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# SPREAD OF RADIOACTIVE CONTAMINATION

# FROM A TOWER-BURST ATOMIC BOMB

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## SPREAD OF RADIOACTIVE CONTAMINATION FROM A TOWER-BURST ATOMIC BOMB.

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__Purpose:__ The purpose of this report is to review the available evidence on the spread of radioactive contamination from an atomic bomb burst on a tower in order to make clear the factors on which the spread of contamination depends. For completeness other types of damage are briefly discussed. This subject is being reopened at this time in connection with determining the feasibility -- from the point of view of the possible effect on the preservation of American lives, well-being, and property -- of conducting physics tests of atomic bombs within the continental confines of the United States.

__Types of Damage:__ In general it can be stated that by removing the test site a distance of 20 miles from the nearest populated region, and by keeping the land and sky above clear of unauthorized persons, then even for an explosion with an energy release equal to that of 100 kilotons of TNT there will be at most minor glass breakage, and this only if the ground contours favour focussing of the blast.

Except for the possible deposition of radioactive materials and of glass breakage, a distance of 20 miles is more than adequate to insure protection against all destructive effects[1]: earth shock, airblast, prompt and delayed gammas and neutrons emitted from the nuclear explosion, incendiary effects, and any flying fragments.

1 With the possible exception of temporary blindness if the bomb is viewed at night from this distance. The bomb gives off __visible__ radiation roughly equal to that of the sun for one second.

The rise in the ball of fire and subsequent cloud and the deposition of plutonium and fission fragments and materials activated by the intense irradiation constitute the only hazard which does not fall off with distance in a reasonably predictable way.

General Factors on Which Spread of Contamination Depends:

In order to indicate the factors on which the spread depends a brief description is given here of an atomic explosion in the close proximity of the earth with special attention to the formation of a crater, the formation and rise of the ball of fire and cloud, and its subsequent dissipation. Comparison is made between the Trinity test with the 100-foot tower and the projected tests employing 200-foot towers.

The nuclear explosion gives rise to an enormous incandescent ball comprising the vaporized bomb, tower, and to some extent, dirt. The maximum diameter reached by this ball of fire is about 2,000 feet[2], as given by the area fused at Trinity. A temperature of about 1400°C is required to fuse Trinity dirt. The expanding pressure pulse generated by the tower-exploded bomb pounded upon the earth forming a compression crater of about 1,000 feet in diameter, a figure which would not be substantially altered by the increased tower height. In the Trinity test a surprisingly small area of ground in the vicinity of the tower was disrupted. Light macadam roads were undestroyed to within approximately 150 feet of the center. Disruptive cratering should depend sensitively on the height of burst as will be discussed more fully after the general description is completed. To anticipate, however, it is of some importance that the soil break-up be minimized because of the increased rate at which the radioactivity in the cloud may be expected to settle if it contains such dust particles.

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(2) The Tower height in this case (100 ft) as in the projected test (200 ft) is small compared with the radius of fused earth. LA-356.

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To continue, since the vaporized mixed mass of bomb, tower, and air is less dense than the surrounding air, it rises causing an enormous updraft which sucks into the rising, extremely radioactive material, air together with whatever loose dust, dirt, and more solid debris exists in the near vicinity. The particles so drawn into the cloud, as the cooling ball of fire is called in its later stages, serve as centers on which the radioactive nuclei condense and deposit. These particles of extraneous matter become intensely radioactive, probably with a higher specific activity than the fused ground below the explosion.[3] The cloud then assumes the shape of a mushroom, the head of which rises to several kilofeet, and drifts along carried by the air currents until it is torn apart by cross-currents and generally diffuses throughout the atmosphere. As it travels along there is a "rain" of radioactive dust formed by condensation, some of which takes place on the dirt particles sucked up into the cloud by the initial updraft. It is expected that the radioactive dust particles so formed would be larger than those condensing on dust nuclei present in the atmosphere before the explosion and hence will fall faster because in the later stages of the initial expansion and when the updraft is still strong, the ball of fire is cool and hence not able to vaporize the external dust and dirt so drawn in. This rain will spread activity over a wide area depending in still dry air on the particle size. If it rains in the conventional way, however, radioactive particles can easily be made to fall in a dangerously small region even in the absence of large condensation nuclei.

An important question arises at this point as to the subsequent fate of the radioactive cloud, assuming that the cloud reaches the lower stratosphere without appreciable activity settling out. The moisture in the heated cloud components may well freeze out as ice crystals in the sub-zero temperature of the stratosphere, entrapping

3 LA-277

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radioactive nuclei. The question of the subsequent precipitation versus a safely wide dispersion of the material by the substratospheric winds should be investigated. A difficulty in predicting the fate of the radioactivity centers about a lack of knowledge of the sizes of the particles condensing on dust particles or other nuclei found in the air prior to the explosion. This point might be investigated by experiments of the type discussed under heading (b) except that they should be performed in an atmosphere containing various amounts of dust. It might be added that the rate of settling out of radioactivity can certainly be altered by the presence of a down draft. The results in the case of Trinity[4] where no attempt was made to keep the dust down are a cause for alarm. For example, a two weeks' dose of from 5 to 10R, or, considering the decrease of intensity with time, roughly 0.5 to 1.0R the first day, was estimated from necessarily rough measurement as in evidence at a distance of 120 miles to the leeward.

<u>More Detailed Considerations:</u>

(a) <u>Keeping the dust down</u>

It seems clear that the first step in diminishing the rapid deposition of radioactivity from the cloud is to prevent it from picking up material from the ground. Although it is not very likely that a crater will be formed by a bomb burst on the 200-ft tower, this point could probably be verified in some positive way by small-scale experiments with ordinary high explosive on the dependence of crater formation on the height of burst. The reason for checking this point is that the answer to the question of whether or not there will be a crater governs to some extent the treatment which the ground should receive to help in keeping the dust down. In the worst case the crater will certainly be less than 150 feet in radius (in Trinity dirt).



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4 LA-277 gives radiation surveys.

A means of preventing crater formation (assuming a crater would be formed if nothing were done to prevent it) which should be checked by scaled experiments, is to first cover the central region with a layer of macadam and then lay in a criss-cross fashion as indicated in Fig. 1a,b a network of heavy, wooden timbers which might be bolted together and treated with some fire-proofing agent.

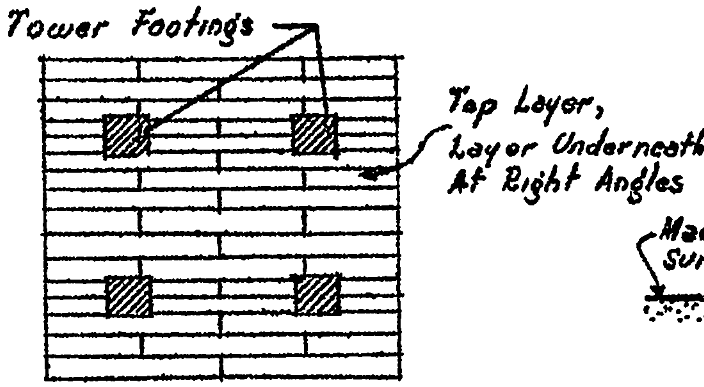


FIG. 1a TOP VIEW

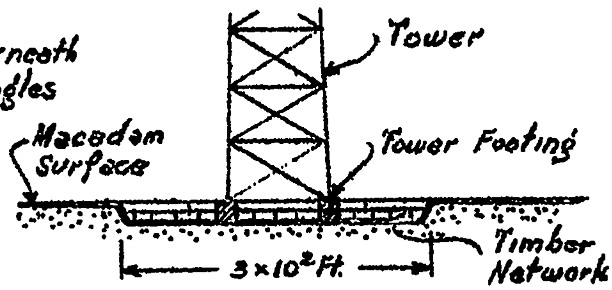


FIG. 1b SIDE VIEW

Such a scheme as this might suffice to keep the surface from breaking up.

The region outside the crater could be protected, as learned from experience, with a standard macadam surface such as previously used at Trinity for roads. If the region from 150 feet to 5000 feet were so surfaced and then cleaned with a portable vacuum cleaner before the shot, dust picked up in the absence of the surfacing might be eliminated. As seen from Trinity[5], this is important because 25% of the dirt moved from the region 0 to 1000 ft came from the region 150 to 1000 feet.

(b) The size of condensed particles

Studies have been made at Chicago (CH-3629) on the particle sizes resulting from the condensation of vaporized materials exploded by the passage of high D-C currents at temperatures estimated to be in the neighborhood of 20,000°C. The particles in a Pu-Al smoke were chain-like, having a mean diameter of ~0.2 micron and a length of ~1 micron.[6]

5 LA-356.

6 $Ce^{144}$ aerosols produced in a carbon arc had a mean particle diameter of ~0.2 micron.

LAMS-277 suggests a modified Stoke's law used in industrial practice for the rate of fall of particles having a specific gravity $\rho$ and a diameter D microns.

$$v = 0.006\ D^2 \rho \text{ feet/minute}$$

This approximate law is obeyed[7] reasonably well for particles between 5 and 300 microns, although the velocity decreases monotonically with radius, smaller particles fall more rapidly than it predicts. Assuming with LAMS-4[illegible] that $\rho = 2.6$, the time for a particle of 5 micron radius to fall 20 kilofeet is ~900 hours or ~40 days.

In qualitative support of this calculation, Hirschfelder and Magee, writing of the air shot at Bikini, say in LAMS-438: "In Able shot..... active material was deposited on the water droplets which remained in the air. There was no evidence of abnormal rain from the cloud or of a trail of active material produced by a fall-out. This was quite different from the situation at Trinity where active material was deposited on dust particles which fell according to Stoke's law."

If one assumes that the particle sizes in an atomic explosion are within a factor of 10 of those produced by the Chicago group in their aerosol studies, the radioactive particles will remain aloft for many days. During this time they will become distributed throughout many hundreds or even thousands of cubic miles and so be rendered less harmful. The question of the required dilution of plutonium and fission products is discussed further below.

This point should be studied further to determine the validity of the a-priori reasonable assumption about the similarity in particle size resulting from a bomb explosion and the vaporization processes employed by Chicago.



7 Since the density of the air varies with altitude, the factor 0.006 is not strictly constant. However, the accuracy of this formula will suffice for the present discussion. A more careful calculation might have as its starting point the Stokes-Cunningham relation (CH-3629,pp 62-3).

A remark might be made at this point regarding the size of particles which can be picked up by filter paper, since the success of this method of efficiency determination at Bikini has been suggested as evidence of large particle sizes. According to CH-3629, a test of a Navy-type asbestos filter (manufactured by A.H.Thomas Co.), consisting of two sheets, one in back of the other, found 99.9% of the particles in an aerosol of mean diameter 0.1 to 0.2 micron collected on the first sheet. We will take this as indicative of the smallest particle size effectively caught. As seen above, such small particles remain suspended in the air for a great length of time during which enormous dilution can occur. It is true, however, that in addition larger particles may have been caught on the Bikini filters even though the small particles trapped were sufficient for the efficiency measurements. If possible, this point should be investigated.

(c) Legally safe doses

Plutonium: According to LA-391 the daily dose of plutonium which is safely tolerated by the body for a five-year period at eight hours of exposure each day is $5 \times 10^{-7}$ micrograms or an air pollution of 0.035 counts/minute per liter of air. This extremely conservative figure (probably by a factor of 100) under test conditions where only a limited exposure would occur, corresponds to a uniform spreading of all the unburnt plutonium over a region having a volume of approximately 200 cubic miles.

Fission Products: A more serious problem is that presented by the fission products. The figure accepted by the medical profession from experience with x-rays as the safe radiation dose is 0.1 R/day. It is suspected, but not too well known, that below certain total doses, say 10 R, the rate at which the dose is received in unimportant. We must therefore base our calculations on the 0.1 R figure. This restriction makes for conditions more difficult to meet.

Except for a relatively small amount of $\beta$ activity, the fission product activity is due to $\gamma$'s . These $\gamma$'s are emitted according to a $1/t^{1.2}$ law which is obeyed reasonably well from seconds on. About 4 mev per fission is given off in the form of $\gamma$'s , 3.6 Mev coming off in the first hour (LAMS-351). This leaves 0.6 mev to be emitted from 1 hour on.

The $\gamma$ source density, s, from an atomic explosion from 1 hour to is $s = \frac{f}{v} \cdot 6.10^5$ ev/cm$^3$, where: f is the number of fissions, and v the volume throughout which products are assumed to be uniformly distributed.

for 100 kilotons, f $2\text{x}10^{25}$ fissions

As an <u>orientation</u> calculation let us assume a wind velocity of 20 miles/hr. so constructed that it takes 1 hour to spread the activity uniformly over a region 20 miles long, 10 miles wide and 5 miles high. (Fig. 2.)

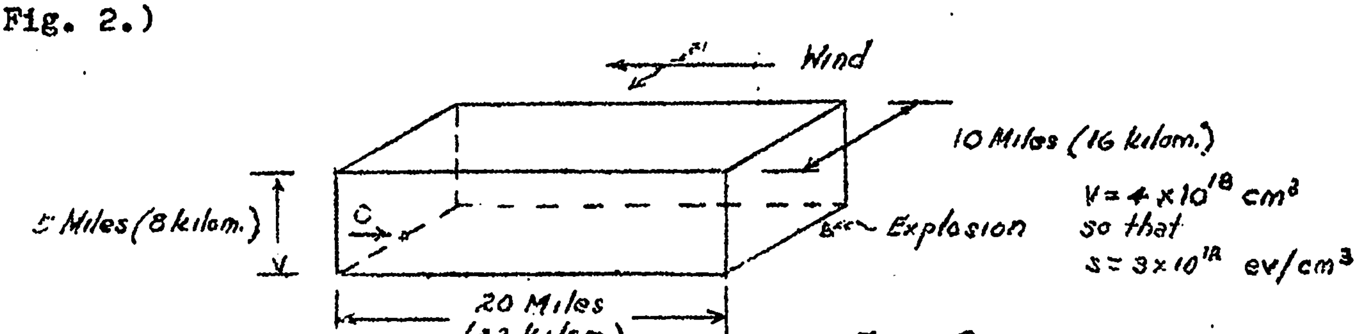


Fig. 2

The radiation flux I received by a person at point O will now be calculated on this assumption.

$$I = \frac{1}{4}\int_0^{r=4000 \text{ meters}} \frac{s(r)}{4\pi r^2} e^{-\lambda r}\, dv = \frac{s}{4}\int_0^{\infty} e^{-\lambda r}\, dr = \frac{s}{4\lambda} \sim 3\text{x}10^{16} \ \frac{\text{ev}}{\text{cm}^2}$$

here s is taken as independent of r and the upper limit is taken as infinite, since 4000 meters is at least 10 mean free paths. The mfp, $(1/\lambda)$ is insensitive to the energy, varying from 350 meters for 5-Mev $\gamma$'s to 250 meters for $\gamma$'s with an energy of 1 Mev.

Converting to R units[8], $R = 5\times10^{-16}\ I = 15$. Allowing for the continuing dilution of contamination, <u>without deposition</u>, this corresponds to an <u>hourly</u> dose of $\sim 0.5$ R (or 5 daily doses) from +1 to +2 hours, where R/hr (at + 1 hours) $\sim 3/t^{1.2}$. This means that allowing for dilution ( $v \sim t^3$ , $R \sim (1/t^3)\cdot(1/t^{1.2}) \sim 1/t^{4.2}$) after a few days the daily dose under the above assumption will have dropped to below $10^{-5}$ R/day.

The above result was obtained under somewhat artificial assumption of uniform mixing of the fission products with air throughout the region from ground level to an altitude of some five miles, whereas it is not inconceivable that most of the activity might be carried in the head of the characteristic mushroom shaped cloud which reaches and may remain at high altitudes for hours or even days. The type of mixing and hence source distributions possible can only be realistically given by an expert meteorologist. This mixing problem is crucial and should be investigated.

<u>A Possible Site:</u>

Trinity would appear in the light of the previous discussion to be as suitable a place as any to hold future atomic bomb tests. It has the virtues of proximity to Los Alamos and existing camp facilities as well as the required distances from populated areas, although the latter point should be re-investigated. In addition, the weather history of Trinity is reasonably well known because of its proximity to the Alamogordo air base as well as the studies made in connection with the first bomb test. The behaviour against cratering is also familiar because of past experience.

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8 Chicago Handbook, Chapter XII, Section A-2.

It should be emphasized, however, that further studies should be made along the lines indicated in this report before any reliable answer can be given to the question of whether an atomic bomb can be safely exploded on continental United States.

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