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26292

THE SCAVENGING ACTION OF SOIL DEBRIS AND RAIN ON THE ATOMIC CLOUD

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I. GENERAL

Very little experimental data exists on the scavenging action of rain on the atomic cloud. Hence it is possible to prepare a logical study under a given set of assumptions to show that rain has the capability of scavenging out sufficient radioactivity from the atomic cloud to produce a definite hazard to life. On the other hand, if it is assumed that the radioactivity scavenged out by rain is not confined to a relatively small surface area, then a study could be prepared to show that the radioactive contamination produced by rain is relatively unimportant. Since there is very little quantitative data on the scavenging action of rain, an attempt is made in this report to study the extent of the radioactive fall-out due to soil debris.

The particle size distribution of the soil debris which is sucked up into the mushroom cloud is known; therefore, it is possible to correlate the scavenging action produced by sand with that of rain of a given intensity. It may be possible to determine the order of magnitude of the scavenging action of rain by such a method and it is just this order of magnitude of the scavenging action of rain that is required in order to evaluate some of the presently available reports dealing with the effects of rain on radioactive fall-out from the atomic cloud.

II. SCAVENGING ACTION OF RAIN AS REPORTED DURING ATOMIC TEST OPERATIONS

During both SANDSTONE (1) and TUMBLER/SNAPPER (2) Atomic Test Operations it was reported that rainfall increased the radioactive fall-out, but this increase in fall-out was never greater than 10 to 15% of the normal fall-out.

III. SCAVENGING ACTION OF SOIL DEBRIS DURING TOWER SHOTS OF T/S TEST OPERATIONS

A. During TUMBLER/SNAPPER Test Operations very little fall-out of radioactivity occurred for air drops, but the fall-out was significant during all four tower shots (200 ft. towers, 12 to 15 KT bombs). As a matter of fact, approximately 5 to 30% of the total H+1 hour activity of the atomic bombs detonated from towers were deposited in an area of from 10 to 200 miles from ground zero. In Figures 1, 2, 3 and 4 this fall-out is plotted in the form of infinity dose lines. The data used in plotting the infinity dose lines is contained in the T/S Radiological Defense Manual which is now in the process of being published. The inclosed tables give more detailed information with reference to the last four tower shots of T/S test operations and the radioactive fall-out resulting from them. There is no doubt that the great increase in radioactive fall-out for the tower shots as compared to the air drops is due to the fact that a considerable amount of sand and soil debris was sucked up into the mushroom of the tower shots, but practically no mixing occurred for the air drops which were exploded from 1000 to 3000 ft. above terrain.

B. A study of the inclosed figures and the tabulated data shows that there was a distinct area of maximum fall-out for each tower shot. The distance of this maximum fall-out area was proportional to the average horizontal wind speed

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aloft. By using a simple fall-out construction it was found that the maxima all fell into the region where a 100 to 150 micron diameter sand particle (density 2.6 gm/cm3) would fall from approximately the center of the mushroom cloud. This indicates that the numerical median particle diameter of the soil at Nevada Proving Grounds should be approximately 125 microns. According to Dr. G. Felt of J-Division, Los Alamos, the soil NMD at Nevada Proving Grounds is 125 to 150 microns (Dr. Felt attributes this to the work of I. T. Alexander of the Department of Agriculture)(See Reference 3). Dr. Felt assumes that the NMD of the fall-out particles during Trinity was 100 microns. The existence of distinct maximum fall-out areas that agree so well with the Stokes' Law relation is remarkable. If it is assumed that the H+1 hour total activity of 1 KT bomb is 3×10^8 curies, and that 3×10^4 curies/ square mile produces a dose rate of 100 mr/hr of gamma rays at a distance of 3 ft. above the ground then the following relation may be used:

$$P = \frac{At^{0.2}D}{50\,y} \text{ - - - - - - - - - - - - - - Equation 1}$$

Where

P = Percentage of the total H+1 hour bomb activity deposited on the ground by fall-out in an area bounded by a given infinity dose line.

D = Infinity Dose

A = Area in square miles inclosed by a given infinity dose line.

y = Total yield of the bomb in KT.

t = Average time of fall-out of radioactivity within the area.

The derivation of Equation 1 is as follows:

$$R_1\, t_1^{1.2} = R_2\, t_2^{1.2} \text{ - - - - - - - - - - - - - - -Equation 2}$$

Where

R = Dose rate in roentgens/hr.

t = Time in hours after H-hour.

$t_1 = 1$

t_2 = Average time of fall-out in area bounded by a given infinity dose line.

$$D = \int_{t_2}^{\infty} R_2 dt = R_1\, t_1^{1.2} \int_{t_2}^{\infty} t_2^{-1.2}\, dt = 5\, R_1\, t_2^{-0.2} \text{ - - - - -Equation 3}$$

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$$P = \frac{(3 \times 10^4 \text{ Curies/mi}^2)\ (A \text{ mi}^2)\ (R_1/0.1)\ (100)}{(3 \times 10^8)\ y} \qquad \text{-----Equation 4}$$

Where

R_1 = Dose rate in r/hr in area A bounded by infinity dose line D, and where the dose rate within the area has been extrapolated back to H+1 hours using the $t^{-1.2}_{\;0.2}$ relation.

but by Equation 3, $R_1 = \frac{D\ t_2}{5}$

therefore

$$P = \frac{(3 \times 10^4)\ (100\ A\ D)}{(5\ t_2^{-0.2})\ (3 \times 10^8\ y)} = \frac{A\ D\ t_2^{0.2}}{50\ y}.$$

$$R_2 = \frac{D}{5t_2} \qquad \text{- -Equation 5}$$

Equation 1 was used to prepare the values given in Table V. It should be noted that the last column of Table V gives the total H+1 hour percentage of the bomb activity deposited on the ground by fall-out ($\sum_i$ Pi.). The percentages given in the tables are not significant beyond two figures.

C. It is possible to estimate the amount of sand and soil debris sucked up into the mushroom of the atomic cloud from a knowledge of the value of P, and by a knowledge of the average specific activity of the soil particles within the atomic cloud. If it is assumed that the average specific gamma ray activity of the fall-out particles is between 1×10^{-2} and 2×10^{-2} microcuries at H+1 hours then it can be shown that the number of radioactive particles deposited on the ground in the fall-out area is given by the following:

$$\frac{3 \times 10^8\ y \sum_i P_i}{(100)\ (1.5 \times 10^{-8})} \qquad \text{- - - - - - - - - - - - -Equation 6}$$

If it is assumed that all of the particles are 125 microns in diameter, spheric and have a density of 2.6 gm/cm^3, then the amount of sand, in grams, mixed into the mushroom of the atomic cloud of a 200 ft. tower shot is given by:

$$8.4 \times 10^{14}\ r^3\ y \sum_i P_i \qquad \text{- - - - - - - - - - - - - - - - - -Equation 7}$$

This means that approximately 6.7×10^{10} gm of sand and soil debris was mixed with the mushroom of shot No. 5 and 2.3×10^{10} gm. of sand was mixed in shot No. 7 cloud of T/S. This represents from 25,000 to 75,000 tons of sand mixed

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in with the atomic cloud. Naturally a question will be raised as to whether such a large quantity of sand does in reality get mixed in with the mushroom of an atomic cloud or are the calculations off by a large factor. In order to answer this question a study was made of the crater volumes of the different tower shots. According to Reines of Los Alamos the Trinity Crater had a measured volume of 1.3×10^6 cu. ft. which represents a displacement of approximately 1×10^{11} gm of sand (110,000 tons of soil). The Trinity bomb was 20KT and it was exploded from a 100 ft. tower; therefore, it would be reasonable to assume that approximately 25% of the H+1 hour total bomb activity could have been deposited on the ground as fall-out within 100 miles of ground zero. From Equation 7 it can be shown that under such an assumption nearly 5.25×10^{10} gm of soil were mixed into the mushroom of the Trinity cloud. Since the crater displacement is greater than the calculated amount of soil mixed into the mushroom of the atomic cloud the calculated values are seen to be reasonable.

D. Relation Between Sand and Rain Scavenging

According to Gauvin and Healy (4) ordinary rain of 0.15 inches/hour has a liquid water content of 0.2 gm/m^3, and the record rain in the U. S. had 4 gm of water per cubic meter of air. It will be assumed that 0.15 inches/hr of rain has a velocity of from 500 to 600 cm/sec and the raindrop diameters are from 500 to 1000 microns. Under these circumstances ordinary rain would produce from 50 to 400 raindrops per cubic meter of air. The number of sand particles in each cubic meter of air during fall-out may be given by the following relation:

$$\frac{7.37 \times 10^3 y P}{A} \text{ - - - - - - - - - - - - - - - Equation 8}$$

Where, y, P and A are as defined previously, and where it is assumed that the radioactive particles start their fall at approximately 6.5 miles above terrain

$$\left[(2 \times 10^{14} y P/A) \frac{1}{((6.5)(4.17 \times 10^9))} = \frac{7.37 \times 10^3 y P}{A} \right].$$

Table VI indicates the number of radioactive sand particles per cubic meter of air for the areas bounded by the given infinity dose lines. If the sand particles are considered equivalent to rain drops, then ordinary rain would occur in the areas bounded by 0.5 r to 2 r infinity dose lines; moderate to heavy rain would occur in the areas bounded by the 5 r to 10 r lines; and the areas bounded by 20 r to 50 r lines would receive record amounts of rain as that from a cloud burst. But it was shown earlier that the radioactive sand particles are approximately 125 microns in diameter. According to Figure 1 of Anderson's report (5) particles (raindrops) with diameters of 500 to 1000 microns have approximately two to four times the collection efficiency of particles whose diameters are 125 microns. However, since the fireball envelopes the sand particles and subsequently these particles are sucked up into the young cloud and rise with it to maximum height before they begin to fall, it is only fair to assume that the collection efficiency of the sand particles must be somewhat greater than that indicated by simply considering their size. It will be assumed that the efficiency of collection of rain drops is twice that for 125 micron sand particles.

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This means that the radioactive fall-out for shot No. 5 of TUMBLER/SNAPPER is equivalent to the situation where the two hour old atomic cloud comes in contact with continuous heavy rain which originates at 40,000 to 50,000 ft. msl. It will be assumed that the rain reaches the ground within 20 or 30 minutes, hence the fall-out will be completed at H+3 hrs. If it is assumed that the rain is uniformly intense throughout the 17,000 square miles, then the two hour old atomic cloud will be assumed to have a "hot core" or central area of maximum activity of 1300 square mile cross-section. The shape of the cross-section will be elliptical with the major axis of the ellipse parallel to the average horizontal wind direction. Around this central "hot core" there will be less radioactive areas. As a matter of fact Figure 1 would be a good representation of the cross-section of the atomic cloud from shot No. 5 provided a correction is applied to account for the motion of the cloud top in the first two hours. Of course, it may be possible to obtain the same fall-out pattern if we assumed that the more intense radioactive fall-out areas are due to heavy rain and the less intense contamination is due to the fact that the rain in these areas was less intense. In other words, if the cloud is assumed homogeneous then it must be assumed that the rain is non-homogeneous, and vice versa, in order to obtain the fall-out patterns shown in the inclosed Figures. This shows that even if the three hour old atomic cloud is scavenged by heavy rain which originates at the unlikely height of 40,000 ft., the radioactive fall-out will not present a hazard to life. There will be a relatively small surface area where the maximum dose rate will be as high as 2r/hr, but where for the most part the average maximum dose rate within the area would be in the order of 200 to 300 mr/hr, and the $t^{-1.2}$ decay law would apply. Certainly this would pose a hardship in the area concerned, but it would not be hazardous to life. It was assumed above, that the continuous type of steady rain originates at 40,000 to 50,000 ft. msl. In reality it would be quite rare indeed to find heavy rain originating at such a high level. On rare occasions or under some turbulent thunderstorm activity precipitation may reach such heights, but to make operational plans based on the assumption that this happens on a continuing basis is certainly unrealistic. It is thought that a more realistic assumption would be that rain originates from 5000 ft. to 25,000 ft. msl. This means the amount of radioactivity scavenged out at H+2 or H+3 hours would be considerably less than that indicated above, because the scavenging would begin at 25,000 ft. or less, hence rain could not possibly come in contact with all of the atomic cloud. As a matter of fact it is difficult to see how the average rain could come in contact with the mushroom of an atomic cloud formed by the detonation of a nominal (20KT) bomb. From the long range Public Health point of view the inclosed Figures indicate that there may be a hazard to health in the areas where fall-out is shown. However, it should be noted that in all of the shots subsequent to shot 5, it was not possible to find a measurable amount of radioactivity in the areas concerned two tothree days after shot time. This indicates that the radioactive fall-out is further diluted by such "weathering" effects as winds, rain, etc. It was possible to find measurable amounts of radioactivity two weeks after shot No. 5 was detonated. It is believed that the available data from TUMBLER/SNAPPER together with the indicated calculations has made it possible to determine the order of magnitude of the radioactive contamination that may be scavenged out by rain from the three hour old atomic cloud. If it is desired to determine the radioactive fall-out from the young atomic cloud then the rate of decay and the diffusion factor of the atomic cloud must be evaluated. The decay factor is relatively simple to evaluate.

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However, it is more difficult to determine the diffusion rate. In order to get some idea of the turbulent diffusion of the atomic cloud it will be assumed that at H+15 minutes the total cross-sectional area of an atomic cloud from a nominal bomb is approximately 10 to 15 square miles. Figure 1 and Table III indicate that the radioactive fall-out from TUMBLER/SNAPPER shot no. 5 was spread over 17,000 square miles. The fall-out began at H+1 hour at a distance of 50 to 75 miles from Ground Zero, at H+2 hours within 100 to 150 miles; and at H+3 hours within 150 to 200 miles from ground zero. Obviously some correction should be applied for the motion of the cloud during the first one to two hours. It will be assumed that this effect has a value as high as a factor of 2. In view of this it will be assumed that the total cross-sectional area of the atomic cloud from shot 5 would be reduced to a value between 5000 and 10,000 square miles. The average cross-sectional area of the H+3 hour atomic cloud of a nominal bomb would be approximately 5000 square miles. This means that in three hours, the atomic cloud has increased in cross-sectional area from 10 to 15 square miles to nearly 5000 square miles. If the cloud is assumed to be spherical, then the radius of the cloud is multiplied by a factor of ~~1.85 t~~ 9t due to turbulent diffusion (including shear), provided the diffusion rate is constant (where t is time in hours after detonation). This means that at H+1 hours the cross-sectional area of the cloud would be 1700 square miles and at two hours the area would be approximately 3400 square miles.

E. Maximum Heights Reached by Atomic Clouds as Compared to the Average Heights Where Rain Originates

A study was made of the cloud heights of the small yield atomic bombs exploded during test operations. The results are summarized in Table VII. The RANGER data was obtained from the Los Alamos Report of Operation RANGER, Volume IV (Secret-Restricted Data). From a study of the cloud heights it seems obvious that 1 to 2 KT bombs will rise from 10,000 to 20,000 ft. msl. It will be assumed that the atomic clouds of 1 to 2 KT bombs will be completely enveloped by the normal rains. It will be assumed that the cloud from 3 to 5 KT bombs will rise from 15,000 to 30,000 ft. msl, hence only in 50% of the cases will rain succeed in completely covering all of the atomic cloud. It will be assumed that 5 to 10 KT bombs will rise to 25,000 to 40,000 ft. msl and only occasionally will rain come in contact with all of the atomic cloud. In the case of a nominal bomb (20KT) it will be assumed that rain will come in contact mainly with the stem of the cloud. It should be noted that the volume of the mushroom cloud is normally five to ten times the volume of the stem. For high airdrops (2000 to 3000 ft. above terrain for nominal bombs) the stem would be negligible to non-existent. For tower shots (100 to 300 ft. towers) the stem may have approximately 10% of the total bomb activity. Based upon these considerations it is possible to evaluate the radioactive hazard produced by the scavenging action of rain on the H+1 and H+4 hour old atomic clouds from bombs of different yields. The values obtained are tabulated in Table VIII. The multiplication factors to obtain the scavenging action of rain from the available data on the scavenging action of sand were obtained using the following relation:

$$\left(\frac{y}{y15}\right)(2)\left(\frac{c1}{co}\right)(2) \text{ - - - - - - - - - - - - - - - - Equation 9}$$

Where

y = KT of bomb

y_{15} = 15 KT

c_1 = Activity of cloud that comes in contact with rain

c_o = Total activity of cloud

And it is assumed that rain is twice as efficient a scavenger of radioactivity as sand, and that the radioactive fall-out area would be only half of the average shown in the Figures for sand fall-out to account for cloud motion during fall-out. In view of the data shown in the inclosed Figures and Tables, it becomes evident rain scavenging has been greatly overestimated in both Anderson's (5) and in Holzman's (6) reports. Reference 6 overestimates the radioactive hazard due to rain scavenging because it underestimates both the heights reached by 10 KT "tactical" atomic bombs and the magnitude of the horizontal diffusion rate of the atomic cloud. Holzman clearly recognizes the limitations of his assumption of the diffusion rate becase he says of the diffusion rate, "This assumption is the weakest of all". From the data presented in this report it is estimated that the radioactive contamination due to the scavenging action of rain cannot produce a hazard to life provided the atomic cloud is 1 hour old or older. It may be possible to deposit on the surface of the ground approximately 100r integrated life time dose of radioactivity if the fifteen minute old cloud of a 1 to 2 KT atomic bomb is completely scavenged out by rain in a short while after detonation, but the contaminated area will be confined to within 1 to 5 miles of ground zero. From the tactical point of view this would be a bonus effect. It is difficult to imagine how rain could possibly produce hazardous contamination at distances greater than 100 miles from ground zero under any circumstances or regardless of the number of 10 KT "tactical" bombs used. Anderson (5) overestimates the radioactive contamination primarily because he assumes rain could originate above the mushroom cloud from a 20KT atomic bomb.

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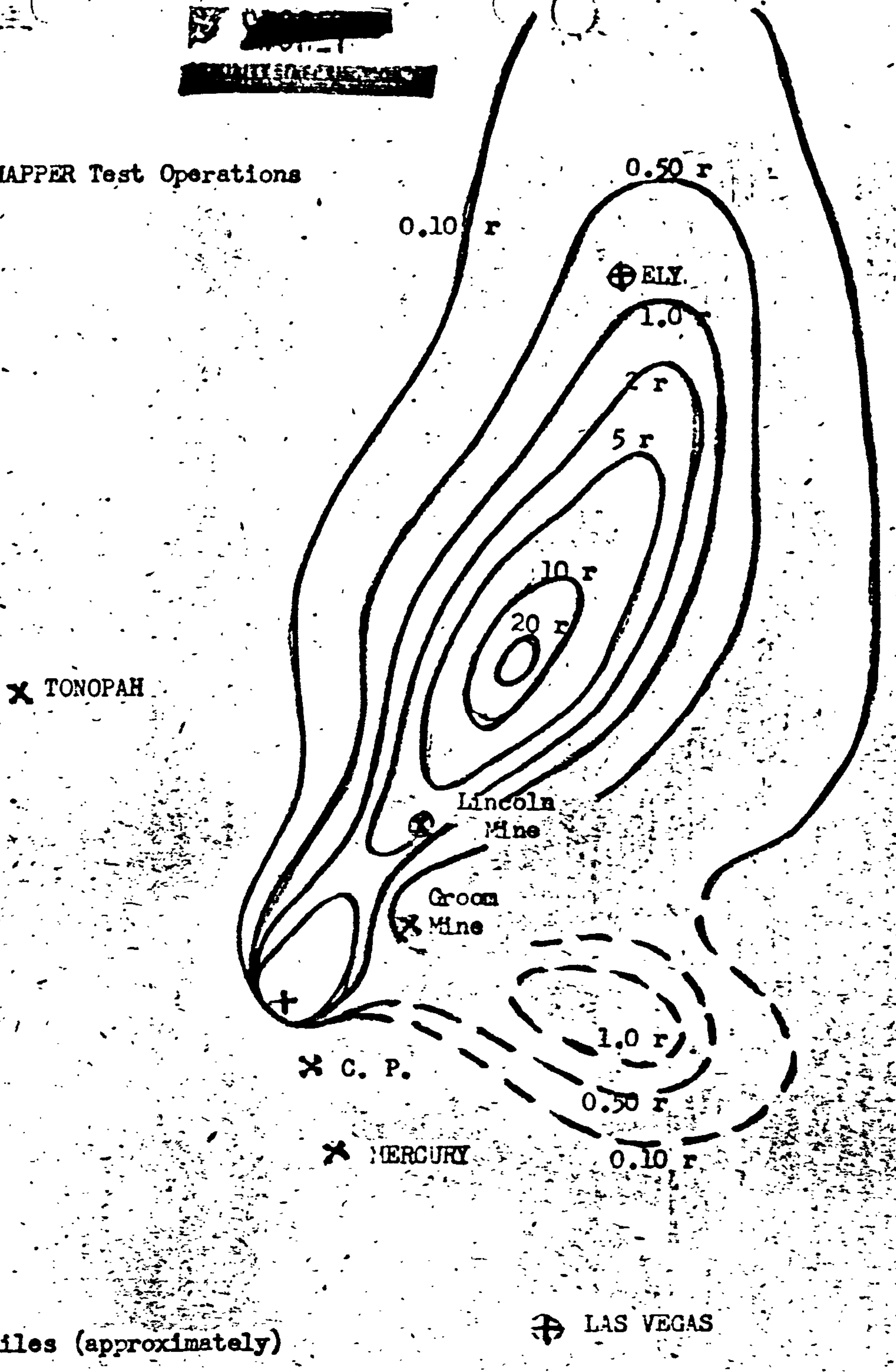
Shot No. 5

TUMBLER/ SNAPPER Test Operations



1" = 32 miles (approximately)

FIGURE I

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Shot No. 6

T/S Test Operations

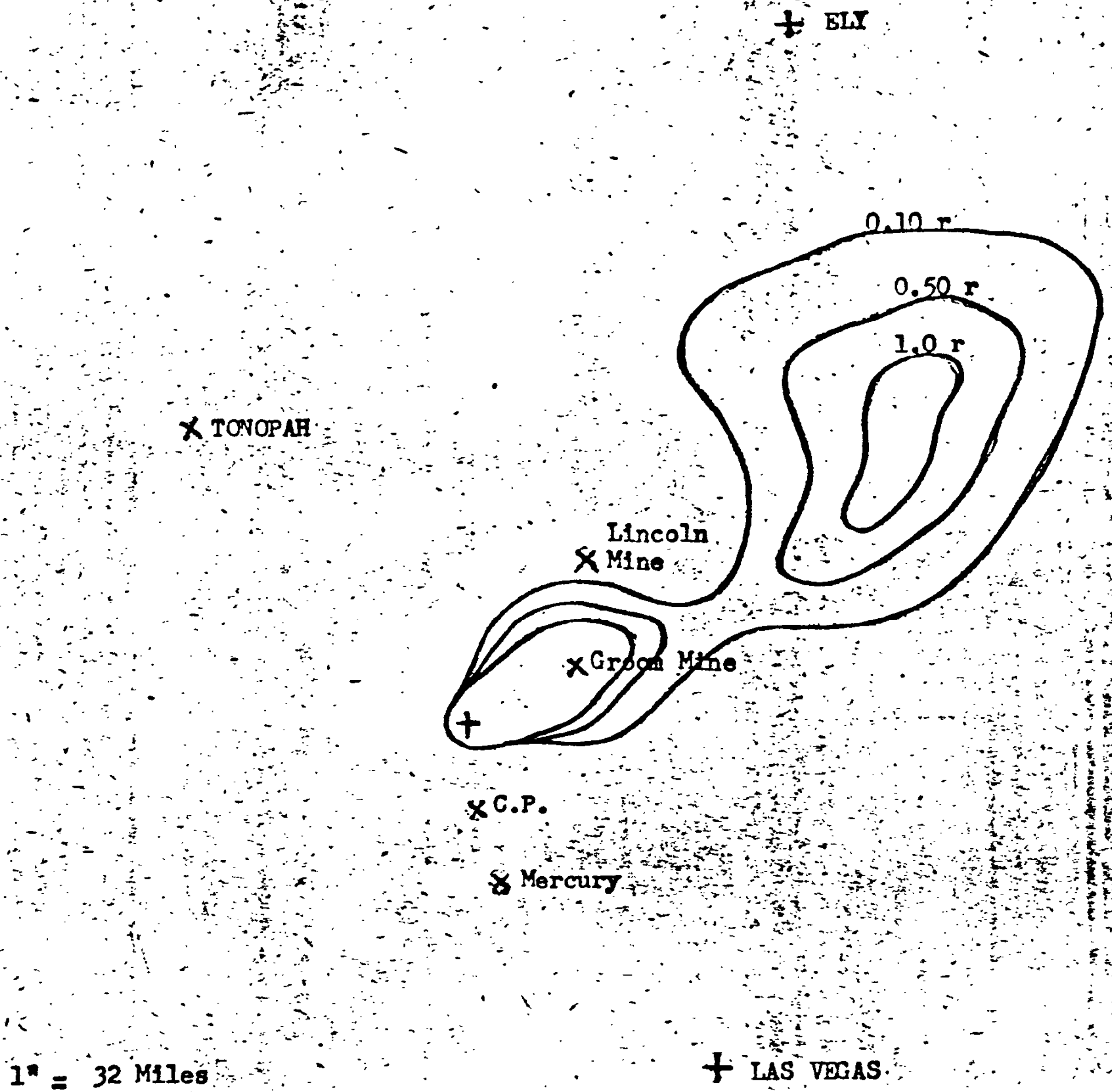

FIGURE 2

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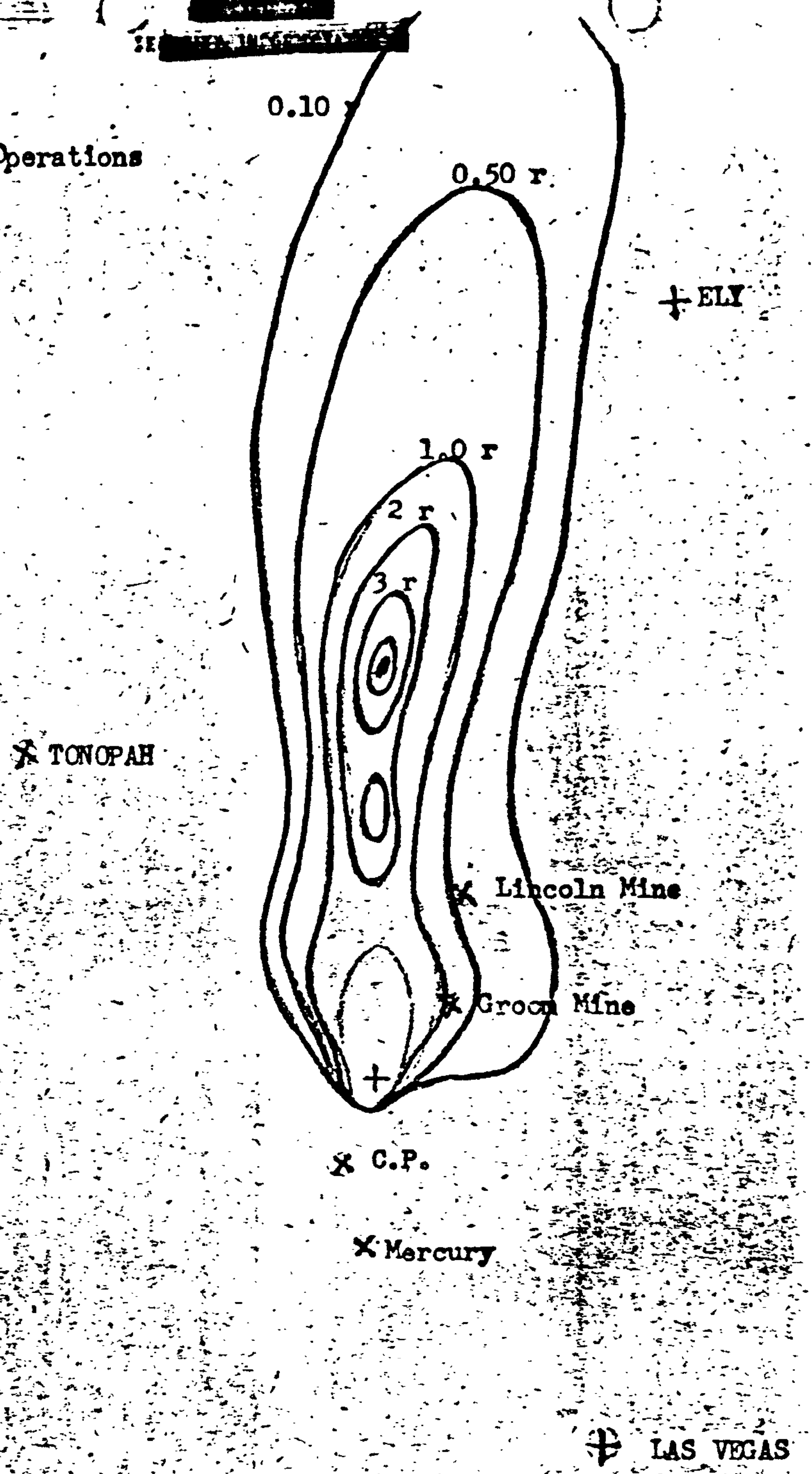
Shot No 7

T/S Test Operations



1" = 32 miles

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FIGURE 3

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Shot No. 8

T/S Test Operations

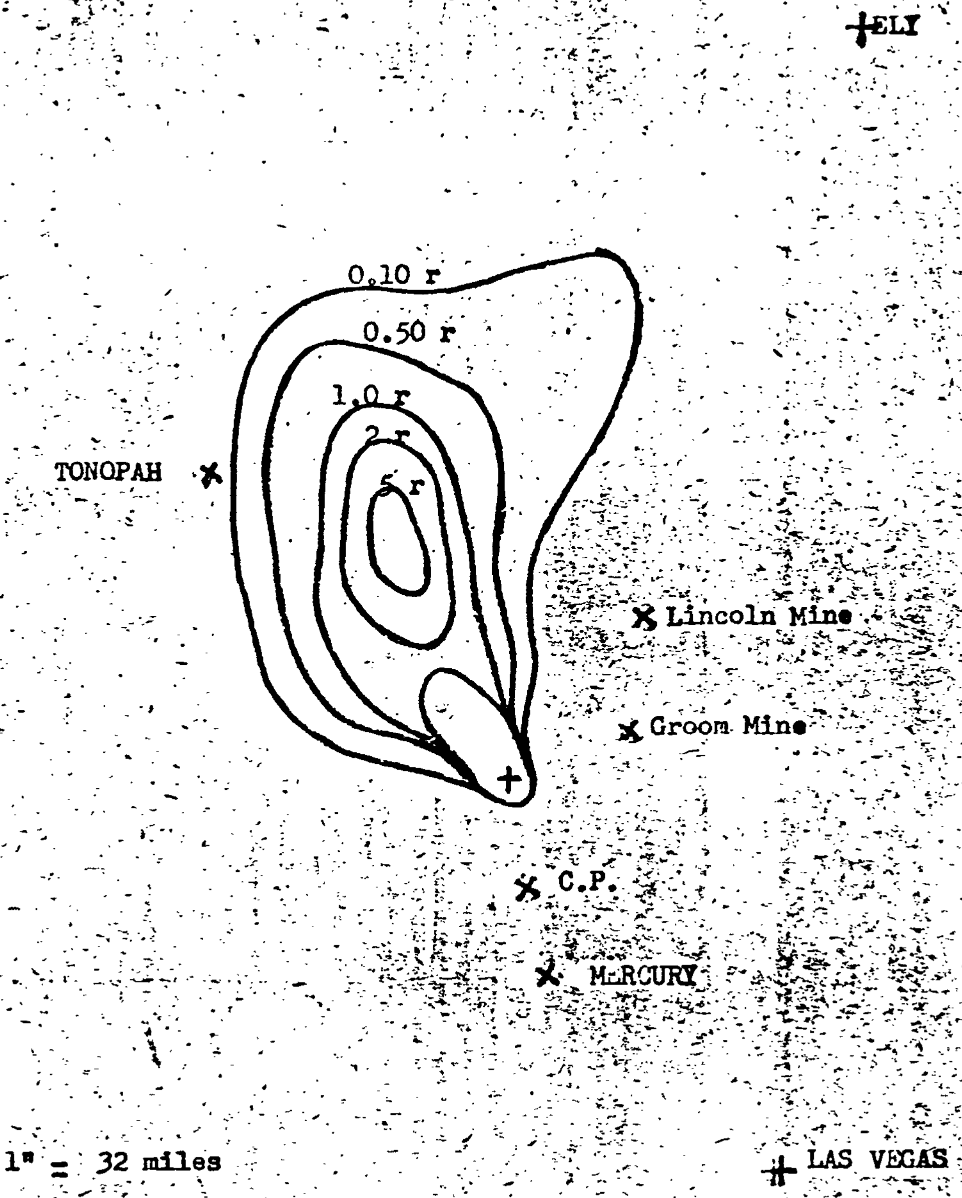

FIGURE 4

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TABLE I

TUMBLER/SNAPPER SHOT NUMBER (All Tower Shots)	YIELD IN KT FROM AUGUST 1952 RADIO-CHEMISTRY RESULTS	MAXIMUM INFINITY DOSE IN THE FALL-OUT AREA IN ROENTGENS	TIME IN HOURS AFTER H HOUR THAT MAXIMUM FALL-OUT OCCURRED
5	11.8	21r	1.8 hrs
6	10.7	2	2.3
7	13.8	30	2
8	14	6	3

TABLE II

T/S SHOT NUMBER	MAXIMUM HEIGHT REACHED BY ATOMIC CLOUD IN FT. ABOVE MEAN SEA LEVEL	AVERAGE WIND SPEED ALOFT IN KNOTS	MAXIMUM WIND SPEED ALOFT	MAXIMUM WIND SPEED SHEAR FROM 10,000 FT. TO 40,000 FT. msl	MAXIMUM ANGULAR WIND SHEAR FROM 10,000 FT. TO 40,000 FT. msl IN DEGREES
5	34,400 ft.	75 Knots	100 Knots	60 Knots	40°
6	40,300	20	45	30	180°
7	37,100	40	48	25	30°
8	41,300	30	45	20	120°

TABLE III

T/S SHOT NUMBER	AREA IN SQUARE MILES OF THE INFINITY DOSE LINES INDICATED										
	0.1r	0.5r	1r	2r	3r	5r	6r	10r	20r	30r	TOTAL ($\sum$A
5	9000mi^2	4000	1300	1450	---	1000	---	200	50	---	17,000 mi^2
6	3000	870	630	---	---	---	---	---	---	---	4,500
7	3200	2250	1000	350	140	---	---	45	5	10	7,000
8	1500	1000	700	450	---	130	20	---	---	---	3,800

TABLE IV

T/S SHOT NUMBER	AVERAGE TIME OF FALL-OUT IN HOURS AFTER H-HOUR FOR THE AREAS INCLOSED BY THE INFINITY DOSE LINES INDICATED									
	0.1r	0.5	1	2	3	5	6	10	20	30
5	2	2	1.5	1.7	---	1.8	---	1.8	1.8	---
7	5	3.5	3.0	2.5	2.5	---	---	2.0	2.0	2.0

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TABLE V

T/S SHOT NUMBER	PERCENTAGE OF THE TOTAL (H+1 HOUR) ACTIVITY OF THE BOMB SCAVENGED OUT BY SOIL DEBRIS FOR THE AREAS INCLOSED BY THE FOLLOWING INFINITY DOSE LINES										
	0.1r	0.5	1	2	3	5	6	10	20	30	TOTAL$(\Sigma_1$
5	1.7%	3.82	2.35	5.35	---	9.25	---	3.25	1.88	---	27.6%
7	0.65%	2.1	1.8	1.22	0.75	---	---	0.77	0.17	0.5	7.96%

TABLE VI

T/S SHOT NUMBER	NUMBER OF RADIOACTIVE SAND PARTICLES PER CUBIC METER OF AIR OVER AREAS BOUNDED BY THE FOLLOWING INFINITY DOSE LINES									
	0.1r	0.5	1	2	3	5	6	10	20	30
5	20	80	150	300	---	750	---	1500	3000	4500
7	25	100	200	400	600	---	---	2000	4000	6000

TABLE VII

CLOUD HEIGHTS OF SMALL YIELD BOMBS

SHOT NUMBER	TEST OPERATION	KT	CLOUD HEIGHT IN FT. msl
1	RANGER	1.3	16,000 ft. msl
2	"	7.2	35,000 (Tropopause)
3	"	1.0	12,500
4	"	6.5	28,000
5	"	22	42,000 (Tropopause)
2	BUSTER	3	30,000
Surface	JANGLE	1	16,000 ft. msl
Underground	JANGLE	1	11,000 ft. msl
1	TUMBLER/SNAPPER	1.05	15,400 ft. msl
2	" "	1.19	14,400 ft. msl

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TABLE VIII

LIFE TIME DOSE IN ROENTGENS WITHIN THE RADIOACTIVE FALL-OUT AREA AT H+3 HOURS DUE TO:

YIELD IN KT	SCAVENGING ACTION OF SOIL	MULTIPLICATION FACTOR	SCAVENGING AIR BURST (bombs detonated at 1000 to 3000 above terrain) ACTION OF RAIN	MULTIPLICATION FACTOR	FOR TOWER SHOTS (Bombs detonated at 100 to 300 above terrain
1 to 2 KT	0.2 roentgen	4	0.8 roentgen	10	2 roentgen
3-5	0.5	2	1	6	3
5-10	1	1	1	2	2
10-20	2	0.5	1	1	2
20	2	0.5	1	1	2
40	2	0.5	1	1	2
60	4	0.2	0.8	0.5	2
80	4	0.2	0.8	0.5	2
100	6	0.2	1.2	0.5	3

NOTE: To obtain H+1 and H+2 hour life-time dose, multiply the dose values by 12 and 6 respectively.

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6. Optimum Use of the Atomic Bomb Strategic and Tactical Implications, Benjamin G. Holzman, the National War College, Second Semester 1951-52 (SECRET)

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