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RADIOACTIVE FALL-OUT FROM ATOMIC BOMBS

by

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AEC Technical Information Service Extension
Oak Ridge, Tennessee

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ABSTRACT

The radioactive fall-out from tower shots of TUMBLER/SNAPPER (R) and UPSHOT/KNOTHOLE (R) Test Operations has been plotted in detail utilizing the radiological monitoring logs of the ground and air monitors. The report brings out the following points:

a. There is no excessive radioactive fall-out from an atomic bomb if the fireball does not touch the ground. (This refers to the maximum fireball radius.)

b. It is possible to detonate the following type of shots regardless of weather conditions (other than rain) without producing excessive radioactive contamination: 3 KT bomb exploded from a 300 ft tower, 8 KT from 400 ft, 18 KT from 500 ft, 45 KT from 700 ft, 100 KT from 1000 ft, and 200 KT from 1300 ft. In this discussion only the residual radioactive contamination is considered and no account is taken of the blast and thermal damage parameters.

c. It is possible to delineate the general fall-out area adequately using a simple Stokes' Law analysis of the winds and assuming that the particle size varies from 150 microns to 75 microns, and the average density of the particles is 2.5 grams per cubic centimeter.

d. The radex based on the actual wind observations made three hours prior to shot time indicates the general fall-out area adequately. It is suggested that the decision to fire a contaminating tower shot (i.e. where the maximum fireball radius is equal to or greater than

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I. GENERAL

The fall-out from TUMBLER/SNAPPER (Restricted) and UPSHOT/KNOTHOLE (Restricted) Test Operations is examined in some detail in this report. The radioactive contamination resulting from the tower shots of the above two test operations is plotted pictorially (see Figures 1 through 9). Both the air and ground radiological monitoring data contained in the Radiological Safety Reports of the test operations have been utilized (1,2).

II. RADIOACTIVE FALL-OUT DUE TO SAND AND SOIL DEBRIS FROM TOWER SHOTS OF TUMBLER/SNAPPER (R) AND UPSHOT/KNOTHOLE (R) TEST OPERATIONS

A. Radioactive Fall-out as a Function of Yield and Height of Detonation Above Ground

During high air drops of nominal bombs there is practically no stem formed to the atomic cloud. As the height of detonation is decreased, or the yield of the bomb is increased, a stem is formed which may or may not reach the rapidly rising mushroom. As the height of a bomb is reduced still further there appears a definite stem to the cloud which is continuous with the mushroom. However, no extensive fall-out occurs within immediate area of the test site unless the height of detonation is so low that the fireball touches the ground. An inspection of Table I brings out the fact that unless the maximum fireball ~~diameter~~ RADIUS is greater than the height of burst there is practically no radioactive fall-out within 200 miles of ground zero (fall-out being less than 1%). During the two test operations this factor was verified in a sufficient number of cases so that it is possible to put considerable

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B. Accuracy of Data Collected by Aircraft

In the past there has been considerable criticism on the advisability of using extrapolated airplane data for radiological monitoring. However, in this study, it is possible for the reader to judge for himself the accuracy and the usefulness of the radiological data collected by aircraft, since the air readings and the ground readings are individually plotted for easy comparison. A careful study of the airplane data shows that it is not possible to obtain accurate indication of the contamination on the ground if the contaminated area is less than five square miles. However, for large area contamination, the airplane data is useful. This means that there need not be any extreme accuracy required in the navigation of aircraft, since errors of one or two miles could be tolerated. In some instances the airplane data is more useful than the ground data in delineating the overall radioactive fall-out picture. This was demonstrated somewhat dramatically during the first shot of U/K Test Operation. During this particular test, St. George, Utah received an infinity maximum dose of 0.5 roentgens in the center of the city (see Figure 5). However, the airplane reading indicated that the contamination at St. George was 3.3 roentgens. This was quite disconcerting at the time. It developed later that just at the northern outskirts of the city there was a small radioactive zone of 6 roentgens and further north there was a five mile wide layer with an average infinity dose of 3 roentgens. What the airplane had done was to average the total and give a 3.3 roentgen reading because it was flying at an altitude of 500 ft, and therefore the instrument in the plane could "see" a

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monitors. If two or three aircraft and approximately one dozen trained personnel are devoted solely to radiation monitoring duties it would be possible to delineate the general fall-out area adequately. A complete fall-out map could be prepared from the air readings where the contamination is given in relative units. Then all that is required is a few ground readings to change the relative readings of the fall-out map to gamma roentgen dose values. If this suggestion is accepted, it should be kept in mind that air readings should not be utilized to determine the contamination of such small areas as ground zero etc., since it is futile to attempt to pin point the contamination of a given small area from an airplane. Experience also indicates that although the conductivity meter used in an airplane is very sensitive to contamination in the air, the normal radiological gamma indicating instruments (MX-5 and T1B) are relatively insensitive to such contamination. If conductivity meters are used, the aerial survey must be made 24 hours after shot time to be sure that the air is cleared of all radioactive fall-out (within 200 miles of ground zero). If MX-5 or T1B instruments are used the aerial survey could start two or three hours after shot time. The flight pattern will be governed by the radex plot to keep the airplane out of the path of the fall-out. Historically there is only one incident in which the MX-5 or T1B instruments carried in the aircraft became contaminated during T/S or U/K Test Operations. This occurred during T/S, Fox Shot (see Reference #1) and is indicated in Figure 2 of this report. During the first shot of U/K (Annie) the radex plot showed a very narrow path of fall-out, and it was indicated that the aircraft could

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of such large particles (70 to 150 microns), it is possible to prepare a simple wind vector plot indicating where the fall-out will touch the ground from a given point in the atomic cloud. These wind plots have been used previously under various names and have been described in great detail (3, 4, 5, 6, 7), therefore no attempt will be made to describe the method in this report. However, such vector wind plots have been used extensively by this writer to obtain a lot of indirect information. There is some indication that soil particle size decreases with altitude in the cloud. It should be clearly understood that the particle sizes indicated above refer to the median soil particle diameter, and that the soil particle size spectrum is wide. The fall-out at a given spot may have come from different levels of the cloud, thus further increasing the spread of the size spectrum. The density of particles at NPG average around 2.5 gm/cm^3, but certainly not all the particles would have the same density nor are they all spherical in shape and this also increases the particle size distribution. Strangely enough, during the domestic test operations it was observed that many particles in the size range of only several microns in diameter fell out within a few hours after bomb burst. According to Stokes' Law (even when corrected for the Cunningham slip factor and for the variation of air viscosity with temperature) it would take a 5 micron particle several months to reach the ground from 40,000 ft. The explanation is to be found in the fact that a large quantity of soil is sucked up into the cloud and as this soil subsequently falls back to the ground, it entrains and traps a lot of air and a lot of small sized primary fission

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static Precipitators, etc., yields particle size distributions that may have no relation to reality, being artifacts introduced by the sampling rate, the sampling method, the counting technique employed, etc. Even mechanical soil analysis of the NPG area produces conflicting results. The median soil particle diameter appears to be a very strong function of the method employed to measure particle sizes. The reader should be cautioned that in this section only the particle size of the soil debris is discussed and no statements are made concerning the particle size distribution of the cloud aerosol itself exclusive of the soil that is sucked up into the cloud during near surface explosions.

D. Identifying Fall-out from the Stem and Mushroom of the Atomic Cloud

A study of Figures 6 through 9 of this report indicates that there is a minimum radioactive fall-out area which is presumed to have come from the area between the base of the mushroom and the top of the stem of the atomic cloud. The minimal radioactive zone between the stem and the mushroom has some reality in observation. During the tower shots of T/S and U/K Test Operations the clear sky showed through in this portion of the atomic cloud after 10 to 15 minutes from time of detonation. For some unexplained reason the formerly continuous stem and mushroom appear to separate after 10 to 15 minutes. The reader may have seen movies of air drops where the stem is seen to be discontinuous with the mushroom from the start, because it forms after the mushroom has begun to rise. This is not the proper explanation for this case, however, because during low tower shots the stem and mushroom are contin-

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of the fall-out comes from the stem. The information available from the fall-out of T/S tower shots is not sufficiently detailed for this type of analysis, but it appears that for lesser KT tower shots (10 KT) the soil in the stem remains relatively inactive, and most of the fall-out comes from the sand mixed in with the mushroom of the cloud. Therefore for T/S Test Operation the P_m/P_s ratio may be 2 or 3. If the ratio of P_m/P_s continues to decrease with decreasing scaled height then for a surface shot a large percentage of the activity will be in the soil within the stem rather than the soil in the mushroom. Attention is invited to the relative constancy of the P_m/P_s ratio for U/K tower shots. This type of constancy tends to increase one's confidence in the fall-out picture indicated in this report and in the air readings utilized to delineate the contaminated area. During T/S tower shots approximately 15% of the total residual activity of the bomb fell out within six hours over an area of 5000 to 10,000 square miles, 5% coming from the stem and 10% from the mushroom. During the tower shots of U/K the average percentage fall-out appears to be 20%, 15% coming from the stem, 5% from the mushroom. According to Reference #9, 50% of the total activity of Trinity was deposited immediately downwind (23 KT, shot from a 200 ft tower). However, it is not clear how complete the study of fall-out was during the Trinity explosion. There is some evidence that although an attempt was made to delineate the fall-out quite accurately some years after the Trinity explosion, the fall-out pattern was not studied in too great a detail on the day of the shot or soon thereafter.

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tower shots. According to Reference #10 there is a definite secondary maximum fall-out area 50 miles NNE of the J-S crater, and the maximum fall-out from J-U is 10 miles NNE of the ground zero. A Stokes' Law analysis of the J-S secondary maximum indicates that according to the vertical wind distribution pattern, this secondary fall-out came from the upper portion of the cloud. Since the fall-out from J-S and J-U shots covered one to two thousand square miles, and because only eight to 10 square miles were examined during fall-out studies, it is the contention of this writer that such sampling was not representative. There is a great likelihood that most of the fall-out downwind was not measured. The Air Force Special Weapons Center also surveyed the J-S and J-U fall-out area on D and D+1 days using aircraft. However, since all the readings (except ground zero and three miles downwind) are made from aircraft, it is not considered reliable by itself. Air readings must be checked with several ground readings before they could be considered reliable. Also, it appears that as the yield of the bomb decreases, the apparent percentage fall-out increases. As a matter of fact for U/K, shot Ray (100 ft tower, 0.3 KT bomb) the percentage fall-out appeared to be in excess of 40%. This value was not entered in the tables since it is not considered reliable. However, it does indicate that when the actual fall-out is small (because the bomb yield is small) there is a tendency to overestimate the percentage fall-out. If the bomb yield is large, a large area is contaminated and the intensity is high and readily measurable. Under such circumstances sampling is adequate and the averaging process used in determining percentage fall-out

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coated with fission products. If it is presumed that the ratio of inactive soil debris to active sand in the fall-out area is 100 to 1, then 100,000 to 500,000 tons of sand and soil debris were sucked up by each U/K tower shot. If this view is correct then certainly the presence of 10 to 50 tons of tower material will not have a profound effect on fall-out from tower shots. The surprising thing is that even when such large quantities of soil is sucked up into the cloud in many instances no crater is formed at ground zero. This means that only a few inches of soil is lifted up from the area of ground zero. Actually one inch of soil from an area of approximately two square miles would account for the total mass of soil debris sucked up in the atomic cloud. It may be possible to reduce the fall-out from low scaled height detonations by stabilizing the soil in the target area. However, it may be necessary to stabilize permanently one to five square miles of the target area in order to prevent a significant amount of soil from being mixed up with the stem and mushroom of the atomic cloud. It is recommended that within a circular area of approximately one mile radius the target area be firmly stabilized by cement or other means of permanent stabilization. It is believed that if a 10 KT bomb is detonated from a 300 ft tower over such a large stabilized area, the amount of soil sucked up into the cloud would be reduced materially, thus reducing subsequent fall-out significantly. However, if it is impractical to permanently stabilize such a large area, then it is suggested that even if a circular area with a radius of 500 ft is permanently stabilized by cement or other permanent methods, there may still be considerable reduction in

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found in References #3 and #4 indicates that the radexes prepared using the actual winds three hours before shot time, delineate the general fall-out area adequately. In Figures 1 through 9 the radex plots based on the H-3 and H-4 hour actual winds are superimposed on the actual fall-out area. A study of these figures shows clearly that radex plots based on the actual winds near shot time delineate the fall-out area adequately. The area of maximum intensity of fall-out could be located by this method within an average angular displacement of plus or minus five degrees. The angular displacement of the center of the maximum fall-out area does not show a displacement greater than 15 degrees. Considering that the winds are four hours old in these radex plots, it becomes at once evident that there is considerable persistence to the winds. Certainly if the decision to fire a potentially contaminating shot is delayed until the last two or three hours, it is difficult to see how large errors could be made in the radex plots. Fortunately it appears that the simple Stokes' Law assumptions are valid for 70 to 150 micron particles, which are the main cause of the radioactive contamination within 200 miles of the domestic test site at the Nevada Proving Grounds.

B. Verification of Radioactive Fall-out Forecasts

After the writer had analyzed the fall-out from TUMBLER/SNAPPER (R) tower shots it was possible to forecast that 10 to 15 KT bombs detonated from 300 ft towers would produce 5 to 20 roentgen life time doses within the populated areas in the periphery of the Nevada Test Site. This information was made a matter of record and called to

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1 roentgen

Nevada Highway 55 - (between Glendale and Caliente) - 1 to 5 roentgens

Alamo - 0.5 roentgen

Glendale - On edge of 0.5 roentgen line

b. Forecast at H-3 hours on D day -

Same as in subparagraph a above.

c. Verification

See Figure 5 for actual fall-out picture.

St. George - 0.5 roentgen in center of city. 3 roentgens in the northern outskirts of the city.

Carp -3.5 roentgens

U.S. Highway 93 - 5 roentgens as a maximum on a 5 mile strip, 1 roentgen on 20 mile strip of the highway between Glendale and Alamo.

Nevada Highway 55 - 3.5 roentgen maximum. 2. and 1 roentgen lines cross this highway.

Alamo - No contamination.

Glendale - No contamination.

2. U.K, Nancy, 26 KT, from a 300 ft tower at 0510 PST, 24 March 1953

a. Forecast at 2000 hours on D-1 day.

Groom Mine - 3 roentgens

Lincoln Mine - 1.5 roentgens

Alamo - 8 roentgens

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Pioche - No contamination

Warm Springs - 0.13 roentgen

Currant - No contamination

Ely - 0.1 roentgen

U.S. Highway 93 - 1 to 1.5 roentgens

Nevada Highway 38 - 2 to 5 roentgens

3. U/K, Climax, 65 KT, exploded at 1334 ft above terrain at 0415 PDT, 4 June 1953

a. Forecast

Shoot this bomb at anytime regardless of the winds. The contamination on the ground would not exceed 15 mr/hr at any point. Since the fireball will not touch the ground, no contamination is forecast

b. Shot delayed because of possible rain on Salt Lake City, Utah. It was feared that the rain may bring down measurable amounts of radioactivity (several mr/hr) and thus precipitate an acute public relations problem.

c. Verification

Maximum dose rate was 11 mr/hr at H+6 hours. There was no extensive fall-out, as forecast.

IV. FORECASTS OF RADIOACTIVE FALL-OUT DOWNWIND FROM MEGATON YIELD BOMBS

A. Forecast of IVY (R) MIKE Fall-out

Practically no information exists of the actual fall-out downwind in the Pacific Test Site, since it is difficult and very expensive to determine the fall-out pattern over a body of water utilizing buoys, In this discussion, it has been assumed that 15% of the total residual activity of the IVY (R) MIKE detonation was deposited downwind within 30 to 50 miles of ground zero in a period of six hours. It is also believed that approximately 35% of IVY (R) MIKE fell out within 12 hours, and at the end of two days 50 to 75% fell out. If this analysis is correct then a large percentage of the residual activity was deposited in the Pacific Ocean within 500 to 700 miles of ground zero. It should be noted that this analysis is primarily based upon scaling factors obtained from U/K tower shots. It may be that the extreme heights reached by the IVY (R) MIKE Cloud may reduce the downwind fall-out by as much as a factor of 10 over that indicated above.

B. Entrapment of Fission Products by Soil Debris and Water from Megaton Bombs in the Pacific

It is assumed that approximately 1,000,000 tons of soil were coated with fission products and sucked into the stem and mushroom of the IVY (R) MIKE cloud. If the ratio of inactive soil to active soil is 100 to 1 then approximately one hundred million tons of soil debris and water were thrown up during this shot. Such a vast quantity of matter upon falling back will entrain large quantities of air, gaseous products of the explosion and fission products. It should be noted that this statement is substantiated by the fact that the Cascade Impactors indicated a mass median diameter of 1 to 5 micron sized particles when the fall-out time indicated that particles of from 150 to 75 microns were falling during TUMBLER/SNAPPER (R) and UPSHOT/KNOTHOLE (R) tower shots. This means that even for the relatively small tower shots

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V. WORLD WIDE CONTAMINATION FROM ATOMIC BOMBS

Reference is made to Figure 10 which indicates the fall-out from the four tower shots of TUMBLER/SNAPPER (R) and five large tower shots of UPSHOT/KNOTHOLE (R). In this composite plot only the fall-out down to one roentgen infinity dose line is indicated. There is evidence that in some areas four shots were superimposed. In other areas only two or three shots were superimposed. With the information available in this report it would be possible to determine the amount of fission products that have fallen in a given area of Nevada and Utah from the NPG Test Operations within 200 miles of the Test Site. A close study of Figure 10 shows that in the Hiko-Alamo fertile valley (population 1200) the following three shots were superimposed: U/K, Annie, Harry and Simon, Certainly the concentration of fission products in such areas is high enough to study the plant and animal uptake of radioisotopes in a practical basis. The Figures in this report indicate radioactive fall-out using isodose lines in roentgens. The dosage indicated would be received when exposure time is considered infinite. The relation between

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the fact that 5, 10, 15 and 20 roentgen infinity dose fall-out areas are shown in the Figures, it appears that in some farming areas the Strontium 90 concentration may be as high as 0.5 to 0.75 curies per square mile from one shot. In areas where the fall-out from several shots are superimposed, the concentration could be higher. However, it is more significant to note that the areas where there is appreciable concentration of Strontium 90 are relatively large. These areas range from 1000 to 5000 square miles for each shot. For greater details consult the figures and the information contained in Table I. It seems apparent to the writer that the immediate area of the Test Site and the farming communities in the periphery of the test site (within 150 miles) may be examined profitably to determine the uptake of fission products by plants and animals, and for the effect of fission products on relatively small water supply sources. It is hoped that the radioactive fall-out areas indicated in this report would be useful along these lines of endeavor. The experience gained in this study indicates that in order to determine the world wide contamination pattern or even the percentage fall-out of residual activity in the United States relatively large number of sampling stations must be utilized. As indicated in Paragraph II, F above, when the fall-out covers a large area and if the intensity of the readings are low, there is a tendency to overestimate the percentage fall-out. This is even more so in the case where rain brings down activity. If such readings are averaged over large areas by the use of planimeters, the percentage fall-out may be highly exaggerated.

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radioactivity will be deposited on or near the target. If many 2 KT bombs are used in a given campaign for area bombardment, rain scavenging must be taken into consideration from the military and civilian defense point of view within the general battle area.

VII. ACCURACY OF THE FALL-OUT PLOTS SHOWN IN FIGURES 1 THROUGH 9

Figures 1 through 4 indicate the fall-out from the last four shots of TUMBLER/SNAPPER (R). It is believed that Figures 1 and 3 indicate the fall-out quite accurately, but Figures 2 and 4 are not as accurate. Figure 2 shows the fall-out from Shot No. 6 of TUMBLER/SNAPPER (R). During this shot the aircraft became contaminated, hence most of the air readings were unusable. Figure 4 shows the fall-out from Shot No. 8 of TUMBLER/SNAPPER (R). Since the radioactive contamination fell in areas where there are no usable roads, there is practically no information from the ground radiological monitoring teams. This means that the fall-out plot is based practically completely on air readings extrapolated to the ground. It should be noted that the percentage fall-out from this shot is well below the average for this series indicating that if only air readings are used the percentage fall-out is underestimated (see Table I for details). Figures 5 through 9 represent the fall-out from the large tower shots of UPSHOT/KNOTHOLE (R). Figure 5 represents the fall-out from U/K Annie Shot. It is believed that although the distant fall-out (50 miles to 120 miles from ground zero) is quite accurate, the fall-out within the gunnery range itself is open to question because it is dependent upon air readings only and no ground checks have been made. It is presumed that the fall-out isodose lines

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to dosage outside has never been determined accurately. Also, leeching by rain and other weathering effects tend to reduce the total dosage received by personnel. The isodose lines are kept in infinity doses as a point of standard reference. For example, if the infinity dose is divided by five the dose rate at H+1 hours is obtained. Also, the fission product concentration within a given isodose line can be determined by a very simple relation as indicated in Paragraph V above.

VIII. AN EMPIRICAL METHOD OF FORECASTING THE INTENSITY AND LOCATION OF RADIOACTIVE FALL-OUT AREAS.

A. The General Method Employed

Intensity of radioactive fall-out is a function of bomb yield, fall-out area and the amount and efficiency of the scavenging agent (such as soil, water, snow, etc). Since the particle size distribution of the soil within the cloud is not known accurately the area covered by the fall-out cannot be determined quantitatively. However, after analyzing the fall-out from the TUMBLER/SNAPPER (R) and UPSHOT/KNOTHOLE (R) Test Operations, it is possible to predict just how far out the contaminating fall-out will extend from a given shot. This gives the general length of the contaminating area, but unless the density and particle size spectrum within every layer of the cloud is known accurately there is no way of determining the width of the contaminating area. Hence an empirical method must be employed based on a study of the fall-out plots shown in Figures 1 through 9. There is some indication that the width of the fall-out area from the lower stem is more or less independent of meteorology, however it appears that the intensity of the fall-out

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is reduced) the soil in the stem becomes more active, thus producing heavy contamination immediately downwind. The total percentage fall-out increases with yield (when height is constant), but the percentage fall-out from the mushroom decreases with increasing yield. To a person who has not analyzed the total fall-out picture and who only chooses to utilize ground readings, the fall-out problem must appear even more complex than it really is. As a matter of fact, recently a set of empirical relations has been developed on fall-out from tower shots utilizing only the ground readings from U/K Test Operation. The air readings were not utilized out of impatience or lack of knowledge on how to use them. The T/S Test Operation data were not used because they were more difficult to reduce, since most of the fall-out during T/S Test Operations fortunately occurred North and Northeast of the Test Site where there are very few good roads and very little population. Sure enough a set of relations were developed which indicated intensity of fall-out to be <u>independent</u> of yield. Here is a good example of the need to evaluate all of the data before empirical relations are developed.

B. Construction of the Forecast Fall-out

1. Particle Size

Assume that the particle size distribution within a nominal bomb exploded at 300 ft is 100 microns if the maximum cloud height does not reach beyond 35,000 ft msl. The maximum cloud height is a function of the yield, the height of the tropopause, the lapse rate of the atmosphere and the speed of the horizontal winds. A nominal bomb cloud will

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axis; and if the wind shear is greater than 120° then the fall-out area from the mushroom is circular. This ellipse would be centered at a point 7500 ft below the top of the mushroom, and it will be referred to as Ellipse A. Within Ellipse A draw a second elliptical area and call this Ellipse B. The major axis of Ellipse B is 1/2 the major axis of Ellipse A, and the ratios of major to minor axis for the two ellipses are the same.

b. Fall-out From Stem

Draw an elliptical area from ground zero to a point representing 25,000 ft msl level on the wind vector plot. The minor axis is 1/4 the major axis. This rectangular or elliptical area is called Ellipse C. Within Ellipse C draw Ellipse D starting from ground zero to a point representing the 20,000 ft msl level on the wind vector plot with minor axis 1/4 major axis. Similarly draw Ellipse E from ground zero to 15,000 ft msl level.

c. Fall-out Connecting Stem and Mushroom Areas.

The fall-out outside of the stem and mushroom areas cannot be drawn by any specified methods. However, the general fall-out from ground zero out to 150 miles appears to cover a pie-shaped area with an apex angle of 15 to 30°. It is recommended that this procedure be following in the construction of the forecast fall-out

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YIELD IN KT	BURST HEIGHT IN FEET	DOSE IN ROENTGENS BOUNDING THE FOLLOWING AREAS ELLIPSE A	ELLIPSE B	ELLIPSE C	ELLIPSE D	ELLIPSE E	AREA F	AREA G
3	300	0.1	0.5	0.1	0.5	1.5	0	0
5	300	0.5	1.0	0.5	1.0	2.5	0.2	0.05
10	300	2	5	3	5	10	0.5	0.1
15	300	3	10	3	10	20	1	0.5
20	300	4	10	5	10	50	1	0.5
30	300	5	10	5	20	200	2	1
50	300	5	10	5	30	500	2	1
3	400	0.05	0.1	0.05	0.1	0.5	0	0
5	400	0.1	0.5	0.1	0.5	1.0	0.2	0.05
10	400	0.5	1.0	0.5	1.0	3.0	0.2	0.1
15	400	2	5	2	5	10	0.5	0.2
20	400	3	5	3	10	20	1	0.5
30	400	5	10	5	20	100	2	0.5
50	400	5	10	5	30	500	2	1
3	500	0	0	0.1	0.5	1.0	0	0
5	500	0	0	0.1	0.5	2.0	0	0
10	500	0.1	0.5	0.1	0.5	3.0	0.05	0
15	500	0.1	0.5	0.1	0.5	3.0	0.05	0.01
20	500	0.5	1.0	0.5	1.0	3.0	0.2	0.05
30	500	2	5	5	10	30	0.5	0.2
50	500	5	10	10	20	100	1	0.5
70	500	5	15	10	50	200	1	0.5
5	700	0	0	0	0	0	0	0
10	700	0	0	0	0	0	0	0
20	700	0	0	0	0	0	0	0
30	700	0.05	0.1	0.05	0.1	0.2	0	0
40	700	0.5	1.0	0.5	1.0	3.0	0.2	0.1
50	700	2	5	2	5	10	0.5	0.2
70	700	5	10	5	20	100	1	0.5
100	700	5	10	5	30	500	2	0.5
20	1000							
50	1000	0.05	0.1	0.05	0.1	0.2		
100	1000	0.5	1.0	0.5	1.0	3.0	0.2	0.05
150	1000	3	10	3	10	30	1.5	1.0
200	1000	5	15	5	20	100	2	1.0
50	1200							
100	1200	0.5	1.0	0.5	1.0	3.0	0.2	0.1
200	1200	5	10	5	10	50	1	0.5
300	1200	10	15	10	30	100	3	1.0

accurately (which anyone can do) what is more pertinent is to "forecast" the fall-out properly. There is no reason to expect a detailed close-fit reconstruction based on past analysis will fit the fall-out picture of a future atomic explosion. It should be noted that in all cases, the radex plot based on the H-3 hour winds delineate the general fall-out area accurately outside of the immediate gunnery range at NPG. Perhaps this fact may be useful in predicting general area fall-out in future tests.

IX. RECOMMENDATIONS

The following recommendations are made based upon the analysis of the TUMBLER/SNAPPER (R) and UPSHOT/KNOTHOLE (R) tower shots:

A. Radiological Operations during future atomic tests in the domestic test site should utilize both aircraft and ground monitoring to delineate the general fall-out area from contaminating tower shots. The air readings alone or the ground readings alone do not indicate the fall-out area adequately.

B. If the tower heights at NPG are increased to 500 ft or higher, there will be significant reduction in contaminating fall-out.

C. If the target area is well stabilized by cement or other permanent means the radioactive fall-out will be reduced materially. However, such permanently stabilized area must be large in size. As a minimum, a circular area of 1000 ft diameter is required to cause an appreciable reduction in fall-out. It is preferred that a circular area with a diameter of two miles be permanently stabilized in order to make

TABLE I

PERCENTAGE RADIOACTIVE FALL-OUT WITHIN 200 MILES OF GROUND ZERO

TEST OPERATION	SHOT NO.	SHOT NAME	SHOT DATE	YIELD IN KT	BURST HEIGHT ABOVE TERRAIN (d)	CALCULATED MAXIMUM FIREBALL ~~DIAMETER~~ RADIUS (d_f) (ft)	DOSE RATE AT GROUND ZERO AT H+1 HOURS	MAXIMUM DOSE RATE DOWNWIND	PERCENTAGE FALL-OUT FROM CLOUD STEM (P_s)	PERCENTAGE FALL-OUT FROM CLOUD MUSHROOM (P_m)	PERCENTAGE FALL-OUT TOTAL	$\frac{P_m}{P_s}$
T/S	1	ABLE	1 Apr 52	1.06	793	188	1.0r/hr	0.001r/hr	---	---	* 1%	---
T/S	2	BAKER	15 Apr 52	1.15	1109	193	1.2	0.07	---	---	"	---
T/S	3	CHARLIE	22 Apr 52	30	3447	572	0.1	0.02	---	---	"	---
T/S	4	DOG	1 May 52	19.6	1040	497	550**	0.015	---	---	"	---
T/S	5	EASY	7 May 52	11.8	300	420	3000	2	---	---	24%	---
T/S	6	FOX	25 May 52	11.4	300	415	3000	6	---	---	17	---
T/S	7	GEORGE	1 Jun 52	13.8	300	442	>3000	6	---	---	13.5	---
T/S	8	HOW	5 Jun 52	14	300	445	2000	1.5	---	---	7.6	---
U/K	1	ANNIE	17 Mar 53	17	300	474	>4000	2.5	21.4%	3.2%	24.6%	0.15
U/K	2	NANCY	24 Mar 53	26	300	545	3000	4.5	10	3.1	13.1	0.31
U/K	3	RUTH	31 Mar 53	0.3	300	123	>10	0.003	---	---	* 1%	---
U/K	4	DIXIE	6 Apr 53	11	6150	410	0.1	0.001	---	---	"	---
U/K	5	RAY	11 Apr 53	0.3	100	123	2 to 20	0.03	---	---	>15%	---
U/K	6	BADGER	18 Apr 53	26	300	545	3000	2.5	15.5	4.5	20%	0.29
U/K	7	SIMON	25 Apr 53	50	300	678	---	6	15.4	5	20.4	0.3[illegible]
U/K	8	ENCORE	7 May 53	26	2420	545	0.15	0.01	---	---	* 1%	---
U/K	9	HARRY	19 May 53	31	300	578	---	5	12.6	5.3	17.9	0.42
U/K	11	CLIMAX	4 Jun 53	65	1334	740	---	0.1	---	---	* 1%	---

* Estimated to be less than 1% (not measured data)

** High Neutron Flux from this Device

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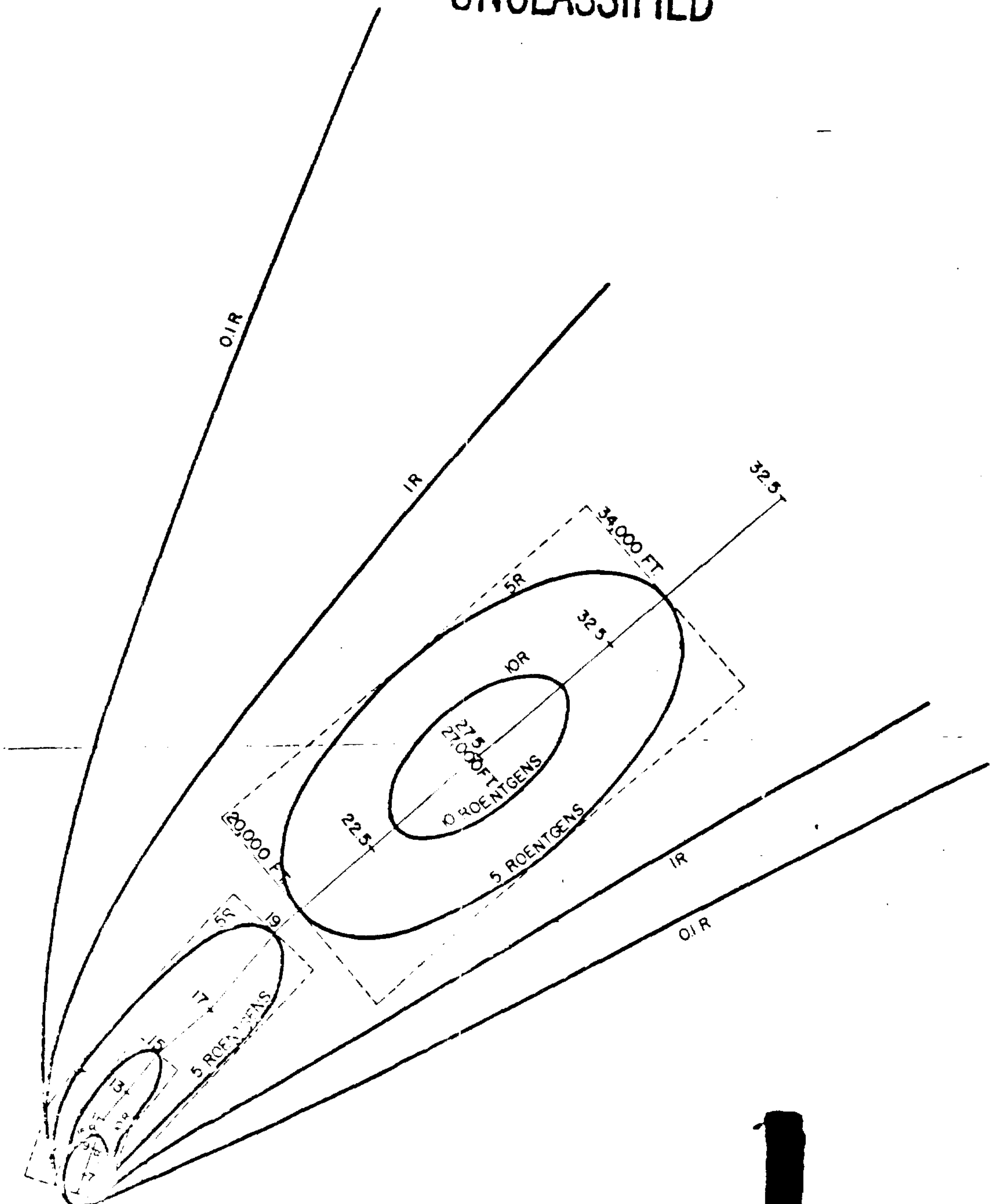

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FIGURE 1A
TUMBLER SNAPPER
SHOT EASY
RECONSTRUCTION *BASED ON H-3 HOUR WINDS (IN ACCORDANCE WITH PAR XIII OF THIS REPORT.)*

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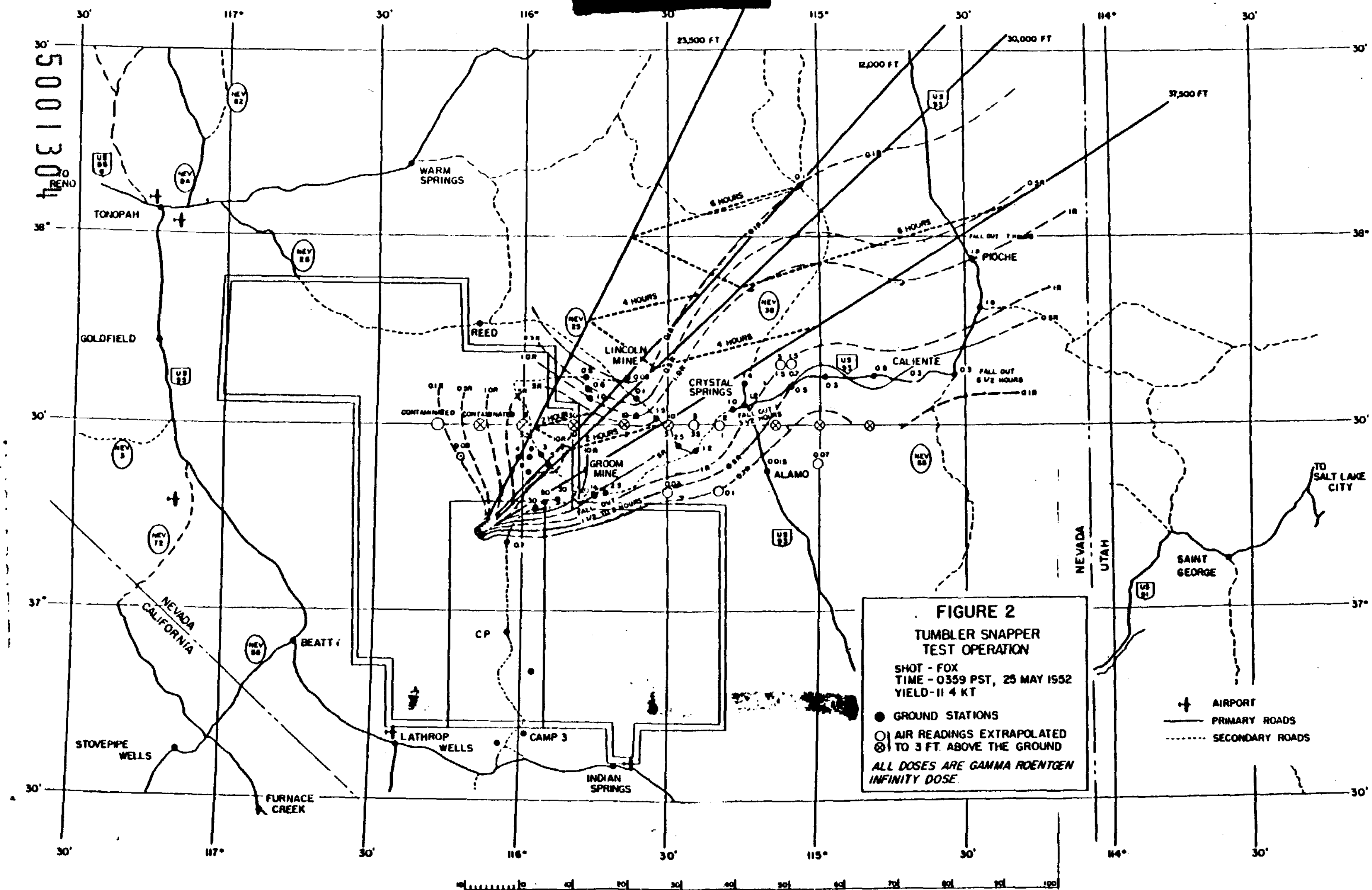

FIGURE 2

TUMBLER SNAPPER TEST OPERATION

SHOT - FOX
TIME - 0359 PST, 25 MAY 1952
YIELD - 11 4 KT

● GROUND STATIONS

○ ⊗ AIR READINGS EXTRAPOLATED TO 3 FT. ABOVE THE GROUND

ALL DOSES ARE GAMMA ROENTGEN INFINITY DOSE.

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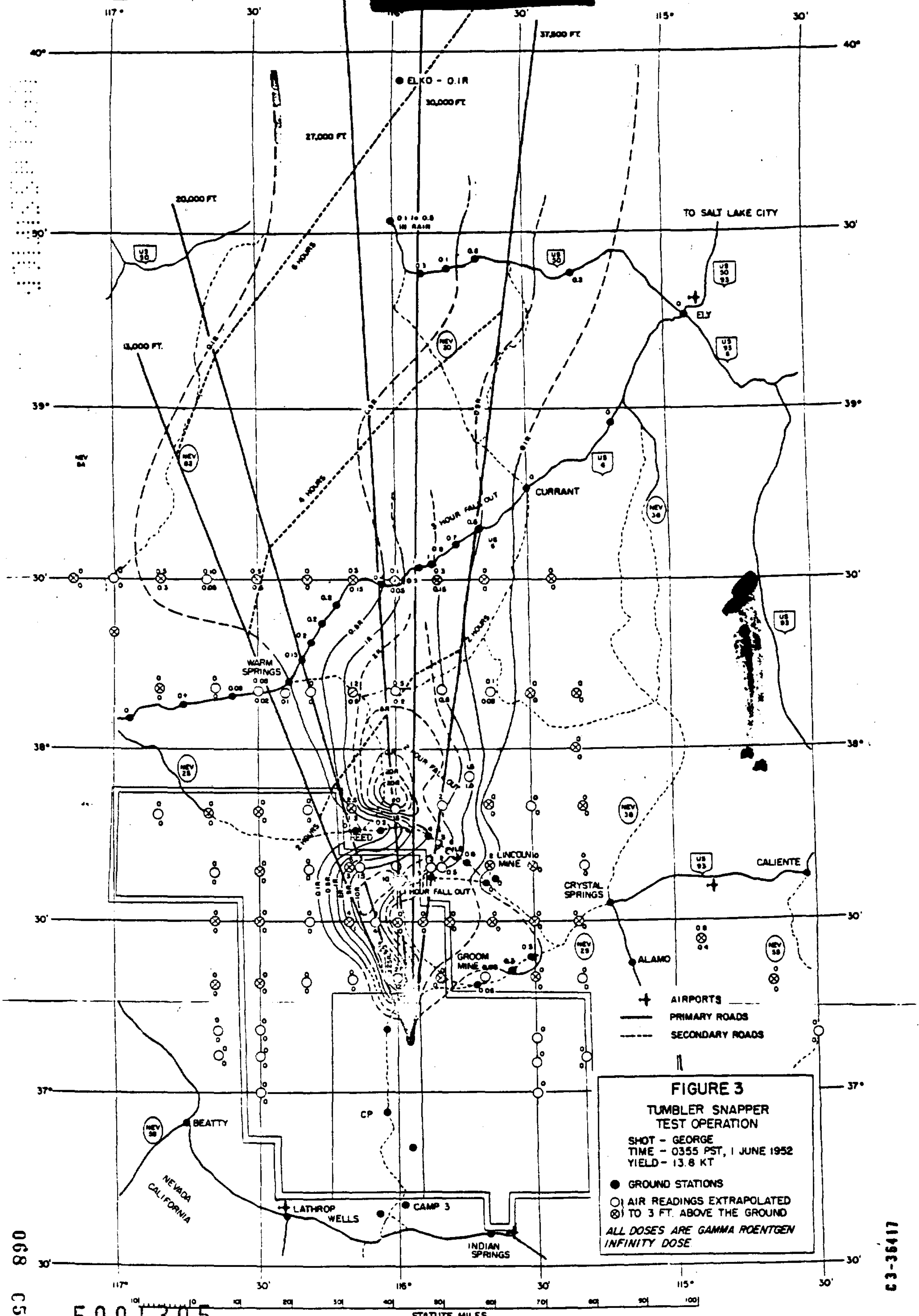

FIGURE 3
TUMBLER SNAPPER TEST OPERATION
SHOT - GEORGE
TIME - 0355 PST, 1 JUNE 1952
YIELD - 13.8 KT

● GROUND STATIONS

○ ⊗ AIR READINGS EXTRAPOLATED TO 3 FT. ABOVE THE GROUND

ALL DOSES ARE GAMMA ROENTGEN INFINITY DOSE

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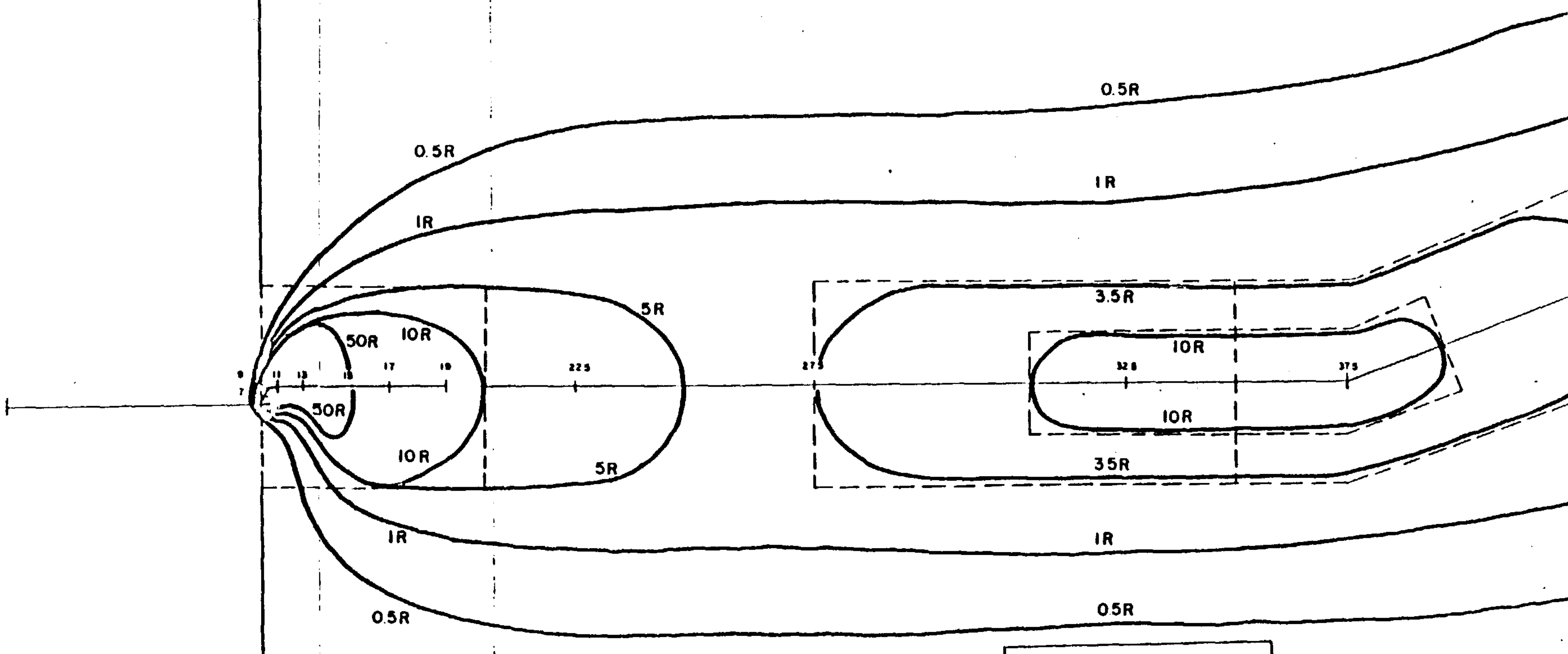

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FIGURE 5A
UPSHOT / KNOTHOLE
TEST OPERATION
SHOT ANNIE

RECONSTRUCTION
-USING H-3 HOUR WINDS

(IN ACCORDANCE WITH PAR III
OF THIS REPORT)

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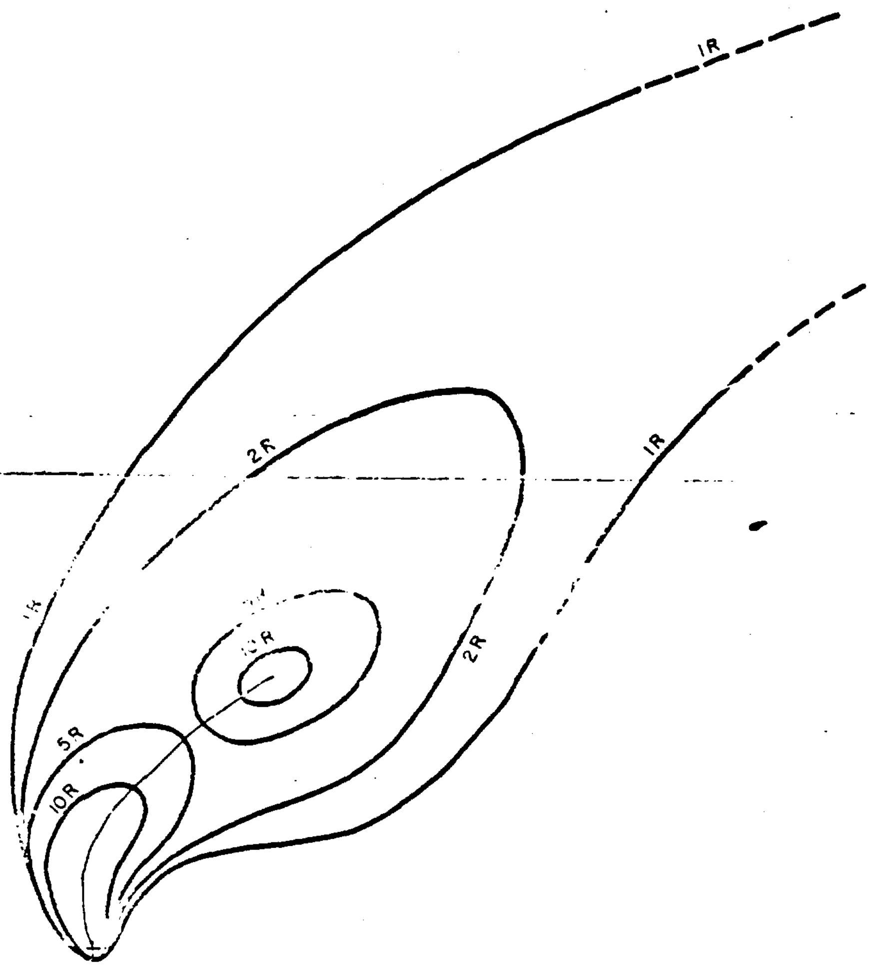

FIGURE 6 B
UPSHOT KNOTHOLE
TEST OPERATION
SHOT — NANCY
FORECAST FALL-OUT PLOT
MADE AT H-8 HOURS

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[redacted]

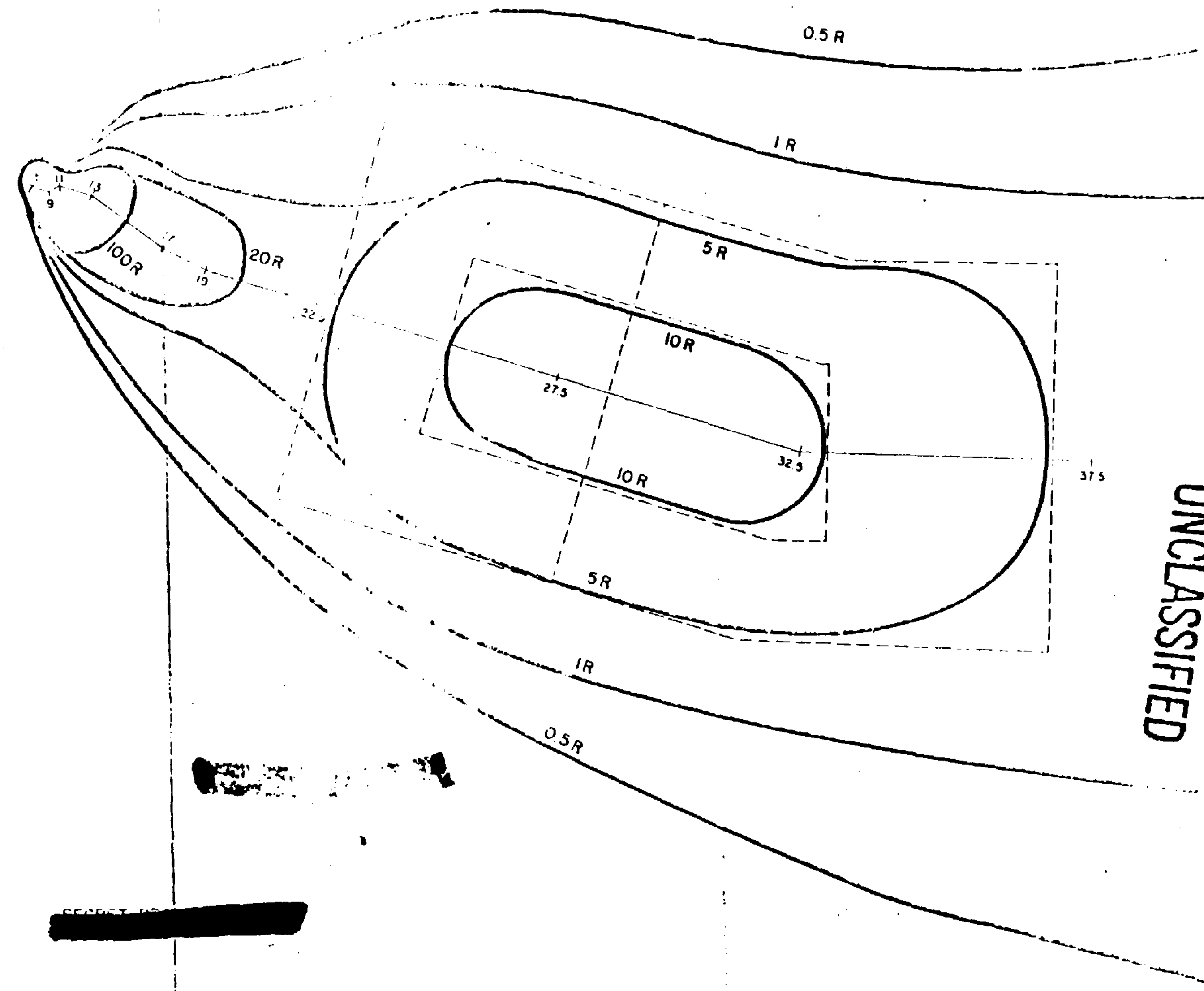

FIGURE 7A
UPSHOT KNOTHOLE
TEST OPERATION
SHOT - BADGER
RECONSTRUCTION BASED ON
H-3 HOUR WIND
(IN ACCORDANCE WITH PAR III
OF THIS REPORT)

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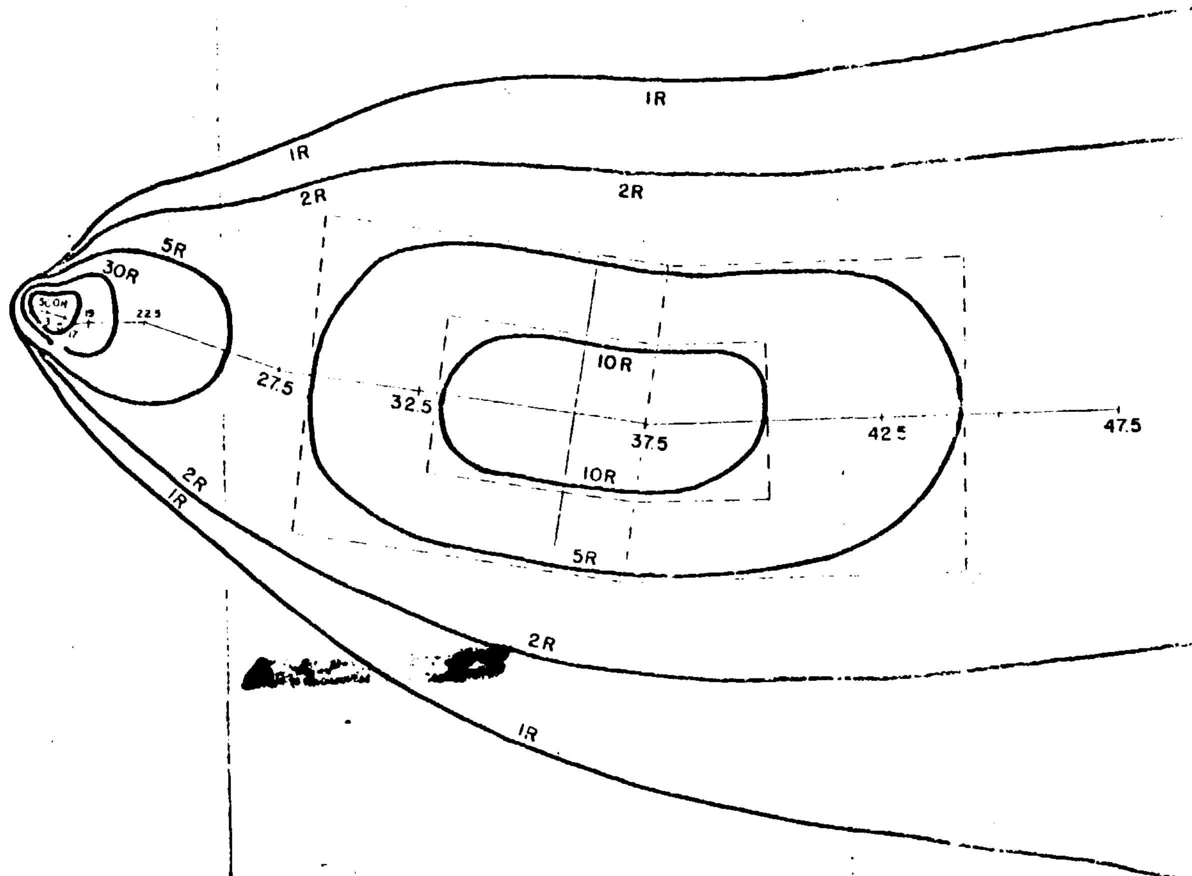

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FIGURE 8A
U/K TEST OPERATION
SHOT SIMON

RECONSTRUCTION *BASED ON H-3 HOUR WINDS (IN ACCORDANCE WITH PAR. III, THIS REPORT)*

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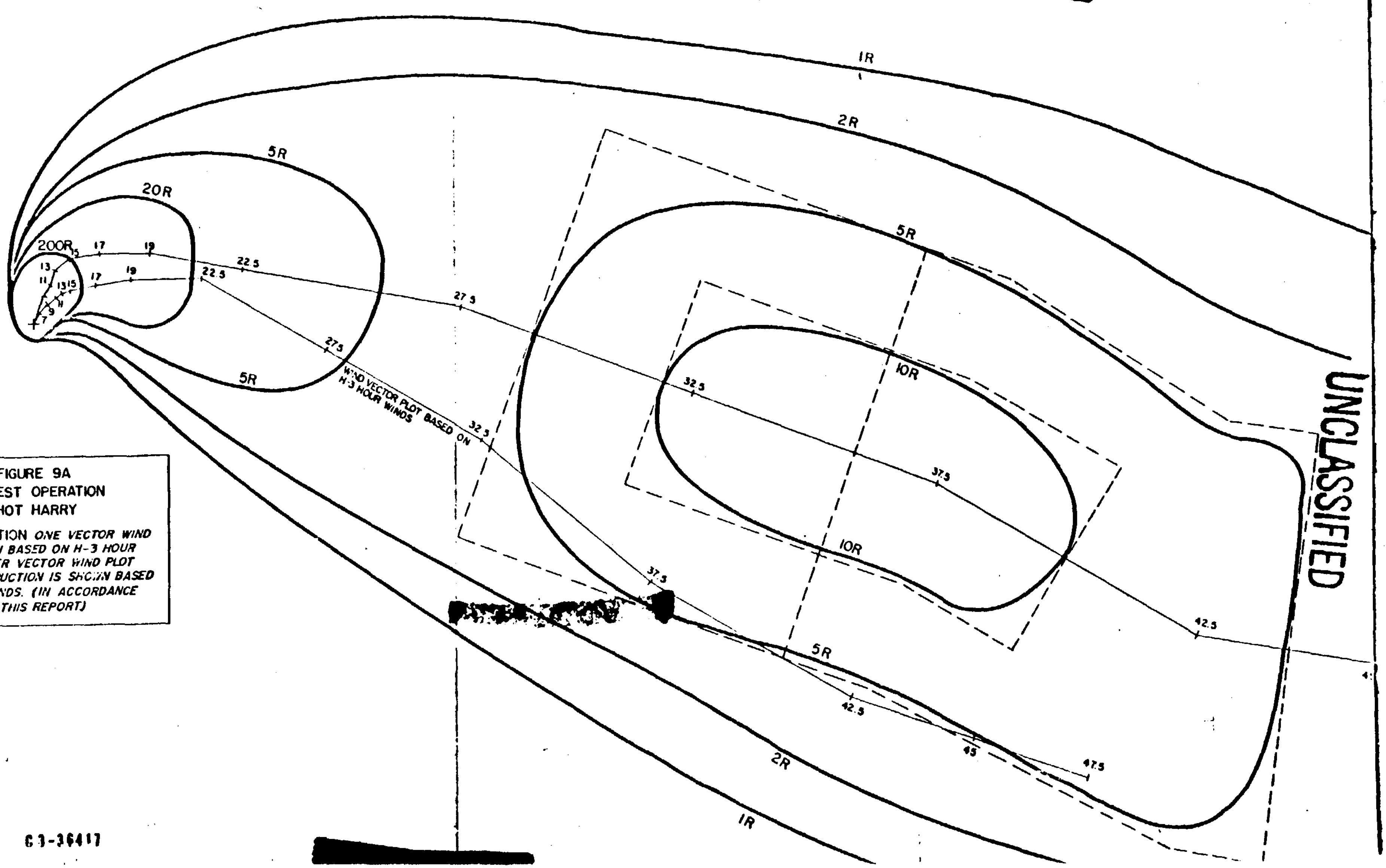

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FIGURE 9A
U/K TEST OPERATION
SHOT HARRY

RECONSTRUCTION *ONE VECTOR WIND PLOT IS SHOWN BASED ON H-3 HOUR WINDS. ANOTHER VECTOR WIND PLOT AND RECONSTRUCTION IS SHOWN BASED ON H-HOUR WINDS. (IN ACCORDANCE WITH PAR. III, THIS REPORT)*

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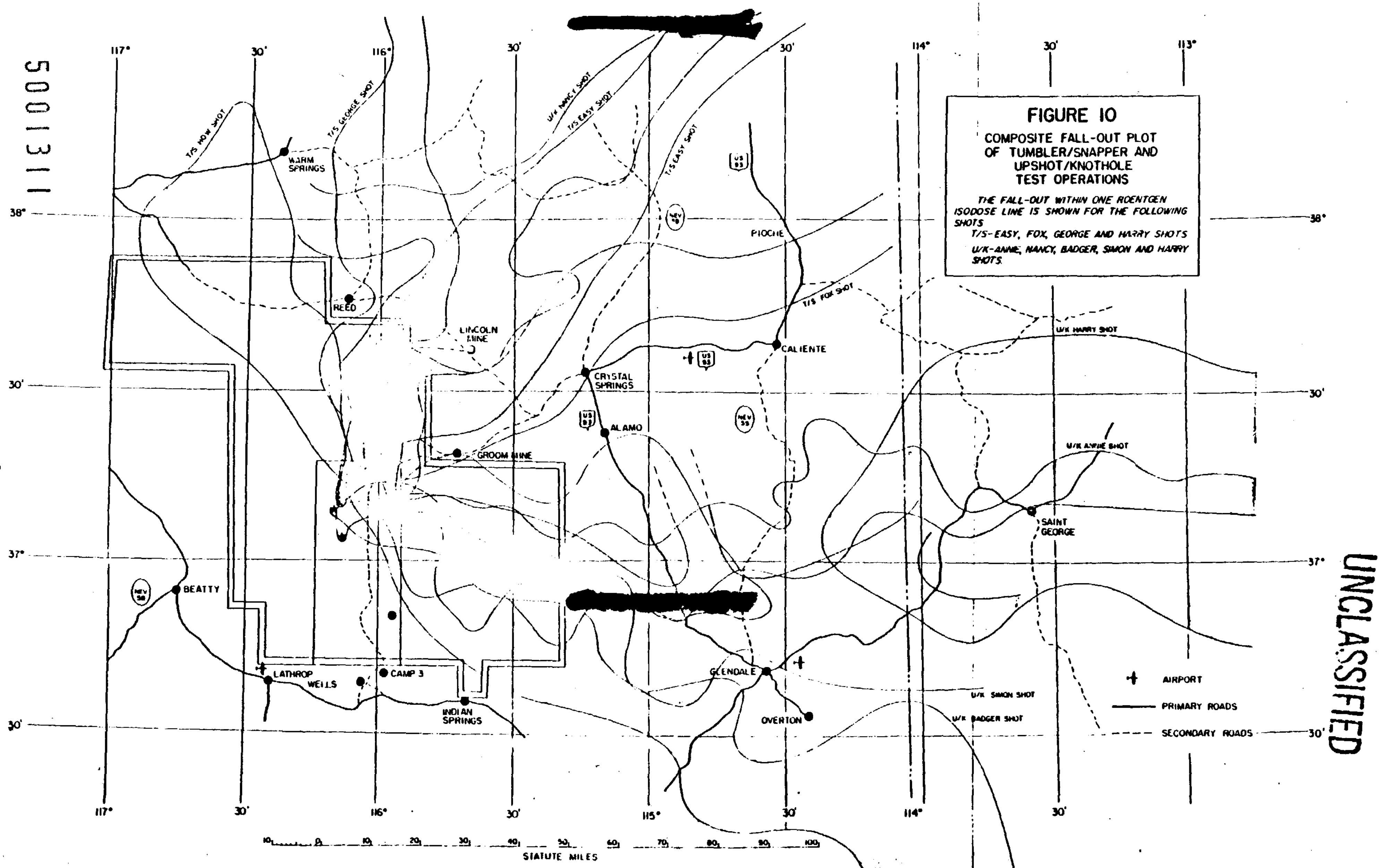

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