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ERRATA
to LAMS-993

Page 11 - Line 12 - Change 40 miles to 27 miles.

Last entry of Table 4 - Change 5000 (sq. mi.) to 2500 (sq. mi.)

These corrected figures are certainly underestimates, as
no provision has been made for the greater cleanliness of
the air at higher altitudes, only the lesser density
having been considered. If account is taken of the lower
concentration of dust, haze, etc., at higher altitudes,
then the radius of 40 miles for a 5-mile-high burst is
probably realistic.

Page 12 - Table 5

The third entry should have the lethal area 860 (sq. mi.)
changed to 900 (sq. mi.).

The fourth entry should read: Lethal distance $\sim$ 4500 yards
                                                   Lethal Area $\sim$ 20 sq. mi.

Page 14 - Line 6 - The formula should read.

$$12 = \left(\frac{40 \times 10^6}{24 \times 10^3} \right)^{1/3}$$
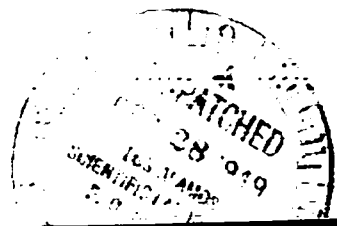
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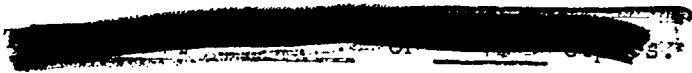# UNCLASSIFIED

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Series A

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This document contains **15** pages.

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Per ___LMF___ 6-20-79
By _Marlene Lujan_ CIC-14 1-5-96

PRELIMINARY SURVEY OF PHYSICAL EFFECTS

PRODUCED BY A SUPER BOMB

PUBLICLY RELEASABLE
Per _M. Jenn_, FSS-16 Date: _12-7-95_
By _Marlene Lujan_, CIC-14 Date: _1-5-96_

Report written by:

F. Reines and
B.R. Suydam

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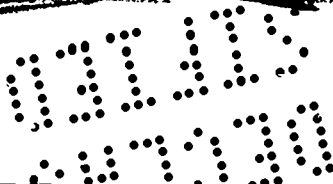
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PRELIMINARY SURVEY OF PHYSICAL EFFECTS
(1)
PRODUCED BY A SUPER BOMB

F. Reines and B.R. Suydam

I. INTRODUCTION

In this brief paper a preliminary statement is given of the nature of effects which might be expected from a super bomb which is capable of liberating an amount of energy equal to 40 million tons of TNT, where a million tons of TNT is defined as 4.2×10^{22} ergs. Such a bomb has 2,000 times the yield of the nominal 20-kiloton fission bomb. It appears possible to make approximate statements about the effects from an air-burst super bomb, and rough estimates are given for the effects of blast, thermal radiation, gamma rays and neutrons.

In consequence of the impressive damage areas which a super bomb is capable of causing, the delivery problem is considerably simplified from the point of view of accuracy requirements. For example, a height of burst anywhere from one to five miles might be acceptable and a radial bombing error of perhaps five miles does not seem seriously to affect the results.

No consideration has been given to the effects of an underwater or underground burst, although it is clear that such work should be undertaken.

From the point of view of blast, it is concluded that a bomb as large as 150 megatons in energy release would not be a great deal more effective

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(1) This discussion will be centered largely around a super bomb having a

40-megaton energy release, although a more complete discussion should clearly consider various yields. As will be mentioned, the scaling laws discussed here can be reasonably applied in the energy range below 40 megatons.

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than a 40-megaton bomb because of the finiteness of the earth's atmosphere. However, from the point of view of thermal radiation, neutron and gamma-ray effects, this limit does not apply [2].

II.   SCALING LAWS

Despite the fact that the energy released by the super bomb can be several orders of magnitude greater than that released by conventional fission bombs, it is, nevertheless, possible to predict with some confidence the magnitudes of the various phenomena, e.g., blast, thermal radiation, and nuclear radiations such as neutrons and gamma rays, if one starts with information as to the performance of the fission bomb.

It is, of course, recognized that the earliest stages of a super bomb explosion find no counterpart in the early stages of a fission bomb explosion because of the enormously higher energy density associated with the super bomb [3].

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(2)   It is understood that such questions as pollution of the atmosphere by the creation of carbon-14 through neutron capture by nitrogen and possibilities of activating the ground by neutron capture are being considered elsewhere, and hence will not be included in the present discussion of effects. (LAMS 983).

(3) It is of some interest to observe that, although the phenomena associated with the explosion of ordinary high explosives and those associated with an atomic bomb explosion are vastly different in the early stages, it has, nevertheless, proved possible to extrapolate the pressure-distance curve from the order of pounds of high explosives to tens of kilotons for a nuclear explosion, a range of energy release of 10^8, and achieve reasonable, better than order-of-magnitude results. In the present discussion we are concerned with extrapolating over an energy range of 10^3 between events which are much more nearly similar than high explosives and atomic bombs.

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A. Blast and Thermal Effects

The earliest stages during which the super bomb and fission bomb explosions differ can be expected to last until the hot central region, or ball of fire, has expanded sufficiently so that the temperature of the engulfed material has dropped to a value which is realized in a fission bomb. The temperatures in the fission and super bombs are to be compared at that stage in the explosion of the fission bomb, achieved in about 1/2 millisecond, at which the ball of fire has engulfed a mass of material which is large compared to the mass of the bomb itself, perhaps 30 meters radius, or a temperature of the order of $50,000^C$. Beyond this stage, it is reasonably to expect that the phenomena are similar. Elementary considerations suffice to show that the radiative loss before the similarity stage in the case of the super bomb is very nearly the same as for the fission bomb in this stage of the explosion.

Therefore, the two events should obey the conventional scaling laws with good accuracy [4]. (cf. however effect of finite atmosphere discussed below).

B. Nuclear Radiations

We will not discuss scaling laws for neutrons and gamma rays because of their relative ineffectiveness compared with blast and thermal radiation. More specifically, with respect to neutrons and gamma-rays: because of the exponential attenuation factor, these radiations are not important over

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(4)   These scaling laws are described in various reports: LA-743R, and
       Volumes II and III of the Scientific Director's Report of Operation
       Sandstone (Sandstone Nos. 8 and 9).

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great enough distances, in the case of the kind of airburst which would tend

to optimize area damage from the blast and thermal point of view, to contribute

appreciately to the over-all effectiveness of the super bomb. In passing, it

seems clear that compared with a smaller weapon e.g. one having a yield of

only a few kilotons, a super bomb is relatively poor for the production of

biological damage by neutrons and gamma rays.

It will be seen from the above that, insofar as its important effects

are concerned, a super bomb differs from a conventional fission bomb only in

that a greater energy can be released[5].

III.   DISCUSSION OF EFFECTS

    A. Blast Effects

        1. Upper Limit

A complication is introduced into the matter of scaling from a

fission bomb to a super bomb because of the finite mass of the atmosphere.

It is clear that if the energy release exceeds a certain critical value, the

super bomb will succeed in "blowing a hole" in the atmosphere in much the same

way that a bomb detonated beneath the surface of the water can cause a bubble

which vents, and so alter the character of the pressure wave expected at the

surface of the earth. A crude estimate of such a critical size can be made

in the following manner.

The height of the atmosphere, computed for air at sea-level density,

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(5)   A super bomb is here understood to imply the use of a self-sustaining
thermonuclear reaction. From present theoretical considerations, this
should be possible over an enormous range extending upward from perhaps
as low as ~ 1/10 megaton.

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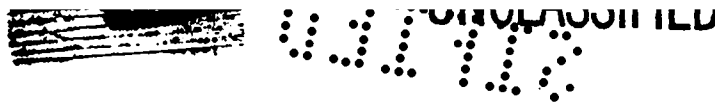
is five miles. If the bomb is of such a size that it produces an overpressure

of 14-7 pounds per square inch, i.e., one atmosphere, in a uniform atmosphere

at sea-level density at a distance of five miles, then it is apparent that

such a bomb is capable of lifting a column out of the atmosphere. A bomb of

40 megatons would just produce this effect. For larger distances, it is to be

expected that the pressure-distance curve which one obtains by scaling will

be modified by the finiteness of the atmosphere. An estimate of the yield of

the super bomb beyond which no appreciable increase in the distance at which

the 14.7-psi pressure level can be realized results from the following considera-

tion of the effect of the rarefaction[*] from the top of the atmosphere. This

tonnage is that for which the rarefaction wave reaches the surface of the earth

in a time equal to that required for the shock wave to propagate out to five

miles. In twice this time the rarefaction wave from the top of the atmosphere

will have again reached the earth's surface and thus tend seriously to modify

the shock at the earth's surface. An estimate carried out on this basis sug-

gests a critical upper limit from the point of view of the blast effect of the

order of 150 megatons. Such a super bomb would produce the 14-7-psi level at

about 7 miles, and greater releases do not significantly increase the distance

over which such a pressure can be realized. Because of the rarefaction, the

shock wave can be expected to decay much more rapidly than would be computed

by simply scaling up blast curves from atomic bombs. (6).

  2. Height of Burst

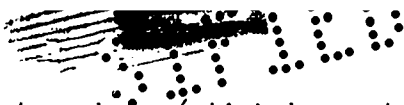   The variable density of the atmosphere makes height-of-burst

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[*] This use of the term "rarefaction" is somewhat misleading inasmuch as the
   true finite atmosphere effect is due to the gravitational instability of
   the shocked gas.

(6). The details regarding the behavior of the pressure-distance curve as it is
   affected by the finite mass of the atmosphere in a realistic case d

the inhomogeneity of the atmosphere (which has not as yet been mentioned) are most complicated and, in consequence, require much more elaborate study than it has been possible to give here. The numbers quoted are intended to serve only as an order-of-magnitude guide. For example, because of the gradual variation of atmospheric density with altitude, it is probably not true that the variation of pressure versus distance is affected in any discontinuous way with increasing yield.

---

considerations such as are suitable for conventional atomic bombs unsuited for

determining that height-of-burst for super bomb which will optimize blast

damage. A simple-minded scaling would indicate a height-of-burst for a 40

megaton bomb of about seven miles if it is desired to optimize pressure at 10-psi.

Because of the tenuous nature of the atmosphere at seven miles, it is clear

that the super bomb would be relatively inefficient in generating a blast wave

at this altitude. The best place, from the point of view of the generation of

a blast wave in air would be at ground level where the air is most dense. How-

ever, if it is desired to optimize air blast, the loss of energy to the ground

must be minimized and, consecuently, a height of burst of at least the fireball

radius at breakaway, or abcut one mile, would be desirable from this point of

view. The breakaway criterion is chosen because of the relatively small coup-

ling between the energy in the ball of fire and the energy in the shock wave

at later times.

A height of burst between one and three miles is probably indicated

and that the variation of pressure with distance on the ground at distances

of a few miles due to such changes in the height of burst are probably small

because the increase in effectiveness due to the reflection pattern is some-

what balanced by the decrease in blast due to the diminution in atmospheric

density.

Table 1 is a summary of the blast characteristics which might be

-5-

expected from a 40-megaton super bomb burst at an altitude of 1-1/2 miles.

TABLE 1

Time from Detonation (Seconds)	Distance (Yds)	Overpressure (Psi)	Blast Wind (In Positive Phase) (MPH)
0.2	1,500	1,500	5,800
8.3	9,300	20	300
10	10,000	15	210
12.7	12,000	12	170
14.2	13,000	10	150

Although, as has been stated, the blast from a super bomb has the same general characteristics as that from a fission bomb, since the increased yield makes an order-of-magnitude difference in the scale factor, the associated phenomena produce what amounts to a qualitative change in such features as the blast winds and the updraft produced by the rising ball of fire. For example, instead of having a blast wind which lasts for the fission bomb a matter of a
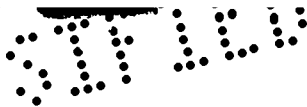
second or so, the super bomb produces a blast wind lasting about 10 - 15 seconds.

3. Updraft

After the shock wave has propagated outward, there is a general upward motion of the ball of fire and shock-heated air which gives rise to the familiar atomic cloud. In the case of a super bomb, the extent of the area over which the updraft can produce damage due to high winds associated with it is probably comparable to and perhaps greater than that over which direct blast damage is inflicted.[7]

The surface winds resulting from the updraft accompanying a 40-megaton super bomb explosion can be estimated as follows: Approximately 20% of the yield of the bomb, i.e., about 3×10^{23} ergs, is carried up by the rise of the ball of fire. As the ball of fire rises, air from a layer containing approximately half the mass of the atmosphere, about $2\frac{1}{2}$ miles, will rush in to replace that which is carried in the updraft. This air flow can be considered as two-dimensional and incompressible; therefore, the velocity of the air at any distance r from the bomb will be given by

$$v = \frac{c}{r\,h}$$

where

$r =$ distance from bomb

$h =$ thickness of layer (about $2\frac{1}{2}$ miles)

and c is a constant which we will now evaluate.

The figure of 20% of the yield of the bomb may be equated to the total kinetic energy involved in the horizontal winds, thus,

$$\int_{r_0}^{r_{max}} 1/2\ v^2 dm = 3 \times 10^{23} \text{ ergs}$$

where r_0 is the minimum radius of interest, i.e., the maximum radius of the

---

(7) There has, as yet, been no measurement made on the updraft associated with conventional fission bombs and the remarks which we make here can be expected to provide only order-of-magnitude accuracy. Incidentally, such measurements are contemplated for the 1951 tests.

ball of fire and r_{max} if some radius beyond which appreciable effects do not occur.

Substituting h for r_0 and integrating, we have

$$\frac{\pi c^2 p}{h} \log\left(\frac{r_{max}}{h}\right) = 3 \times 10^{23} \text{ ergs}$$

Taking $h = 2\frac{1}{2}$ miles and $r_{max} = 20$ h, we can calculate the value of c, and Table 2, showing horizontal wind velocity versus distance, results.

TABLE 2

Distance (Yds)	Wind (MPH)
3,000	600
6,000	300
10,000	200
20,000	100
30,000	60

The choice of r_{max} is here somewhat arbitrary; however, since the value of the constant c depends on the square root of the logarithm of r_{max}, the results are quite insensitive to the value of r_{max} selected.

It is seen, then, that the updraft from a 40-megaton explosion will produce winds of hurricane velocity (~ 100 mph) over an area of about 400 square miles.

B. **Thermal Effects**

As has been previously stated in Section IIA, fission bomb explosions can be considered similar to one another after the ball of fire has expanded to a radius of about 30 meters. Consequently, from our knowledge of scaling, we can expect a super bomb of 40-megaton yield, detonated within a mile or two of sea level, to be similar to a fission bomb explosion after the radius of the ball of fire has expanded to 400 meters. From this point on, the scaling laws can be applied to thermal radiation as well as to blast.

In particular, the percentage of the total bomb energy radiated after this time should be the same as for a fission bomb, i.e., about 1/3 [8] of the total energy. Although the early stages of a super bomb explosion before the radius of the ball of fire has reached 400 meters, have no counterpart in a fission bomb explosion, the fraction of the total energy radiated away is not significantly different from that for a fission bomb.

1. Thermal Radiation as a Function of Time

As scaling will apply to all but the earliest stages of a super bomb explosion, the super bomb explosion will show the familiar minimum and other qualitative features of the fission bomb explosion. We can, then, making use of the scaling laws, give the following table comparing a 40 megaton super bomb with a 20 kiloton fission bomb.

TABLE 3

	Fission Bomb (20 KT)	Super Bomb (40 MT)
t_m	.012 sec	.17 sec
t_∞	3 secs	40 secs
Q_m	$\sim \frac{1}{2}\%$	$\sim \frac{1}{2}\%$
Q_∞	1/3	1/3

where

t_m - time of the minimum, in seconds

t_∞ - time at which essentially all the thermal radiation has come out

Q_m - percentage of the total yield radiated away before the minimum

Q_∞ - fraction of the total yield radiated away

2. Thermal Effects from a Very High Burst

It has been remarked that a super bomb burst at a very high altitude would be inefficient in the production of air blast. This inefficiency

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[8] We are only concerned here with radiation of sufficiently long wavelength to penetrate significant distances in air.

is reflected in an _increased_ production of thermal radiation. As we have seen, however, even an airburst at moderate altitudes succeeds in converting a reasonable fraction of the energy ($\sim$1/3) into thermal radiation capable of producing distant burning.

A more important result of a high-altitude burst is the increase in the thermal radiation effective in burning because of the decreased attenuation by the less dense air along its path. In the following, we will neglect the possible increase in thermal radiation indicated above and consider only the effect of decreased attenuation. For example, a 40-megaton super bomb detonated at a one- to two-mile altitude can be expected to char wood at a distance of about 20 miles[9]. Detonated at a height of 5 miles, it should char wood at a distance of about 40 miles, an increase in area in which the effect occurs by a factor $\sim$ 4. Table 4 summarizes these results.

TABLE 4

Height of Burst (Miles)	Area of Wood Charring (Square Miles)
2	$\sim$ 1500
5	$\sim$ 5000

C. Effects on People and Structures

In the following sections, we will summarize the effects of an air-burst and near-ground-burst 40-megaton super bomb.

1. Damage to Personnel

Table 5 indicates the lethal distances and areas for various causes of damage to a man standing in the open from a 40-megaton bomb burst at an altitude of 1 1/2 miles.

It is to be observed that such a weapon would clearly be

(9) Wood was observed to char at a distance of about two miles from the fission bomb explosion in Japan. We assume an atmospheric transmission of 0.3 through a 1-mile thickness of atmosphere or an absorption of 10^{-3}/gm per cm^2, a figure characteristic of sea-level atmosphere at Eniwetok.

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extremely effective against troop concentrations over areas of the order of
at least a few hundred square miles.

TABLE 5

Man in Open (As in Troop Concentration)
40-Megaton Super Bomb, Air-Burst at 1 1/2 Miles

Cause of Damage	Lethal Distance (Yards)	Lethal Area (Square Miles)
Neutrons*	3200	10
Gamma Rays**	5400	30
Thermal Radiation		
(>1st Degree burns, Skin Charring)	30000	860
Blast		
(Crushing, e.g., lung damage) ~100 psi	~9000	~50

* The following differences in the neutron sources, i.e., a 40-megaton
super bomb versus a 20-kiloton fission bomb, are considered in the estimate:

 1. 2000 times greater energy release.

 2. 70 times more neutrons emitted in super bomb in primary process
per gram of material involved.

 3. Lessened attenuation in bomb material of higher-energy neutrons
from super bomb.

** The fission and super bombs were taken as equivalent gamma ray sources per
unit energy release, although it is probable that the super bomb is a rela-
tively weaker source.

2. Damage to Structures

Scaling the observed movement of massive structures at
Sandstone[10] yields the following interesting table for the predicted movements

(9)(cont'd) In view of the increased transmission of the atmosphere with alti-
tude due to the diminution of dust and other particles the mass absorption
coefficient drops with increasing altitude. This effect has not been con-
sidered in the above estimates. Consequently, the areas quoted probably
represent a lower limit.

(10) Annex 6, Part I, Sandstone No. 24 of the Scientific Director's Report
of Operation Sandstone.

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of 70-ton unanchored structures (e.g., tanks), originally located at 5,000 and 8,300 yards from a super bomb exploded at a 1 1/2 mile altitude.

TABLE 6

70-Ton Structure, Unanchored
40-Megaton Super Bomb, Air-Burst at 1 1/2 Miles

Original Distance (Yards)	Distance Moved (Yards)	Area Involved (Square Miles)
5,000	600	25
8,300	15	70

The damage to structures such as it is expected would exist in an industrial or city complex is listed for a 40-megaton super bomb, burst at the assumed 1 1/2 miles altitude, in Table 7. The references to Types A, B and C damage are nominal, since the strengths of various structural elements play an obvious part in the more precise statement of damage which will result from a given overpressure.

TABLE 7

Damage to Structures in City Complex
40-Megaton Super Bomb, Air-Burst at 1 1/2 Miles

Overpressure (PSI)	Area (Square Miles)	Type of Damage
20	90	A
10	170	B - A
8	210	B
2 - 4	10^3	C

For Conventional Structure: A - Complete demolition.
B - Not complete but irreparable damage.
C - Severe but reparable damage.

3. Effect on Underground Installations

A 40-megaton super bomb might reasonably be expected to incapacitate large underground installations having an area of 1 1/2

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square miles from a height of burst in the neighborhood of 1500 feet. This statement follows from an application of the scaling laws to the effects produced by the fission bomb at Trinity[11].

The crater depth at the center should be 100 feet. The scaling factor on distance is taken as

$$12 - \left(\frac{40 \times 10^6}{24 \times 10^3}\right)^{1/3}$$

Under this 1 1/2 square mile area there will be damage comparable to that from a severe earthquake. Electrical conduits will be broken, machinery rendered inoperative, people will be injured or killed (depending on their position in the underground shelter) down to a depth of 100 feet or more.

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(11) LA-365, Permanent Earth Displacement. The Trinity crater produced by a 20-kiloton explosion on a 100-foot tower was dug out and depressed by about 10 feet directly below the tower and by about 2 feet at a distance 300 feet from the center.

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