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June 28, 1951

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JANGLE FALLOUT PROBLEMS

SD-9441

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A. The JANGLE test program has raised, for the first time since Trinity, serious problems of radiological safety at moderate distances from the test site. A meeting was held on 25 June 1951 to discuss these problems and to arrive at decisions on the relative safety of the proposed shots and on the radiation levels to be expected. Those present were Shipman, White, Schulte, Harris, Brennan, Williams, and Heft from H-Division, and Ogle, Suydam and Felt from J-Division. The principal conclusions are given below:

1. The surface shot is considered the best shot with which to begin the program.

2. Under the worst conditions the integrated γ-dose at 50 miles would not exceed 10 roentgens from a single shot and for good conditions the estimated dose of about 3 roentgens is conservative on the side of safety by a factor of 3 to 5. The expected levels are acceptable to H-Division.

3. There is no predictable relation between radiation levels measured on the ground and the concentration of particles small enough to be retained in the lungs. Furthermore, the concentration of small particles in a region of space near the ground is completely uncertain and is virtually independent of the point of detonation, (underground or surface). It is felt, however, that on the average worse conditions will result from lower cloud heights than from higher.

4. Conditions necessary to produce β-ray burns will be accompanied by γ-ray levels higher than those tolerable to H-Division.

B. The conclusions listed above are based on arguments presented by various people at the meeting of 25 June. Rather than append the complete minutes, I will list below those points pertaining to the above subjects:

1. The data which best apply to the JANGLE problem are the Trinity data. The JANGLE shot which most nearly corresponds to Trinity is the surface burst. The theoretical model (see C below) developed to fit the Trinity data can therefore be trusted to predict results more closely for the surface shot than for the subsurface.

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2. The model, matched to Trinity's 25-mile hot spot, predicts higher levels at greater distances than were actually recorded at those distances and may be considered conservative. Calculations for Greenhouse, though less convincing because of the lack of complete dose-rate contours and therefore of the exact numbers to be used, also give answers which are correct in order of magnitude, but are again conservative. (See Tables I and II.)

3. Surface winds are very difficult to predict over a period of hours. They are furthermore strongly affected by local terrain features. At greater altitudes, wind velocities and directions are steadier and more predictable.

4. The path of an active cloud can be predicted with some accuracy if the cloud reaches the higher altitudes. Experience from Ranger stems indicates that a low cloud will most likely follow the valleys. In that case the cloud would probably not disperse the 1 mile in 6 assumed in the calculations and would probably not follow a path based on local wind directions at the site except in a general sense. Mountain ridges and passes would not be effective in containing the small particles if the wind velocity were low. With higher winds the greater local turbulence would very likely increase local deposition, particularly on reverse slopes.

5. Trapping of fission fragments in the crater is very largely offset by the increase in neutron induced activity. There is, therefore, little to choose between one shot and another so far as total activity in the cloud is concerned.

6. The trajectories of particles small enough to be retained in the lungs are not predictable under actual conditions. Natural air turbulence will keep such particles suspended indefinitely until they are rained out or reach the earth by some other special mechanism. At ground level, in the absence of rainout, the concentration of such particles will be dilute. Still, it is better that these particles come from a higher altitude than a lower, since the numbers of such particles at ground level and at moderate distances will depend very little on the initial cloud height while the activity contained in those from a low cloud will be greater. The problem of small particles is, incidentally, little more significant for the JANGLE shots than for any other shots already fired or to be fired in the future. For all practical purposes, the time of descent of these particles to ground level is fortuitous and beyond the range of prediction.

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7. Our lack of knowledge of the effects of retention of a given number of active particles in the lungs does not permit a dividing line to be set up between a harmful and a harmless concentration. We are sure only that a zero concentration is harmless, and a zero concentration cannot be guaranteed. In view of paragraph 6 above, one may expect appreciable concentrations of small particles at any place and at any time beyond some minimum following a shot.

8. Our knowledge of the effects of external γ- and β-dosage is considerably more precise than is that of the effects of inhalation or ingestion. Damage from both γ- and β-radiation may be expected from exposure to the products of a nuclear explosion. The radiations will be quantitatively related and the more serious will be the γ-radiation. The severe β-burns noted on cattle near Trinity are a strong indication that these same cattle were subject to γ-doses of the same order as the emergency tolerance and possibly higher. For the present, the γ-dose is the best criterion for judging the degree of radiological hazard. In the case of sporadic exposure of the kind contemplated, in contrast with the repeated regular exposure suffered by workers in radiological fields, the allowable dose can, from the safety point of view, very well be raised to 5 or 10 roentgens (publicity considerations disregarded).

C. The theoretical model used to predict radiation levels as a function of distance for various conditions of particle size, cloud height, and wind velocity is based on the following assumptions:

1. The wind is constant in velocity and direction from the surface to the top of the cloud.

2. Directional and velocity wind shears are implied in the assumption that the cloud spreads horizontally 1 mile in 6.

3. Stoke's Law governs the rate of fall of all particles of interest.

4. The activity in the cloud at the time it begins to move away from the site is more concentrated at the top than at the surface. At any height the activity is initially proportional to $h^{7/2}$.

5. The fraction of the total activity carried by particles of diameter between D and D + dD is given by

$$dA = Kx^2 e^{-x^2} dx$$

where

$$x = \frac{D}{a}$$

and "a" is a parameter representing a mean particle size, and "K" is a normalizing constant.

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6. The yield is 1 KT and the total activity at the end of 1 hour is 300 megacuries. A deposition of 1 megacurie/mi^2 is equivalent to 4 r/hr.

A few remarks should be made in amplification and support of these assumptions. The assumption of constant wind velocity is better suited to work in the U. S. than to work at Eniwetok. Also, for the JANGLE shots, the clouds are not expected to rise to the great heights at which pronounced wind shears are found. The assumption of a spreading of the cloud corresponds to the observation that clouds do spread, but no detailed mechanism has been included in the calculations. Stoke's Law is used in the absence of anything better and in the knowledge gained from Eniwetok that it gives results not too far out of line with the facts. Similarly from experiments, all of which were above ground, it is clear that the higher parts of the cloud are more active than the lower (this fact may not hold for subsurface bursts). The choice of the 7/2 power law increase with height is, of course, arbitrary, and was made in order to obtain a hot spot like that found at Trinity. The odd half integral power was chosen to simplify the integrations. Stoke's Law relating the height from which a particle of given diameter must come in order to reach the earth at a given time indicates

$$h = KD^2 .$$

In the integration of height and particle size which determines the activity at a given distance, one thereby obtains an odd power of x in the integral

$$\int_0^{x_0} x^{(2n + 1)} e^{-x^2} dx$$

and can obtain the answer without reduction of the integral to a sum of terms plus an integral of the form

$$\int_0^{x_0} e^{-x^2} dx .$$

The choice of a particle size distribution function is likewise arbitrary and is justified on several grounds. A Gaussian distribution is perhaps more logical but is equally arbitrary, implies some particles of negative diameter, and introduces an additional parameter, the standard deviation. The fact that the function chosen

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predicts that there will be more particles of 1-Å size than of 1-μ size is offset by the assumption that the activity carried by a particle is proportional to its area. The resulting curve of activity (rather than number of particles) as a function of particle diameter seems sensible enough. (One might point out that the effect of making the activity proportional to the area rather than the volume of a particle is largely washed out by the high power of the particle diameter introduced by the height function mentioned in the preceding paragraph). Normalization of the activity function shows that one-half of the total activity is concentrated in particles of diameter less than 1.1 a, where "a" is a mean particle size.

The form in which the calculated results are presented consists of a family of curves in which the parameter is h_0/a^2, the maximum cloud height divided by the square of the mean particle diameter. The abscissae are reciprocals of the times at which the fallout begins, wind velocity divided by distance to the point under consideration, while the ordinates are given by the distance squared multiplied into the integrated dose. Since fission fragments alone are considered in the calculations and the $t^{-1.2}$ decay law is assumed, one may find the initial dose rate by dividing the total dose obtained from the curves by 5t where "t" is the time at which the fallout began. Some typical results are given in the tables below:

Table I

Radiation rates at Trinity for a fit at the 25-mile hot spot. (Predicted mean particle size a = 75μ)

Distance (Miles)	Roentgens/hour	
	Measured	Predicted
120	0.1	0.5
180	0.01	0.09

Table II

Greenhouse Item (Based on a = 40μ calculated from Dog fallout on Parry)

Time of Fallout (hours)	Effective Distance (Miles)	Roentgens/hour	
		Measured	Predicted
5	100	0.05	0.26
10	200	0.07	0.23

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Table III

Estimated total dose in roentgens from JANGLE shots.
Wind velocity = 10 mph*, mean particle size = 75 microns (Trinity)

Cloud Height (Miles)	Distance (Miles) 5	10	20	35	50	100
½	920	100	9	1.3	0.4	0.03
1	1200	240	30	4.6	1.4	0.1
3	145	160	63	15	5.2	0.6

* - Dose beyond 40 miles will increase with wind velocity for all three cloud heights.

Table IV

Estimated total dose in roentgens for JANGLE.
Wind velocity = 10 mph*, mean particle size = 20 microns.

Cloud Height (Miles)	Distance (Miles) 5	10	20	35	50	100
½	145	160	63	15	5.2	0.6
1	18	60	48	18	7	0.9
3	0.5	2	8	10	7	1.7

* - At 50 miles, level decreases for increasing wind velocities if cloud height is 3 miles.

The estimated doses in Tables III and IV will bear further comment. Our interests from the safety viewpoint center on the region from 35 to 100 miles. Table III shows a marked increase of dose with cloud height and is apparently in contradiction with the statement that the surface burst is the best. It is felt, nevertheless, that the deposition from a low cloud may well be higher than indicated because of the confinement of the cloud to the valleys. It is mainly our uncertainties about the path of a low cloud, the extent of neutron activation, and the true particle size distribution which leads to the conclusion that the surface shot is the best one to start with.

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Table IV indicates the effect of particle size. The levels are generally raised at the distances of interest -- 20 microns is about the worst size -- but it is apparent that the predictions are beginning to favor the higher cloud height. If the mean particle size is 12.5 microns, all levels fall and the dose from the 1/2-mile cloud height, though down to 3r, is a factor 10 greater than the dose from the 1-mile cloud. In the case of 12.5-μ particles, the doses are considerably greater for all cloud heights if the wind velocity is reduced from 10 to 5 mph.

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GLF:lh

Distribution:
Cpy 1B thru 5B - Felt

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Appendix

The attached curves are those from which the numbers in the tables were computed. For any given case one first determines which of the family of curves to use from the relation

$$\frac{h_o}{a^2} = 2^n \times 10^{-4}$$

where "h_o" is the cloud height in miles and "a" is the mean particle diameter in microns. If one then chooses a wind velocity "V" in mph and a distance "D" in miles from zero one can determine the integrated dose "I" in roentgens from the curve labeled by the parameter "n".

The following points are immediately evident from the curve:

(1) For fixed "V" and "D" a unique value of "n" gives the heaviest dose at D. Thus for a fixed mean particle diameter "a" the dose will be decreased both by higher and lower cloud heights. Physically the higher cloud leads to greater dilution and the lower leads to greater deposition, near the crater.

(2) For fixed "h_o" and "a", two regions of wind velocity "V" exist such that the dose at "D" is below the maximum possible at that distance. For example, if, at D = 50 miles and n = 4, one wants the integrated dose to be less than 5 roentgens, the condition will be met by

$$V \geqslant 18 \text{ mph}$$

or

$$V \leqslant 3.4 \text{ mph}$$

The condition n = 4 corresponds to a cloud height of 2 miles and a mean particle size of about 35 microns.

Distribution:

Cpy 1A thru 6A - Felt (w/1 att. each)
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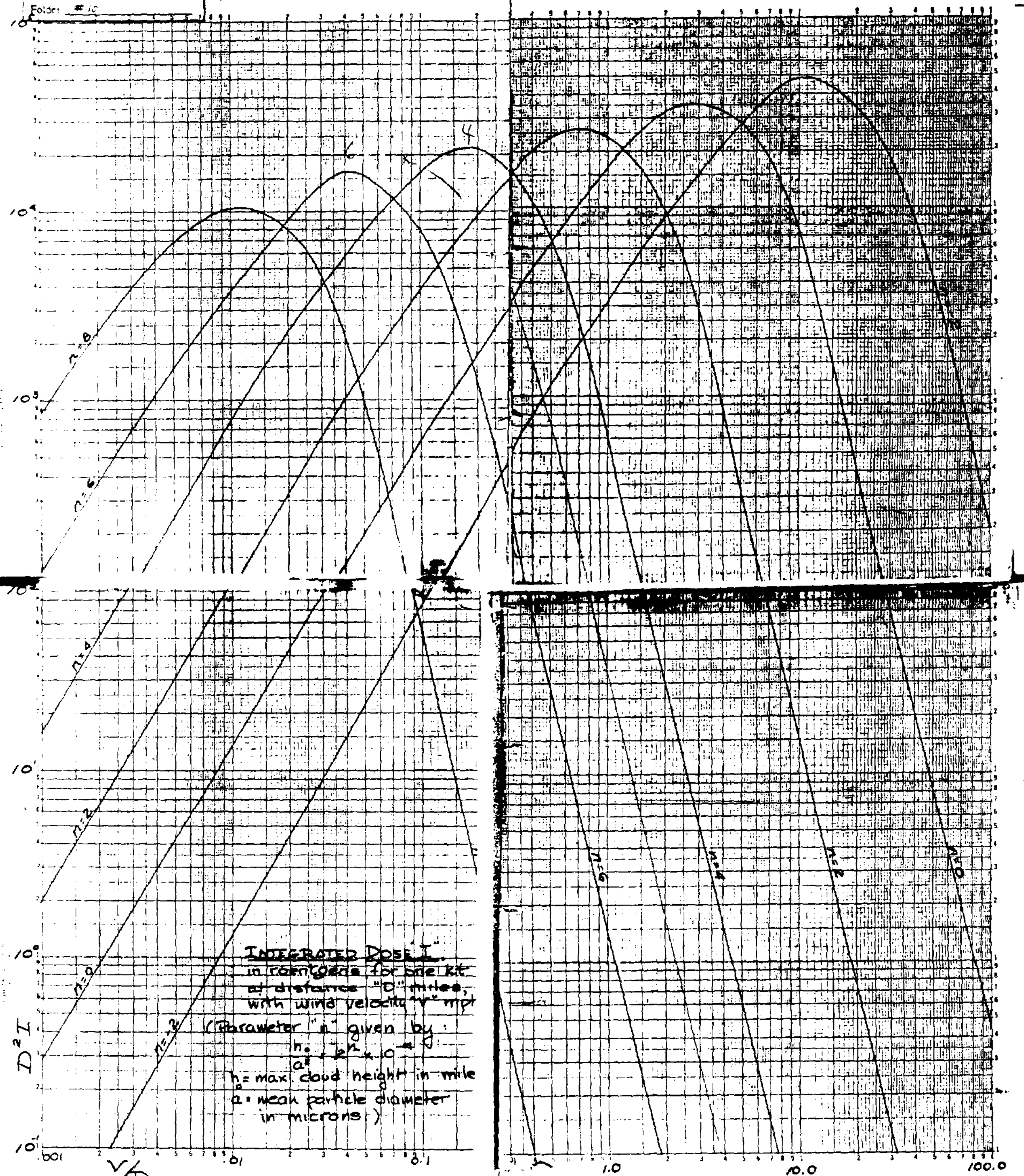
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
$D^2 I$
.001
.01
0.1
1.0
10.0
100.0
V/D
n=8
n=6
n=4
n=2
n=0
n=-2
INTEGRATED DOSE "I"
in roentgens for one kt
at distance "D" miles,
with wind velocity "V" mph
(Parameter "n" given by:
$\frac{h_0}{a^2} = 2^n \times 10^{-4}$
h_0 = max. cloud height in miles
a = mean particle diameter
in microns.)