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[redacted] BOOK NO. 480 -L

ISSUED BY: Information Division
UCRL Livermore

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SHOT EFFECTS

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Cox, E., "Meteorology Directs Where Blast Will Strike".
(Development for near-ground bursts)

(See also WT-303)

Shock wave velocity

$$\sigma = c\left(1 + 0.857\, p/P\right)^{1/2}. \qquad 1)$$

for $p < 1$ psi: $\sigma = c(1 + 0.428\, p/P)$.

where

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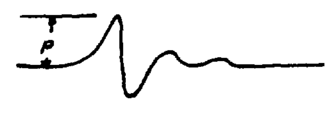
$\sigma \equiv$ shock wave velocity
$c \equiv$ speed of sound
$p \equiv$ peak over-pressure:



$P \equiv$ ambient air pressure

Divergence rapidly reduces peak overpressures, as:

$p \approx 1$ psi 600 ft from one ton TNT on ground.
$p \approx 1$ psi 3.7 mi from 20 KT burst 2000 ft up.

LAplace:

$$c = (\gamma\, P/\rho)^{1/2} = (\gamma\, RK/M)^{1/2}$$

P = ambient press. ρ = density

γ = sp. ht. ratio
R = gas constant
M = mol. wt.
R = gas const.

$$c = 38.98\, K^{1/2} \text{ knots}$$
$$= 65.84\, K^{1/2} \text{ ft/sec} \qquad 2)$$
$$= 20.07\, K^{1/2} \text{ m/sec}$$
$$= 44.89\, K^{1/2} \text{ stat. mi/hr}$$

where $K \equiv$ air temperature, degrees Kelvin: $°C + 273$
$c \equiv$ velocity of sound, still dry air. (humidity correction is small)

For humidity correction use "virtual" temperature

The ensuing developments assume that $\sigma \approx c$.

$$C + u\cos\theta = A\cos\theta \quad \text{(Snell's Law)} \qquad 3)$$

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where $C \equiv$ velocity of sound
$u \equiv$ component of wind velocity in bearing considered.
$\theta \equiv$ inclination of shock ray from horizontal
$A \equiv$ velocity of wave front intersection with horizontal.

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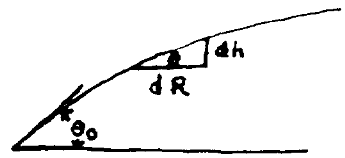
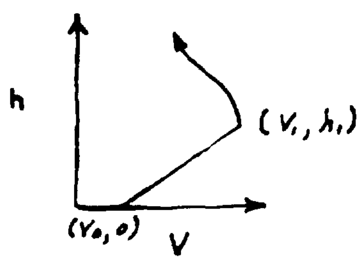
Equation 3) comes from Fermat's principle of least time. $\int \frac{ds}{V} \equiv$ minimal

Derivation of equations 6) and 7):



Because of trajectory symmetry:

$$R/2 = \int_{\theta_0}^{0} \cot\theta \, dh \qquad 5)$$



From inversion diagram, to (h_1, V_1):

$V = C_1 h + C_2$

for $h = 0$, $V = V_0$;

$C_2 = V_0$

$V = C_1 h + V_0$

for $h = h_1$, $V = V_1$;

$C_1 = \frac{V_1 - V_0}{h_1}$

and

$$V = \frac{V_1 - V_0}{h_1} h + V_0 = A \cos\theta \quad \text{from } 4)$$

$$\frac{V_1 - V_0}{h_1} dh = - A \sin\theta \, d\theta$$

$$dh = - \frac{h_1}{V_1 - V_0} A \sin\theta \, d\theta$$

and

$$R/2 = - \frac{h_1 A}{V_1 - V_0} \int_{\theta_0}^{0} \cos\theta \, d\theta$$

$$= \frac{h_1 A}{V_1 - V_0} \sin\theta_0$$

From 4) $A = \frac{V_0}{\cos\theta_0}$

and so

$$R = \frac{2 h_1 V_0}{V_1 - V_0} \frac{\sin\theta_0}{\cos\theta_0} = \frac{2 h_1 V_0}{V_1 - V_0} \tan\theta_0 \qquad 6a)$$

For small θ_0, $\tan\theta_0 \approx \theta_0$

and

$$R = \frac{2 h_1 V_0 \theta_0}{V_1 - V_0} \qquad 6)$$

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3) assumes small θ. A is invariant for any selected sound ray.

For $u \cong 0.10\, c$:

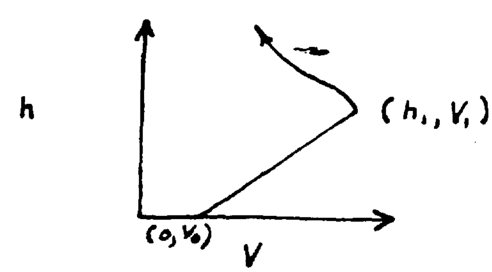
$$c + u = A \cos\theta = V \qquad 4)$$

The horizontal range of the shock wave is:

$$R = 2\int_{\theta_0}^{0} \cot\theta \, dh \qquad 5)$$

where $R \equiv$ range
$\theta_0 \equiv$ initial ray inclination
$h \equiv$ height of ray front above ground

Case I. Simple inversion.



$$R = \frac{2 h_1 V_0 \tan\theta_0}{V_1 - V_0} \approx \frac{2 h_1 V_0 \theta_0}{V_1 - V_0} \qquad 6)$$

$$R_{max} = \frac{2 h_1 (V_1 + V_0)^{1/2}}{(V_1 - V_0)^{1/2}} \approx \frac{2.8\, h_1 V_0^{1/2}}{(V_1 - V_0)^{1/2}} \qquad 7)$$

No focusing

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For R_{max}, $\theta = 0$ (at $R/2$) for $V = V_1$, $h = h_1$

From 4),

$$V \sec\theta = V_0 \sec\theta_0$$

so

$$V_1 = V_0 \sec\theta_0$$

and

$$\sec(\theta_0)_{R_{max}} = \frac{V_1}{V_0}$$

$$(\theta_0)_{R_{max}} = \cos^{-1}\frac{V_0}{V_1}$$

and

$$R_{max} = \frac{2h_1 V_0 \cos^{-1} V_0/V_1}{V_1 - V_0}$$

$$= \frac{2h_1 V_0 \tan\theta_0}{V_1 - V_0} \qquad (6a))$$

$$= \frac{2h_1 V_0 (V_1^2 - V_0^2)^{1/2}}{(V_1 - V_0) V_0}$$

$$= 2h_1 \frac{(V_1^2 - V_0^2)^{1/2}}{V_1 - V_0}$$

$$= \frac{2h_1 (V_1 + V_0)^{1/2}}{(V_1 - V_0)^{1/2}} \qquad 7a)$$

<u>General equation for Case II</u>

$$\frac{R}{2} = \frac{h_1}{V_0 - V_1}\left[(V_0^2\sec^2\theta_0 - V_1^2)^{\frac{1}{2}} - (V_0^2\sec^2\theta_0 - V_0^2)^{\frac{1}{2}}\right.$$

$$\left. - \frac{(h_1 - h_x)}{(V_1 - V_x)}\left[(V_0^2\sec^2\theta_0 - V_x^2)^{\frac{1}{2}} - (V_0^2\sec^2\theta_0 - V_1^2)^{\frac{1}{2}}\right]\right]$$

where x lies between p and z on the V vs h curve.

For grazing ray, $x = p$

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For Level at h_p, $x = z$, $\sec\theta_0 = \frac{V_z}{V_0}$

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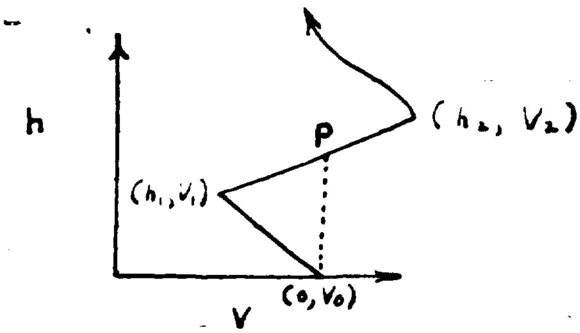
Case II



$$R/2 = \int_{h=0}^{h=h_1} \cot\theta \, dh + \int_{h=h_1}^{h_2 \geq h_0 \geq h_p} \cot\theta \, dh \qquad 8)$$

Grazing:

$$R_1 = 2.8 \; V_0^{1/2} (V_0 - V_1)^{1/2} \left[\frac{h_1}{V_0 - V_1} + \frac{h_2 - h_1}{V_2 - V_1} \right] \qquad 9)$$

Peak at h_2:

$$R_2 = 2.8 V_2^{1/2} \left\{ h_1 \left[\frac{(V_2 - V_1)^{1/2} - (V_2 - V_0)^{1/2}}{V_0 - V_1} \right] + \frac{h_2 - h_1}{(V_2 - V_1)^{1/2}} \right\} \qquad 10)$$

$dR/d\theta = 0$:

$$R_3 = 2.8 \left\{ V_0 (V_0 - V_1) \left[\left(\frac{h_2 - h_1}{V_2 - V_1} \right)^2 + \frac{2 h_1 (h_2 - h_1)}{(V_0 - V_1)(V_2 - V_1)} \right] \right\}^{1/2} \qquad 11)$$

$$(\theta_0)_{R_3} = \tan^{-1} 1.4 \, h_1 \left\{ V_0 (V_0 - V_1) \left[\left(\frac{h_2 - h_1}{V_2 - V_1} \right)^2 + \frac{2 h_1 (h_2 - h_1)}{(V_0 - V_1)(V_2 - V_1)} \right] \right\}^{-1/2} \qquad 12)$$

This gives focusing, with bounds set by one pair of R_1, R_2, R_3.

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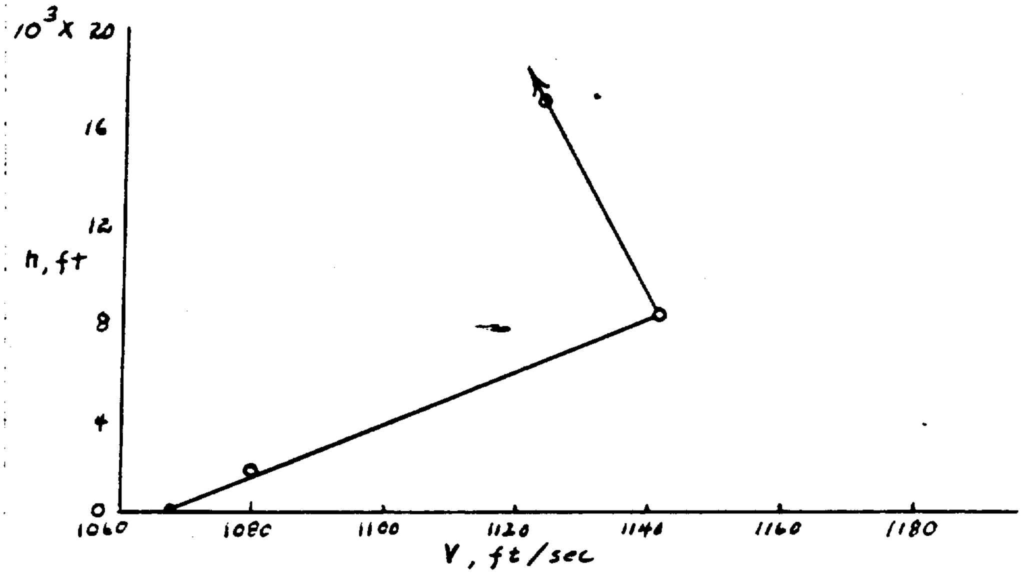
Sample calculation: Ranger B2, Feb. 2, 1951

(This shot broke and removed large plate glass windows in Las Vegas, a distance of ~ 65 miles)

Las Vegas heading ~135°

P	h_{MSL}	h_{gnd}	t	Wind dir	Wind speed	u	K	c	V
909 mb	4000 ft	0 ft	−10.0°c	calm		0	263°K	633 kn	633 kn
855	5700	1700	−2.5	180°	4 kn	−2.8 kn	270.5	642	639
700	11900	7900	1.6	290	30	27.2	274.6	647	674
508	21030	17030	−17.7	305	45	44.4	255.3	623	667



from 7),

$$R_{max} = \frac{2h_1(V_1+V_0)^{1/2}}{(V_1-V_0)^{1/2}} = \frac{2\cdot 7900(1307)^{1/2}}{(41)^{1/2}} = \frac{15800\cdot 36.2}{6.4} = 89200\,ft$$

$$= 17\,mi.$$

For 26):

$W = 7 \times 10^3\, Kt$

$V_1 = 1140\, ft/sec$

$V_0 = 1070\, ft/sec$

$h_1 = 7900\, ft$

$R_f = 65\, mi$

$r = 0.8$

$N = 4$

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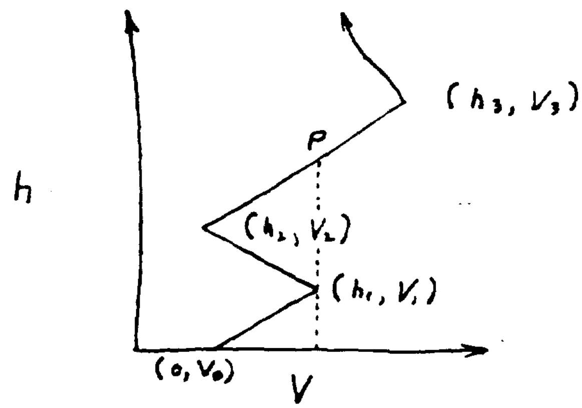
Case III



Apex at h_p:

$$R_1 = 2.8\, V_1^{1/2}\left\{\frac{h_1}{(V_1-V_0)^{1/2}} + \left[\frac{h_2-h_1}{V_1-V_2} + \frac{h_3-h_2}{V_3-V_2}\right](V_1-V_2)^{1/2}\right\} \qquad 13)$$

Apex at h_3:

$$R_2 = 2.8\, V_3^{1/2}\left\{\left[\frac{(V_3-V_0)^{1/2} - (V_3-V_1)^{1/2}}{V_1-V_0}\right] h_1 + \left[\frac{(V_3-V_2)^{1/2}-(V_3-V_1)^{1/2}}{V_1-V_2}\right](h_2-h_1) + \frac{(V_3-V_2)^{1/2}(h_3-h_2)}{V_3-V_2}\right\} \qquad 14)$$

For R_3: Find $(\theta_0)_{min}$ such that:

$$\frac{h_1}{V_1-V_0} - \left[\frac{h_1}{V_1-V_0} + \frac{h_2-h_1}{V_1-V_2}\right]\left[1-\left(\frac{V_1^2}{V_0^2}-1\right)\cot^2(\theta_0)_{min}\right]^{-1/2} \qquad 15)$$

$$+\left[\frac{h_2-h_1}{V_1-V_2} + \frac{h_3-h_2}{V_3-V_2}\right]\left[1-\left(\frac{V_2^2}{V_0^2}-1\right)\cot^2(\theta_0)_{min}\right]^{-1/2} = 0$$

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Then:

$$\xi = -\frac{7\times10^{3}\cdot 4.2\times10^{16}}{4\pi}\cdot\frac{1140-1070}{7900\cdot12^{2}\cdot2.54^{2}\cdot1070\cdot65\cdot5280}\underbrace{\left[\frac{\ln(1-\overset{.5}{.8})}{.8^{.5}}+\frac{\overset{.5}{.8}{}^{0}}{1}+\frac{\overset{.5}{.8}{}^{1}}{2}+\frac{\overset{.5}{.8}{}^{2}}{3}+\frac{\overset{.5}{.8}{}^{3}}{4}\right]}_{-7\times10^{-3}}$$

from which

$$\xi = 4.7\times10^{4}\ \text{ergs/cm}^2$$

$$P = 2\left(\frac{2\times1.3\times10^{-3}\times1.1\times10^{3}\times30.48\times4.7\times10^{4}}{2.3}\right)^{\frac{1}{2}}$$

$$= 2(1.59\times10^{6})^{\frac{1}{2}} = 2\times1260 = \underline{\underline{2520}}\ \mu b$$

<u>Tabular form for complicated cases:</u>

Column	Title
1	Level (j)
2	Height (h_j)
3	V_j
4	$V_j^{2} = (\text{col. } 3)^{2}$
5	$h_{j+1} - h_j = \Delta(\text{col. } 2)$
6	$V_{j+1} - V_j = \Delta(\text{col. } 3)$
7	col. 5 / col. 6
8	$V_p^{2} - V_j^{2} = (\text{col. } 4)_p - (\text{col. } 4)_j$
9	$(V_p^{2} - V_j^{2})^{1/2} = (\text{col. } 8)^{1/2}$
10	Δ col. 9
11	(col. 10) $\times$ (col. 7)

The total horizontal travel distance is $2\sum(\text{col. } 11)$

See page 20 for $(dR/d\theta)_{h=0}$ form.

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Then, if this $(\theta_0)_{min}$ is greater than $\cos^{-1} V_0/V_3$:

R_1 and R_2 give boundaries ... ..

If $(\theta_0)_{min}$ is less than $\cos^{-1} V_0/V_3$ the focused energy lies between R_1 and R_3, where

$$R_3 = 2V_0 \left\{ \frac{h_1}{V_1 - V_0} \tan(\theta_0)_{min} - \left[\frac{h_1}{V_1 - V_0} + \frac{h_2 - h_1}{V_1 - V_2}\right]\left[\sec^2(\theta_0)_{min} - \frac{V_1^2}{V_0^2}\right]^{1/2} \right.$$

$$\left. + \left[\frac{h_2 - h_1}{V_1 - V_2} + \frac{h_3 - h_2}{V_3 - V_2}\right]\left[\sec^2(\theta_0)_{min} - \frac{V_2^2}{V_0^2}\right]^{1/2} \right\} \qquad 16)$$

This gives focusing over a general noise field.

For complicated Cases :

Let subscript j represent the j^{th} level. Then, if p is the level where the ray is horizontal :

$$x_p - x_0 = \sum_{j=0}^{j=p-1} \left[\frac{h_{j+1} - h_j}{V_{j+1} - V_j}\right]\left[\left(V_p^2 - V_j^2\right)^{1/2} - \left(V_p^2 - V_{j+1}^2\right)^{1/2}\right] \qquad 17)$$

where $x_p - x_0$ is $R/2$ for this particular ray.

If $V_{j+1} = V_j$:

$$x_{j+1} - x_j = (h_{j+1} - h_j)\cot\theta_{j+1} = \frac{(h_{j+1} - h_j)\, V_{j+1}}{(V_p^2 - V_{j+1}^2)^{1/2}} \qquad 18)$$

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Use h vs V curve and

$$V \sec\theta = V_0 \sec\theta_0 \qquad \text{(from 4))}$$

to find V's for level ray..

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Derivation of 19)

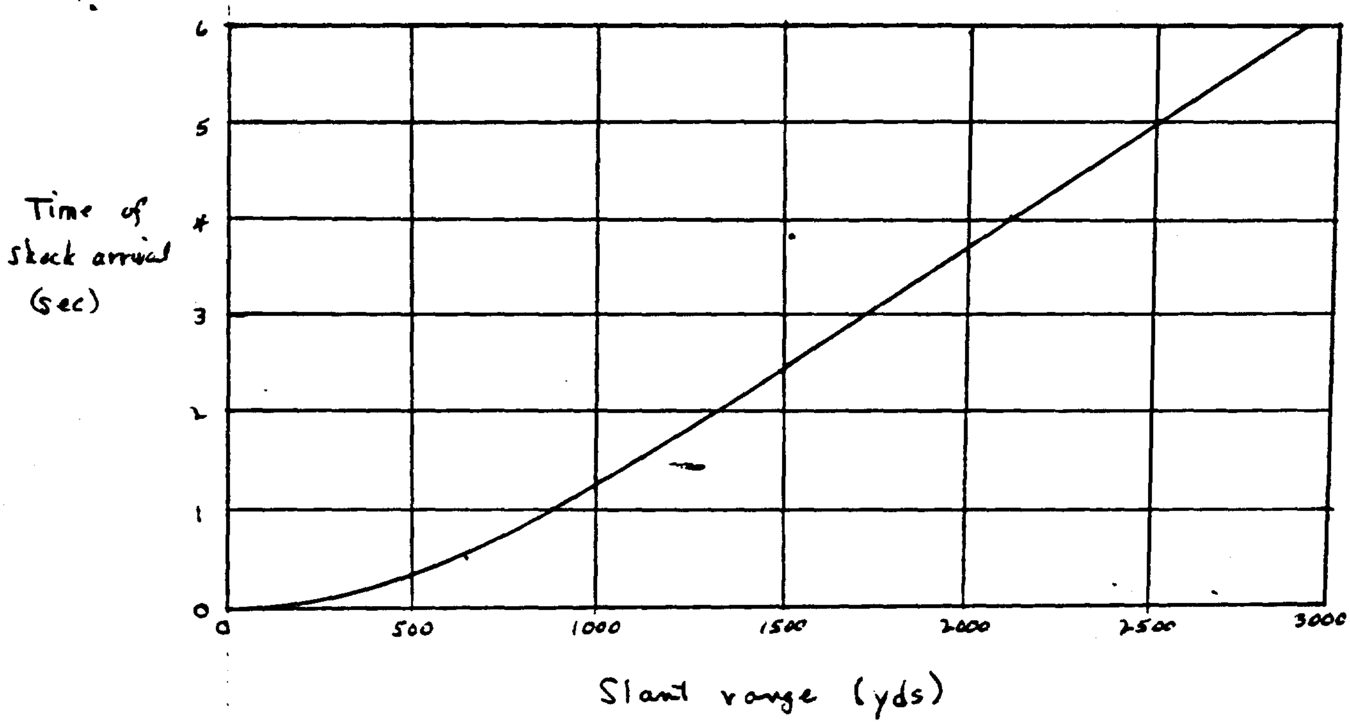
The energy passing through an elemental area of angular depth $d\theta_0$ on the sphere at latitude angle θ_0 and longitude angle ϕ_0:

$$dW = W \cos\theta_0 \cdot d\phi_0 \cdot d\theta_0 / 2\pi$$

from which

$$\rho = \frac{W}{2\pi} \cdot \frac{\cos\theta_0}{R} \cdot \frac{d\theta_0}{dR} \approx 19)$$

Shock wave time of arrival $W = 20 KT$ air burst



At shock wave breakaway time (about 15 ms, $R = 300$ ft) the shock wave velocity is about 15,000 ft p s.

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Damage

Peak-topeak overpressures of $\sim$ ~~8~~ 2 mb will break large plate glass windows. The same at 15 mb will break small windows.

General equation for energy density:

$$\xi \approx \frac{W}{2\pi R} \frac{d\theta_0}{dR} \qquad 19)$$

where $\xi \equiv$ energy surface density
$W \equiv$ energy release of blast = ~~4.2~~ 4.16 $\times 10^{16}$ ergs/ton TNT
$R \equiv$ earth striking distance
θ_0 never large

$$\xi = \int \frac{p_0^2}{\rho V} \, dt \qquad 20)$$

where $p_0 \equiv$ peak-to-peak overpressure $\div$ 2
$\rho \equiv$ air density
$V \equiv$ velocity of shock wave
$t \equiv$ time

The integration extends over the signal duration τ.

If a sinusoidal signal is assumed:

$$\xi = \frac{(p_{o\,rms})^2 \tau}{\rho V} = \frac{p_{peak}^2 \tau}{2 \rho V} \qquad 21)$$

and

$$p = 2 \left(2 \xi \rho V / \tau \right)^{\frac{1}{2}} \qquad 22)$$

where p = peak-to-peak over pressure.

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For reflection of the wave on a rigid surface, peak-to-peek overpressure is twice that given in 22)

[redacted] For 0.3 to 2.4 tons TNT, a good approximation for τ is 1 sec

(For revision of above, see page 21) (2)) 152

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Case I. (simple inversion)

For $R < R_{max}$; from 19) and 6) :

$$\xi = \frac{W(V_1 - V_0)}{4\pi R h_1 V_0} \qquad 23)$$

In general :

$$\xi_{total} = \frac{W}{4\pi R_f} \cdot \frac{V_1 - V_0}{h_1 V_0}\left(1 + \frac{r}{2} + \frac{r^2}{3} + \cdots + \frac{r^{n-1}}{n} + \cdots\right) \qquad 24)$$

where $R_f \equiv$ distance of concern

$r \equiv$ earth reflection coefficient ≈ 0.8, depending upon terrain

See pg 21

then

$$\xi_{total} = \frac{W}{4\pi} \cdot \frac{V_1 - V_0}{h_1 V_0 R_f} \sum_{n=N+1}^{n=\infty} \frac{r^{n-1}}{n} \qquad 25)$$

where $N \equiv$ integral portion of R_f / R_{max}

for calculations :

$$\xi_{total} = -\frac{W}{4\pi} \cdot \frac{V_1 - V_0}{h_1 V_0 R_f}\left[\frac{\ln(1-r)}{r} + \sum_{n=1}^{n=N} \frac{r^{n-1}}{n}\right] \qquad 26)$$

If no wind (inversion only) ; $R_f < R_{max}$;

$$p = 50\left[w(T_1 - T_0)/R_f h_1\right]^{\frac{1}{2}} \text{ mb}$$

where $w \equiv$ pounds TNT

$T_0 \equiv$ surface temperature, °C.

$T_1 \equiv$ inversion level temperature, °C.

R_f and h_1 in feet.

For $R_f > R_{max}$ see reflection coefficient application in 26)

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Derivation of 3)

$$dR = \left[\left(\frac{V_0}{V} \right)^2 - \cos^2\theta_0 \right]^{-\frac{1}{2}} \cos\theta_0 \, dh$$

$$x_{i+1} - x_i = \left(\frac{h_{i+1} - h_i}{V_{i+1} - V_i} \right) \left\{ \left[\left(\frac{V_0}{\cos\theta_0} \right)^2 - V_i^2 \right]^{\frac{1}{2}} - \left[\left(\frac{V_0}{\cos\theta_0} \right)^2 - V_{i+1}^2 \right]^{\frac{1}{2}} \right\}$$

$$\frac{dR_i}{d\theta} = \sum_{i=1}^{p-1} \left(\frac{h_{i+1} - h_i}{V_{i+1} - V_i} \right) \left[\frac{2 V_0/\cos\theta_0 \cdot V_0 \sin\theta_0/\cos^2\theta_0}{+2\sqrt{V_p^2 - V_i^2}} - \left(\frac{\text{same}}{+2\sqrt{V_p^2 - V_{i+1}^2}} \right) \right]$$

$$2 \sum_{i=1}^{p-1} \frac{h_{i+1} - h_i}{V_{i+1} - V_i} \left[\frac{V_0^2 \sin\theta^0}{\cos^3\theta_0} \left(\frac{1}{\sqrt{V_p^2 - V_i^2}} - \frac{1}{\sqrt{V_p^2 - V_{i+1}^2}} \right) \right]$$

$$\sin\theta_0 = \frac{\sqrt{V_p^2 - V_0^2}}{V_p} \qquad \cos\theta_0 = V_0/V_p$$

$$V_0^2 \sin\theta^0/\cos^3\theta_0 = \frac{V_p^2\sqrt{V_p^2 - V_0^2}}{V_0}$$

Thus 3)

Tabular form for $\left(dR/d\theta \right)_{n=0}$

Column	Title
1	Level (i)
2	$m_1 = \frac{h_{i+1} - h_i}{V_{i+1} - V_i}$
3	$\frac{1}{\sqrt{V_p^2 - V_i^2}}$ $(\equiv 0 \text{ for } V_i = V_p)$
4	$\Delta(3)$ $(\equiv +)$
5	$m\,\Delta$
6	$\frac{V_p^2 (V_p^2 - V_0^2)^{\frac{1}{2}}}{V_0}$
7	$2\sum(\text{col } 5)(\text{col } 6) = \left(dR/d\theta \right)_{n=0}$

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Equations and Techniques in Blast Forecasting.
(Jack Reed)

For bursts (nuclear) at or near the ground:

$$P = a\,W^{b}\,R_f^{-\frac{1}{2}}\left(\frac{r^{n}}{n+1}\cdot\left(\frac{d\theta}{dR}\right)_{n=0}\right)^{\frac{1}{2}} \qquad 1)$$

where $P \equiv$ peak-to-peak overpressure in μb
$W \equiv$ yield in KT : $W \geq 1$
$a \equiv 2.65 \times 10^{7}$
$b \equiv 0.27$
$r \equiv$ reflection coef. $\equiv$ .5 (Nevada Proving Ground)
$n \equiv \mathrm{Int}\ {}^{R_f}/R_0 \div 1$
$R_f \equiv$ distance of concern in miles.
r Large for smooth terrain, small for rough terrain.

Experimental pressure periods:

$$\tau = a\,W^{\frac{1}{3}} \qquad 2)$$

where 1) $a = 1.2$ for $1\,KT \leq W \leq 60\,KT$
2) $a = 0.4$ for $W \leq 1T$
$W \equiv$ yield in tons TNT for 2) : KT.TNT for 1)

For any situation:

$$\left(\frac{dR}{d\theta}\right)_{n=0} = \frac{V_p^{2}\sqrt{V_p^{2}-V_0^{2}}}{V_0}\left[2\sum_{i=0}^{p-1}\left(\frac{h_{i+1}-h_i}{V_{i+1}-V_i}\right)\left(\frac{1}{\sqrt{V_p^{2}-V_i^{2}}}-\frac{1}{\sqrt{V_p^{2}-V_{i+1}^{2}}}\right)\right] \qquad 3)$$

where $V_p \equiv$ shock wave speed where ray horizontal

LLNL

For a simple inversion; $R_f \leq R_{max}$

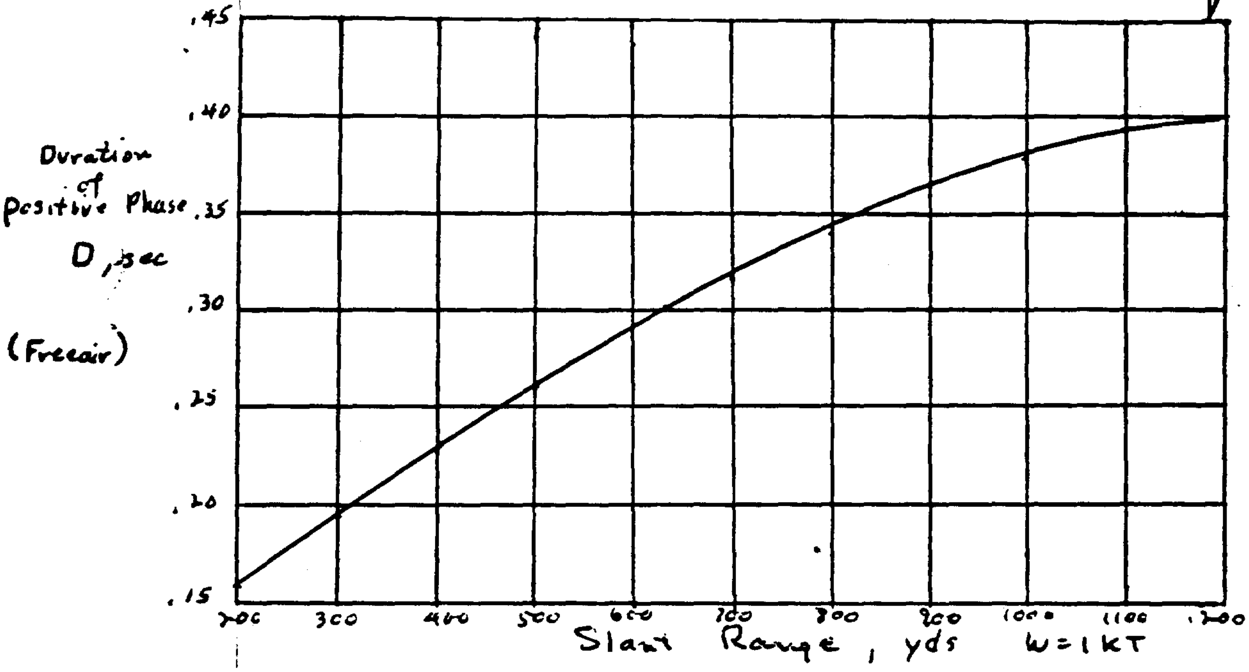
$$\xi = -\frac{W}{4\pi}\cdot\frac{V_1-V_0}{h_1 V_0}\cdot\frac{1}{R_f}\;\frac{\ln(1-r)}{r} \qquad \text{(See 24), pg 19)}$$

1 dyne / $cm^2 \equiv 1\,\mu b$
1 μb corresponds to 42 db over hearing threshold (0.0002 μb)

[redacted]

[redacted]

For 3), 4), + 5), use 3D from graph below, no matter what W is, then multiply equations by $\sqrt{\frac{1.2}{3D}}$



The $\sqrt{\ }$ modification works approximately for ground bursts.

For an air burst

$$P = 18.5 \sqrt{\frac{W}{\tau}}$$

W in KT
τ in sec
P in PSI
R = 300 yds

$$P = \frac{5550}{R} \sqrt{\frac{W}{\tau}}$$

W KT
τ sec
P PSI
R yds

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None of the equations given here and on page 23 seem to account for the over-pressures as quoted in TM 23-200. τ is probably in doubt.

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$\underline{\underline{\tau}} = 1.156 \times 10^{-6} W^{\frac{1}{3}}$ $\quad W \leq 1$ ton $\quad$ 1)

where $W \equiv$ yield in ergs

$$\underline{\underline{P}} = \frac{\overset{1183}{\cancel{374}}\, W^{\frac{1}{3}}}{r} \qquad \text{(Shot on surface)} \qquad 2)$$

where $W \equiv$ yield in ~~ergs~~ pounds TNT $\quad W \leq 1$ ton.
$r \equiv$ distance in miles
$P \equiv$ peak-to-peak pressure in μb.
This does not account for change of τ with time.
(homogoneous Atmosphere)

Sound traveling over different paths will have different transit times and result in more than one "boom". This will be the case when winds are present.

For $W \geq 1$ KT (Ground burst)

$$P = \frac{1183\, W^{\frac{1}{3}}}{r}\left(\frac{.4}{1.2}\right)^{\frac{1}{2}} = \frac{682\, W^{\frac{1}{3}}}{r} \qquad 3)$$

W in lbs
r in miles

For an air burst, $W \geq 1$ KT

$$P = \frac{482\, W^{\frac{1}{3}}}{r} \qquad 4)$$

W in lbs
r in miles
P in μb.

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$$P = \frac{6.07 \times 10^{4}\, W^{\frac{1}{3}}}{r} \qquad 5)$$

W in KT
r in miles
P in μb

The above 3 formulae must be multiplied by $\sqrt{\frac{1.2\,[redacted]\,W^{1/3}}{30\,[redacted]}}$ 158
for $D \leq 3600$ ft. See page 22 for 1kT.

[redacted]

[redacted]

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Precursor Effect

TM 23-200
(Oct. 1952)

For relatively Low burst heights:

1) Earth absorbs much thermal energy
2) Surface rapidly reaches several thousand degrees
3) Surface undergoes explosive decomposition
4) Decomposition products expelled to surface air (100')
5) Surface air layer absorbs radiant energy

As a result of these energy transfers, either independent of or in conjunction with the incident blast wave:

1) A precursor pressure wave is formed
2) It precedes incident wave along the surface
3) Picks up surface material
4) Surface material fed into following incident and reflected waves

Resulting in:

1) Longer rise times in main shock wave
2) Lower peak pressures " " " "

The effect disappears at some critical distance and shock wave resumes its normal shape.

Scaling Laws and mechanism unknown

For 1) dry, dusty soil
2) Nominal bomb burst
3) burst height 1,040'
the critical distance is 2500'

Development of precursor effect unknown for other terrain conditions.

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Frank Willig' would expect a precursor effect for burst on water as well as on land.

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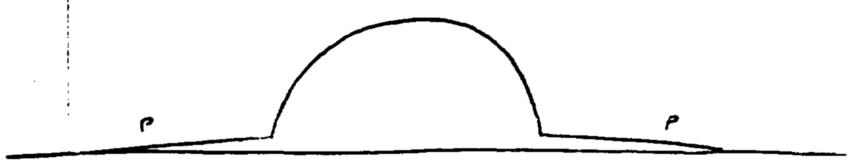
Precursor profile.



The precursor exerts a force normal to its surface (upward). This results in more damage than would be expected on moveable objects such as tanks.

The precursor will proceed only as far as strong heating has occured.

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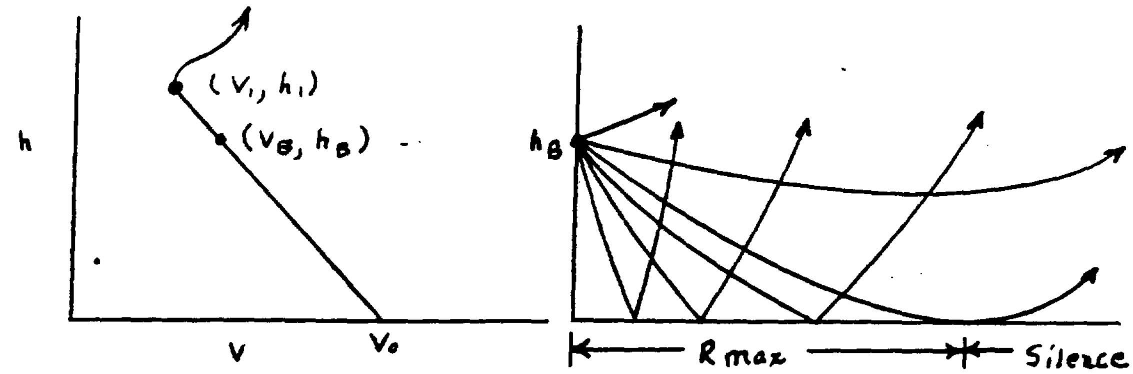
"Damaging Air Shocks at Large Distances from Explosions"

Case I. Explosion in the Air.



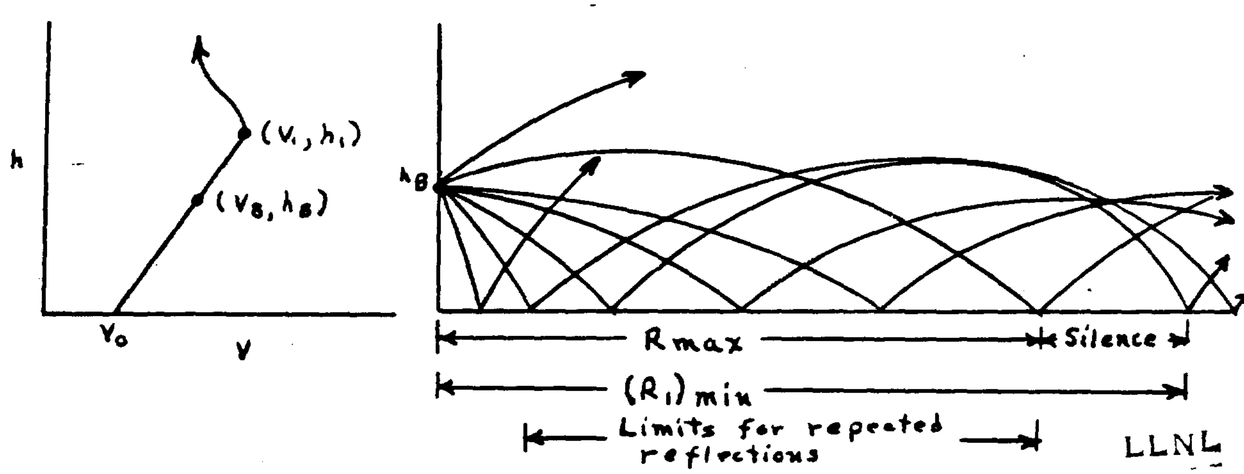
$$R_{max} = h_B \left(\frac{V_0 + V_B}{V_0 - V_B} \right)^{\frac{1}{2}} \qquad 1)$$

Energy striking the ground in the direction of interest is contained within the initial angle

$$\pi/2 - \cos^{-1}\left(V_B/V_0\right) \qquad 2)$$

This theory will hold for receiving stations Located at great distances with respect to h_B.

Case II. Explosion in the air.



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Energy striking the ground <u>once</u> is that included in the angle

$$\pi/2 + \cos^{-1}(V_B/V_1) \qquad 3)$$

Only that included between $+\cos^{-1}(V_B/V_1)$ and $-\cos^{-1}(V_B/V_1)$ is repeatedly reflected.

$$R_{max} = \frac{h_1}{V_1 - V_0}\left[(V_1^2 - V_0^2)^{1/2} + (V_1^2 - V_B^2)^{1/2}\right] \qquad 4)$$

For rays which undergo repeated reflections:

$$R_{\text{first strike}} = \frac{h_1 V_0}{V_1 - V_0}\left[\tan\theta_0 \pm \left(\sec^2\theta_0 - \frac{V_B^2}{V_0^2}\right)^{1/2}\right] \qquad 5)$$

where + goes with rays starting in the upper quad.

After n reflections a ray starting in the lower quadrant lands at

$$R_n = \frac{h_1 V_0}{V_1 - V_0}\left[(2n+1)\tan\theta_0 - \sqrt{\sec^2\theta_0 - V_B^2/V_0^2}\,\right] \qquad 6)$$

$$(\tan\theta_0)_{min\ R_n} = \frac{\sqrt{V_B^2 - V_0^2}}{2V_0} \cdot \frac{2n+1}{\sqrt{n(n+1)}} \qquad 7)$$

$$(R_n)_{min} = \frac{2h_1\left[n(n+1)(V_B^2 - V_0^2)\right]^{\frac{1}{2}}}{V_1 - V_0} \qquad 8)$$

n zones of silence will exist, where n is the lowest integer satisfying the inequality:

$$2\sqrt{V_B^2 - V_0^2}\,\sqrt{n(n+1)} \geq (2n-1)\sqrt{V_1^2 - V_0^2} + \sqrt{V_1^2 - V_B^2} \qquad 9)$$

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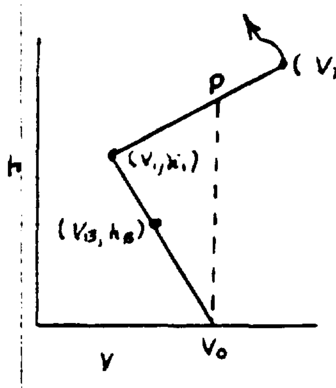
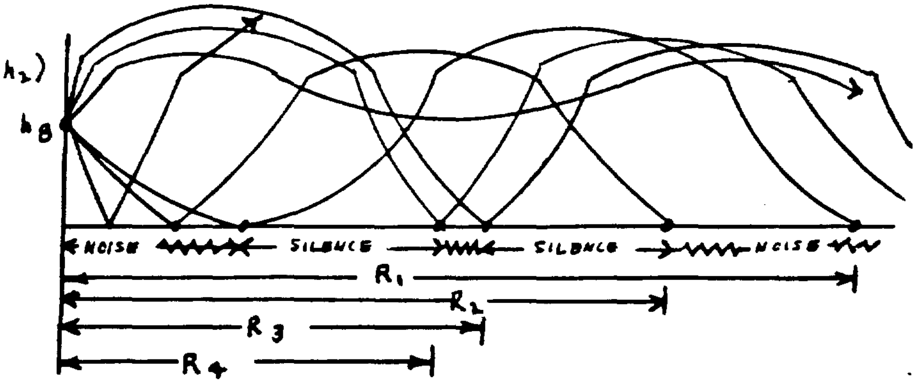
Case III. Explosion in the air.





Rays with $+\cos^{-1} V_B/V_0 \geq \Theta_0 \geq -\cos^{-1} V_B/V_0$ are channeled and never strike the ground or travel higher than h_P.

Downward starting energy which strikes the ground initially is contained within the angle

$$\pi/2 - \cos^{-1} V_B/V_0$$

Energy such that $\cos^{-1} V_B/V_0 \geq \Theta_0 \geq -\cos^{-1} V_0/V_2$ will undergo repetitive reflection

Of the energy starting up ward, that for which

$$\cos^{-1} V_B/V_0 \geq \Theta_0 \geq \cos^{-1} V_0/V_2$$

Strikes the ground and is repetively reflected.

Focusing takes place.

Landing distances:

1) $\Theta_0 = -\cos^{-1} V_B/V_0$, after n reflections:

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$$R_1 = n(R_1)_{Eq\,9)\,p\,11} + h_B\left[\frac{V_0+V_B}{V_0-V_B}\right] \qquad 10)$$

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2) $\theta_o = -\cos^{-1} V_B/V_2$ after n reflections:

$$R_2 = n(R_2)_{Eq\ 10)\ p11} + \frac{h_1}{V_0 - V_1}\left[\sqrt{V_2^2 - V_B^2} - \sqrt{V_2^2 - V_0^2}\right] \qquad 11)$$

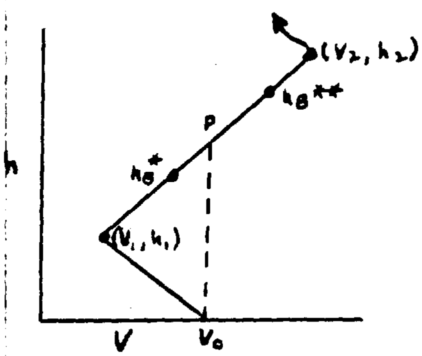
3) $\theta_0 = \cos^{-1} V_B/V_0$ after n reflections:

$$R_3 = (n+1)(R_1)_{Eq\ 9)\ p11} - \frac{h_1}{V_0 - V_1}\left[V_0^2 - V_B^2\right]^{\frac{1}{2}} \qquad 12)$$

4) $\theta_0 = \cos^{-1} V_B/V_2$ after n reflections:

$$R_4 = (n+1)(R_2)_{Eq\ 10)\ p11} - \frac{h_1}{V_0 - V_1}\left[V_2^2 - V_B^2\right]^{\frac{1}{2}} \qquad 13)$$

Case IV. Explosion in the air.



For h_B^*:

1) $\theta_0 = -\cos^{-1} V_B/V_0$ after n reflections

$$R_1 = (n+\tfrac{1}{2})(R_1)_{Eq\ 9)\ p11} - \frac{h_2 - h_1}{V_2 - V_1}(V_0^2 - V_B^2)^{\frac{1}{2}} \qquad 14)$$

2) $\theta_0 = -\cos^{-1} V_B/V_2$ (apex h_2) after n reflections

$$R_2 = (n+\tfrac{1}{2})(R_2)_{Eq\ 10)\ p11} - \frac{h_2 - h_1}{V_2 - V_1}(V_2^2 - V_B^2)^{\frac{1}{2}} \qquad 15)$$

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3) $\theta_0 = \cos^{-1} \frac{V_B}{V_0}$ (apex h_P) after n reflections

[redacted]

$$R_3 = (n+\tfrac{1}{2})(R_1)_{Eq\ 9)\ p11} + \frac{h_2 - h_1}{V_2 - V_1}(V_0^2 - V_B^2)^{\frac{1}{2}} \qquad 16)$$

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4) $\bar{\theta}_0 \doteq \cos^{-1} V_B/V_2$ (apex h_2) after n reflections

$$R_4 = (n+\tfrac{1}{2})(R_2)_{Eq\,10)\,pH} + \frac{h_2-h_1}{V_2-V_1}\left(V_2^2 - V_B^2\right)^{\frac{1}{2}} \qquad 17)$$

For h_B^{**}:

15) and 17) valid

Replace 14) and 16) by:

$\theta_0 = 0$ after n reflections

$$R_5 = (n+\tfrac{1}{2})\left\{\left[\frac{h_1}{V_0-V_1} + \frac{h_2-h_1}{V_2-V_1}\right]\left(V_B^2-V_1^2\right)^{\frac{1}{2}} - \frac{h_1}{V_0-V_1}\left(V_B^2-V_0^2\right)^{\frac{1}{2}}\right. \qquad 18)$$

General ray picture similar to Case III.

For a ray tracing method using RAOB see

Rothwell, P. J., J. Acoust. Soc. Amer. 19, 205 (1947)

Damage: air bursts.

$$\xi = \frac{W}{4\pi}\,\frac{\cos\theta_B}{R}\,\frac{d\theta_B}{dR} \qquad 19)$$

For Case I page 31:

$$R = \frac{h_1 V_0}{V_1 - V_0}\left[\frac{V_B}{V_0}\tan\theta_B - \left(\frac{V_B^2}{V_0^2}\sec^2\theta_B - 1\right)^{\frac{1}{2}}\right] \qquad 20)$$

thus

$$\xi = \frac{W\sin\theta_0\cos^2\theta_0}{4\pi R^2}\left(\frac{V_B}{V_0}\right)^2 \qquad 21)$$

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Near ground zero: $\sin\theta_0 \approx 1$, $\cos\theta_0 \approx R/h_B$

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$$\xi_{max} = \frac{W}{4\pi}\left(\frac{V_B}{V_0}\right)^2\frac{1}{h_B^2} \qquad 22)$$

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Near R'_{max} $\quad \sin\theta_0 \approx \theta_0, \quad \cos\theta_0 \approx 1$

$$\xi_{limit} = \frac{W}{4\pi}\left(\frac{V_\theta}{V_0}\right)^2 \frac{\theta_0}{R_{max}^2} \qquad 23)$$

Pre-shot NPG 1.2 & 0.6 Ton TNT pressures.

Roughly: shot safety if p below average, danger if above average.

1.2 ton TNT , Troposhere

P, μb Distance, miles

Distance →	37	41	77	81	88	91	99	135
Pmax →	195	743	767	24	110	22	86	17
Pmin →	1	6	1.7	1.7	1	1.5	1.2	0.8
Pave →	30	15	20	7	30	7	13	4

1.2 ton TNT Ozonosphere

Distance →	77	81	88	91	99	135
Pmax →	4	5	12	100	740	60
Pmin →	1.3	1.5	1.3	1.5	0.6	0.5
Pave →	2.5	2.3	4.5	7	6	12

← Party ionosphere (Below 4 μb)

0.6 ton TNT

Distance →	24	37	67	78	81	88	91	99	135
Pmax →	14	11	8	6	11	12	8	1.8	22
Pmin →	4	1.3	0.5	0.7	0.7	0.4	0.4	0.7	0.4
Pave →	9	5	1.0	1.8	2.0	1.0	2.0	1	4.0
	Trop.	Trop.	Trop	.5 Trop .5 ozon	.8 ozon,	.8 ozon	.8 ozon	.8 ozon	½ ozon. ½ ion.

At 135 mi: LLNL

Troposphere sound travel time ~ 645 sec.
Ozonosphere " " " ~ 730 sec.
Ionosphere " " " ~ 900 sec.

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Stoke's Law

$$v = \frac{2}{9}\left(\frac{g r^2}{\eta}\right)(\rho - \rho_m)\left(1 + A\frac{L}{r}\right) \qquad 1)$$

where

$v \equiv$ rate of fall
$g \equiv$ acceleration of gravity
$r \equiv$ radius of drop
$\eta \equiv$ coefficient of viscosity
$\rho \equiv$ particle density
$\rho_m \equiv$ air density
$L \equiv$ mean free path
$A \equiv$ experimental constant, important for $L \geq r$
(See Millikan, "Electrons, Prot., Phot, Neut, Mesons, + Cos. Rays." U of Chi Press.)

$$L = 1.145\,\frac{\eta}{p}\sqrt{\frac{T}{M}} \times 10^4 \qquad (= \lambda) \qquad 2)$$

where

$L \equiv$ mean free path in cm
$\eta \equiv$ coefficient of viscosity
$p \equiv$ pressure in μb
$T \equiv$ absolute temp.
$M \equiv$ molecular weight.

$$\frac{\eta_T}{\eta_0} = \frac{1 + C/T_0}{1 + C/T}\sqrt{\frac{T}{T_0}} \qquad 3)$$

where

$\eta \equiv$ coefficient of viscosity
$C \equiv$ 112 for air
$T \equiv$ absolute temperature

For $T = 25°C$; $\eta = 1.845 \times 10^{-4}$ cgs

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Time Of Fall Graph Data

Level	Top Height	$\overline{\eta}$	$\overline{T}$ °K
1	40,000	1.440×10^{-4}	218.4
2	35,000	1.496×10^{-4}	229.1
3	30,000	1.552×10^{-4}	239.7
4	25,000	1.602×10^{-4}	250.3
5	20,000	1.664×10^{-4}	260.9
6	15,000	1.716×10^{-4}	271.5
7	10,000	1.768×10^{-4}	282.1
8	5,000	1.820×10^{-4}	291.7

$v = \dfrac{7.72 \times 10^{-4}\, r^2}{\eta}$ r in μ, v in ft/hr

Temp. Surface 25°C

Temp Tropopause −60°C

Height Tropopause 40,000 ft.

Particle density 3 g/cm^3

Steady temp. fall-off surface to 40,000'.

Level	Top	V r=0.5	V r=2.5	V r=5	V r=6	V r=8	V r=12.5	V r=25	V r=37.5	V r=50	V r=100	V r=17.5
1	40000	1.34	33.5	134	192	343	837	3350	7540	13400	53600	1630
2	35000	1.29	32.2	129	186	330	807	3220	7270	12900	51700	1580
3	30000	1.24	31.0	124	179	318	776	3100	6980	12400	49700	1520
4	25000	1.20	30.1	120	173	308	752	3010	6770	12000	48200	1470
5	20000	1.16	29.0	116	167	296	723	2900	6520	11600	46300	1420
6	15000	1.12	28.1	112	162	288	702	2810	6330	11200	44900	1380
7	10000	1.09	27.3	109	157	279	681	2730	6140	10900	43710	1340
8	5000	1.06	26.5	106	153	271	661	2650	5970	10600	42400	1300

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Values of v are given for Stokes-Cunningham equation in the Chemical Engineer's Handbook. They do not differ more than ~10% from those calculated from Stokes Law.

Brownian effect: Temp. 70°F, air.

Particle Size	Brownian v	Stokes v
0.1µ	29.4 µ/sec	1.73µ/sec
0.25µ	14.2µ/sec	6.30µ/sec
0.50µ	8.92µ/sec	19.9µ/sec
1.00µ	5.91µ/sec	69.6µ/sec

Stoke's Law commences to fail somewhere above 100µ particle size.

From R-251-AEC: (Used in fall-out calculations)

$$v = \frac{g\rho D^2}{18\eta}\left[1+\left(1.644+0.552\,e^{-0.656\,d/\lambda}\right)\frac{\lambda}{d}\right]$$

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"Criteria for Future Continental Tests." (from CIL-5888) (vol 2)

Peak Infinity Dose

For shots on 300 ft. towers: (NPG)

$$\frac{5D}{W} = \frac{\Delta V}{\Delta h} \qquad 1)$$

where

$D \equiv$ Peak infinity dose in roentgens

$W \equiv$ Yield in kilotons

$\Delta V \equiv$ difference in wind speed between cloud top and 10,000 ft MSL in ~~[illegible]~~ knots

$\Delta h \equiv$ difference between effective cloud height (5000 ft. below top) and 10,000 ft. MSL in kilofeet

10,000 ft level chosen as being above terrain effects and light and variable lower winds.

Record of equation application:

Shot →	TS-5	TS-6	TS-7	TS-8	Uk-1	Uk-2	Uk-6	Uk-7	Uk-9
Yield, kT →	13	12	17	17	18	24	27	56	32
Max. Speed Shear, knots →	60	30	25	20	68	25	51	40	55
Max. Direction Shear, degrees →	40	180	30	170	20	80	50	20	100
Speed, cloud top, knots →	100(?)	35	50	45	70	38	46	45	77
Speed, 10,000 ft. MSL, knots →	35	10	15	20	25	12	15	7	20
Effective cloud height, kft. →	29	37	30	37	37	37	32	38	39
Measured dose, R →	(15)	(2)	(6)	(3)	6	5	7	15	12.5
Dose, equation 1), R →	9.0	2.2	6.0	3.1	6.0	4.6	26	14.1	12.6

To account for $\Delta V = 0$ a small (very) constant term should be added to 1).

Prediction accuracies:

Yield : 20%

Δh : 5%

ΔV : 20%

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[redacted]

[redacted]

[redacted]

The most critical direction is in the region between St. George and Cedar City to the northeast and Las Vegas to the southeast.

Cloud Height.

At NPG under usual conditions the cloud will reach the tropopause for $W \geq 10 kT$.

For $1 kT \leq W \leq 10 kT$:

$$h_1 = 17 + 2.16\, x_1 - 5.43\, x_2 + 0.34\, x_3 \qquad 2)$$

For $10 kT \leq W \leq 30 kT$

$$h_2 = 14.2 + x_1/3 - x_2/3 - x_3/4 + 0.7\, x_4 \qquad 3)$$

where

$h_1 \equiv$ height of cloud top in kilofeet above burst height
$h_2 \equiv$ height of cloud top in kilofeet above MSL
$x_1 \equiv$ yield in kilotons
$x_2 \equiv$ mean lapse rate in degrees C between 600 and 400 mb taken at 50 mb intervals. (°C/kft)
$x_3 \equiv$ mean wind speed in knots from burst height to estimated top of cloud (requires successive approximation)
$x_4 \equiv$ forecast height of tropopause in kilofeet.

3) applies if 2) predicts above tropopause, in which case 2) is not applicable.

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Hot-Spot Forecasting.

Have in past followed 125μ particle down from mean height of puff. Present evidence indicates 125μ may be too large. Size may be a function of speed gradient of forecast winds.

In forecasting hot-spot, favor near edge of range if high speed gradient, favor far edge of range if low speed gradient.

Average range error = 10% } Exclusive of forecast
Average direction error = 10° } wind errors.

Average deviation from forecast wind direction = 15%
Average deviation from forecast wind speed ~10%

Problem is being studied by Dr. Machta, USWB.

General Tower Shot Conclusions

Three kT has never given more than D = 3.

Weather is more important than yield in effect on D.

Effects of Burst Height.

If the burst is off the ground (fireball does not reach ground), off site contamination is zero or 2-3 magnitudes down from ground bursts.

Main effect is amount and time of ground mixing with fireball.

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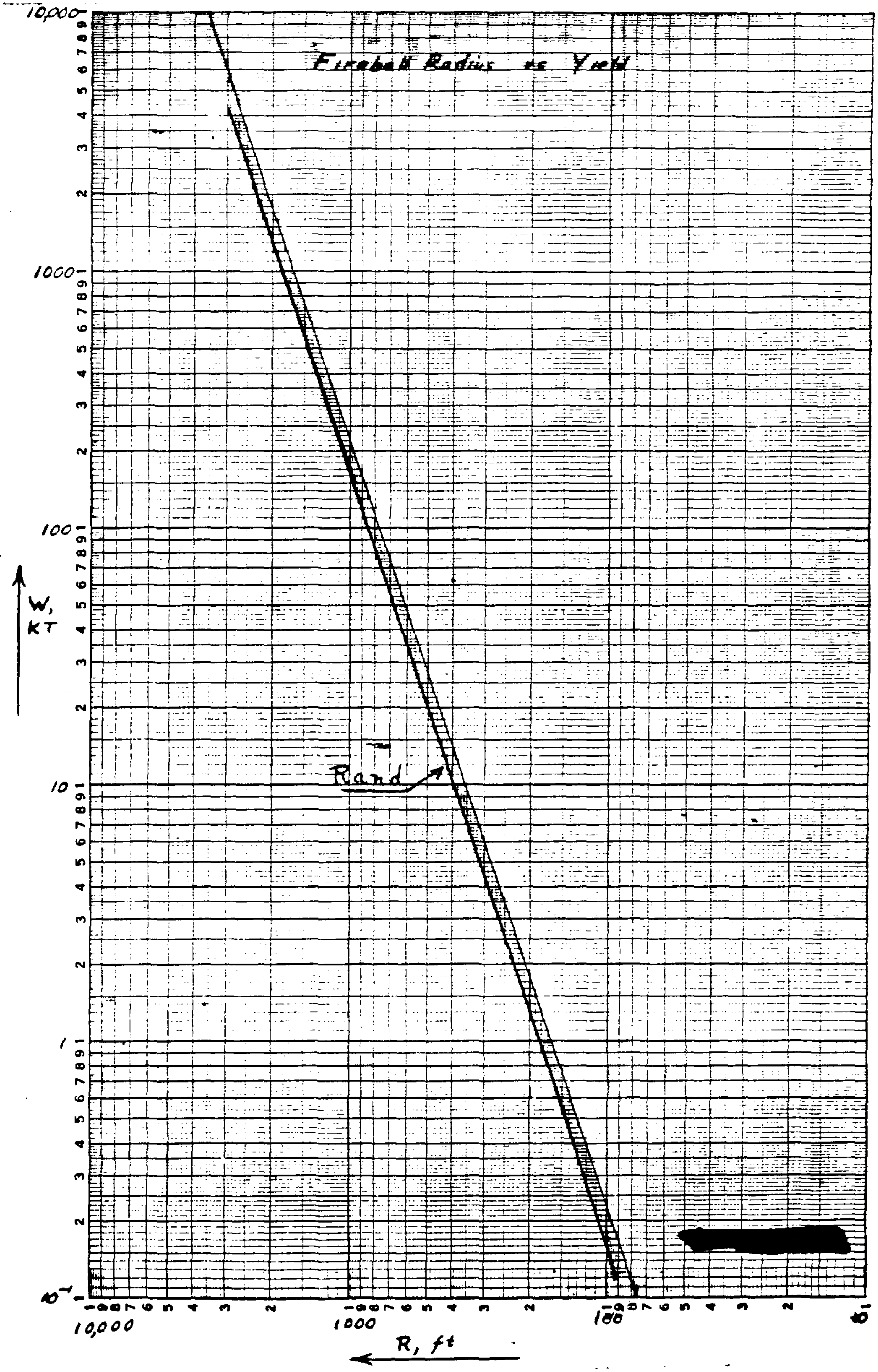

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Hazard "H" : a term, which when combined with weather data, should yield D. It should have a sharp threshold at fireball radius equal to burst height.

Hazard consists of two terms, one resulting from the area of intersection of the fire-ball with the ground, the other with the area of the "thermal explosion". Each is proportional to the appropriate area and inversely proportional to the mean time of mixing of the soil within that area.

1) Intersection term:

$$A_i = \pi r^2 \qquad 4)$$

where $$r^2 = R^2 - h^2 \qquad 5)$$

$$R = 450\left(\frac{W}{20}\right)^{1/3} \qquad 6)$$

where $W \equiv kT$
$R \equiv feet$

Thus

$$A_i = (450)^2\pi\left(\frac{W}{20}\right)^{2/3}\left[1-\left(\frac{h}{450}\right)^2\left(\frac{20}{W}\right)^{2/3}\right] \qquad 7)$$

When the fireball reaches the ground, the mean time of mixing is taken to be 0.01 seconds.

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The natural intersection hazard is proportional to the intersection area per ton, the yield, and inversely proportional to the mixing time.

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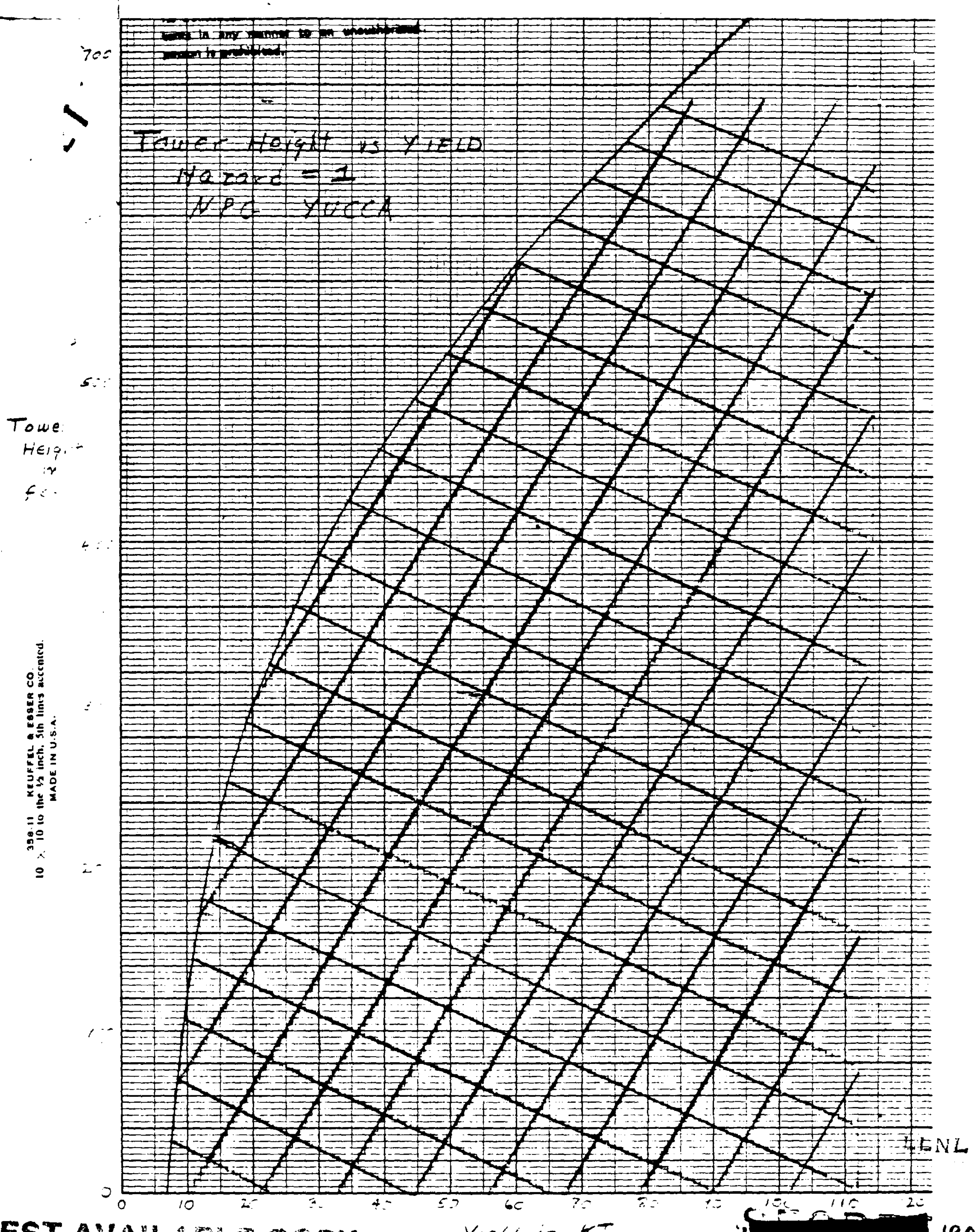

359-11 KEUFFEL & ESSER CO.
10 X 10 to the 1/2 inch, 5th lines accented.
MADE IN U.S.A.

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Thus:

$$N_i = 6.35 \times 10^4 \left(\frac{W}{20}\right)^{\frac{2}{3}} \left[1 - \left(\frac{h}{450}\right)^2 \left(\frac{20}{W}\right)^{\frac{2}{3}}\right] \qquad 8)$$

The N_i is zero if the fireball does not touch the ground. Thus:

$$\left(\frac{h}{450}\right)^2 \left(\frac{20}{W}\right)^{2/3} \geq 1 \qquad 9)$$

2) Thermal term (small compared with N_i)

Since it is important only if $N_i = 0$, it has been computed only for $h \geq R$.

Thermal energy / cm^2 (distance $L \approx R$)

$$Q_n \approx \frac{kW}{4\pi L^2} \cos\theta \quad L = \text{slant range} \qquad 10)$$

$$\cos\theta = h/L \qquad 11)$$

Area of thermal explosion is that area where the energy absorbed is greater than or equal to 10 cal/cm^2. For normal incidence ($\cos\theta = 1$ or $h = L$) this 10 cal/cm^2 distance from a 20 KT device is 6000 ft.

Thus

$$k = \frac{10 \times (6000)^2 \times 4\pi}{20} \qquad 12)$$

And

$$\left(\frac{W}{20}\right) \frac{h}{L^3} \times (6000)^2 = 1 \qquad 13)$$

Intersection radius

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$$S^2 = -h^2 + L^2 \qquad 14)$$

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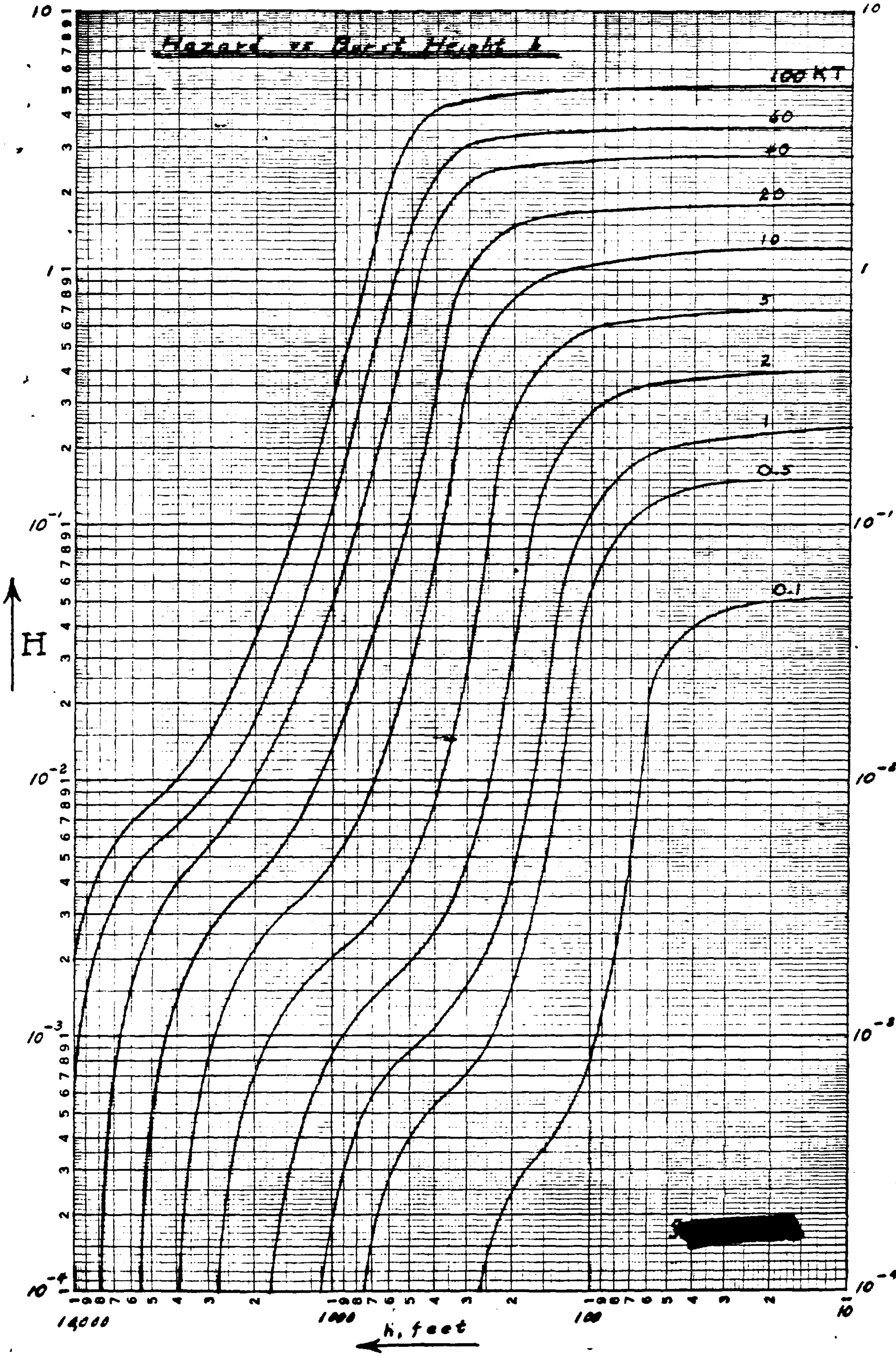

Hazard vs Burst Height h
100 KT
60
40
20
10
5
2
1
0.5
0.1
H
h, feet
14000
1000
100
10

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[redacted]

The thermal area is then

$$A_t = \pi S^2 = \pi(6000)^2\left(\frac{L}{6000}\right)^{2/3}\left(\frac{W}{20}\right)^{2/3}\left[1-\left(\frac{h}{6000}\right)^{4/3}\left(\frac{20}{W}\right)^{2/3}\right] \qquad 15)$$

Mean mixing time is found by averaging the time it would take soil at a radius r from ground zero to travel directly at a speed of 1100 ft/sec to the surface of the fireball at its maximum radius.

$$\bar{t} = \frac{\frac{1}{V}\int_0^S \frac{(L-r)}{1}\, r\,dr}{\int_0^S r\,dr} \qquad 16)$$

$$= \frac{1}{V}\left[\frac{2}{3}\frac{(S^2+h^2)^{3/2}}{S^2} - R\right] \qquad 17)$$

Since the thermal explosion involves only a thin layer of soil, the area of thermal explosion is taken to be 1% as effective as the area of intersection.

18)

Then:

$$N_t = 1.242\times10^6\left\{\frac{\left(\frac{h}{6000}\right)^{2/3}\left(\frac{W}{20}\right)^{2/3}\left[1-\left(\frac{h}{6000}\right)^{4/3}\left(\frac{20}{W}\right)^{2/3}\right]}{\frac{4\times10^3\left(\frac{W}{20}\right)^{1/3}\left(\frac{h}{6000}\right)^{1/3}}{1-\left(\frac{h}{6000}\right)^{4/3}\left(\frac{20}{W}\right)^{2/3}} - 450\left(\frac{W}{20}\right)^{\frac{1}{3}}}\right\}$$

The thermal hazard vanishes for $h=0$

and

$$\left(\frac{h}{6000}\right)^{4/3}\left(\frac{20}{W}\right)^{2/3} \geq 1 \qquad 19)$$

The total natural hazard

$$H_1 = N_i + N_t \qquad 20)$$

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Application of 22)

V/K	W	h	R	$4\frac{\Delta V}{\Delta h}$	H	$D=4H\frac{\Delta V}{\Delta h}$	D Measured
1	18	300	433	6.66	0.9	6.0	6
2	24	300	479	3.85	1.2	4.6	5
3	0.2	300	94	6.68	2×10^{-4}	.001	.001
4	11	6000	366	13.88	0	0	0
5	0.3	100	111	6.00	2×10^{-2}	.12	.13
6	27	300	500	5.64	1.3	7.4	7
7	52	300	616	5.42	2.7	14.6	15
*8	26	2400	490	19.18	4.2×10^{-3}	.08	.005
9	32	300	528	7.85	1.6	12.6	12.5
*10	15.5	500	413	15.28	8.0×10^{-2}	1.22	.12
11	60	1350	650	2.44	6.0×10^{-2}	.15	.30

* Fired over very fine silt in Frenchman's flat.

[redacted]

[redacted]

The normalized natural hazard is

$$H(w,h) = \frac{N(w,h)}{N(70,300)} \qquad 21)$$

$$N(70,300) = 3.54 \times 10^{4} \cdot N_i + N_t$$

Thermal contribution is neglected for $h < R$.

Peak Infinity dose:

$$D = 4H \frac{\Delta V}{\Delta h} \qquad 22)$$

(from $W = 20H$).

where terms as equation 1)

Difficulties with fall-out seem to arise for $H \geq 1$

Infinity dose **BEST AVAILABLE COPY**

$D = 5 I_0$ $\quad I_0$ in R/hr $\quad$ D in R

For total D extrapolate I_0 back to ~~EPP~~

t = fall out time according to $t^{-1.2}$;

$$\frac{I_{\text{fall time}}}{I_{\text{meas. time}}} = \left(\frac{\text{time from shot for fall}}{\text{time from shot for meas}}\right)^{-1.2}$$

Mike (10 MT) showed decay in fallout according to $t^{-1.3}$ instead of $t^{-1.2}$ to 500 hrs. The decay is due partly to weathering effects.

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Origin, Nature + Distribution of Radioactive Debris

(R-251-AEC)

Air Bursts

Most of the particles originate as metallic oxides condensed during the cooling of the fireball.

Nucleation and growth proceed simultaneously and at comparable rates.

In the range $0.01\mu \leq D \leq 500\mu$

$$N_D = N_0 e^{-D/b} \qquad 1)$$

where $N_D \equiv$ number of diameter D
$N_0 \equiv$ total present.

Below $\sim 0.01\mu$ there is apparently a decrease in N_D.

Thus, the smaller 50% by number of the particles accounts for $\sim 2\%$ of the total mass of all particles.

The mean particle diameter is not well known, but lies below 1μ.

The microscope-determined median for Ranger + Greenhouse is 1.2 to 2.2μ.

"The activity present in all particles having a diameter less than one-fifth of the median diameter is entirely negligible compared with that in particles having diameters four times larger than the median diameter."

For Ranger and Greenhouse the range of interest is then considering 1)) 0.8μ to 15μ. 197
(Except for inhalation problems)

[redacted]

[redacted]

Contribution of elements as percentage of total activity at various times.*

Element	10 sec	20 sec	1 min	1 hr	1 day	1 week
Kr	18	15	10	4.5	–	–
Xe	14	14	13	3.5	18	15
I	20	15	9	6	19	17
Rb	13	12	12	5	–	–
Br	8	8	6	1	–	–
Cs	7	12	17	9	–	–
Sb	5	6	7	–	–	–
Te	4.5	6	6	12	4	8
La	3.5	5	7	12	1.5	9
Sr	2.0	3.5	6	4.5	6	2
Mo	1	1.5	2.5	3.5	4	9
Nd	1	1	–	1	–	4
Y	–	1	2	13	19	2
Ba	–	–	–	10	1	–
Pr	–	–	–	6	3	8
Ce	–	–	–	5	6	8
Zr	–	–	–	–	9	3
Nb	–	–	–	–	9	–
Rh	–	–	–	–	–	3
Ru	–	–	–	–	–	2

* dashed lines indicate Less than 1%

$$1 \text{ dpm}/ft^2 = 1.256 \times 10^{-5} \text{ curies}/mi^2 \qquad 2)$$

$$\beta \text{ MC}/\text{KT} = 1.108 \times 10^{7} t^{-1.2} \quad t \text{ in sec.} \qquad 3)$$

$$= 13.2\, t^{-1.2} \quad t \text{ in days}$$

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1 KT in U^{235} produces 1 g Sr^{90}

Tolerance: .005 μg

[redacted]

The time for cooling of the fireball to a given temperature can be scaled approximately by the factor $(W/20)^{1/2}$.

If $W = 1$ MT
$T = 2500°K$
then $t = 25$ sec

Surface Bursts

Molten silica acts as a good solvent for the metallic oxides. Glass particles containing fission products seem to concentrate in the stem of the cloud just under the mushroom. A large percentage of the total activity is found in these particles, and falls out within a very short time.

Calc. Carbonate materials (coral) are not as good at dissolving metallic oxides and thus do not collect so large a fraction of the activity.

Very gross measurements indicate that 80% of the β activity may still be in the air after two months.

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Ground Zero Contamination

. An equation developed from UK series:

$$I = \frac{K H^{1/2}}{\bar{V} R^3}$$

where $I \equiv$ R/hr at H+1
$K = 2.1 \times 10^{10}$
$H \equiv$ normalized hazard (pp 56, 59)
$\bar{V} \equiv$ average wind speed (knots) to 15000 ft taken at 6000, 8000, 10000, 15000 ft. Omit 6000' speed for air bursts > 2000'.
R = distance from GZ in yds. (upwind)

Works as follows for the UK series:

	I = 10 R/hr		I = 1 R/hr		I = 0.1 R/hr	
UK 1	500 yd calc	500 yd meas	1080	800	2370	1300
2	~~1080~~ 610	800	1720	1000	3700	1600
3	114	100	245	200	~~460~~ 526	600
4	0	0	0	0	0	0
5	222	200	480	400	1040	1000
6	500	340	1070	800	2300	2000
7	~~1210~~ 790	900	1700	2400	3650	2800
8	0	~~500~~ 0	0	0	740	500
9	500	400	1070	800	2300	1200
10	~~1300~~ 280	600	600	1000	1300	1300
11	1000	700	2150	1200	4600	1800

For 2 KT, $\bar{V} = 18$, h = 300'

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$I = 10$ R/hr: $R^3 = \frac{2.1 \times 10^{10} (5 \times 10^{-3})^{1/2}}{18 \times 10} = 8.3 \times 10^6$

R = ~~.94 x 10^2 = 94 yds~~ 202 yds

$I = 1$ R/hr R = ~~202~~ yds 440 yds

$I = 0.1$ R/hr R = ~~430~~ yds 950 yds

$I = 0.01$ R/hr R = 2030 yds [redacted]

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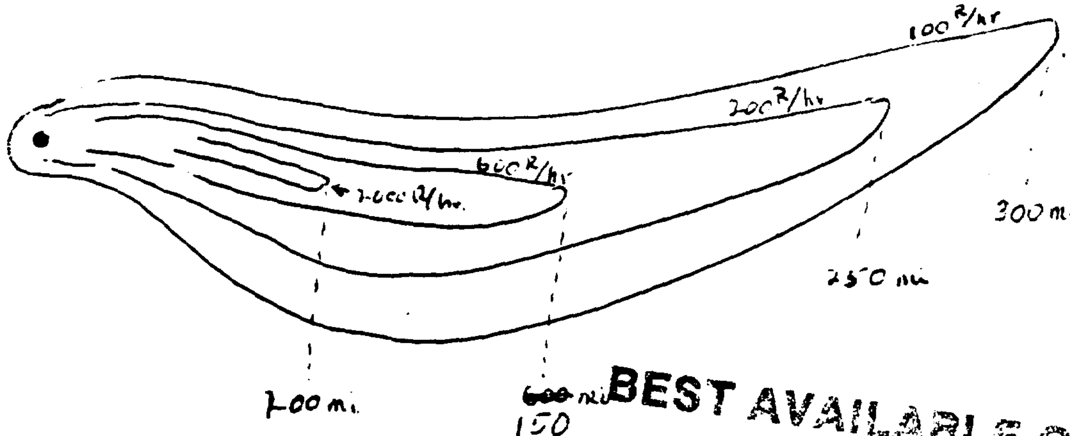
Castle - Bravo Fall-Out H+1 (15 MT)
(AFSWP-507)



An approximation to this pattern is given by

$$I = 7.6 \times 10^{7} R^{-2.28} \qquad 1)$$

where I in R/hr
R in miles

I and R are assumed to scale as $W^{\frac{1}{3}}$

To convert to 10 MT:

$$\left(\tfrac{10}{15}\right)^{-\frac{1}{3}} I = 7.6 \times 10^{7} \left[\left(\tfrac{10}{15}\right)^{-\frac{1}{3}} R\right]^{-2.28}$$
$$.874^{-1} I = 7.6 \times 10^{7} \left[.874^{-1} R\right]^{-2.28}$$
$$1.14\, I = 7.6 \times 10^{7} \left[1.14\, R\right]^{-2.28}$$
$$I = 7.6 \times 10^{7} \left[1.14^{-3.28}\right] R^{-2.28}$$
$$= 7.6 \times 10^{7} \times 0.652\, R^{-2.28}$$

Then:

$$I = 4.96 \times 10^{7} R^{-2.28}$$

or ~~

$$I = 5 \times 10^{7} R^{-2.3} \qquad 2)$$

To account for decay take

$$I = 5 \times 10^{7} R^{-2.3} T^{-1.2} \qquad 3)$$

where T is Fall time to distance R.

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Taking $T = R/\bar{u}$ where $\bar{u}$ = average wind velocity:

$$I = 5 \times 10^7 R^{-3.5} \bar{u}^{1.2} \qquad 4)$$

Take an average (gross) velocity of

$$\bar{u} = 40 \text{ mi/hr}:$$

$$I = 5 \times 10^7 \times 83.2 \times R^{-3.5} \qquad 5)$$

$$I = 4.15 \times 10^9 R^{-3.5}$$

For $I = 0.02$ R/hr ($D = 0.100$ R)
$R = 1700$ mi

If assume air burst, $I_a = 10^{-3} I_{surf}$:

For $I_a = 0.02$ R/hr
$R = 240$ mi

To convert to 0.250 MT:

$$I = 2 \times 10^5 R^{-3.5} \bar{u}^{1.2} \qquad 6)$$

For $\bar{u} = 40$ mph:

$$I = 1.66 \times 10^7 R^{-3.5}$$

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For $I = 0.02$ R/hr ($D = 0.100$ R):

$R = 355$ mi.

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LASL Trip July 8, 1954
Air Weather Service Representative at LASL:
Maj. George Newgarden, H division.

Problem of forecasting improvement being handled by Machta, USWB.

Tom White is working on fall-out theory and practical forecasting.

Fall-out forecasting technique as used in Castle (to appear as a JTF report by, perhaps, House, Lt Col.

Assumptions:

1. Activity uniformly distributed in height (Later altered to emphasize middle region of the cloud)

2. Particle size distribution is uniform. This restricts validity to several hundred miles.

3 The amount of activity deposited by a particle is proportional to its area. (Plating assumption)

4. $t^{-1.2}$ Law.

5 Stoke's Law

6. Surface area covered by particles from a given height is proportional to the time of fall squared. (divergence - diffusion)

[redacted]

7. Radial distance is proportional to the time of fall.

[redacted]

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[redacted]

[redacted]

1 megacurie / mi^2 ~ 3r/hr 3' above Land.

dose rate $\propto$ $t^{-1.2}/t^2$ t = time of fall.

Integrated dose $\propto t^{-2.2}$

Define dose index as: 10 MT

$$D = d^2/t^2$$

d = dia. in μ
t = fall time in hours.
D = infinite dose in R

If particle arrives from two heights, add 2 D's arithmetically.

Use t^{-2} instead of $t^{-2.2}$.

from Stokes Law:

$$\frac{h}{t} = k d^2$$ h = starting height

(Assume constant viscosity.

Then

$$D = \frac{h}{K} \cdot \frac{1}{t^3}$$

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And

$$D = h/K' \quad 1/R^3$$ R = radial distance from GZ

Hodographs usually drawn for fall rate of 5000'/hr.

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[redacted]

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Assume (PPE) 75μ falls at 4000'/hr.

An alternate form (handy) for D is.

$$D(\theta, R) = {v_0}^3 / K_s {h_0}^2 \cdot (R_0/R)^3$$

V_0 = hodograph fall rate (5000/hr)

h_0 = intercept height in ft.

$K_s = \frac{4000}{5625}$

R_0 = intercept. radius in miles

R = is distance in miles to a point on the bearing θ.

~~Ha~~ For constant θ intercept height and distance are constant and the dose index along the line falls off as R^{-3}.

Thus find D at R_0, determined by intercept height alone.

Then draw Line of slope −2 which gives dose index D_0 for $R = R_0$

find dose at any R by placing straight edge with slope −3 through point "D_0, R_0"

For yields other than 10MT:

$$I = W/10 \cdot d^2/t^2$$

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[redacted]

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Fall velocity

$$v = \left(\frac{10 I K_s h^2}{W} \right)^{\frac{1}{3}}$$

where v in ft/hr
I in R
W in MT
K_s : $4000/5625$
h = starting height in ft

And

$$\Delta t = \frac{\Delta h}{v}$$

Note reference: C3-36417

"Radioactive Fall-Out from Atomic Bombs"

Lt. Col. N. M. Lulejian

Hdqtrs. Air Research + Development Command.

+ Supplement to above report (C3-37455).

Note that the necessary fall time determines d as:

$3740'/hr \approx 72.4\,\mu$

LETED

At 15 mi from GZ, [redacted] 40 R/hr at H+1
Cross wind.

[redacted]

[redacted]

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[redacted]

[redacted]

In applying the nomo graph method; The weighted height factor Line goes as:

H	D
10,000'	1.8×10^{2}
32,000'	1.3×10^{2}
56,000'	6.5×10^{1}
90,000'	30×10^{-1}

Instead of a line of slope I.

This presumes to account in a crude way for concentration of activity in the cloud puff.

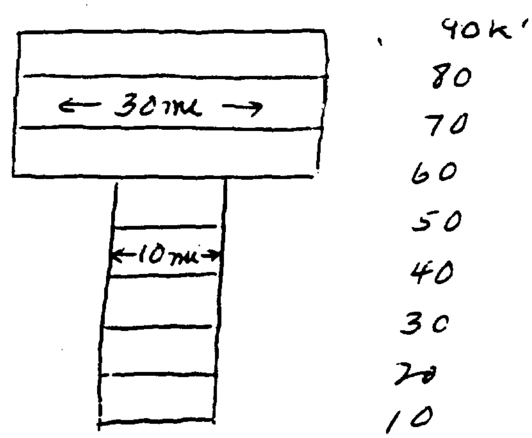
Felt's example gives 100 R infinite at 100 mi. (10 MT)

Assuming a $\frac{1}{R^2}$ fall-off: 0.1 R : 1000 mi
4 R : ~300 mi

Discussion with Tom White, Health Division.

Fall-out model (under development)

The cloud and stem is divided into Layers, such as:



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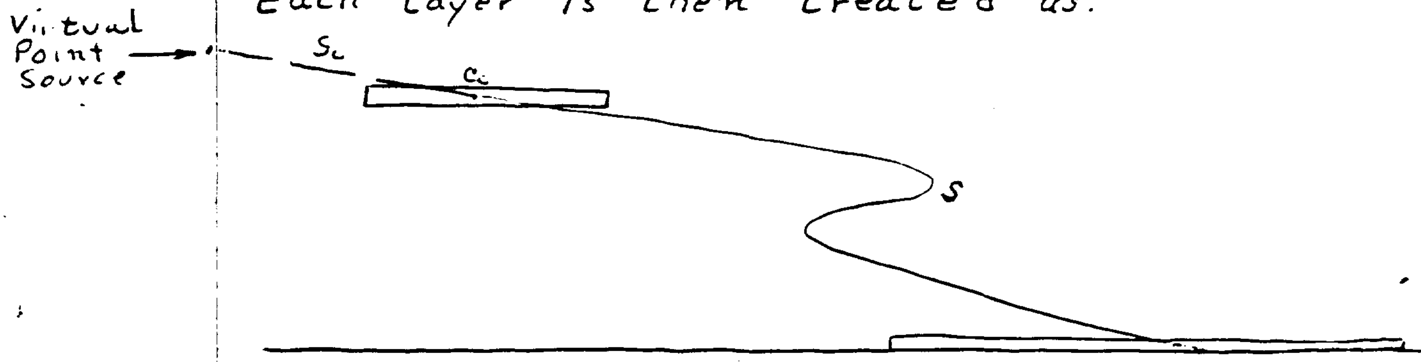
Each Layer is then treated as:



In the cloud:

$$c = c_o e^{-\frac{r^2}{a_o^2}} \qquad 1)$$

where C_o is the center (peak) concentration
C is the concentration at radial distance r.
a_o is cloud radius.

On the ground:

$$c = c_o' e^{-\frac{r^2}{a^2}} \qquad 2)$$

$$c_o' = c_o \left(\frac{S_o}{S_o + S} \right)^2 \qquad 3)$$

$$a = a_o \left(\frac{S_o + S}{S_o} \right) \qquad 4)$$

Best fit seems to be for particle time of fall of 50,000 ft per hour. Size is about 300μ.

[redacted]

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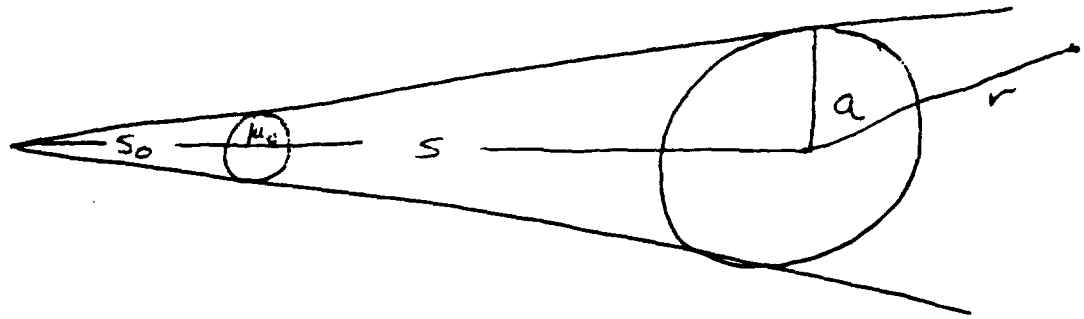
Looking down on the pattern:



If the puff diameter is D,

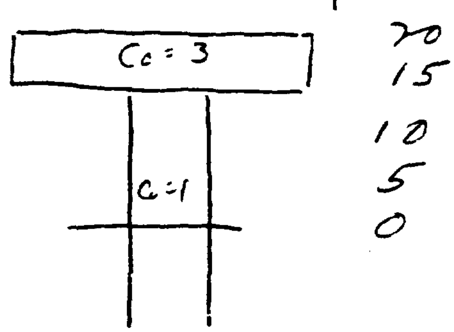
$a_o \approx D/5.2$ For PPG & NPG

~~$a_o \approx D/4$ For NPG~~

$S_o/D \approx 10/1$ For NPG (to 5/

$S_o/D \approx 2+/1$ For PPG
Because of wind direction shear.

As an example for NPG: 2 kT



D = 1 mi
D = 0.2 mi
"
"

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Ht, kft	D, mi	a_o	s_o	$\rho = \frac{S_o + S}{S_o}$
20	1	.2	.25	40 (20 kt wind)
15	.2	.04	.05	etc —
10	.2	.04	.05	
5	.2	.04	.05	

[redacted]

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[redacted]

It is convenient to use:

$$c = c_0 \left(\frac{S_0}{S_0+S}\right)^2 e^{-r^2/a^2} = \frac{C_0}{p^2} e^{-\frac{r^2}{a_0^2 p^2}}$$

$$= \frac{C_0}{p^2} e^{-\lambda^2/p^2}$$

$$a = \left(\frac{S_0+S}{S_0}\right) a_0 = p a_0$$

For various Levels, the pattern may look Like:

*

In case of overlap one would add Intensities arithmetically.

If one wants to consider C_0 as μc/cc or the Like, it is necessary to normalize to a shot.

Development consists of IBM analysis of relation between a_0 & D, S_0 & D, for various types of shots.

The hodograph paper used by Felt + White is published by the Navy Hydrographic Office, Wash. D.C.

No. 2665
MAneuvering Board

[redacted]

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Operation Teapot

Date 1955		Device	Yield	Area	Tower H/T *
18 Feb	1	Wasp	1.2	7	800 / —
22 Feb	2	Moth	2.5	3	300 / 59.4
1 Mar	3	Tesla	7.0	9b	300 / 89.4
7 Mar	4	Turk	40.0	2	500 / 260.4
12 Mar	5	Hornet	3.6	3a	300 / 108.4
22 Mar	6	Bee	7.0	7.1a	500 / 160.6
23 Mar	7	Ess	1.2	10	-65 / —
29 Mar	8	Apple	15	4	500 / 242.5
29 Mar	9	Wasp'	3.5	7	800 / —
9 Apr	10	Post	2.8	9c	300 / 108.3
15 Apr	11	Met	25	F	400 / 139.6
5 May	12	Apple II	30-32	1	500 / 389.1
15 May	13	Zuchinni	30-35	7	500 / 133.5
6 Apr	14	HA	3.5	1	37,000 / —

* Total weight of metals + magnetite

Code		Precursor ?
T 1	Turk	YES
2	Wasp	No
3	Moth	No
4	Tesla	?
5	Hornet	No
6	Apple	YES
7	Bee	No
8	Ess	No
10	Post	No
11	Met	YES LLNL
12	Apple II	No ?
13	Zuchinni	No ?

[redacted]

[redacted]

1. Wasp 1.2 KT
1200 PST 18 Feb

Cloud height

Winds

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[redacted]

[redacted]

2. Moth 2.5 KT
0540 PST 22 Feb

Cloud height 24,000' MSL

Winds Yucca 0610 PST

SFC	C
4	C
5	220/07
6	230/18
7	250/16
8	230/17
9	310/24
10	310/32
12	310/33
14	310/36
16	300/41
18	300/54
20	300/52
23	300/61
25	310/60
30	300/75

Measured fall-out 45 MC

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[redacted]

[redacted]

3. Tesla 7.0 KT
0530 PST 1 March

Cloud height 27,000' MSL

Winds Yucca 0600 PST

4	C
5	C
6	C
7	C
8	220/10
9	220/12
10	230/10
12	300/13
14	290/14
16	270/12
18	270/19
20	280/26
23	280/27
25	280/29
30	270/24

Measured fallout 189 MC

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[redacted]

[redacted]

4. Turk 40.0 KT
0520 PST 7 March

Cloud height 42,000 MSL

Winds Yucca

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[redacted]

[redacted]

5. Hornet 3.6 KT
0520 PST 12 March

Cloud height 38,000' MSL

Winds Yucca 0530 PST

5	220/7
10	270/6
15	280/18
20	290/24
25	280/27
30	290/35
35	280/42
40	270/53
45	250/45

Measured 81 mr (crude rad-safe)

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[redacted]

[redacted]

6. Bee 7.0 KT
0505 PST 22 March

Cloud height 39,000' MSL

Winds	Yucca 0515 PST
6	260/8
8	260/9
10	300/17
12	320/25
14	330/29
16	320/30
18	320/27
20	320/45
23	320/41
25	320/40
30	320/46
35	310/43
40	310/47

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[redacted]

[redacted]

7. ~Ess 1.2 KT -65'
1100 PST 23 March

Cloud height 11,000' MSL

Winds Yucca

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[redacted]

[redacted]

150

8. Apple 15 kT
0455 PST 29 March

31

Cloud height 30,000' MSL

Winds Yucca

	0200 PST	0500	0800	1000	calc 0600
5	180/06	200/09	150/08	180/16	180/09
6	180/06	180/12	170/11	190/16	180/12
7	180/13	180/16	180/16	190/19	180/16
8	180/14	190/20	200/21	210/31	190/20
9	180/15	190/23	210/24	220/29	200/23
10	180/15	190/19	220/27	240/33	200/22
12	260/08	240/15	230/31	240/35	240/20
14	300/19	260/25	240/32	240/37	250/27
16	280/24	260/20	240/33	240/40	250/25
18	290/21	260/27	240/31	250/35	250/28
20	300/25	270/35	250/32	260/40	260/37
23	280/37	270/35	260/41	250/52	
25	280/42	290/38	260/45	250/54	270/33
30	280/44	270/46		250/63	266/48
35	280/43	270/48		250/59	266/49
40	270/50	270/50		250/59	266/52
45	270/43	260/53		250/59	260/54

Meas. mc: 80 (from 13 miles out) (UCLA)
102 Total

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[redacted]

[redacted]

9. "Wasp' 3.5 KT
1100 PST 29 March

Cloud height 34,000' MSL

Winds : see page 95

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[redacted]

[redacted]

10. -HA 3.5 KT
1000 PST 6 April

Cloud height 55,000' MSL
Burst height 37,000' MSL

Winds Yucca

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[redacted]

[redacted]

11. Post 1.8 KT
0430 PST 9 April

Cloud height 15,000' MSL

Winds Yucca 0450 PST

4-12	C
13	360/08
14	350/08
15	340/08
16	330/09

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[redacted]

[redacted]

12. Met 25 KT
1115 PST 15 April

Cloud height 42,000' MSL

Winds Yucca 1130 PST

sfc	200/15
4	200/14
5	210/08
6	210/09
7	210/13
8	210/15
9	220/14
10	240/15
12	260/21
14	260/25
16	240/33
18	240/32
20	240/31
23	250/47
25	250/56
30	250/63
35	240/73
40	240/74
45	240/67
50	240/78
55	230/40
60	230/30

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Measured MC 458 mean UCLA and radsafe

[redacted]

[redacted]

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[redacted]

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[redacted]

14. Zucchini

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[redacted]

[redacted]

Calculated

Shot	mc	area	volume	squ	α=.0038	.0025	.003
Uk-1	883	1589	1000	768			
Uk-7	3000	6138	5600	2874			
Moth	45	45	67	67	44		53
Tesla	189	213	156	192	156		
Hornet	81	100	124	124	82		98
Apple	102	253	276	276	181		218
Met	458			458			
Apple II	1035	747	672	858	705		765
Zucchini	210			528			

Shot	Mc calc. from squ + actual lower wts	Meas. from Larson	Measured from WB curves
Uk-9	1536		2058
Uk-7	2754	1967	1722
Uk-2	1098	846	741
Uk-1	696		454
Uk-6	1236	1037	936
ST-7			513

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[redacted]

Area dependence

$$Z = 300\,(Wa + .003\,T\,2^{2a})$$

Volume dependence

$$Z = 300\,(Wa\omega + .0038\,T\,2^{2a})$$

Sger

$$Z = 300\,(\beta\,\xi A_i + .0038\,T)$$

Layer	g_i/σ_i	$a=1.5$ $\frac{g_i}{a\sigma_i}$	$a=2.0$ $g_i/a\sigma_i$	g_i
1	.128	.085	.064	.23
2	.200	.133	.100	.32
3	.228	.152	.114	.32
4	.068	.045	.034	.09
5	.026	.017	.013	.03
6	.009	.006	.005	.01

$\overset{x}{\text{Ave}}$	$57.3a/x\sqrt{2}$ σ_a ($a=1.5$)	σ_a^2	σ_a ($a=2$)	σ_a^2
10	6.08	37	8.1	65.5
20	3.04	9.24	4.05	16.4
30	2.03	4.12	2.70	7.30
50	1.21	1.46	1.62	2.63
100	.61	.37	.81	.66
150	.40	.16	.54	.29
200	.30	.09	.40	.16

[redacted]

[redacted]

Winds for the hand calculation manual example:

sfc	180 / 5
5	190 / 15
10	220 / 25
15	230 / 30
20	240 / 35
25	250 / 40
30	260 / 50
35	270 / 60
40	270 / 70
45	270 / 60

Trop 38,000'
H 40,000'
GZ sea level
YZ = 50 × 1.5 = 7.5

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[redacted]

[redacted]

[redacted]

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[redacted]

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[redacted]

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