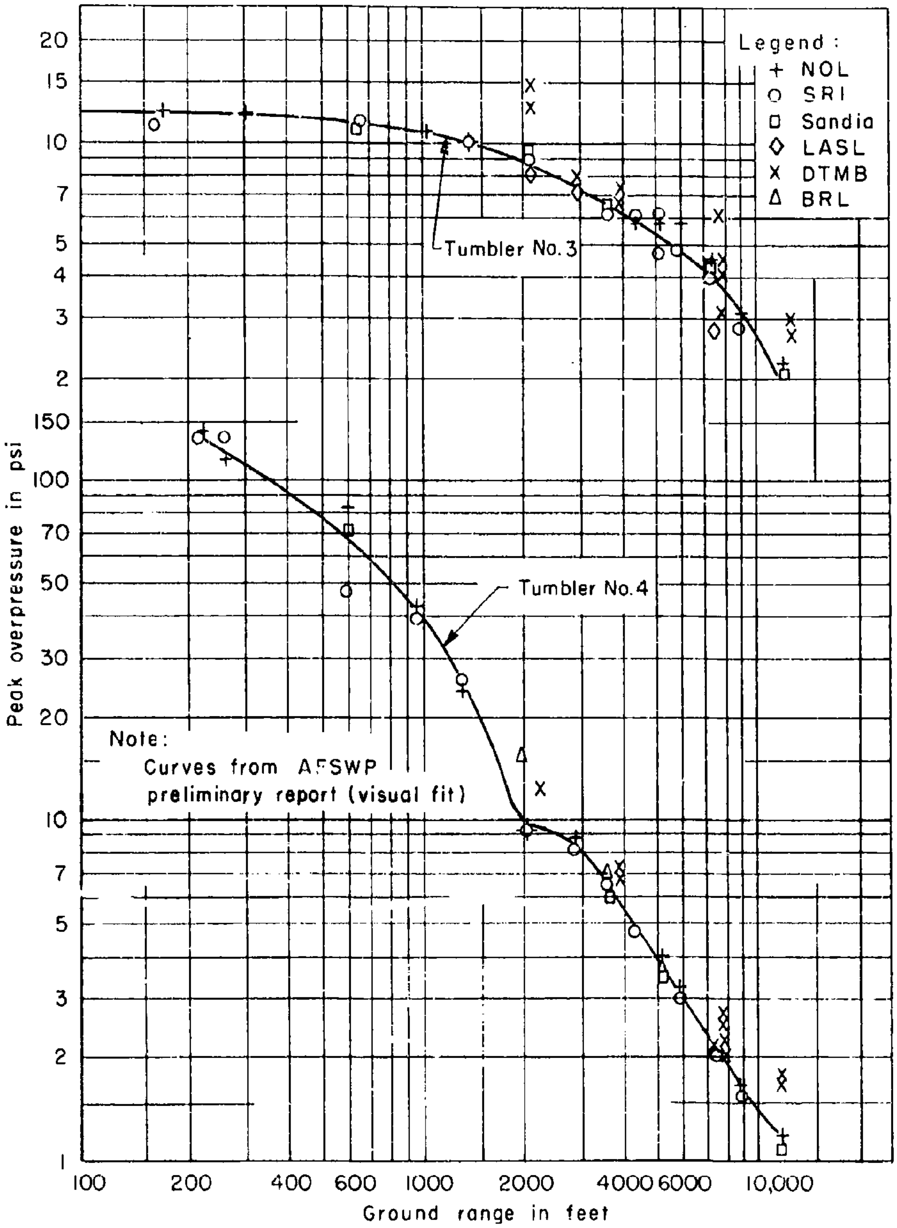

Fig. 3 — Peak overpressure data
Tumbler No. 3 and No. 4

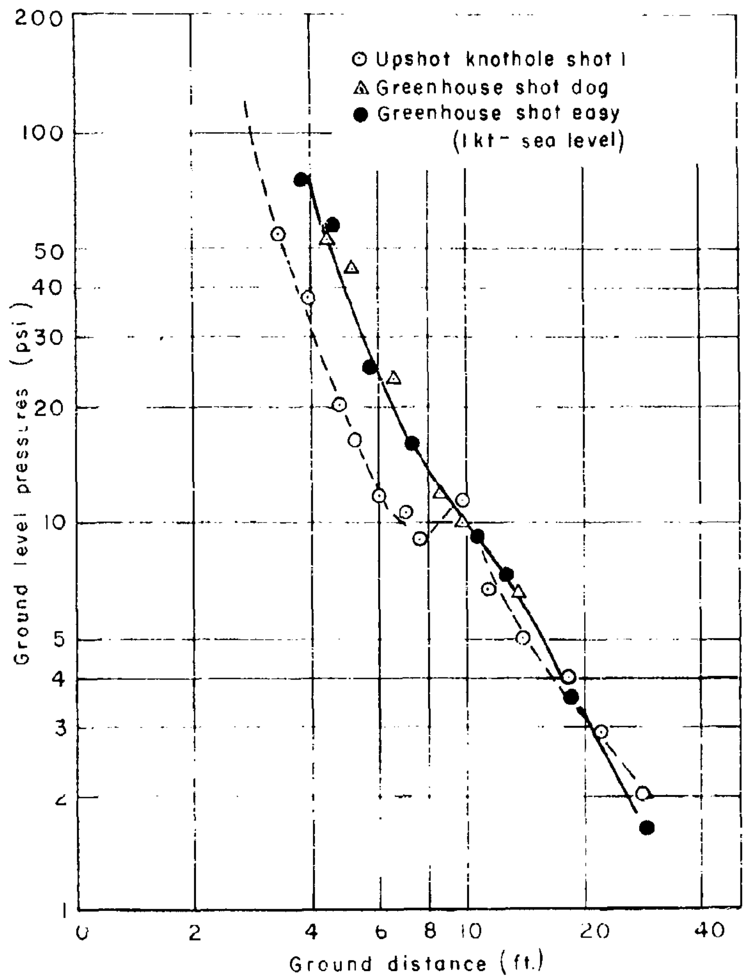

Fig 4. Peak overpressure data (Sandia corp.)
Upshot - Knothole #1
(Scaled HOB 112)

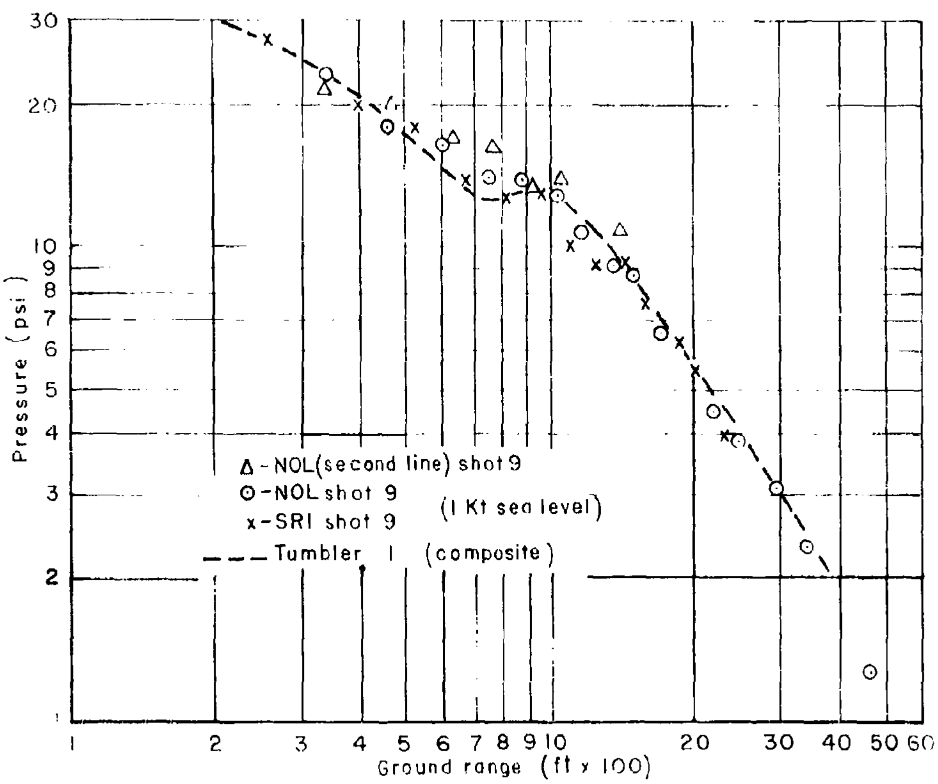

Fig 5. Peak overpressure data
Upshot Knothole shot # 9
(Scaled HOB 760 ft

UKP 72 Fig. 2.17 and Fig. 2.3

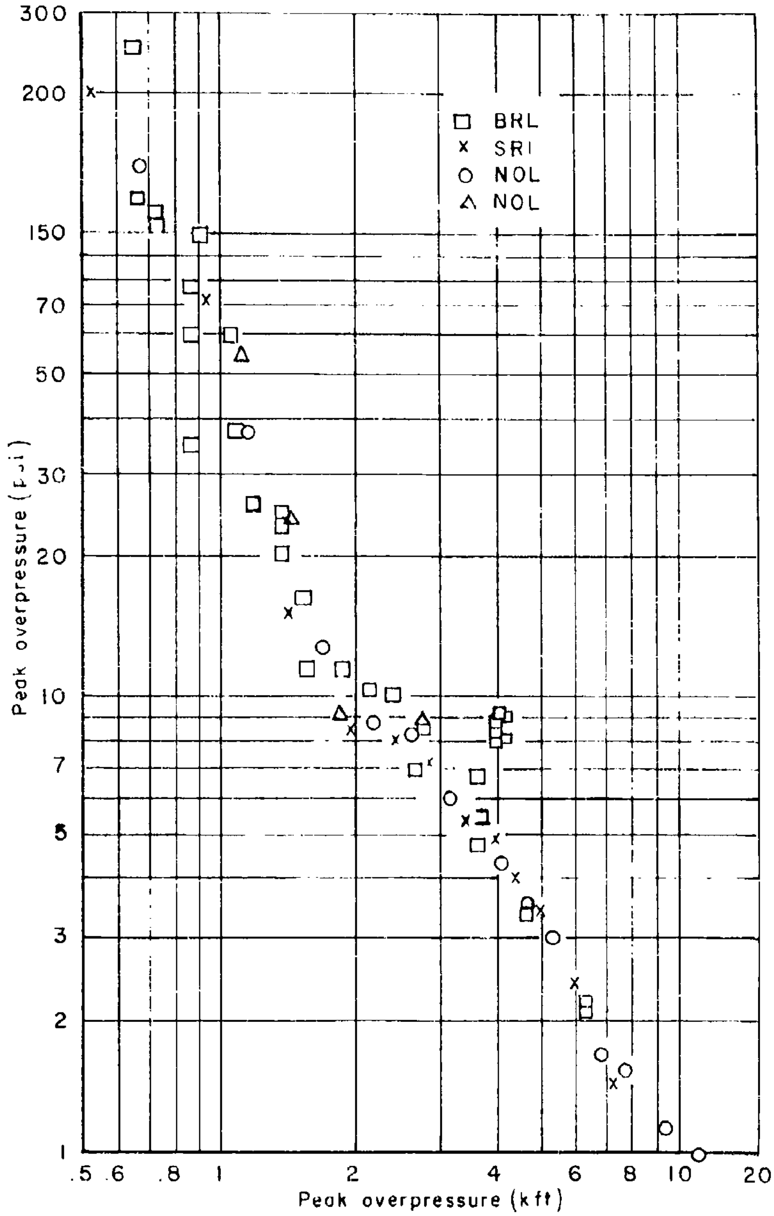

Fig. 6 Peak overpressure data (as observed)
Upshot knothole #10
(Scaled HOB 201 ft)

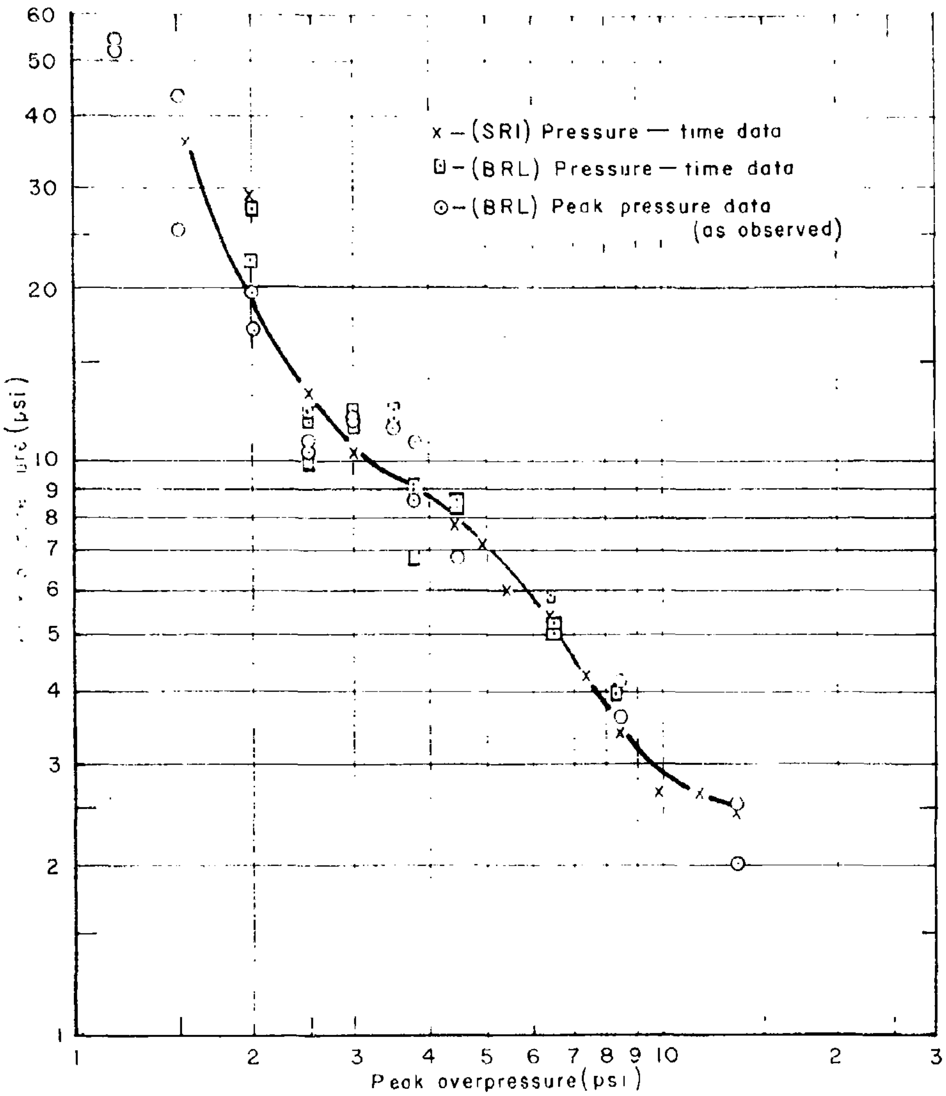

Fig 7. Peak overpressure data
Upshot-knothole shot #11
(Scaled HOB 318')

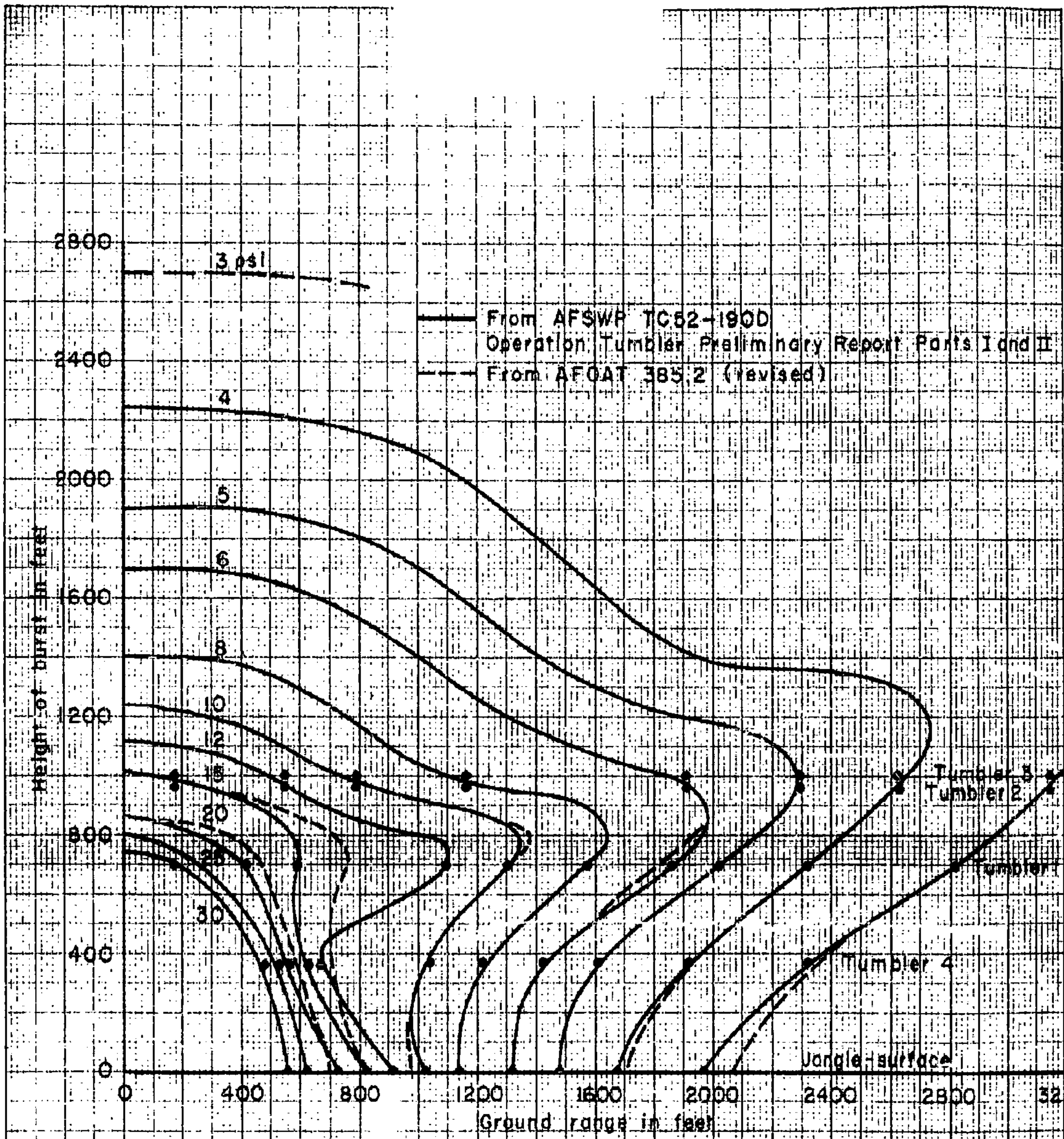

Fig. 8 — Tumbler height of burst curves

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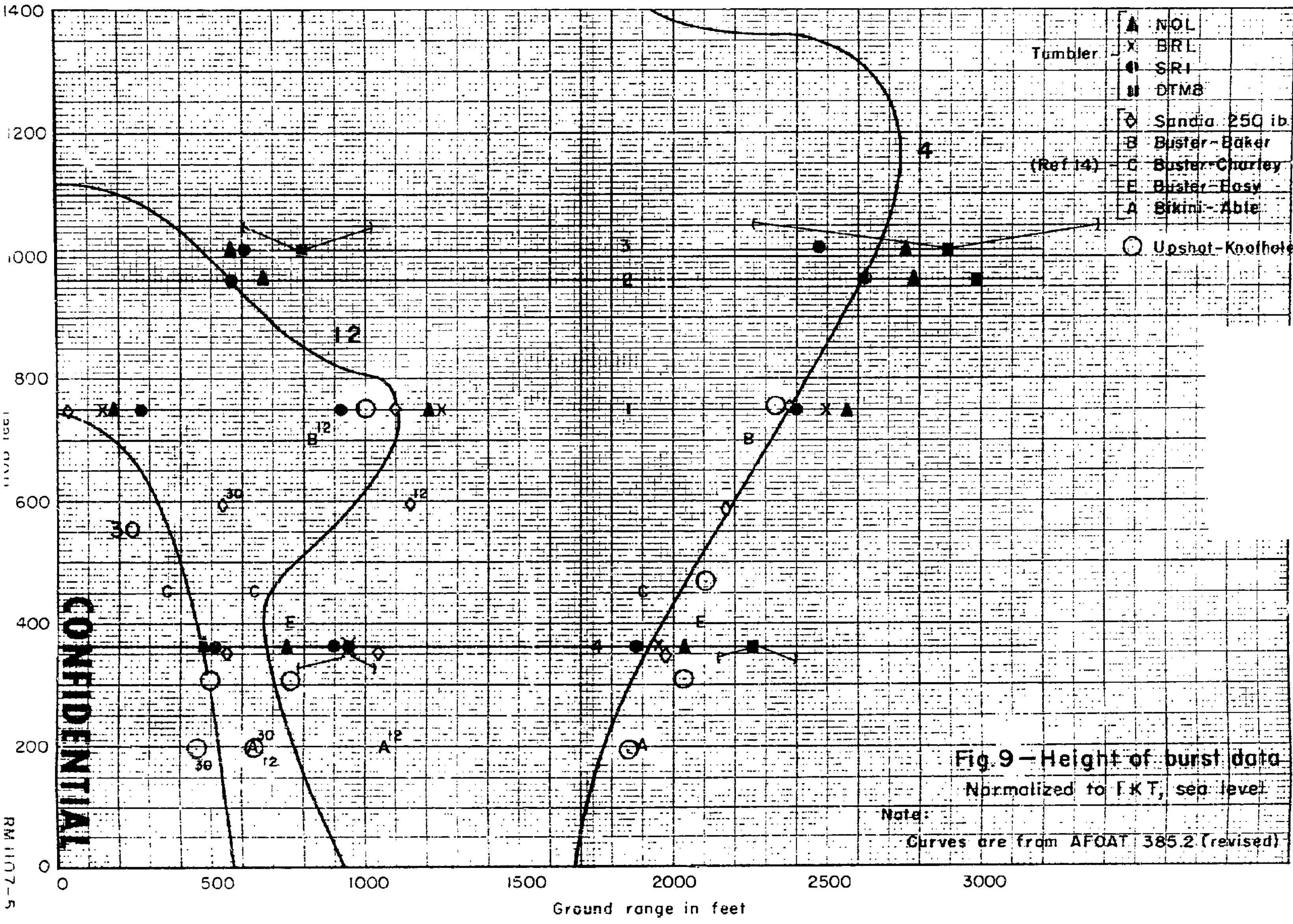

Fig. 9 — Height of burst data
Normalized to 1 KT, sea level

Note:
Curves are from AFOAT 385.2 (revised)

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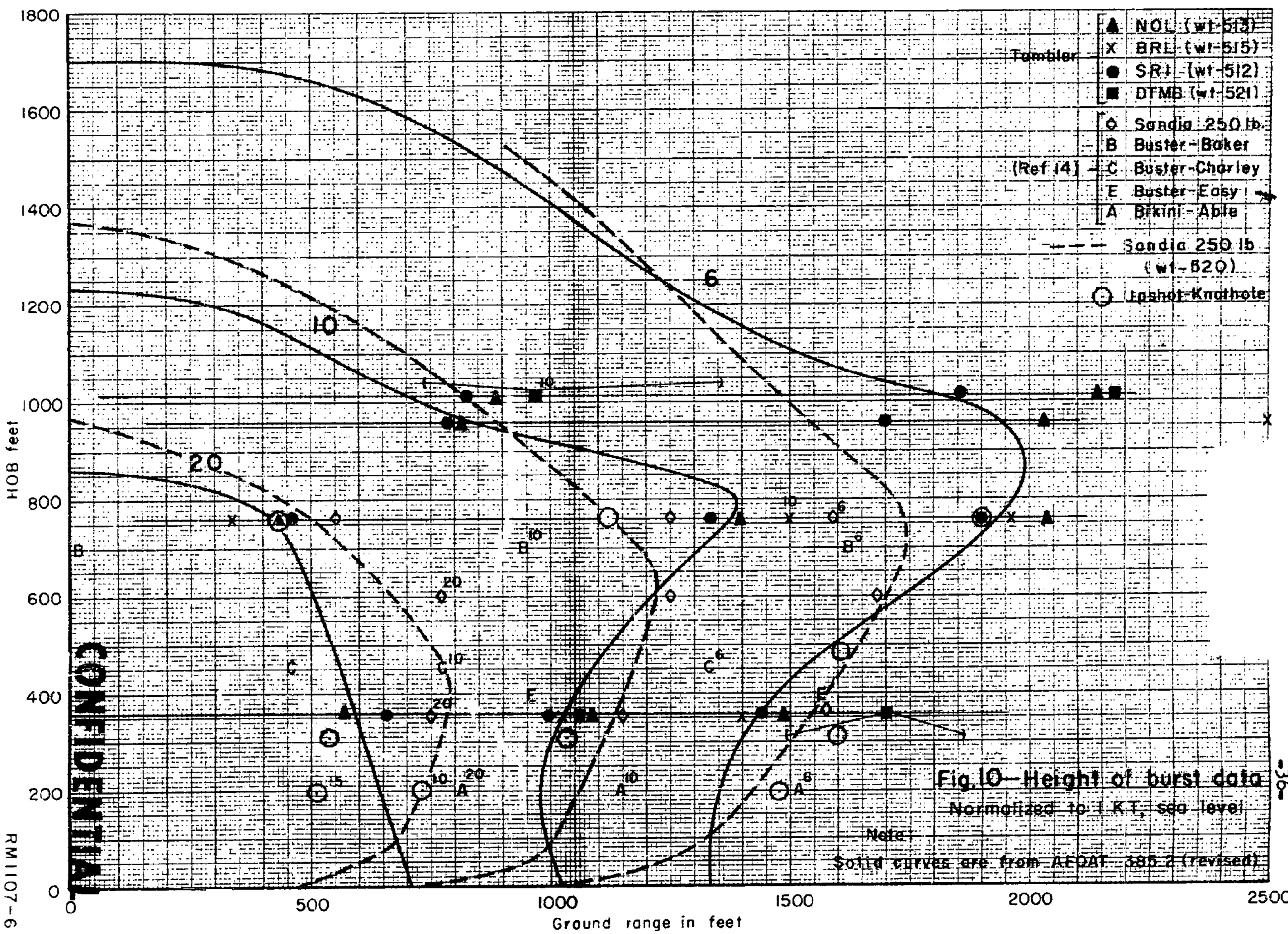

Fig. 10—Height of burst data
Normalized to 1 KT, sea level

Note:
Solid curves are from AECAT 385.2 (revised)

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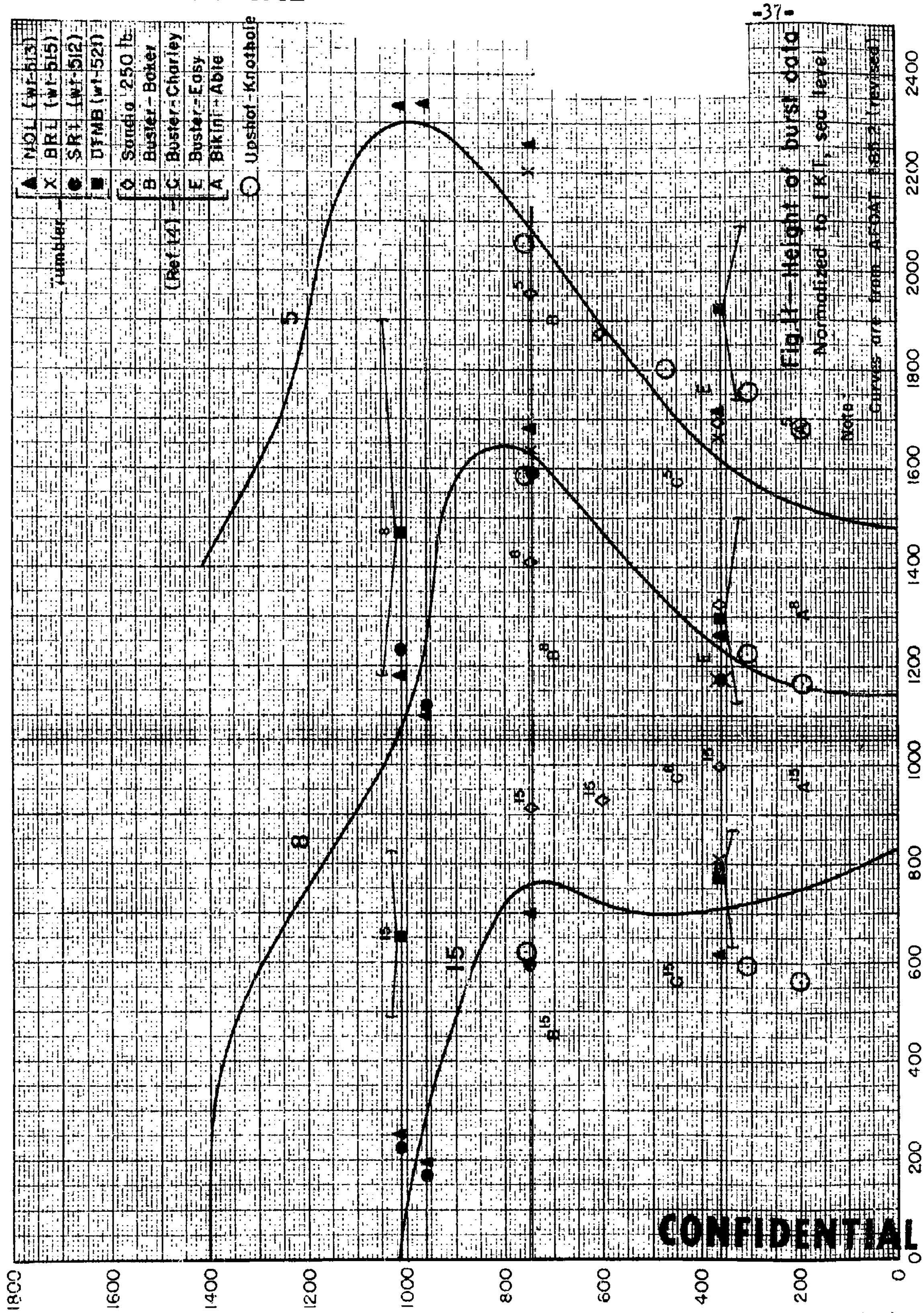

Fig. 11 — Height of burst data
Normalized to 1 KT, sea level

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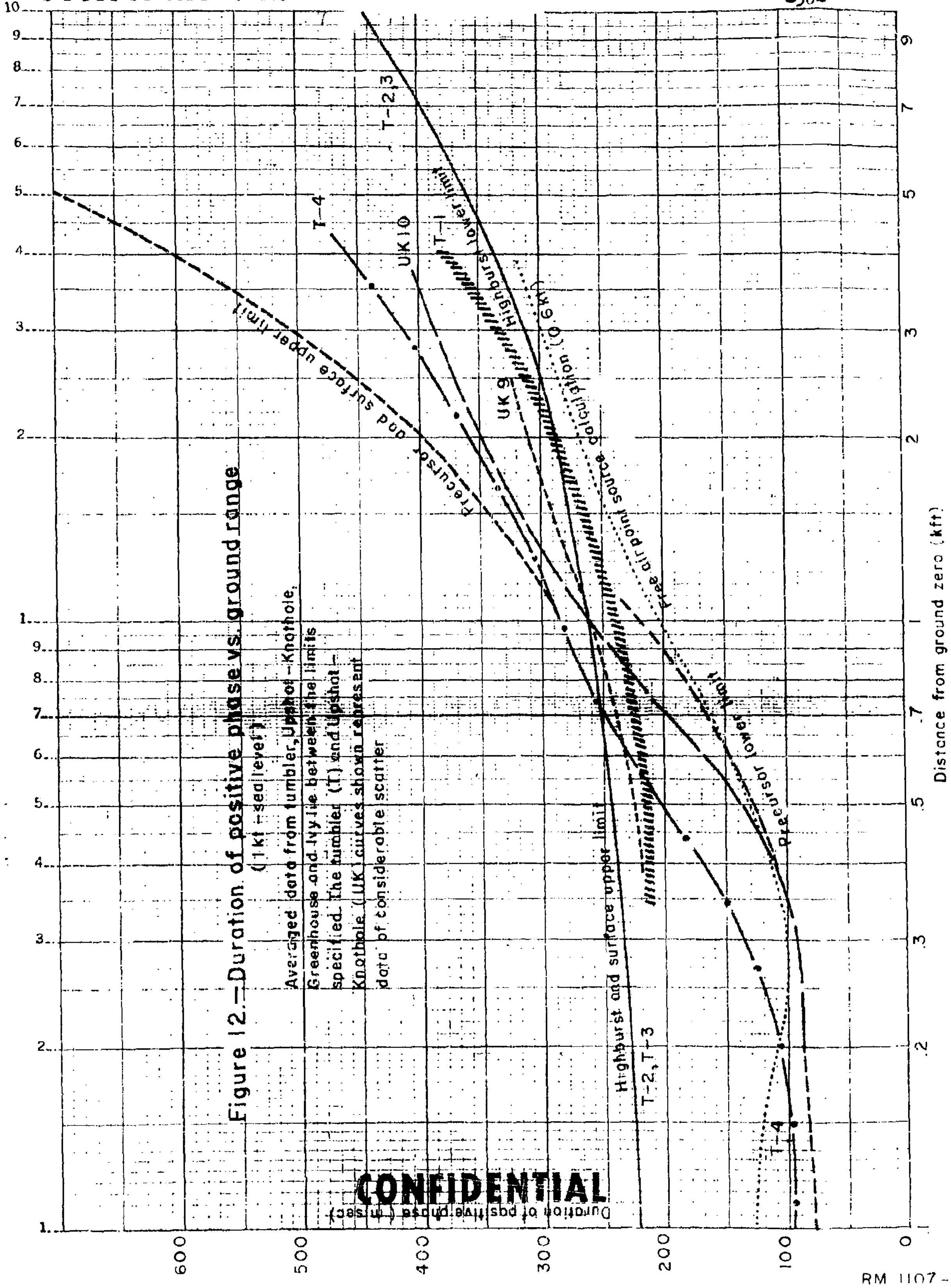

Figure 12.—Duration of positive phase vs. ground range (1 kt—sea level)

Averaged data from Tumbler, Upshot—Knothole. Greenhouse and Ivy lie between the limits specified. The Tumbler (T) and Upshot—Knothole (UK) curves shown represent data of considerable scatter

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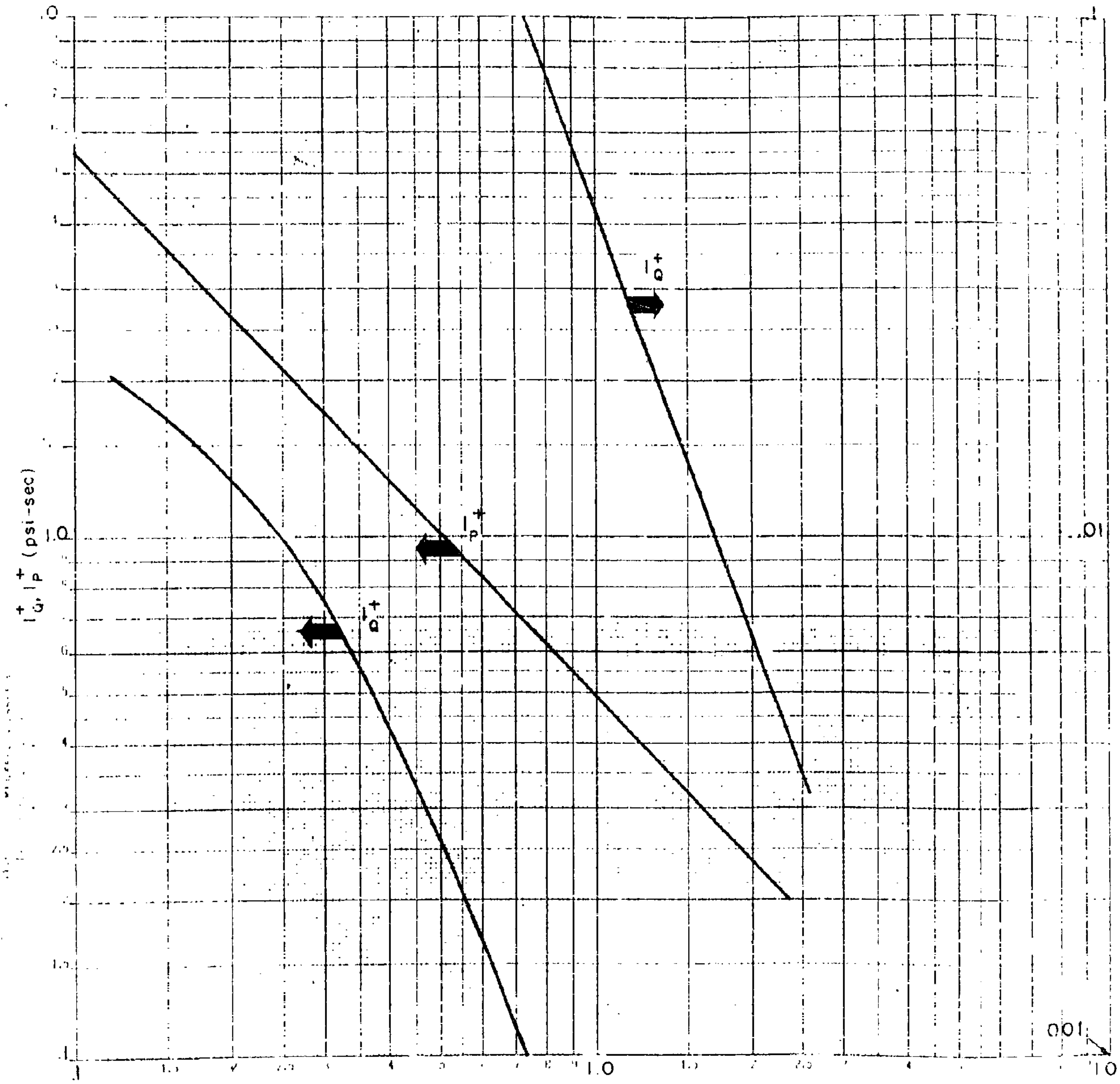

Fig. 13—Impulse from positive phase for overpressure (ΔP) and drag pressure (Q) versus distance
(free air 1 kt) (0.6 kt point source calculation)

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7 September 2004

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SUBJECT: Declassification Review of Rand Reports:

RM-640
Altitude Effects On the Shock Wave From An Atomic Burst (U)
June 29, 1951

RM-1107
Height Of Burst For Atomic Bombs (After Upshot-Knothole) (U)
June 1, 1954

Reviewed both subject reports, they should be downgraded to Unclassified. There is no reason to preclude the public release of these two documents.

Byron L. Ristvet

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DTRA/DTRIAC