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RADIOACTIVE FALL-OUT FROM ATOMIC BOMBS

by

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From B-36417

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HEADQUARTERS
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AEC Technical Information Service Extension
Oak Ridge, Tennessee

[redacted], [redacted]

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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

the height of the tower) be made after consulting the radex plot based upon the latest available winds prior to shot time.

e. It is estimated that 50,000 to 200,000 tons of sand and soil debris is sucked up into the stem and mushroom of an atomic cloud when a nominal bomb is detonated from a 300 ft tower. In view of this, it is suggested that the radioactive fall-out due to the relatively small mass of the tower would be negligible.

f. If it is intended to use soil stabilization to reduce fall-out, the soil within a radius of approximately one mile from ground zero must be stabilized by cement or other permanent methods. Even if a circular area of only 1000 ft diameter is permanently stabilized, it may still reduce contaminating fall-out. Merely stabilizing the soil around the immediate ground zero area with oil or water will probably have very little effect upon radioactive fall-out, since it was shown above that very large quantities of soil are involved in a contaminating tower shot.

g. Extrapolation of the fall-out information in this report to the case of 10 megaton bombs exploded on the surface indicates that lethal concentration of radioactivity may extend 30 to 50 miles downwind.

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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 RADIUS ~~diameter~~ 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 confidence in the fact that no radioactive fall-out would occur from 3 KT bombs exploded from 300 ft towers, or for 8 KT bombs from 400 ft towers, 18 KT bombs from 500 ft towers, 45 KT from 700 ft towers, etc. It is also possible to explode a 100 KT bomb at 1000 ft and a 200 KT bomb at 1500 ft above terrain without producing excessive fall-out in the absence of rain. It is realized that construction of towers higher than 300 ft may not be feasible from an engineering standpoint. However, if the maximum fireball radius is kept above the ground, it would be possible to test atomic bombs in the domestic test site at NPG independently, of the weather (with the exception that it should not be raining at time of detonation within 100 miles). The mass of the tower does not contribute materially to the fall-out. In order to produce 10 to 20% fall-out from nominal bombs, approximately 50,000 to 100,000 tons of sand and soil debris is required. Certainly the presence of 10 to 100 tons of tower material would not alter the situation materially. A considerable amount of sand and soil debris is sucked up into the atomic cloud for low air bursts when the fireball comes close to the ground. However, this sand does not scavenge out any significant portions of the bomb (less than 1%). This is surprising. It appears that before sand could scavenge out any radioactivity from the atomic bomb, the fireball must lap the ground. Apparently, sand is coated with a significant amount of fission products only during the very early stages of the cloud history. Also it appears that induced activity in the soil of NPG contributes little if anything to the fall-out, except for the contamination on the target area itself.

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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 greater area than the instrument of the radiological monitor held at three ft above the ground in the center of the city. Actually the airplane reading should not be pinpointed to one spot on the ground. It should be considered rather an average area reading of from two to five square miles. In the event that the reader is skeptical about the value of airplane readings it would be highly instructive to plot the contamination pattern using air readings only and then to fill in the ground readings on main roads. This would indicate the general accuracy of the method involved. It is not clear to the writer how it would be possible to measure the radioactive fall-out adequately from large tower shots (10 to 50 KT, detonated from 300 ft towers) at the domestic test site without the use of aircraft, because in such cases the fall-out area covers 5000 to 10,000 square miles. Certainly it would be necessary to make at least four readings over 100 square miles. This means that 200 to 400 stations must be established within the fall-out sector. Experience from past atomic test operations indicates that the actual fall-out area becomes clearly evident only three to six hours previous to bomb detonation. This means that at least 1000 to 2000 fall-out stations must be established in a given quadrant in order to obtain adequate sampling of the radioactive fall-out. Certainly the cost of such an operation is prohibitive. If proper communications and usable roads were available, it would be possible to sample the fall-out adequately by using approximately 25 highly mobile teams. However, at the domestic test site there are very few usable roads. The fall-out would be discovered only if it contaminated a given community where there were

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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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not cross this path for six hours without contamination. Since the information was required before this time, one airplane was allowed purposely to cross the area that was presumed to be contaminated. The aircraft received an external contamination of 15 mr/hr, but the instruments inside the aircraft did not appear effected. In many cases, notably during U/K, the aircraft showed the same contamination pattern from one day to the other provided the $t^{-1.2}$ decay factor was taken into consideration. In some examples readings were displaced four or five miles in space, but this is to be expected due to weathering and because of the speed of the aircraft. The very fact that an airplane would show about the same intensity of radiation on one day as the next (provided decay is accounted for) and the contaminated area remains essentially the same from one day to the next should be sufficient proof to the skeptic that air readings are useful. For greater details it is recommended that Reference #2 be studied more closely.

C. Particle Size Distribution of the Soil Sucked up into the Atomic Cloud

A study of the fall-out plots shows that the sand and soil debris sucked up into the stem and the mushroom of the atomic cloud averages from 70 to 150 microns in diameter if it is assumed that the density of the particles is approximately 2.5 gm/cm^3. The determination of the particle size distribution of the soil debris sucked up into the atomic cloud at Nevada Proving Grounds is possible because the vertical wind distribution and the radioactive fall-out on the ground have been measured. By assuming the Stokes' Law of fall-out applies to the case

[redacted]

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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fragments. This means that in a typical fall-out area where the wind vector plot indicates an average particle diameter of 100 microns, there will be found a considerable number of smaller (1 to 5 micron) as well as larger (150 to 500 micron) particles. However, the majority of the fall-out particles will be approximately 100 microns in diameter. But the majority of the fall-out activity will be in particles greater than 100 microns when the numerical median particle diameter is 100 microns. This is because activity of the soil particles coated with fission products is proportional to the square or the cube of the particle radius. For example; if it is assumed that the following numerical particle size distribution exists:

50% of the particles are 100 microns
20% of the particles are 75 microns
5% of the particles are 50 microns
20% of the particles are 150 microns
5% of the particles are 200 microns.

Then the activity median would be carried not by 100 micron particles but by the 150 or 200 micron particles. Within a few miles of ground zero, the particle size distribution is even wider. Particles of 5000 to 10,000 microns will fall at the same time as 500, 100, 70, 5 and 1 micron particles. It is believed that the fall-out method of determining general particle size indicates the correct order of magnitude especially when the vertical wind distribution has large angular wind shears (thus pinpointing the exact height from which the fall-out particles arrived). However, the use of Cascade Impactors, Electro-

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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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uous from the very start and until the cloud is 10 minutes old after which time the discontinuity begins to appear. Perhaps the toroidal motion in the mushroom which forces vast quantities of outside air into the cloud has something to do with this discontinuous region between the top of the stem and the lower portion of the mushroom. Since the blue sky is readily observed in this region, it is assumed that the radioactive concentration is lower. Certainly the U/K fall-out plots shown in Figures 6 through 9 verify this assumption. In effect then, the fall-out plot may be thought of as the "shadow" of the stem and the mushroom of the 15 minute old cloud. If this be true, then it may be possible to utilize the fall-out plots of this report to determine the rate of growth of the cloud with time. This information would be of some value in determining the average rate of dilution of activity in the cloud with time. The rate of growth of the tower shot clouds are indicated in Table II. A study of the table indicates that, on the average, the radius of an atomic cloud mushroom increases four fold every hour after time of detonation. This average has been observed to hold until eight hours after shot time. However, the fall-out occurs more or less as an elliptical area where the major axis may be twice or three times as long as the minor axis.

E. Percentage Fall-out from Stem and Mushroom

Table I indicates the percentage fall-out from the stem (P_s) and the mushroom (P_m) of the atomic cloud. The ratio of P_m/P_s is approximately equal to 0.3 for Operation UPSHOT/KNOTHOLE (R). This indicates that for 20 to 50 KT bombs detonated from 300 ft towers most

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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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F. Calculated Percentage Fall-out from JANGLE (Restricted) Shots

During JANGLE (R) - Surface and JANGLE (R)-Underground shots, fall-out measurements were made only close to ground zero. Actually no detailed measurements were made beyond three miles downwind of ground zero, and the total area covered by the measuring stations did not exceed 10 square miles. From Table I it is readily apparent that 10 to 50 KT bombs from 300 ft towers produce contamination which spreads over several thousand square miles. It would be logical to assume that even for the 1.1 and 1.2 KT yields of the JANGLE (R) shots the fall-out must have spread out significantly beyond three miles downwind. Within three miles of ground zero, 10 to 15% of the residual activity of the JANGLE (R)-Surface bomb was deposited in 3.5 square miles. Similarly ~~15 to 20%~~ 50% of the JANGLE (R)-Underground shot was deposited in the vicinity of ground zero within ~~3.7~~ 4 square miles. It is the contention of this writer that if the fall-out was studied 50 to 75 miles downwind it would have been found that more than 35% of the J-S and more than 30% of the J-U shots fell out due to soil and sand scavenging. This contention is based on the relation of percentage fall-out to scaled height as indicated in Table I. Certainly as the height of detonation approaches the ground the percentage fall-out must be at least greater than 20%. There is also some evidence that actually the fall-out from the JANGLE (R) shots covered relatively large areas. An aerial survey made at D+1 day of J-S and J-U areas (10) indicates that the total fall-out area was 2500 square miles for J-S and 1700 square miles for J-U. This is in agreement with the relatively large areas found for the T/S and U/K

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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 does not produce large errors. However, for very low KT bombs, the total fall-out on the ground is small even if all of the residual radioactivity is deposited, say over 1000 square miles. Integrating few weak readings over large areas will produce large errors and tend to show high percentage fall-out incorrectly. As a matter of fact, U/K Ray Shot shows 25% fall-out within 225 square miles and a total of 40% fall-out within 2500 square miles. This is certainly too high and due to samples which are unrepresentative. An inspection of the fall-out plots shown in Figures 1 to 9 indicates that as a minimum there are four air readings per 80 square miles. These readings are then interspersed with many ground readings. It should be noted that although in this study 200 to 500 readings are utilized to sample 5000 to 10,000 square miles, in studying the world-wide radioactive fall-out only 200 to 500 sampling stations are available for all of the United States or the world. It is the contention of this writer that such sampling may incorporate large errors in it.

G. The Weight of Soil Debris Sucked up into an Atomic Cloud.

Since the percentage fall-out and the area covered is plotted in Figures 1 through 9 of this report, it is a relatively simple task to determine the order of magnitude of the weight of soil sucked up into an atomic cloud for near surface explosions. It will be assumed that all fall-out particles are 100 microns in diameter, have a density of 2.5 gm/cm^3 and the specific activity of each particle is 10 microcuries of fission products at H+1 hours. Under such assumptions it is clearly evident that from 1000 to 5000 tons of sand and soil debris are

[redacted] [redacted]

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 the radioactive fall-out. This recommendation is based upon the fact that no excessive fall-out occurs unless and until the fireball actually touches the ground. In cases where the fireball came near the ground, but did not actually touch the ground, it was observed that a large amount of soil was mixed into the atomic cloud without producing excessive fall-out. This suggests that, contaminating fall-out is not determined so much by the amount of soil mixed into the cloud, but primarily by the early time of entry of this soil into the fireball. If the fireball touches the ground which is permanently stabilized, it is hoped that only a small amount of this stabilized area would be pulverized and thrown up into the fireball. It is assumed that the sand and soil debris that will rush into the stem and mushroom of the cloud from the periphery of the stabilized area will not arrive in time to be coated with fission products by the fireball. However, it must be kept in mind that the soil stabilization must be of a permanent nature, so that the extreme suction created by the fireball will fail to pick up very much dust from a relatively large area around ground zero. Certainly oil or water stabilization of the immediate ground zero area could not possibly reduce the fall-out. Also, if the scaled height of detonation is so low that craters are formed, no amount of permanent soil stabilization could possibly be of any help in reducing fall-out.

III. VERIFICATION OF FORECAST FALL-OUT PLOTS

A. Verification of Radexes for TUMBLER/SNAPPER (R) and UPSHOT/KNOTHOLE (R) Test Operations

A study of the radex plots for T/S and U/K Test Operations

[redacted]

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 the attention of interested personnel in AFSWP and Los Alamos several months prior to the start of UPHCT/KNOTHOLE (R) Test Operation. Even with the limited data available from a study of only the four tower shots of T/S it was possible to make contamination forecasts which were amply verified. This was possible only because data from previous test operations was examined in detail. It is the opinion of the writer that although sufficient information has been collected by the air and ground monitors during both T/S and U/K Test Operations, very little use is being made of the complete data gathered. A detailed study of the previous fall-out data should make it relatively simple to forecast quantitatively the intensity of fall-out from a bomb of given yield detonated from a given height. It is hoped that the pictorial plots of fall-out indicated in the Figures of this report will heighten the interest of more people in the residual radioactive contamination that will always exist for nominal bombs exploded at altitudes less than 500 ft above terrain. The forecasts made by this writer during three U/K shots are listed below together with the verification of the contamination forecasts.

1. U/K, Annie, 16.8 KT, detonated from a 300 ft tower at 0520 PST, 17 March 1953.

   a. Forecast at 2000 hours on D-1 day

      St. George - 1 roentgen infinity dose

      Carp - (between Glendale & Caliente on Nevada 55) - 5 roentgens

      U.S. Highway 93 - (between Glendale and Alamo) -

[redacted]

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

Caliente - 8 roentgens

Pioche - 1 roentgen

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

See Figure 6B for a map of the forecast fall-out. Certainly as Figure 6B is compared with actual fall-out shown in Figure 6, one is tempted to ask just what else is required from a forecaster.

Groom Mine - 1.5 roentgens

Lincoln Mine - 10 roentgens

Alamo - No contamination

Caliente - No contamination

Pioche - No contamination

Warm Springs - No contamination

Currant - No contamination

Ely - No contamination

U. S. Highway 90 (between Pioche and Ely) - 1 roentgen

Nevada Highway 38 (between Hike and Ely) - 2 roentgens

c. Verification

See Figure 6 for actual fall-out picture.

Groom Mine - No contamination but 25 roentgen line approached within 8 miles of this place.

Lincoln Mine - 4.2 roentgens, 18 roentgens within 5 miles of this mine.

Alamo - No contamination

Caliente - No contamination

[redacted]

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,

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etc. Because downwind fall-out information is almost completely lacking for the large yield bombs exploded in the Pacific, every statement made concerning such fall-out must be taken as mere conjecture until verification is obtained at some future date. Keeping these provisions in mind, it is possible to make the following forecast of what might have fallen out from IVY (R) MIKE cloud. It is believed that approximately 3% of the residual activity of the bomb fell around ground zero within three miles of the crater in cross-wind or upwind direction. This means that the upwind dose rate would be between 1000 to 2000 r/hr extrapolated to H+1 hours at a distance of three miles from ground zero. Downwind the dose rate may have been 1000 to 2000 r/hr at a distance of 15 miles from ground zero. The dose rate 30 to 40 miles downwind (NW then N) must have been approximately between 100 and 500 roentgens per hour extrapolated to H+1 hour. Fall-out then swerved to the ENE and then south and west. The fall-out 30 to 40 miles downwind must have been completed in six hours. It probably started in one hour and the maximum fall-out in this area must have occurred at three hours (neglecting immediate fall-out within 15 miles of ground zero). This means that if personnel remained 12 hours in an area within 30 to 40 miles NW and N of ground zero, they may have received a 400 to 800 roentgen dose.

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

(12 KT from 300 ft towers) a sufficient amount of soil debris is picked up to entrap micron sized particles as this soil falls back. Certainly when megaton weapons are exploded on the surface, the amount of soil thrown up increases significantly and when this returns to earth it entraps a large amount of air, gaseous products and fission products. It is assumed that water would be equally as efficient as soil debris (if not more so) in this matter of entrapment. This may have implications important in the radiochemistry of atomic debris and in air sampling of the atomic cloud. It also means that the close in fall-out would contain large particles together with micron sized particles falling out at the same time in apparent contradiction of Stokes' Law.

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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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infinity dose and concentration of fission products (extrapolated to one hour after shot time) within the area is very simply as follows: $5R \times 10^4$ curies per square mile, where R is the infinity gamma ray dose in roentgens as indicated in Figures 1 through 9. To illustrate this, let us take a few examples. Refer to Figure 7. This shows the fall-out from U/K shot Badger. In this illustration there is a 5 roentgen isodose area on U.S. Highway 93 between Las Vegas and Overton. This 5 roentgen area also extends to the Lake Mead region. Within this area the concentration of fission products would have been 2.5×10^5 curies per square mile had the fall-out occurred one hour after shot time. Since the average time of fall-out was six hours after detonation, the concentration of fission products at time of fall-out was approximately 3×10^4 curies in each square mile of the area. It should be noted that this indicates the fission product concentration provided the infinity dose within the area is 5r throughout. Actually the average infinity dose within the area is more nearly 7 roentgens so that the fission product concentration at time of fall-out was more nearly 4×10^4 curies per square mile. Similarly it is possible to determine the Strontium 90 concentration within an area enclosed by a given isodose line. If it is assumed that 200 curies of Strontium 90 is formed from a one KT bomb, then the following relation applies: there are $3.3R \times 10^{-2}$ curies of Strontium 90 within an area enclosed by an infinity isodose line of R roentgens. This means that within the 5 roentgen area mentioned above the minimum concentration of Strontium 90 is 0.15 curies per square mile, and the average concentration is 0.25 curies per square mile. Considering 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 endeaver. 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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VI. SCAVENGING ACTION OF SOIL RELATED TO EFFICIENCY OF RAIN SCAVENGING

An attempt was made earlier by this writer to correlate sand scavenging to that of rain (11) in order to obtain some indication of the extent of the contamination area that may be produced by rain. In the past, there have been numerous statements made concerning the scavenging action of rain, but since no atomic bomb has been shot in the rain, all of these reports were based on unverified conjectures. Some of the reports exaggerated the radioactive contamination by assuming that 25 or 50% of the total residual bomb activity may be brought down by rain and deposited over 10 or 100 square miles.

However, the fall-out from TUMBLER/SNAPPER (R) Test Operation showed that the contaminated areas covered 3000 to 10,000 square miles, and not 10 to 100 square miles. Even if proper normalizing factors are used, it is obvious that on the average, rain fall-out will be over extended areas of 1000 to 3000 square miles. This means that the total activity deposited on the ground by rain will be considerably less than earlier anticipated. Also it is obvious that since rain originates on the average below 20,000 ft msl, it cannot come in contact with the mushroom of a bomb greater than 5 KT, since test experience shows that all bombs of this yield or greater reach the tropopause (normally at 40,000 ft msl in mid-latitudes). This tends to reduce the fears once raised concerning the lethal concentrations of radioactivity that may be brought down by rain. However, it is believed that for 1 or 2 KT bombs exploded during rain, a significant amount of

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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 within 30 to 40 miles of ground zero probably cover too large an area. Actually the reader is advised to study the air or ground readings themselves that are plotted in detail in the figures. These are more accurate than the isodose lines drawn about them. Figure 6 represents fall-out from U/K Nancy shot. Despite the many readings shown in this figure the close in fall-out was not adequately covered, because there are no roads in the region where the close in fall-out occurred. This has reduced the apparent percentage fall-out for this shot. Figure 7 represents the fall-out from U/K Badger Shot. Here again the close in fall-out is not deemed accurate because there are relatively few air readings in this area and no ground checks. However, this fall-out is within the gunnery range where there is no human habitation, but the distant fall-out in the Lake Mead region is presumed to be accurate. Figures 8 and 9 represent fall-out from U/K Simon and Harry Shots. It is presumed that the fall-out is adequately represented. The radex plots prepared from the actual winds three to four hours prior to shot time are superimposed on the actual fall-out plots in Figures 1 through 9. These radexes were taken from References 3 and 4. Since the ground zero and the basic maps in References 3 and 4 are different from that used in this report, some adjustments were made to correct this. This is especially the case with the radex plot of Figure 7. It is fully realized that the infinity dose values indicated in the figures do not represent the actual dosage received by people living in the indicated areas. This is because the dosage within a house may be less than the dosage outside. It should be kept in mind, however, that ratio of dosage inside

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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 in the lower stem is strongly proportional to bomb yield. The width of the fall-out area from the mushroom of the cloud appears to be proportional to the angular wind shears from 18,000 ft msl to a height approximately 7000 ft below the maximum height of the cloud. The fall-out from the mushroom is assumed to be elliptical in shape with the major axis of the ellipse obtained by a Stokes' Law analysis of the winds with the particle sizes indicated in the section below. The minor axis of the ellipse is generally one half the length of the major axis. However, if the angular wind shear from 18,000 ft msl to the upper third of the mushroom is greater than 120° then the fall-out from the mushroom is wide. The fall-out area in this case may be almost circular. In the event that the angular shear in this same region is only 10° or less, then the minor axis may be 1/4 to 1/8 the length of the major axis. As indicated in paragraph II, D, the fall-out from the stem and mushroom can be identified separately, and it can be shown that there is a minimum fall-out area between them. The intensity of contamination in the lower stam increases with yield, but the intensity of fall-out from the mushroom dees not appear to be proportional to the yield. As indicated in paragraph II, E above, 10% of the activity in the mushroom cloud of T/S tower shots is scavenged out, but only 5% of the activity in U/K tower shots are scavenged out by sand. Since on the average the bomb yield for T/S tower shots were half the yield of U/K tower shots, then this explains why the fall-out from the mushroom appears to be independent of yield. Actually as the yield of the bomb is increased for a given height of detonation (i.e. as the scaled height

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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 independent 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 reach the tropopause unless the winds aloft are above 70 knots, in which case the cloud may remain several thousand feet below the tropopause. If it is calculated that the cloud will rise up to 40,000 or 42,000 ft msl, then the particle size distribution in the cloud is assumed to be as follows: 125 microns in lower third of stem, 100 microns in the middle third, and 90 microns in the upper third of the stem; the particles in the mushroom range from 80 to 70 microns in diameter. The density of all soil particles at NPG is assumed to be 2.5 gm/cm^3. With this information it would be simple to prepare a vector wind plot based on Stokes' Law. This has been done using the H-3 hour winds. See Figures 1A, 5A, etc. for illustration.

2. Fall-out Areas

Once the maximum height of the cloud is established, and the vector wind plot is drawn, one may begin to plot the fall-out areas as follows:

a. Fall-out From Mushroom

Assume the mushroom is 15,000 ft thick vertically. Draw an ellipse whose major axis is represented by the wind vector plot from a level representing the top of the mushroom and down 15,000 ft from this point. If the angular wind shear is 10 degrees or less from 18,000 ft msl to a point approximately in the upper third of the mushroom, then the minor axis is 1/4 or 1/8 the length of the major axis; if the wind shear is less than 120°, then the minor axis is 1/2 of the major 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 areas. The first connecting area between the stem and mushroom may be 10 to 20° and is called "connecting area F" and the second one 25 to 35°, called "connecting area G." It should be noted that in the presence of high shear, the wind vector plot will not be straight. In such instances the name "elliptical areas" or "rectangular areas" should not be taken literally. In all cases the shape of the fall-out area is guided by the wind vector plot. A study of Figures 1A, 2A, etc., will illustrate the method employed.

3. Intensity of Fall-Out

The intensity of fall-out is determined by the infinity dose line values assigned to the various "elliptical" and other areas of fall-out. The infinity dose lines are given in roentgens. The intensities of the various fall-out areas are indicated below for different yields and heights of detonation:

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
1	0	0	0	0	1	100	0.1	0.01
2	0	0	0	0.5	5	200	0.05	0.01
3	0	0	0	2	10	300	0.2	0.1
4	0	0.5	1.0	5	20	400	0.2	0.1
5	0	1.0	2.0	10	30	500	0.5	0.1
10	0	5	10	50	100	1000	1	0.5
20	0	5	10	100	200	2000	1	0.5
30	0	5	10	200	300	3000	2	0.5
40	0	5	10	300	400	4000	2	1
50	0	5	10	400	500	5000	3	1

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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

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In the event that bombs greater than 10 KT are calculated to remain materially below 40,000 ft msl (say 30,000 to 35,000 ft msl) then the intensity on elipses A and B should be increased by one third of the values shown in the above tabulations.

C. Discussion of the Forecast Fall-out Reconstructions in This Report.

A study of the reconstructions found on the transparancies (Figures 1A, etc.) indicates that the forecast fall-out pictures generally cover more area than the actual fall-out and the reconstruction does not follow the actual fall-out in detail. This is done purposely because the author feels that any attempt at refining the forecast fall-out is unjustified. It is amazing enough that despite the simplifying assumptions used (simple Stokes' Law, no vertical components to the winds, assumptions as to particle size, weight and shape, neglect of molecular and eddie diffusion, etc.) the fall-out occurs in the general area of the forecast reconstruction. It is believed that the fall-out reconstruction based upon the H-3 hour winds will indicate which half or quarter of a given quadrant will be subject to contamination. The reconstructions show that one is able to determine quite well just how far the contamination from a given bomb will reach during the first 10 hours. There is no doubt that if the reader is interested he can develop his own empirical formulas and prepare fall-out reconstructions that fit the actual fall-out more closely. However, such close fits are not justified in view of the many errors inherent in this process. The problem is not one of "hindcasting"

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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

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sure that contaminating fall-out will be decreased significantly. Simple stabilization of the soil within the target area by oil or water will not reduce contamination.

D. The fall-out downwind from megaton bombs should be studied. From a study of this report it appears that surface burst bombs in the yield range of megatons may produce lethal concentrations of residual radioactive fall-out 30 to 50 miles downwind. Since this would have important military and civil defense implications, the fall-out downwind during the next Pacific Test Operations should be checked.

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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TABLE II

RATE OF GROWTH OF ATOMIC CLOUDS

<u>SHOT</u>	<u>RATE OF GROWTH</u> Where Z_s, X_s and A_s are the length, width and cross-sectional area of the stem, and Z_m, X_m, and A_m are the same parameters for the mushroom and <u>t</u> is time after detonation in hours.	
	<u>STEM GROWTH</u>	<u>MUSHROOM GROWTH</u>
UPSHOT/KNOTHOLE - Annie	10 $Z_s t$ 7 $X_s t$ 150 $A_s t$	30 $Z_m t$ 1.5 $X_m t$ 42 $A_m t$
UPSHOT/KNOTHOLE - Nancy	7 $Z_s t$ 2 $X_s t$ 60 $A_s t$	6 $Z_m t$ 1.5 $X_m t$ 50 $A_m t$
UPSHOT/KNOTHOLE - Badger	6 $Z_s t$ 2 $X_s t$ 12 $A_s t$	4 $Z_m t$ 1.3 $X_m t$ 40 $A_m t$
UPSHOT/KNOTHOLE - Simon	3.3 $Z_s t$ 1.7 $X_s t$ 31 $A_s t$	6 $Z_m t$ 2.2 $X_m t$ 83 $A_m t$
UPSHOT/KNOTHOLE - Harry	10 $Z_s t$ 5 $X_s t$ 38 $A_s t$	11 $Z_m t$ 5 $X_m t$ 26 $A_m t$

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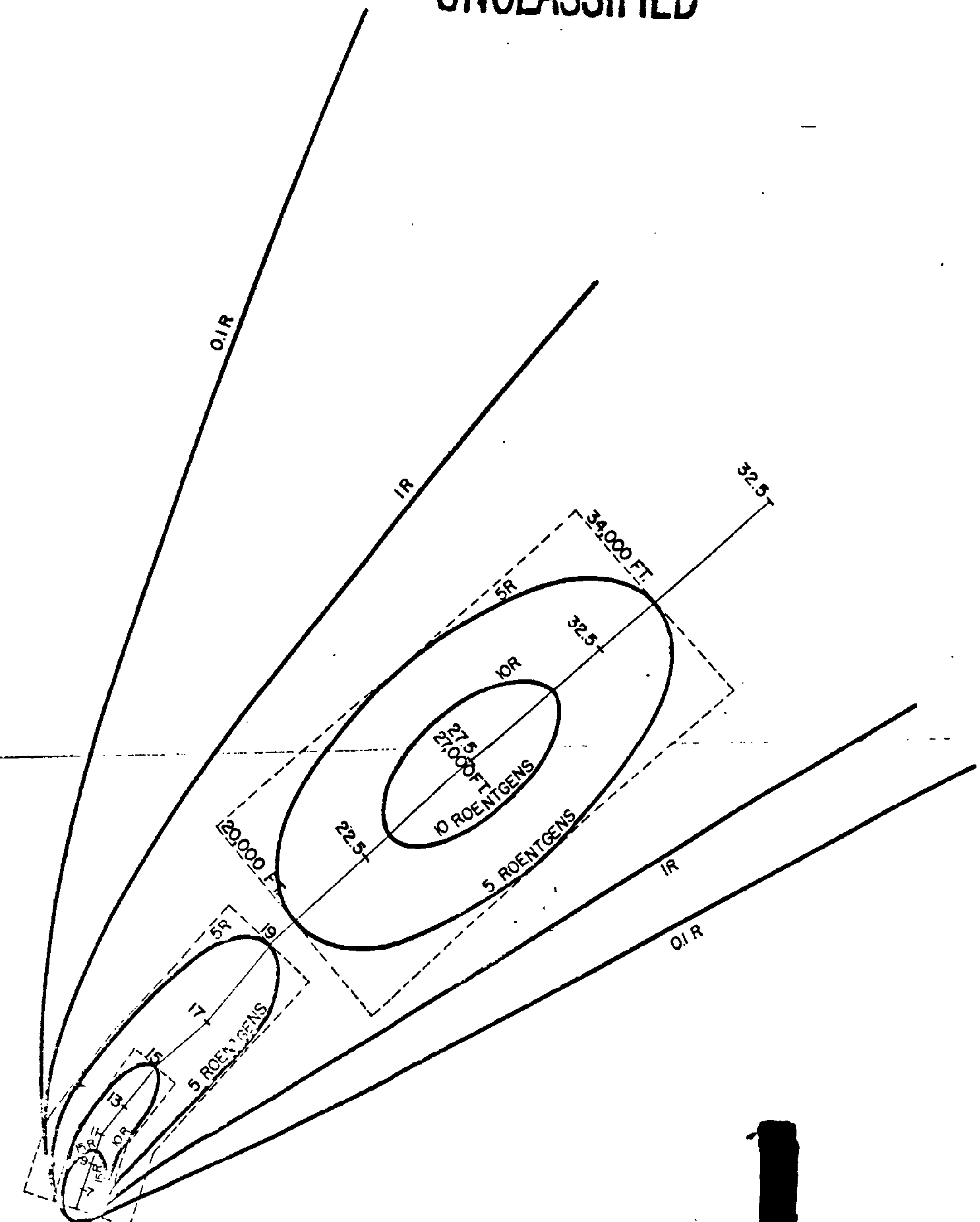

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FIGURE IA
TUMBLER SNAPPER
SHOT EASY
RECONSTRUCTION *BASED ON H-3 HOUR WINDS (IN ACCORDANCE WITH PAR. VIII OF THIS REPORT.)*

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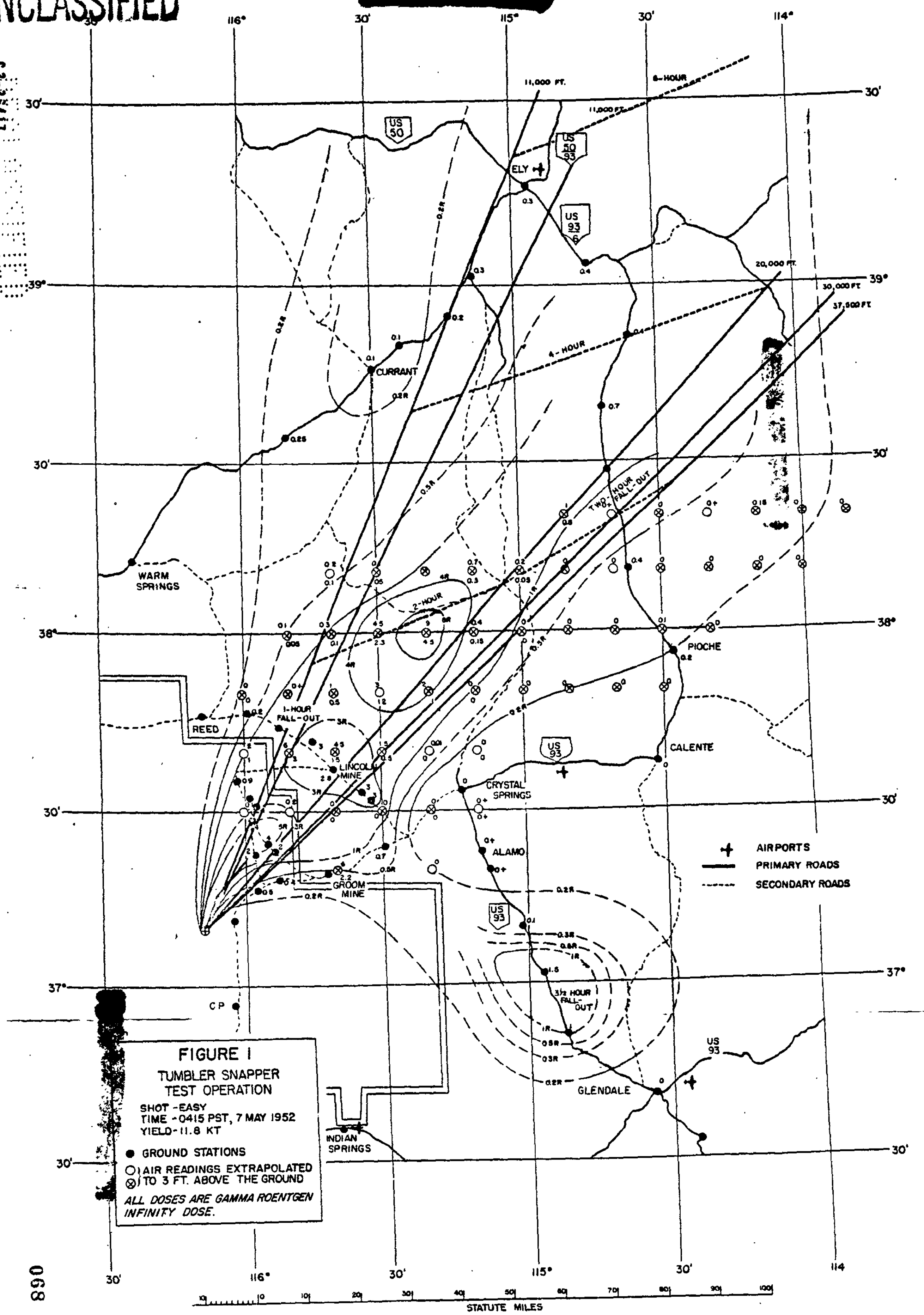

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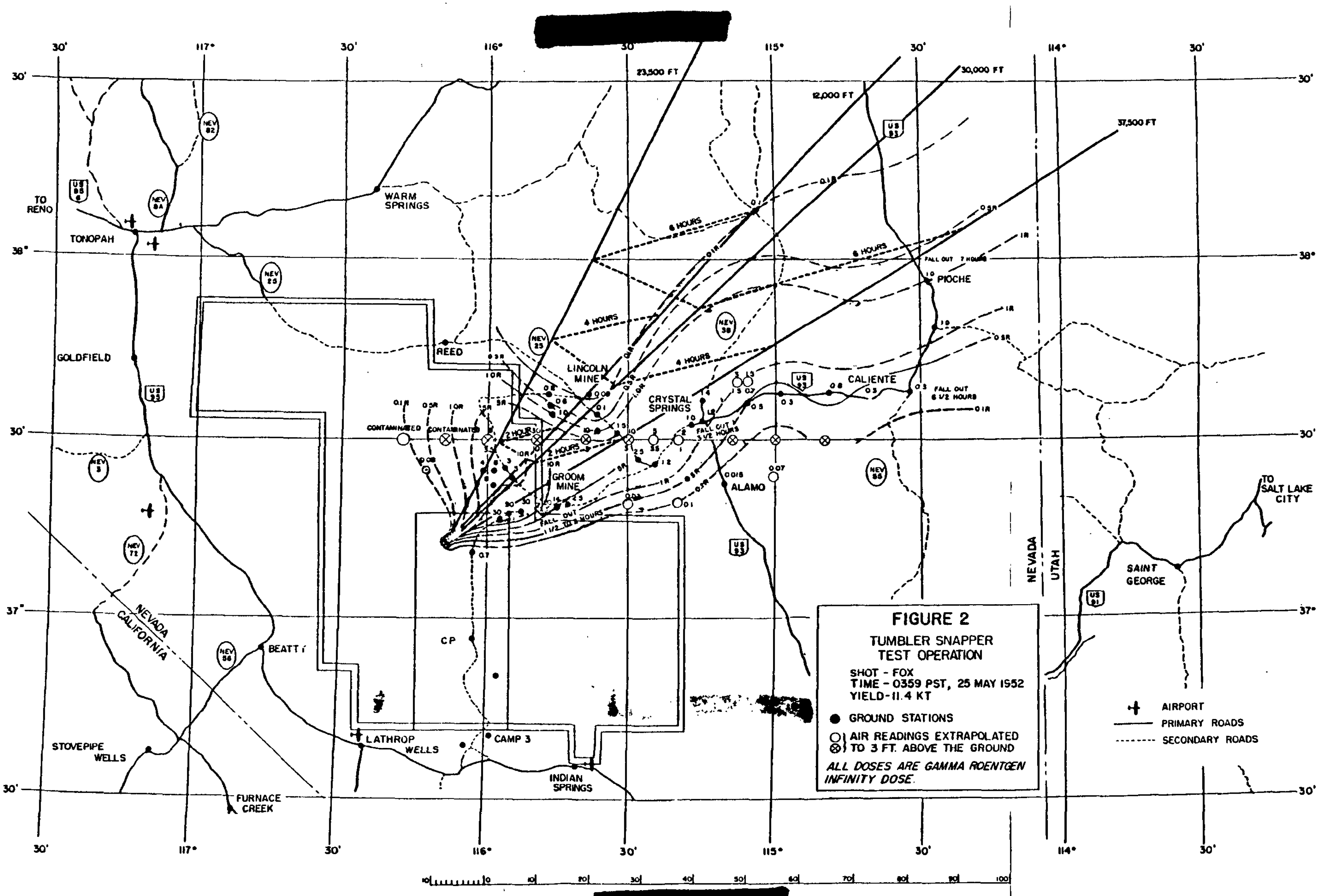

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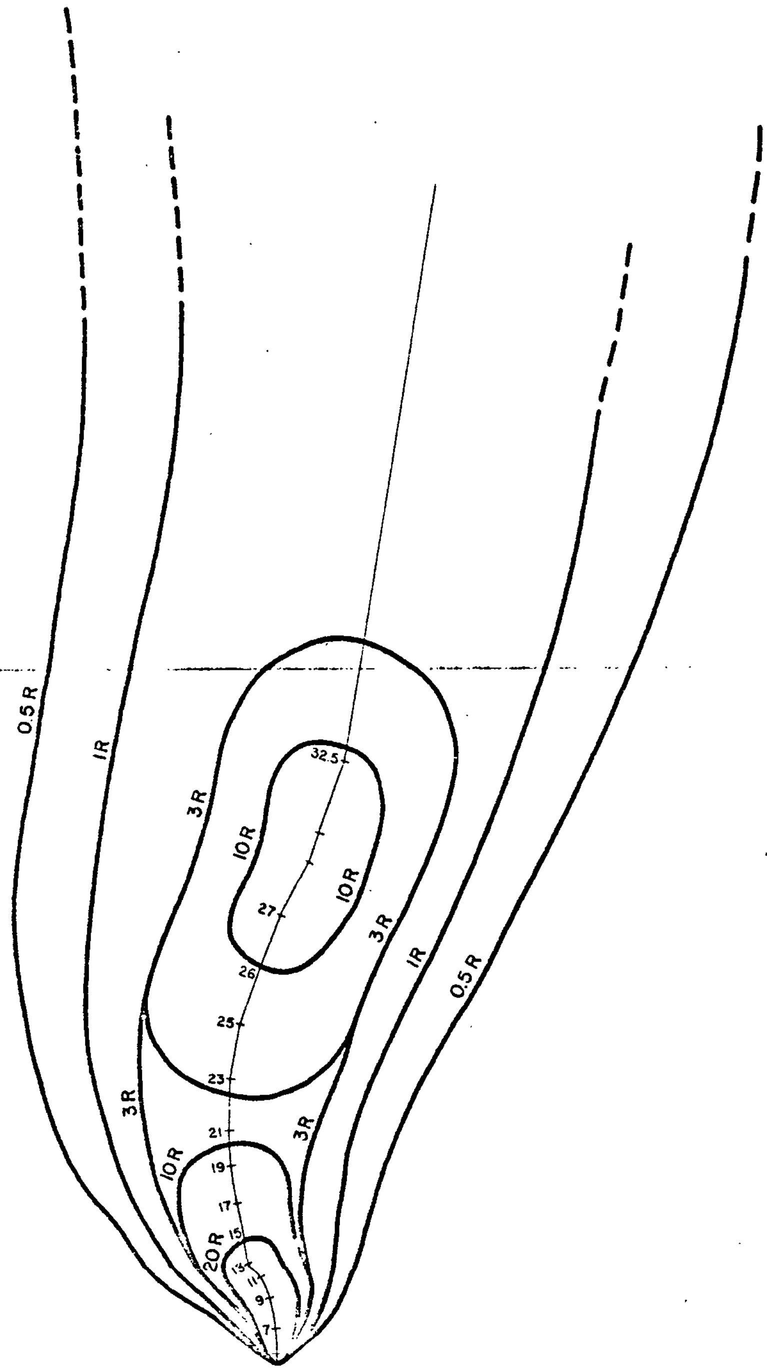

FIGURE 3A
TUMBLER/SNAPPER
TEST OPERATION

SHOT – GEORGE
RECONSTRUCTION – *USING H–3 HOUR WINDS (IN ACCORDANCE WITH PARAGRAPH VIII OF THIS REPORT)*

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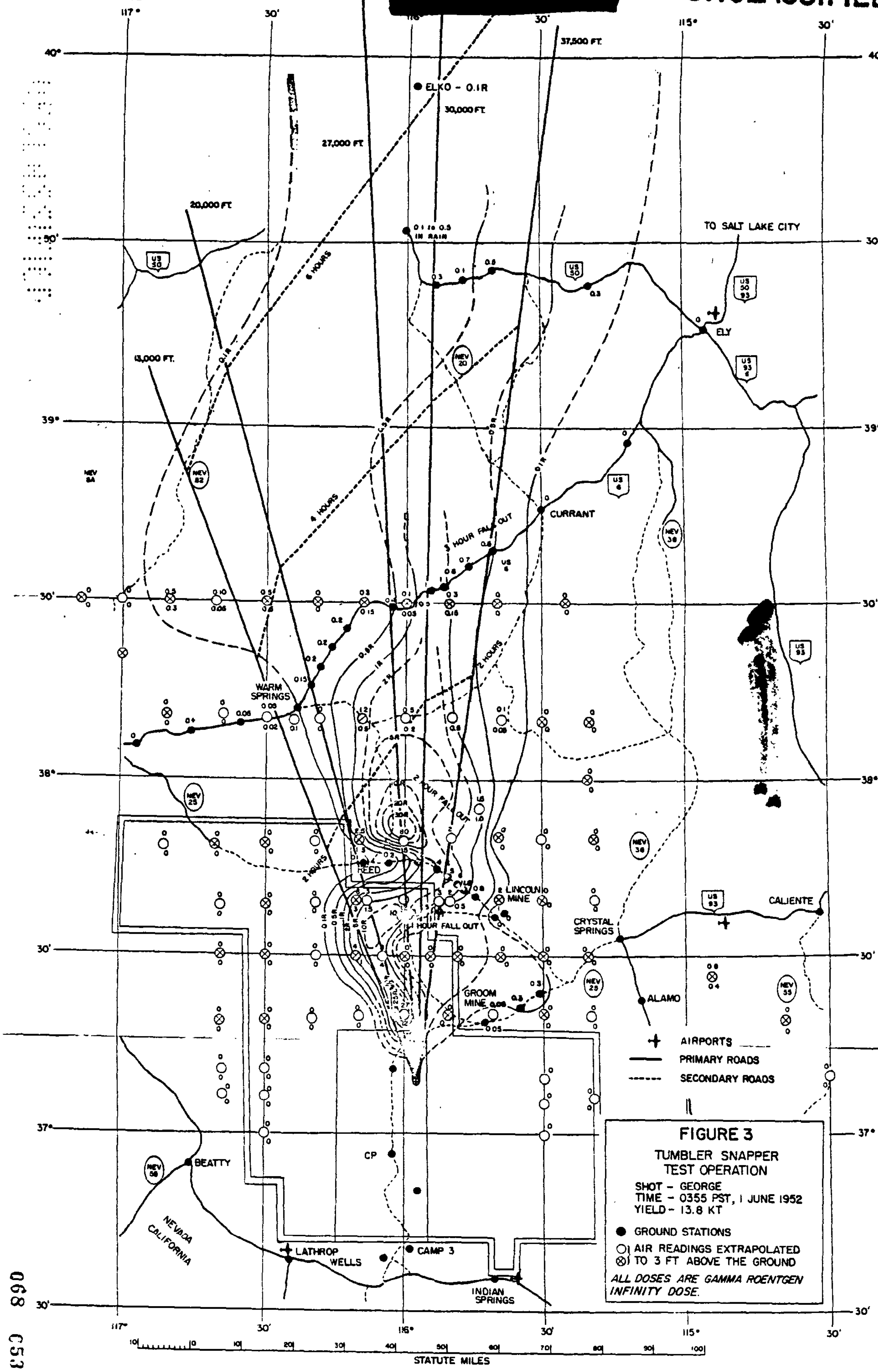

FIGURE 3
TUMBLER SNAPPER
TEST OPERATION
SHOT - GEORGE
TIME - 0355 PST, 1 JUNE 1952
YIELD - 13.8 KT
● GROUND STATIONS
○ ⊗ AIR READINGS EXTRAPOLATED TO 3 FT ABOVE THE GROUND
ALL DOSES ARE GAMMA ROENTGEN INFINITY DOSE.

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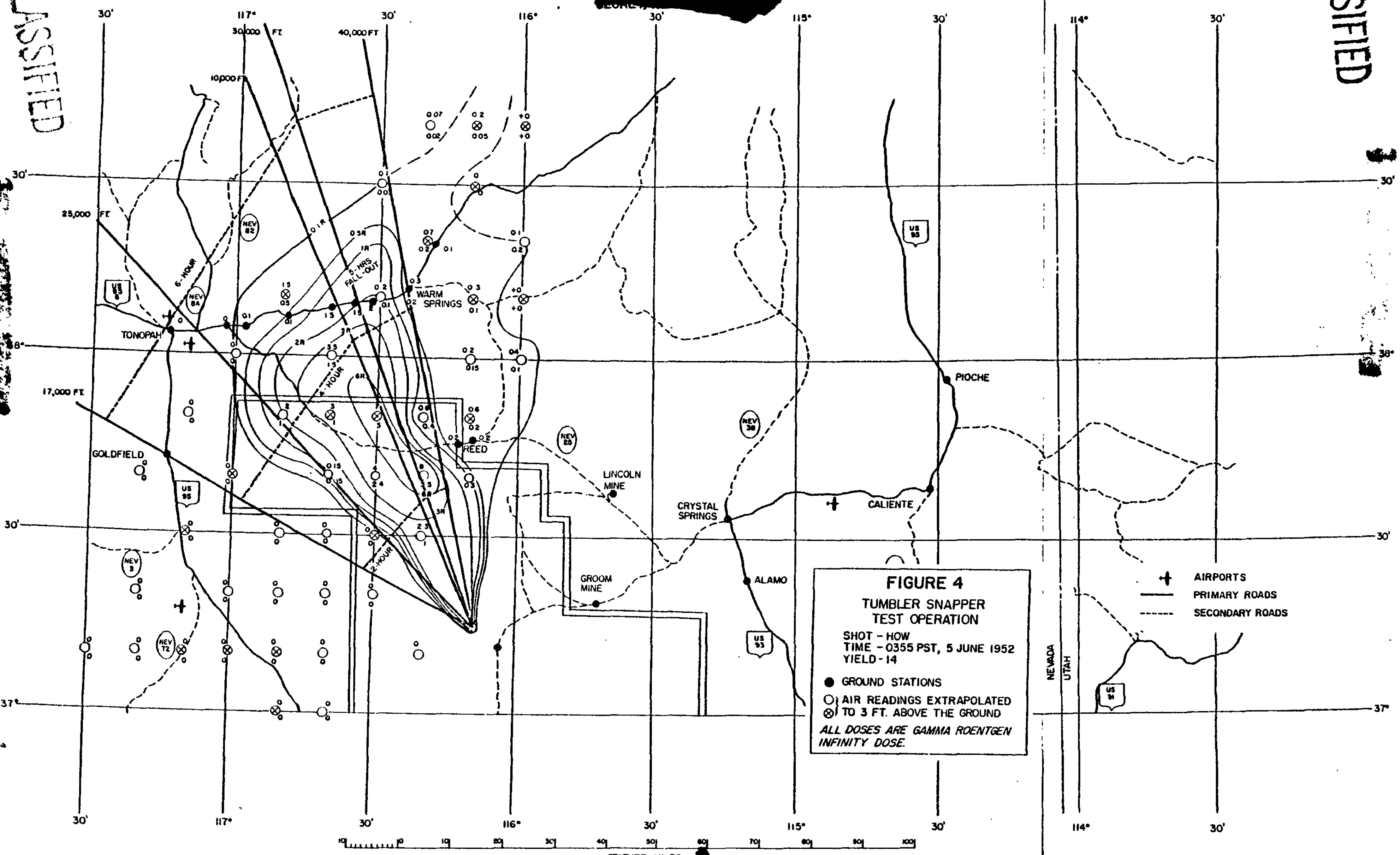
[redacted]



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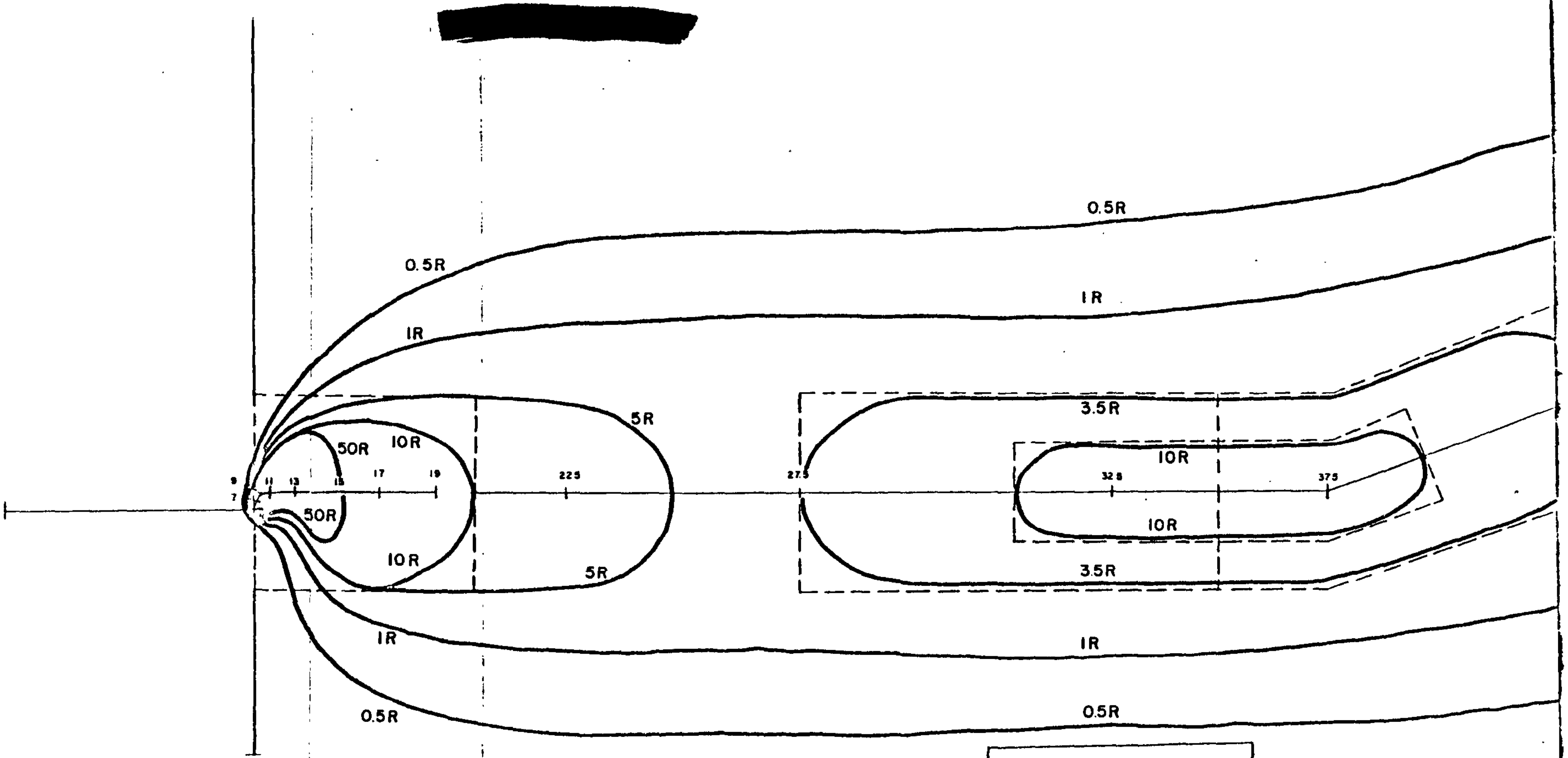

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FIGURE 5A
UPSHOT / KNOTHOLE
TEST OPERATION
SHOT ANNIE

RECONSTRUCTION
-USING H-3 HOUR WINDS

(IN ACCORDANCE WITH PAR III
OF THIS REPORT)

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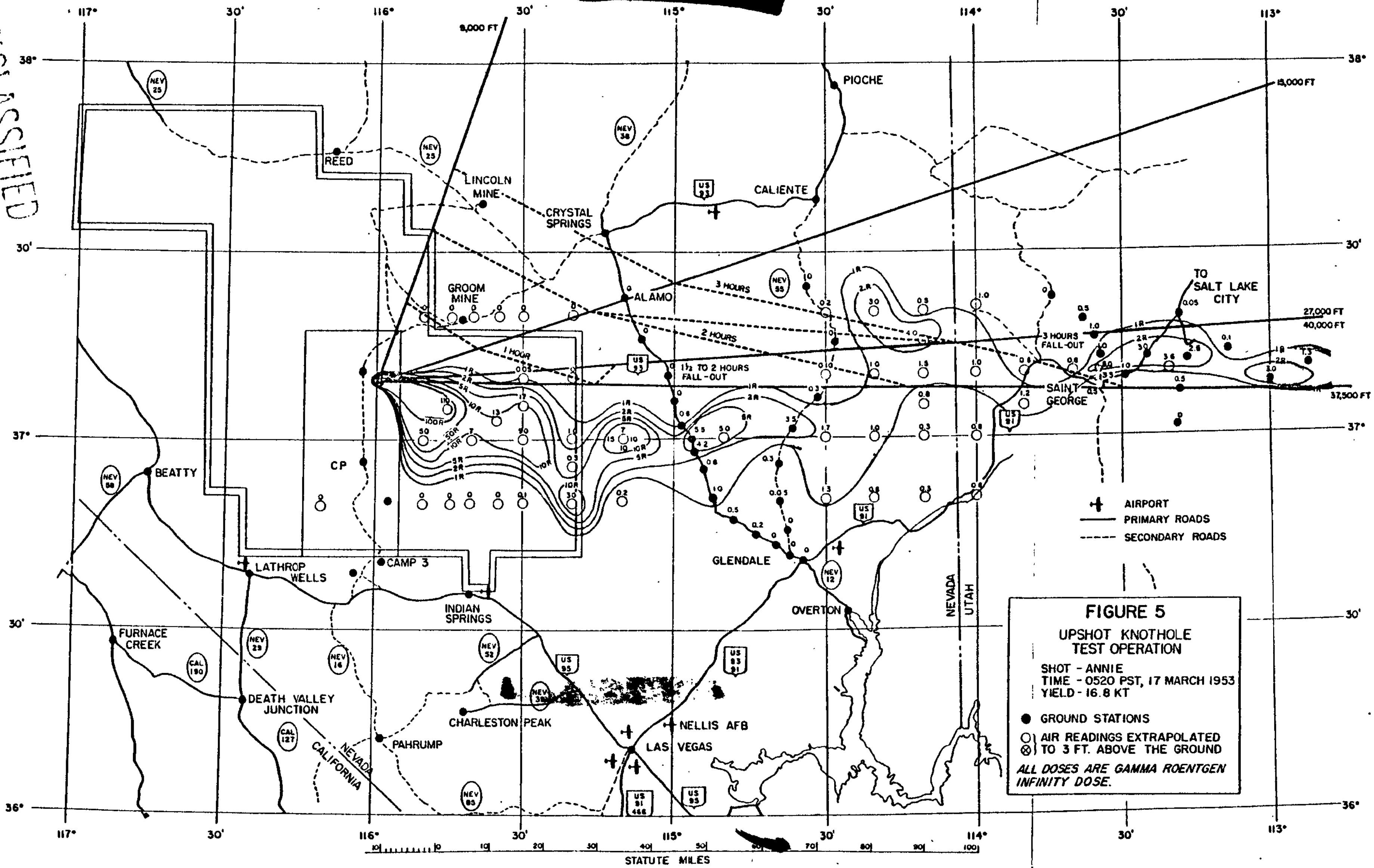

FIGURE 5

UPSHOT KNOTHOLE TEST OPERATION

SHOT - ANNIE
TIME - 0520 PST, 17 MARCH 1953
YIELD - 16.8 KT

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

ALL DOSES ARE GAMMA ROENTGEN INFINITY DOSE.

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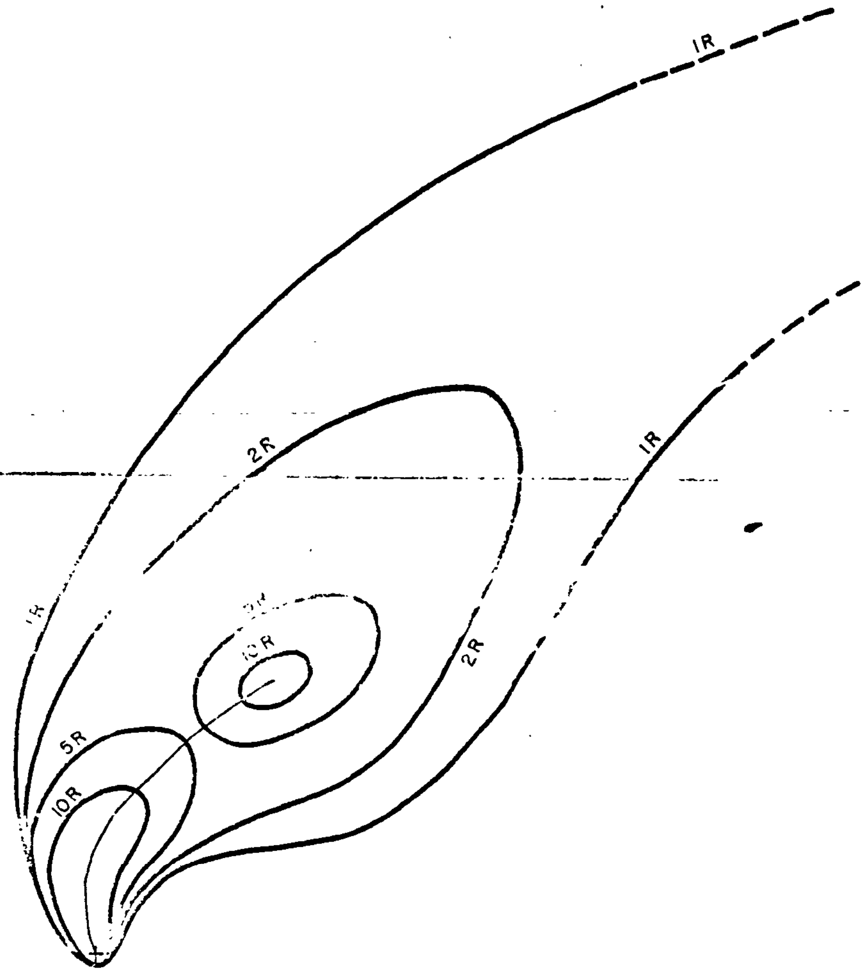

FIGURE 6 B
UPSHOT KNOTHOLE
TEST OPERATION
SHOT — NANCY
FORECAST FALL-OUT PLOT
MADE AT H-8 HOURS

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[redacted]

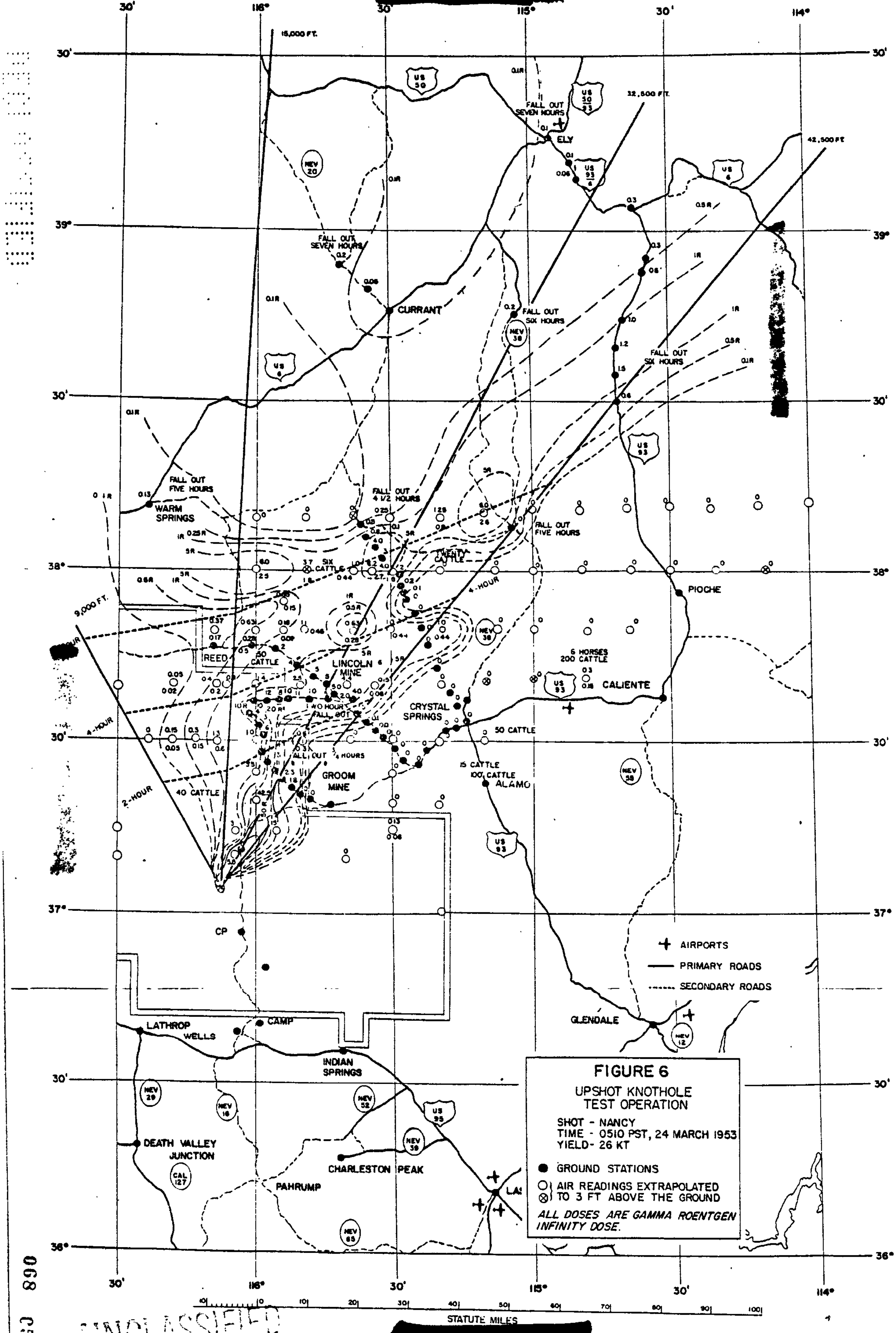

FIGURE 6

UPSHOT KNOTHOLE
TEST OPERATION

SHOT - NANCY
TIME - 0510 PST, 24 MARCH 1953
YIELD- 26 KT

● GROUND STATIONS
○ ⊗ AIR READINGS EXTRAPOLATED TO 3 FT ABOVE THE GROUND

ALL DOSES ARE GAMMA ROENTGEN INFINITY DOSE.

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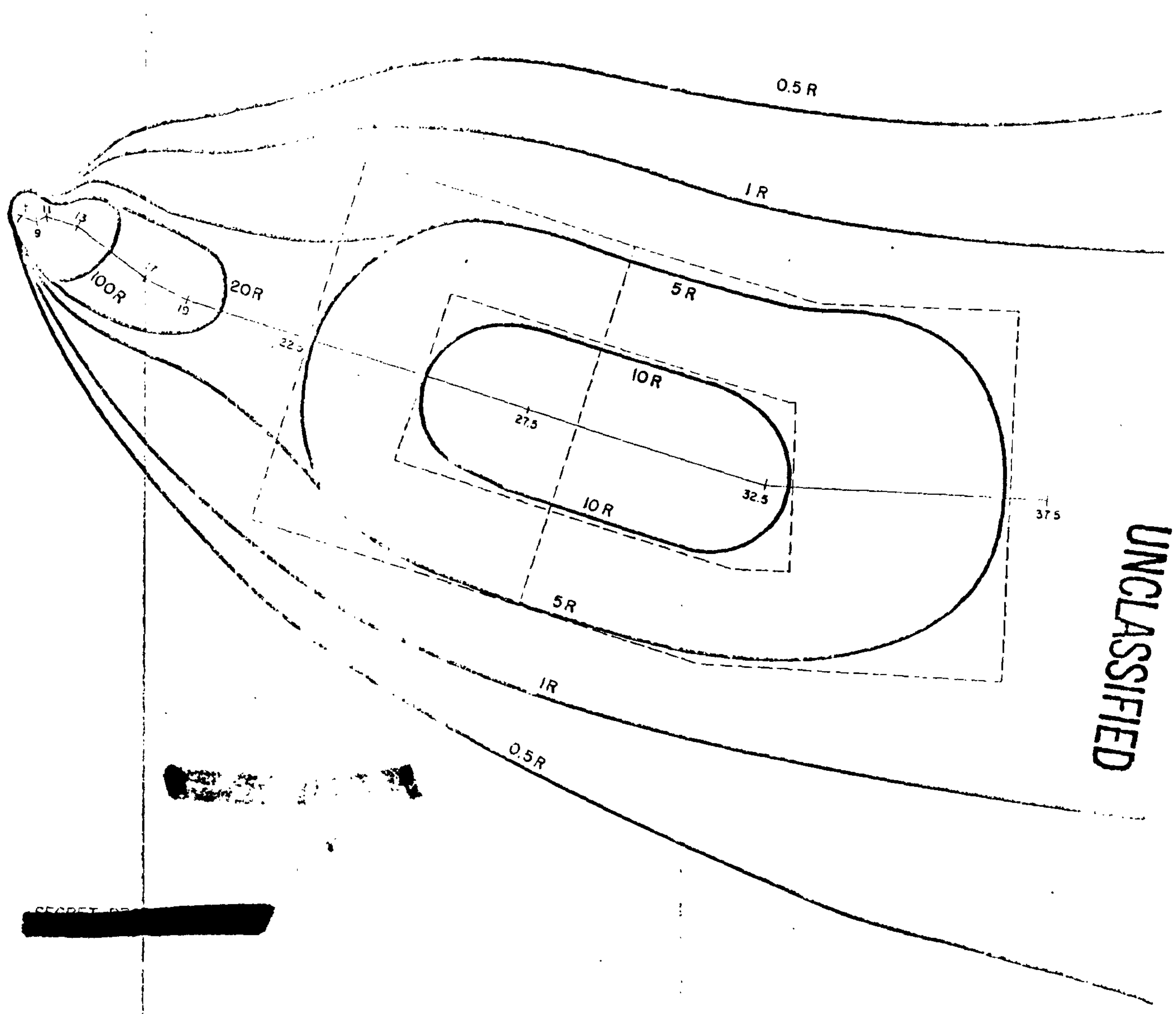

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FIGURE 7A

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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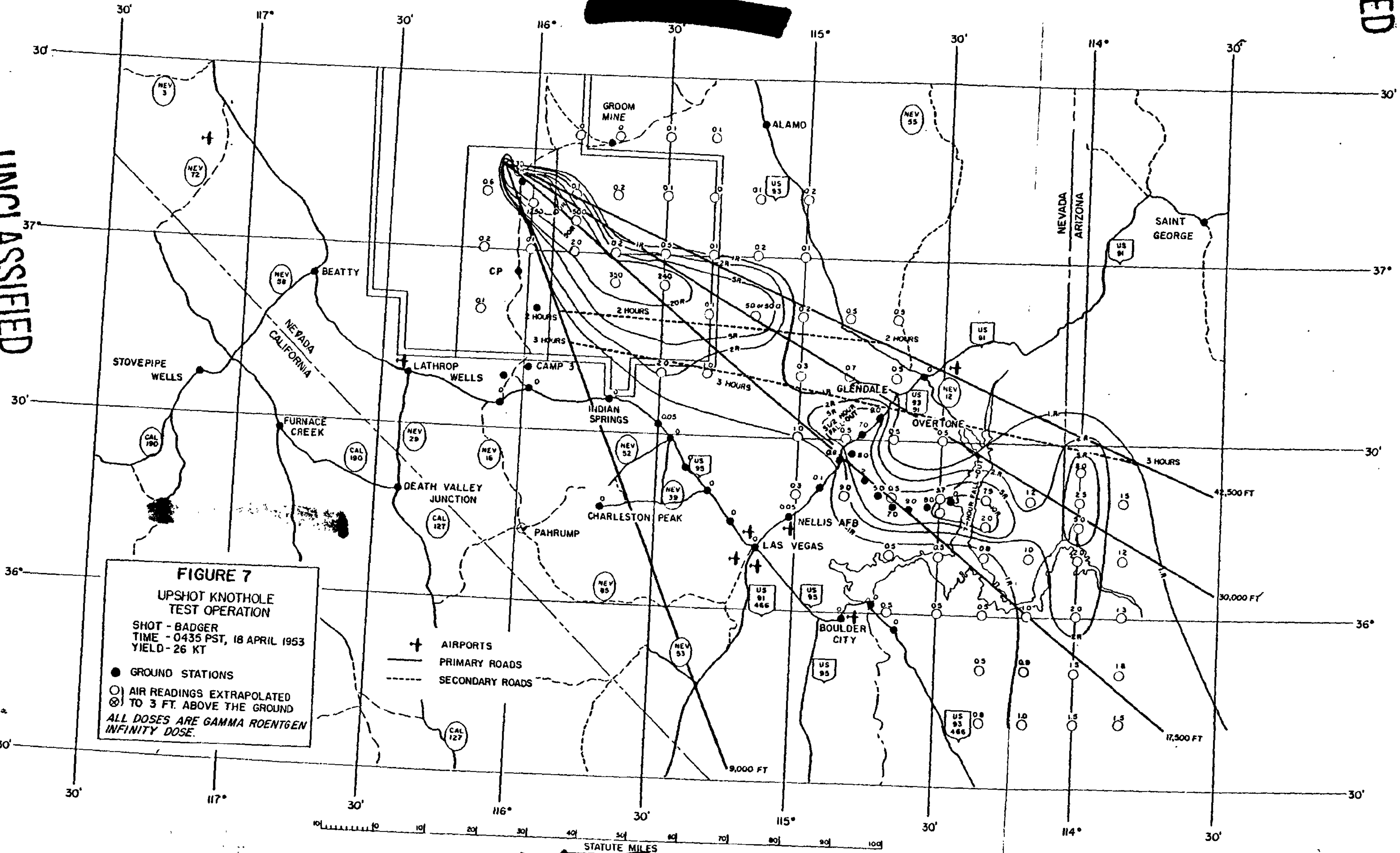

FIGURE 7
UPSHOT KNOTHOLE TEST OPERATION
SHOT - BADGER
TIME - 0435 PST, 18 APRIL 1953
YIELD - 26 KT

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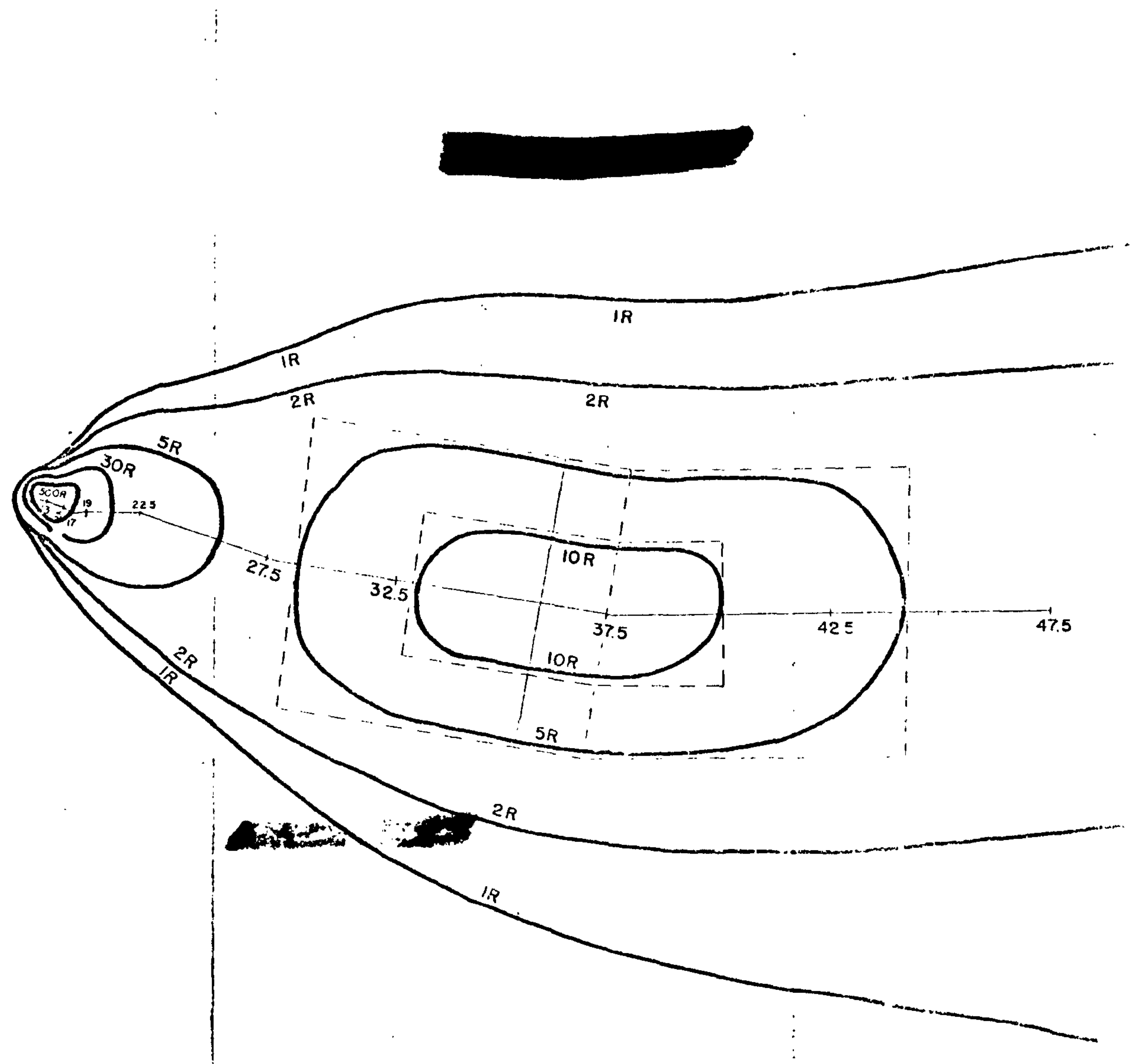

FIGURE 8A
U/K TEST OPERATION
SHOT SIMON

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

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[redacted]

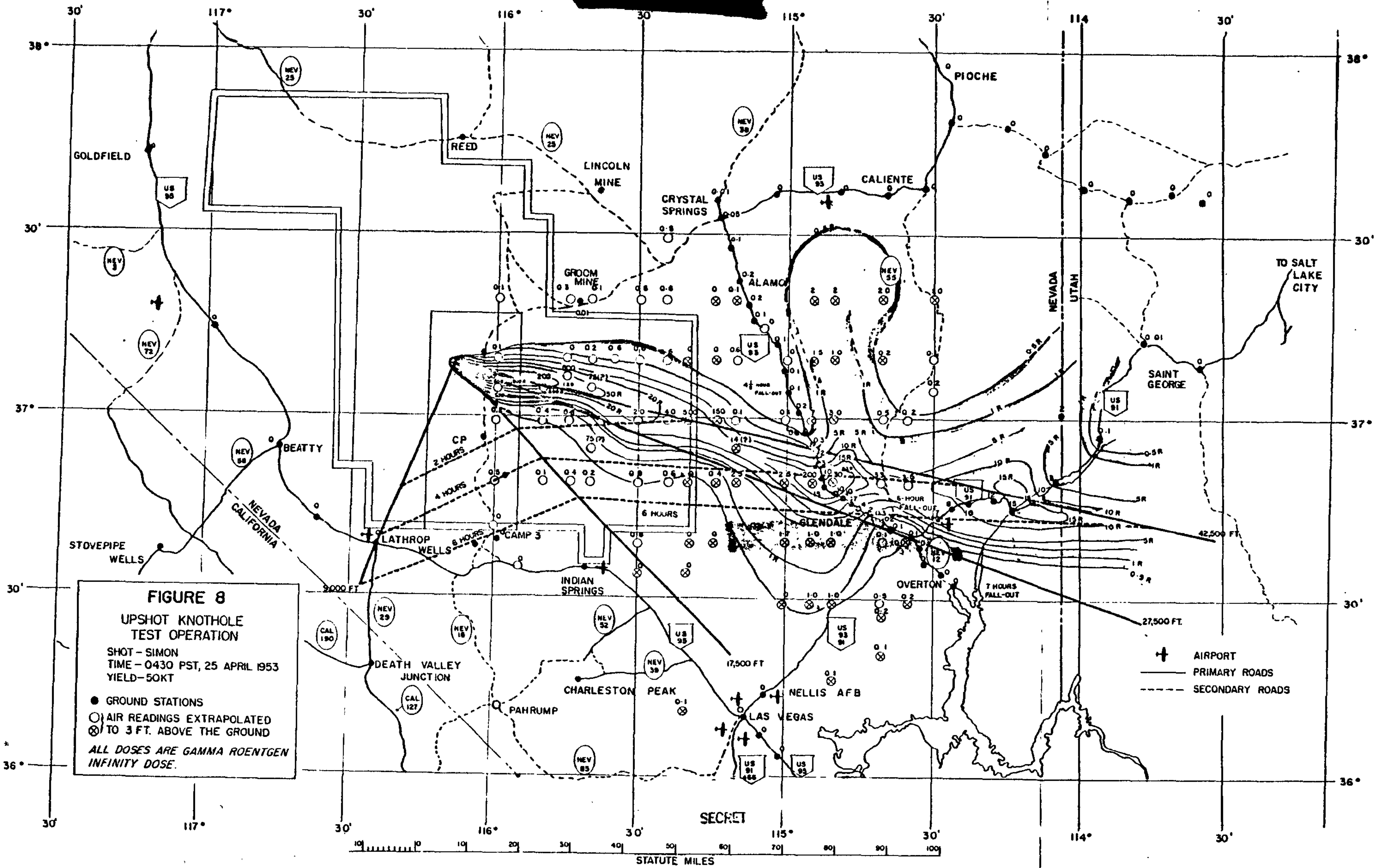

FIGURE 8

UPSHOT KNOTHOLE TEST OPERATION

SHOT - SIMON
TIME - 0430 PST, 25 APRIL 1953
YIELD - 50KT

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

ALL DOSES ARE GAMMA ROENTGEN INFINITY DOSE.

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[redacted]

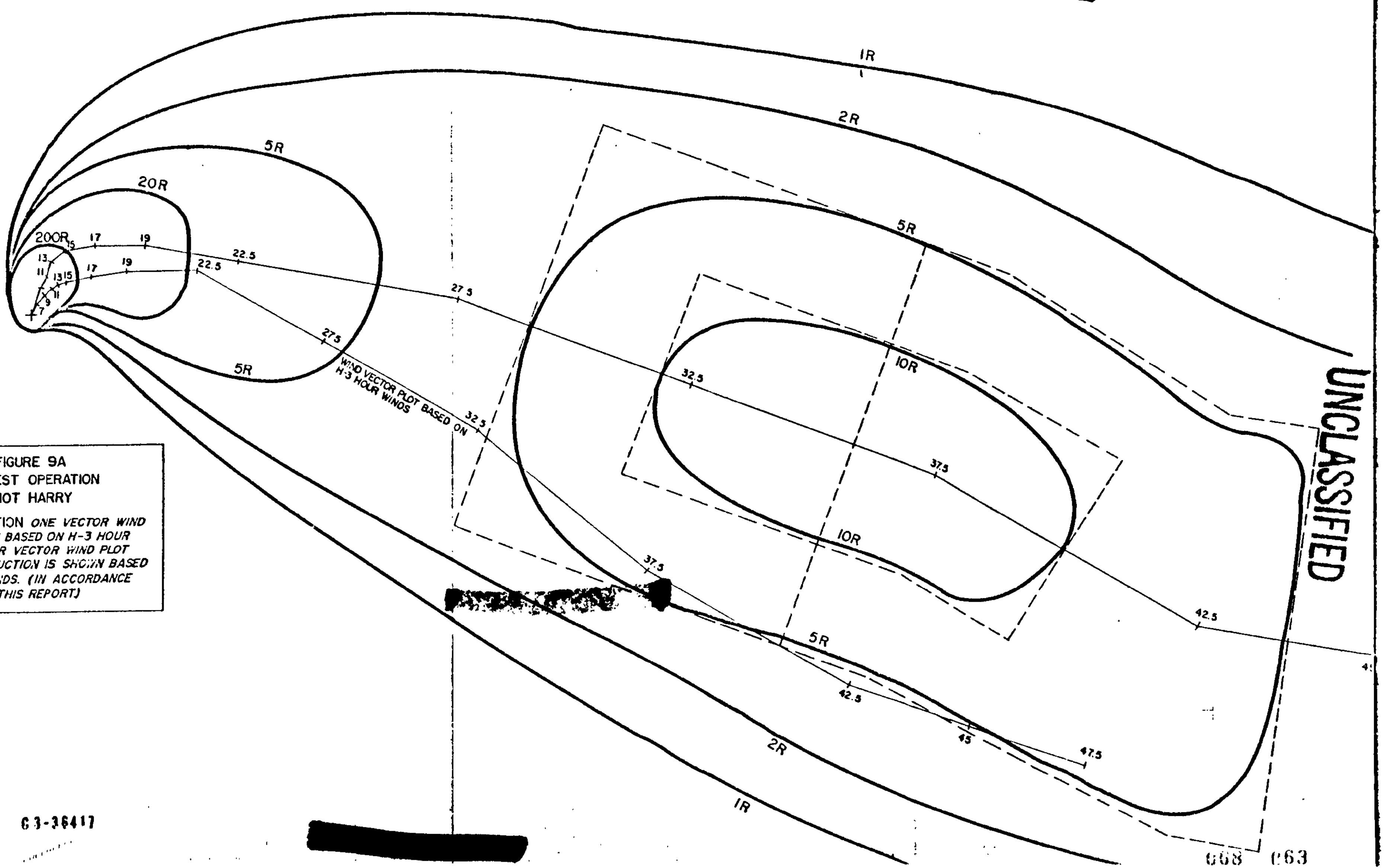

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FIGURE 9A
U/K TEST OPERATION
SHOT HARRY

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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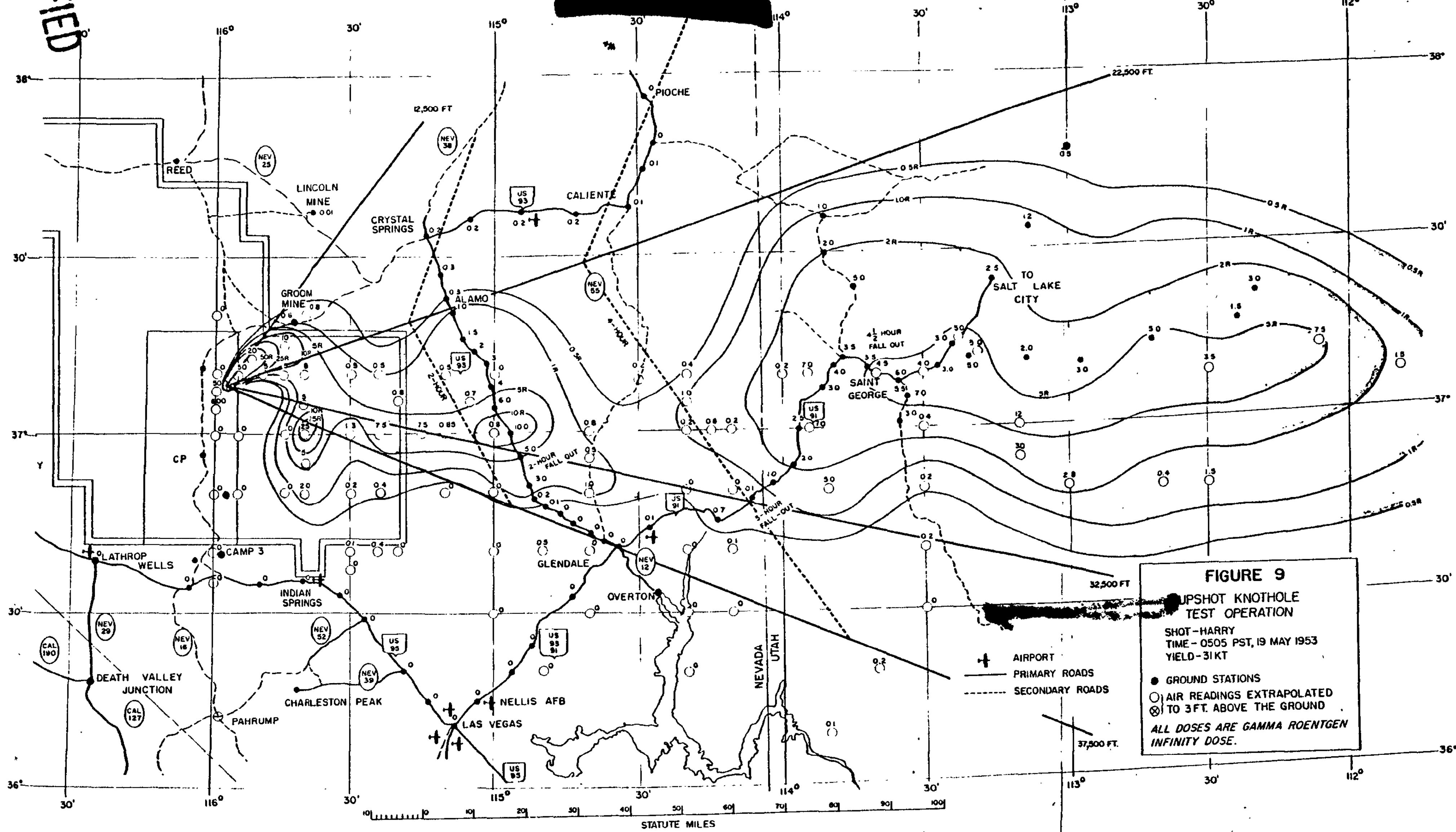

FIGURE 9
[redacted] UPSHOT KNOTHOLE TEST OPERATION
SHOT-HARRY
TIME-0505 PST, 19 MAY 1953
YIELD-31 KT

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

ALL DOSES ARE GAMMA ROENTGEN INFINITY DOSE.

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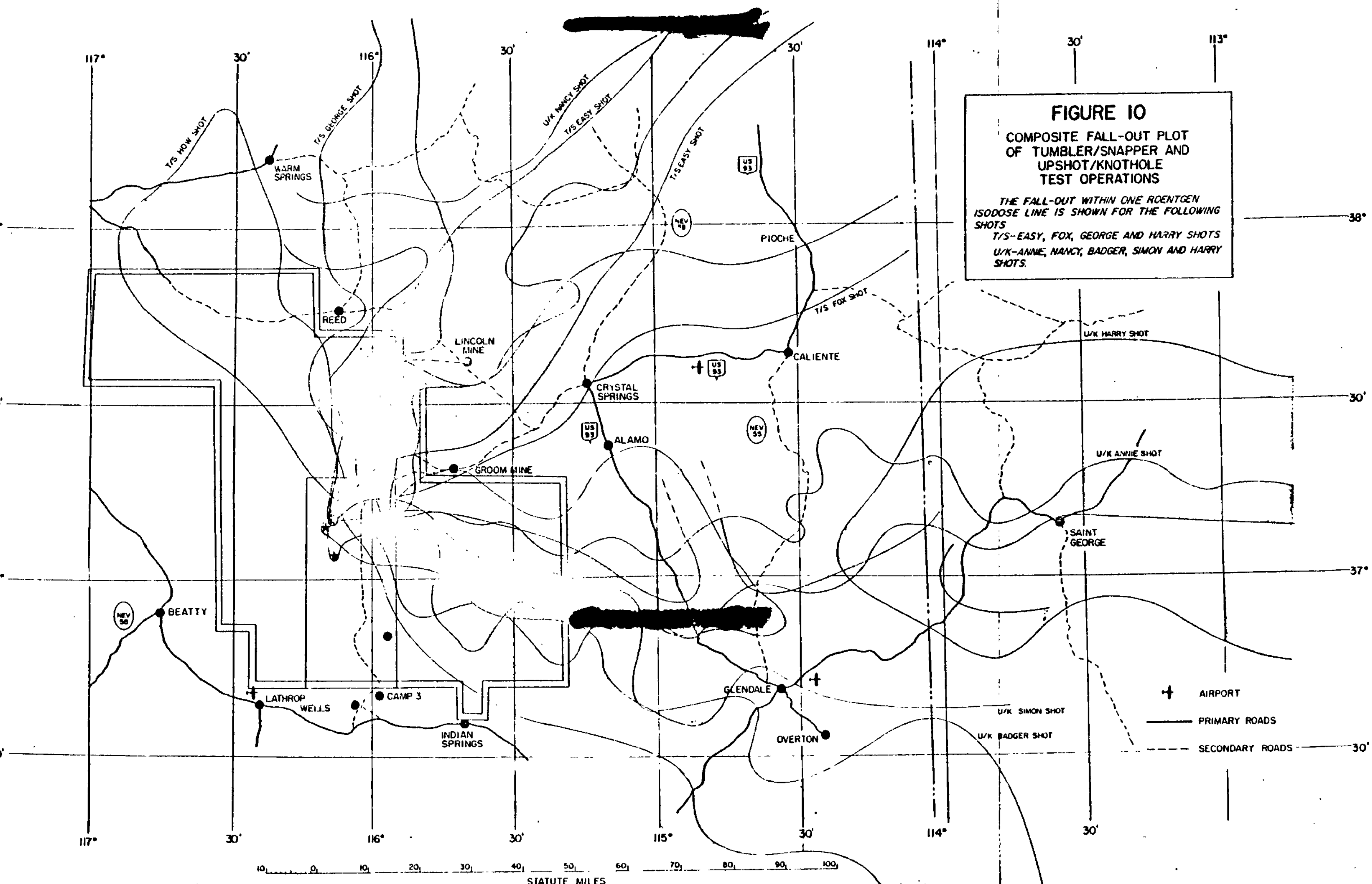

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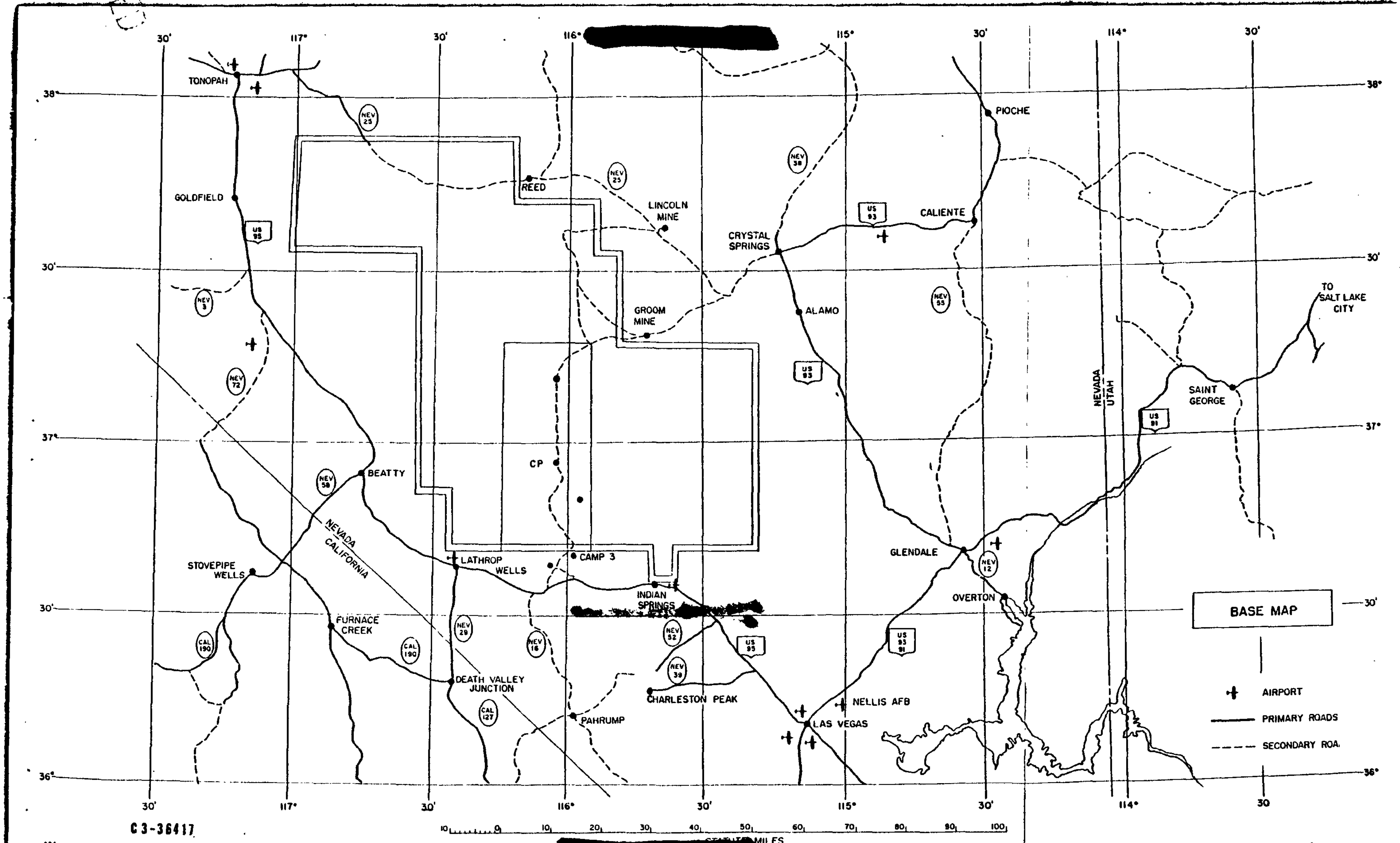

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