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RADIATION HAZARDS DURING ATOMIC WARFARE (U)

by

LT COL N. M. LULEJIAN

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NOVEMBER 1954

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Table of Contents

S[redacted]

RES[redacted]A
Ato ergy 1946

4

C4-23676

[redacted]

b. Detailed Study of Fall-out from First Shot of CASTLE Test Operation

   1. Existing Wind Distribution

   2. Variation of Winds Aloft with Time and Space and Its Effect on Radex Plotting

   3. Assumed Activity and Particle Size Distribution within the Cloud at Time of Stabilization

   4. Measured Activity and Particle Size Distribution within the Cloud

c. Scaling of Radioactive Fall-out to Different Yield Bombs Detonated at Various Heights Above the Target

d. Accumulation of Dosage in Fall-out Areas

e. World-Wide Radioactive Contamination

IX RECOMMENDATIONS

~~RES[illegible]TA~~
~~Ato[illegible]ergy [illegible] 1946~~

DOE ARCHIVES

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5

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ACKNOWLEDGEMENTS AND A REVIEW OF THE WORK OF OTHER AGENCIES IN THIS FIELD

Most of the information concerning the radioactive contamination levels during CASTLE test Operation were first obtained from Dr. Dunning of the Division of Biology and Medicine of the AEC. He kindly transmitted to us the NYOO airplane readings of the contaminated islands taken by Merrill Eisenbud's unit. Dr. Dunning also transmitted to us the JTF-7 radiological survey data and the gamma ray readings of Rongelap, Rongerik and Alinginae which were made by Dr. Scoville of AFSWP and which helped considerably in the final analysis of CASTLE BRAVO shot. The above information was used to prepare a preliminary report (See Reference 6). Subsequently most of the same data became available in the Project 2.5a report (See Reference 12). Other personnel who kindly furnished us basic data were Lt Col Bonnott of JTF-7 and Col Houghton of AFSWC. We have worked closely in the past with RAND in the problem of radioactive fallout up to but not including CASTLE data. At this point the RAND and ARDC analyses vary considerably. Primarily RAND believes that 90% of the activity in the cloud is in the mushroom and only 10% in the stem. ARDC analysis shows 80% activity in the stem and only 20% in the mushroom most of which is non-scavengable or falls out at much later times. RAND assumes fallout originates from 100,000 ft. msl for CASTLE BRAVO, ARDC assumes that the fallout in the first 15 to 30 hours does not come from above 60,000 ft. The USNRDL scaling of Jangle-Surface shot did not consider any fallout beyond 3 to 5 miles downwind of ground zero. Within this area only 10 to 15% of the total residual activity was deposited. The ARDC Analysis (See Reference 1) showed that the immediate downwind fallout reached as far as 90 miles downwind and this fallout area accounted for approximately 85% of the total activity. It is presumed that the NRDL scaling model will be altered to account for this discrepancy. It appears to us that the AFSWP Report 507 adopted the NRDL scaling model for CASTLE BRAVO shot. Undoubtedly AFSWP and NRDL have in more recent work changed their scaling model, but such changes are not yet made known to us. The U. S. Weather Bureau and the Air Weather Service have studied the fallout problem primarily from the point of view of minimizing contamination during atomic test operations. The Army Chemical Corps and the Signal Corps have also studied the fallout problem. It is clearly shown above that at the present time the effort in this field of endeavor throughout the Defense Department, AEC and the Weather Bureau is quite extensive. It is hoped that at some future date a coordinated picture will be obtained on the mechanism and magnitude of the fallout.

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6

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ABSTRACT

1. The first shot of CASTLE Test Operation is analyzed in detail, and this, together with Jangle-Surface shot, is used for scaling of fallout intensities and areas for yields of 1 KT to 225 MT. A method is also given to predict the fallout for any scaled height. Table I (see following page) gives the 48 hour integrated dose in roentgens within downwind contaminated areas in square miles for different yield bombs exploded on the surface. The values given in Table I are generally much higher than the predictions made by other agencies in this field. It is possible to determine the extent of downwind contamination for any yield bomb detonated at any scaled height by the use of Table II (see following page).

2. The offensive and defensive implication of such highly contaminated areas are discussed. Calculations are made on the dosage received by aircrews accidentally penetrating young atomic clouds from multi-megaton bombs. Estimates are given on the contact beta hazard to the hands of maintenance personnel from contaminated engine parts.

3. The fallout picture is given for all of the United States when 111 bombs of 15 megaton yield are surface detonated over 106 cities whose population is 100,000 or more and on five other selected airbases. This is illustrated graphically in Figure 11. An inspection of this Figure shows that there is "no place to hide" in this country under above listed circumstances.

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TABLE I [redacted]

48-hour Integrated Dose in Roentgens	Areas in Square Miles for the Following Yield (KT) Surface Burst Bombs *										
	1.75	10	100	500	1,000	5,000	15,000	45,000	60,000	100,000	225,000
13,000	0.013	0.22	3.18	25	44	288	1,000	3,620	5,030	8,900	22,600
3,330	0.042	0.47	6.9	53	95	620	2,160	7,820	11,000	19,200	48,800
670	0.42	4	47	258	560	3,060	10,000	33,000	43,600	76,000	183,000
250	0.84	7.5	81.4	430	900	4,750	15,000	47,200	62,200	106,000	246,000
33	1.75	14.5	147	750	1,560	8,100	25,000	76,500	100,000	173,000	400,000

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TABLE II

λ	Percentage Fallout	Burst Height Above Terrain for 15 MT Bomb
1.0	0%	5,000 feet
0.45	30%	2,000 feet
0.2	50%	1,000 feet
0.0	80%	0
- 0.1	95%	- 450 feet (underground)

* For a justification of Table II, see the Appendix and References 1 and 6.

$$\lambda = \frac{h}{500(w/20)^{1/3}}$$

where

h = height above terrain in feet

w = bomb yield in kilotons [redacted]

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C4-23676

DOE ARCHIVES

8

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I. General

The primary damage area from an atomic bomb is more or less confined to a radius of from half a mile to perhaps ten miles, depending on the energy yield of the bomb. If large atomic bombs are detonated on the surface, lethal concentrations of residual contamination will reach out well beyond the thermal and blast damage perimeter and may extend several hundred miles downwind. In an earlier report (1) dated November 1953, we stated that if Washington, D. C. was bombed by a five to ten megaton surface weapon, then the city of Baltimore may have to be evacuated in order to prevent excessive casualties from the radioactive fall-out. It now appears that our earlier prediction was, if anything, conservative. It is the purpose of this report to evaluate the amount of fallout from surface or near surface burst nuclear weapons and to indicate the military implications of such a hazard both from the offensive and defensive points of view.

II. History

In the Fall of 1951, two small atomic bombs were detonated at Nevada, one on the surface and the other underground. These detonations produced excessive contamination downwind. Unfortunately, the contamination was measured accurately only within five miles of ground zero. In the Fall of 1952, a large yield thermonuclear device (ten megatons) named "Ivy-Mike" was detonated on the surface of an atoll island in Eniwetok. This shot produced excessive upwind and crosswind contamination, but the extent of downwind contamination was not measured at all. Data available from the recent Pacific Test Operation CASTLE (March 1954) shows considerable radioactive contamination several hundred miles downwind from a surface burst thermonuclear weapon of approximately fifteen megaton yield.

III. Military and Civilian Tolerance Dose Standards

One of the most important reasons for writing this report is to discuss radiation tolerance doses for the military during combat as compared to the existing tolerance doses for the civilian population.

a. Background Radiation

As we all know, cosmic radiation from the sky and natural radioactivity from the soil produce a certain normal background of radiation through which we all live. Normally, the gamma-radiation background at sea level ranges from .01 to .05 milliroentgens per hour. At higher elevations the background may be increased two or three-fold. If we go underground, the background is reduced provided there is no uranium or radium ore present. As a start, then if we

REST[redacted]
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9

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want to protect the human race against all radioactivity, we should all go live in lead mines deep underground. We realize, however, that the normal radiation background of the world is not sufficient to cause any appreciable damage to the human body. We may be really squeamish about it and decide not to live in Denver or in Peru or in Switzerland or in other places where the elevation is significantly above sea level in order to reduce the radiation background. If we are concerned to this extent, then we should also look at our radium dial wristwatches, since they too put out radiation which might be as high as 10 to 1000 times background. There is also the problem of x-rays for medical purposes. Every time we take a chest x-ray we get a certain amount of radiation in our bodies and some people may consider this quite dangerous. The doctor weighs this so-called "danger" from the x-radiation as compared to the benefits that the patient will receive upon examination of such x-ray photographs. Medical practice today apparently condones the use of x-ray pictures and allows the administration of several roentgens of x-rays to the patient in order to get such pictures. From this, it would be fair to conclude that the medical profession as a whole today does not regard the administration of several roentgens to the patient as dangerous.

b. Civilian Tolerance Doses During Peace Time

As soon as the first atomic bomb was detonated it became obvious that the world would be exposed to more radioactivity than we were able to obtain from our x-ray machines or more radioactivity than nature intended for us to receive. For this reason, the Atomic Energy Commission set up some rigid standards to control the amount of radiation that could be received by workers in the plants of the AEC. These standards are quite well known and readily available from government sources. One of the basic tolerance standards states that a worker of the Atomic Energy Commission should not receive more than 0.3 roentgens per week of normal work. This refers to gamma-radiation and it refers to radiation received throughout the body, that is, total body radiation. There are other standards for radiation to the hands or to the feet, etc., which are higher than 0.3 roentgens per week.

c. Civilian and Military Tolerances During Atomic Warfare

Although we accept the Atomic Energy standards for radiation during peacetime, it is believed that as soon as a general atomic war is initiated these standards must be revised in order to prosecute the war against the enemy properly, and in order to defend ourselves without undue panic which might be caused by a superstitious fear of the damage produced by radiation. It is quite difficult for the uninitiated to understand and appreciate this point of view. However, after being exposed to many atomic tests, and to radiation which by present peacetime standards may be

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considered excessive, some personnel in the Air Force have learned that they can take calculated risks with radiation in order to remain operational during combat. Without denying the essentially harmful effects of radiation on the human body, it is possible to develop common sense practical radiation tolerance standards which fit the emergency of a given situation. The Air Surgeon has already recognised this and has stated that at the discretion of the Commander, a person may receive a total body instantaneous dose of 100 roentgens without running the risk of producing radiation casualties. The first shot of CASTLE Test Operation which was held in the Pacific during March of 1954 exposed approximately 28 Air Force personnel and 230 natives of Rongelap and Rongerik Islands to radiation which was assumed to be between 50 and 250 roentgens total body gamma due to the fallout of residual radioactivity. This problem is discussed in detail in Reference 13. After study of the effects of radiation on the natives at Rongelap, it is now assumed that 200 roentgens can be given to a military person during combat operations without unduly endangering the life of that person. It is believed that some people will get slightly sick temporarily if they receive 200 roentgens of gamma radiation total body. However, during combat, a Commander may decide to expose his personnel to such a "hazard" if he can prevent disaster by doing so. Our problem today is how to indoctrinate military personnel not to fear radiation excessively and yet to respect it. We find that in the Air Force there are many people who have learned this trick of avoiding as much radiation as possible, and yet not losing their heads when they have to be exposed to doses of from 10 to 50 roentgens. These people are few and far between and they have achieved this experience only after repeated exposures to many atomic tests. Unfortunately, we have evidence that there are many people in the Air Force who are quite concerned about small doses of radiation. It is hoped that this report may help put this problem in the proper perspective. The only way we know of allaying the fears of personnel in this regard is to state the obvious over and over again, and to repeat whatever has already been written about tolerance doses. Despite the fact that we caution everyone to receive as little radiation as possible, we still believe firmly that even if a person receives 100 to 200 roentgens total body instantaneous gamma radiation, he will not become a casualty. The problem is how to acclimatize personnel to this, or how to make sure that military personnel will not panic in the face of a radiac instrument which is going off-scale. We have many examples during atomic test operations where otherwise experienced personnel have actually panicked when they thought they were being subjected to excessive dosages of radiation. The only real cure against such panic is to expose personnel to relatively large doses of radiation. It is like exposing troops to enemy fire. We realize that no one will allow us to expose a large number of people to big doses of radiation for purposes of indoctrination. However, there should at least be some sort of a training program which realistically explains the dangers of radiation, and compares these radiation hazards, say, to

11

a broken arm or a broken leg or to the hazards of a bullet going through the guts. Actually, comparisons of this sort make it very clear that radiation is the lesser of two evils. However, there is a limit to this thing. If the radiation dosage goes significantly beyond 500 roentgens then it is as sure a killer as any bullet. So, our problem is to see that the military man is not unduly afraid of radiation of the levels of 25 to 250 roentgens, but at the same time he should know enough that if he is exposed to a total body instantaneous gamma radiation of 600 to 800 roentgens, then he is quite sure to die from such an exposure. This, again, is well known and published and readily available from unclassified sources. We will repeat the following gamma dosage values for ready reference:

100 roentgens total body	No radiation sickness.
200 roentgens total body	10% of exposed personnel may show slight symptoms of temporary radiation sickness such as a tendency to vomit, etc.
600 roentgens total body	Will probably kill 50% of the personnel within 30 days.
800 roentgens total body	Will kill probably everyone exposed within 30 days.

We note that there is a gap in our information between 200 roentgens and 600 roentgens total body dose. This gap in our knowledge is a real one. We have not exposed a statistically large number of human beings to dosages between 200 and 600 roentgens accidently or otherwise. Therefore, we do not know with certainty just what the response of the human being will be to such dosages. However, it is fair to assume that this is a danger zone, perhaps 350 to 400 roentgens may kill 10% of the people so exposed. Perhaps at some future date, after sufficient animal experimentation has been done, we may have more accurate numbers here.

d. Internal Dose as Compared to the External Dose

So far, we have been discussing the external gamma total body radiation that may be received by human beings in a short period of time. There are also dangers of inhalation of fission products during fallout of radioactivity. There are also dangers of ingestion of fission products in the food and in the drinking water. It is in this region of radioactive hazards that we find the greatest lack of information and therefore the greatest tendency to panic. Our experience so far, meager as it is, seems to indicate that by far the greatest danger is from the external gamma radiation. This was proved over again during Operation CASTLE (13). In the Islands of Rongelap approximately two hundred natives were exposed to

12

fallout after which time they stayed in the same area for two days before they were evacuated. During these two days they drank contaminated water. As a matter of fact, they actually drank water which was covered with the gray "snow" or "mist" which fell down on the island. This means that they were drinking active fission products together with the gray coral of the islands that was brought up to high altitudes by the atomic explosions and which subsequently fell out upon the inhabited island of Rongelap, Rongerik, etc. These people also ate food that was exposed to the fallout. Nevertheless, according to Reference 13 there were no internal radiation hazards. This indicates once again that it is best to assume that if you are not exposed to excessive radiation from gamma rays, that if you do not receive from 400 to 600 roentgens of instantaneous gamma radiation, you should not fear what might be getting into your lungs by inhalation nor should you fear excessively what is getting into your stomach by ingestion. Paradoxically, if a person has received 600 roentgens of gamma, his chances of survival are so slim that he need not worry about the ingestion or inhalation hazard. This is a general rule which apparently seems to hold despite the fact that we realize the theoretical objections of introducing such fission products into the body. In later sections you will see that animals were flown through atomic clouds and allowed to ingest the fission products directly and yet the inhalation and ingestion dose was found to be insignificant (Reference 2). We have exposed other animals in other Test Operations. Notably, during JANGLE Test Operation (14) animals were exposed to the fallout and they too showed no internal radiation despite the fact that they were exposed to lethal doses of gamma rays. All this is meant to put before the reader the available data from past Test Operations, and to stress that, as a rule, protection against radiation hazard is primarily against the external gamma ray dose. If we believe this, then it simplifies our problem, and it also simplifies the problem of defense during atomic warfare. The succeeding sections will show that in an atomic war if multi-megaton bombs are exploded on the surface, then large areas of the country will be exposed to lethal concentrations of radioactivity. Even if people take adequate countermeasures against this radioactivity, they must come back and live in areas which have relatively high concentrations of fission products. This means that the background dose will be increased a hundred fold, or possibly a thousand fold, and yet we will be forced to live under such circumstances. Certainly, the Federal Civil Defense and the Atomic Energy Commission will have to devise new standards of tolerance to meet such a horrible emergency during total atomic warfare. However, this is a problem for agencies outside of the Defense Department and beyond the scope of this report. It is merely mentioned here to indicate that during warfare, the military and civilian tolerances may not be so far apart after all.

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IV. Dosage to Aircrews Penetrating Young Atomic Clouds

a. During UPSHOT-KNOTHOLE Atomic Test Operation, a project was established to measure the dosage within the young atomic cloud by means of cannisters and droned aircraft (2). The results showed that dosage accumulated was less than 50 roentgens for the flight of an aircraft through a four minute old cloud from a bomb of 26 KT when the speed of the aircraft was 400 knots. Dose rates within the cloud ranged from 38,000 r/hr to 7500 r/hr when times of entry varied from 2.7 to 5.2 minutes. The average dose rate in a cloud was represented by:

$$D = 1.31 \times 10^{5} t^{-2.06} \quad \text{- - - - - - - - - - - - - - Equation 1}$$

In this equation time, t, is given in minutes after bomb detonation, and average dosage, D, in roentgens per hour. Reference 2 indicates that this Equation applies for the time period of 2.5 to 25 minutes after bomb detonation. To prepare this equation, Reference 2 used not only the UPSHOT-KNOTHOLE, but also the GREENHOUSE data available at the time. Recently, Plank and Steele (3) have shown that for CASTLE data, the following relation applies:

$$D = k\,t^{-4} \quad \text{- - - - - - - - - - - - - - - - - - Equation 2}$$

Equation 2 is said to be valid for times from two hours to six hours after bomb detonation. Using Equation 2, Captain Steele of SWC has shown that in order to get 170 roentgens accumulated dosage, the cloud should not be penetrated earlier than thirty minutes after bomb burst, if the cloud diameter or the stem diameter is ten miles in length. Similarly, the times are 35 and 45 minutes for fifteen and fifty mile cloud diameters. In this analysis it was assumed that the activity within the cloud was uniform throughout. It will be shown in subsequent sections that for a surface burst megaton yield weapon, the stem may have 10 to 20 times the activity per unit volume when compared to the specific activity of the mushroom.

b. It is our opinion that there is a good physical explanation why there is a break in the curve of dosage rate with time within the cloud, as shown in Equations 1 and 2 above. The explanation of this phenomena is to be found in the fact that for surface or tower shots considerable amount of sand and soil debris is sucked up into the cloud and it is eventually coated with fission products which later fall out due to their own gravity. Colonel Pinson (2), during Operation UPSHOT-KNOTHOLE, measured the dose rate within the cloud which was burst high enough to be considered a pure air burst. Under these circumstances, there were no active soil particles to be found

14

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in the mushroom of the cloud. Therefore, it is our opinion that if Colonel Pinson had used only the UPSHOT-KNOTHOLE data, he may have found that dose rate is only a linear function of time rather than a second power of the time. The GREENHOUSE data, which he also used, was based primarily on tower shots. Considering the relatively low height of the towers with the yields involved in GREENHOUSE Test Operation, it becomes obvious that a considerable amount of the total activity of the bomb was scavenged out by the soil particles which were first mixed with the fireball and then subsequently fell out. It is our opinion that it was this phenomena which changed the dose rate relation from a linear function of time to a function of the second power of time. It is significant that during CASTLE Test Operation (which had nothing but surface shots) the time relation to dosage is a power of four, as shown in Equation 2. I believe this is because during surface shots, approximately 80% of the total residual activity of the bomb is coated on large soil particles which subsequently fall out of the bomb. Therefore, if one were to measure the change of dosage with time within the stem of such a cloud, he would find that the dosage decreased very strongly with time. This is because of the linear expansion of the cloud and also because of the normal decay of fission products; but more importantly, this is because the majority of the residual radioactivity of the bomb is falling out of the stem and is being deposited on the ground. Upon some reflection of these sequence of events, it becomes obvious that the dose rate varies with time in a very complicated fashion. As a matter of fact, the exponent of time, t, must itself be a variable with time. In view of these complicating factors, and because it is practically impossible to give any quantitative answers to the change in the size of the cloud with time due to eddy diffusion and due to wind shears, it is our opinion that another approach should be made to this problem.

c. It may be possible to approximate the integrated dosage that may be received by the pilot without recourse to a dose rate equation. In order to develop this thesis, it will be assumed that the volume of an atomic cloud is proportional to the yield. Once this assumption is made, it becomes obvious that the dose rate within such a uniform atomic cloud is independent of yield. It is believed that such an assumption is a valid one so long as the cloud remains within the troposphere and the bomb is burst high above the target, i.e., a true airburst. This means that we are talking about weapon yields ranging from small bombs to bomb yields of several hundred kilotons. However, when we go into the megaton yield range, the body of the cloud rises significantly into the stratosphere. When this happens we are not certain whether volume of cloud remains exactly proportional to the yield. Because of the more nearly isothermal distribution in the stratosphere, the cloud rise in the vertical direction is severely damped as compared to the rate of rise in the troposphere. From this we can conclude that a cloud which rises significantly into the stratosphere must be somewhat flattened and quite elongated in the

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horizontal direction and shortened in the vertical direction. References 4 and 5 make it possible for us to compare the depth of the mushroom of the atomic cloud for different yield atomic weapons. Specifically, we have chosen for study the cloud from UPSHOT-KNOTHOLE, shot 9 which was one of the clouds successfully penetrated by Colonel Pinson's unit (Reference 2). This cloud will then be compared to the cloud dimension of the first shot of CASTLE Test Operation. In Table I, we have listed the actual cloud dimensions as compared to the extrapolated data.

Table I

Extrapolated and Measured Cloud Dimensions Using UPSHOT-KNOTHOLE and CASTLE Test Operations Data

Yield in KT	Time after Bomb Detonation (Minutes)	Cloud Dimensions		
		Volume of Mushroom in cubic ft.	Maximum Mushroom Diameter in ft.	Depth of Mushroom in ft.
26 KT	4	7.3×10^{11}	12800	8500
14500 KT	4	8×10^{14}	155000	58000
*14500 KT	4	4×10^{14}	105000	70000

* Extropolated data assuming volume is proportional to yield.

It should be remembered that the extrapolation is made on the assumption that volume of cloud is proportional to the yield of the bomb. A study of Table I indicates the extrapolation overestimates the depth of the mushroom and underestimates the maximum diameter of the mushroom, but we were able to anticipate this earlier by stating that clouds rising into the stratosphere would have a tendency to flatten out and to spread in a lateral direction in order to preserve cloud volume. It should be noted that the extrapolated cloud volume is one half of the actual cloud volume for the first shot of CASTLE Test Operation. We are not certain at this time whether this discrepancy in volume is a real one or whether it is an artifact introduced by the errors we have made in estimating the actual volume. It must be remembered that at the present time we only have rate of rise and maximum cloud diameter and cloud height information in Reference 5. It is significant to note that EG&G has not yet made any official estimates of the volume of the clouds from CASTLE Test

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Operation. It is not clear to me whether the data gathered during Project 9.1 of CASTLE Test Operation is sufficiently extensive to indicate cloud volume accurately. We must await the decision of EG&G in this matter. It may be that the cloud volume for the CASTLE BRAVO shot appears larger because of the excessive moisture present in the atmosphere in the Pacific test site as compared to the very low amount of moisture present normally in the desert at Nevada Proving Grounds.

d. Armed with the above information, it is now possible for us to make a first approximation of the integrated dosage received by the pilot and the aircrew when an airplane goes through a relatively young atomic cloud. Our reasoning is as follows: If the cloud volume is proportional to yield then the diameter of the cloud must be proportional to the cube root of the yield. If this is true, then the time spent within the radioactive cloud by an airplane is proportional to the cube root of the yield also. This relation is indicated below:

$$D_2 = D_1 \left(\frac{W_2}{W_1}\right)^{1/3} \text{ - - - - - - - - - - - - - - Equation 5}$$

where D = dose accumulated within the cloud

W = bomb yield.

However, it should be noted that Equation 5 does not correct for the different lengths of time spent by the aircraft within the radioactive cloud. To correct for this effect Equation 6 below is given:

$$D_2 = D_1 \left(\frac{W_2}{W_1}\right)^{1/3} \left(\frac{t_{a_1}}{t_{a_2}}\right)^{1.2} \left(\frac{t_{a_1}^{-0.2} - t_{b_1}^{-0.2}}{t_{a_2}^{-0.2} - t_{b_2}^{-0.2}}\right) \text{ - - - Equation 6}$$

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where t_a = Time of start of aircraft penetration into cloud

t_b = Time of exit of aircraft from cloud

It should be noted that Equations 5 and 6 assume that the airplane penetrates the mushroom of the cloud at its maximum diameter. The cloud from a fifteen MT bomb would rise to 110,000 feet. The maximum diameter of the mushroom would be 70,000 to 80,000 feet above sea level and the diameter would be about 150,000 feet in length (5). Present day aircraft traveling at altitudes of 30,000 to 40,000 feet

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would penetrate only the stem of a fifteen MT surface burst cloud, and they would miss the cloud completely if the bomb was airburst so high that it did not have an active stem. (This would be the case if the bomb is exploded 5,000 feet above target.) In order to correct for stem penetration, the actual length of the flight path through the radioactive cloud must be known, a correction must be made for the fact that cloud volume does not extrapolate proportionally to yield; a correction must be made for fusion as compared to fission yield of the bomb; a correction must be made for the fact that the specific activity (activity per unit volume) in the stem is much greater than the activity within the mushroom for large yield surface burst weapons; and finally a correction must be made for the change in air density with altitude in the atmosphere. To account for these facts, Equation 7 below is given:

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$$D_2 = D_1\left(\frac{F_{t_1} F_2}{F_{t_2} F_1}\right)\left(\frac{V_2 \omega_1}{V_1 \omega_2}\right)\frac{y_1}{y_2}\left(\frac{t_{a_1}}{t_{a_2}}\right)^{1.2}\left(\frac{s_2}{s_1}\right)\left(\frac{d_1}{d_2}\right)\left(\frac{t_{a_1}^{-0.2} - t_{r_1}^{-0.2}}{t_{a_2}^{-0.2} - t_{r_2}^{-0.2}}\right) \quad \text{--- Equation 7}$$

where F = Fission yield

F_t = Total yield (fission plus fusion)

V = Cloud Volume

y = Length of flight path through atomic cloud

d = Density of atmosphere at flight altitude

$\frac{s_2}{s_1}$ = Ratio of activity per unit volume in stem and mushroom for bombs detonated at different scaled heights.

An analysis of the Jangle-Surface and CASTLE BRAVO shots shows that approximately 80% of the total residual activity of the bomb is within the stem of the cloud. In the case of CASTLE BRAVO shot the stem has only 1/5 to 1/10 the volume of the mushroom, hence, the specific activity within the stem at 35,000 feet would be approximately fifteen to twenty times the specific activity within the mushroom. The specific activities for other burst heights could be determined from information contained in Table II.

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TABLE II

Percentage Fallout as a Function
of Scaled Height, λ , where

$$\lambda = \frac{h}{500(w/20)^{1/3}}$$

h = burst height in feet above terrain

w = total bomb yield in Kilotons

λ	Percentage Fallout	Burst Height Above Terrain for 15 MT Bomb
1.0	0%	5000 feet
0.45	30%	2000 feet
0.2	50%	1000 feet
0.0	80%	0
- 0.1 *	95%	- 450 feet (underground)

* For a justification of Table II, see the Appendix and References 1 and 6.

It is our belief that relatively few airplanes would go through the center of the cloud during combat operations. Most aircraft would go right or left of center and practically all aircraft will go below the center of multi-megaton clouds. Let us assume that the wind at flight altitude (40,000 feet) is from the west and at 40 knots. If the same target is to be hit by several strike aircraft at intervals of fifteen minutes, the cloud center at the 40,000 ft. level will be ten nautical miles east of the target. If the delivery tactic employs maximum breakaway maneuver then the second strike aircraft cannot go through the center of the first cloud, provided the second aircraft at 40,000 feet has a tail wind, and provided the first aircraft did not make a gross error of missing his target by ten miles. Since the wind direction at flight altitude is known, it is recommended that all delivery aircraft approach the target from such a direction as to have tail winds at bombing altitude. This is because the winds may have strong directional shears at different altitudes, but usually at a given height the winds show considerable persistence both in direction and in speed. During bad weather, the winds at 40,000 feet would normally not be effected by frontal conditions because few storms

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reach such a height. It is presumed that the tropopause is significantly above (in tropics) or below (in the arctic) the 40,000 foot level. To take maximum advantage of persistent winds, it is best not to bomb at the altitude of the tropopause. In the winter at Russian latitudes, the tropopause may get down to 20,000 to 25,000 feet above mean sea level and in the summer it rises to 25,000 to 35,000 feet.

e. Table III lists dosages received when atomic clouds from different yield bombs are penetrated by manned aircraft. In Table III, we have also indicated the maximum dose that could be received by the aircrew assuming that the cloud grows in dimensions in all directions, even late, 30 to 60 minutes after bomb detonation. This gives the values under "t_b max" and "D max" columns of the Table. For example, if the 15MT cloud is penetrated 30 minutes after bomb detonation at a flight altitude of 30,000 feet above sea level, then the dose accumulated by the crew would be from 105 to 300 roentgens. If the cloud is penetrated 45 minutes after bomb detonation, then dose would be 40 to 200 roentgens, and finally, if the time is 60 minutes after bomb detonation, then the dose would be 15 to 80 roentgens. One significant fact is that if the flight altitude could be increased to 60,000 feet or 70,000 feet msl, then the dosage would be only 5 to 15 roentgens for a 30 minute penetration, provided the 15MT bomb is surface detonated. It is hoped that at some future date this hypothesis could be tested during an atomic operation. Table IV shows the effect of different heights of burst upon integrated dosage. It shows that as the burst height is increased to more nearly a true airburst, then penetrations at 60,000 to 70,000 feet would produce maximum dosages. Also, for airbrusts of 15MT weapons (burst height 5,000 ft. above target) flight altitudes of 20,000 to 40,000 feet would give minimum dosage to the aircrew, according to our calculations as listed in Table IV. It is mandatory that at the next atomic test operation in the Pacific (REDWING), the dosage accumulated by aircrews penetrating multi-megaton weapons be determined experimentally. The importance of this parameter to the SAC atomic delivery operations cannot be overestimated. It is recommended that an attempt be made to penetrate such clouds first by instrumented drones, and then by manned aircraft starting at H + 2 hours and reducing the time down to H + 1 hour or even to H + 30 minutes, if possible.

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TABLE III

Dosage Accumulated in Passing through a 15MT Cloud at Different Altitudes for Different Times of Cloud Penetration by an Aircraft whose True Air Speed is 400 Knots. ([redacted]

Flight Altitude Above msl Thousands of Feet	Time of Cloud Penetration in Minutes after Bomb Detonation	Length of Flight Path Through Cloud in Thousands of Feet	Specific Activity	Time Spent in Cloud (Minutes)	Gamma Dosage Accumulated in Cloud in Roentgens	Maximum Time Spent in Disorganized Cloud	Maximum Gamma Dosage that may be Accumulated While in Cloud
h	t_a	y	$\frac{s_2}{s_1}$	t_b	D min	t_b max	D max
20	30	68.7	17.3	1.72	75	5	220
20	45	68.7	17.3	1.72	30	10	150
20	60	68.7	17.3	1.72	10	15	60
30	30	68.7	17.3	1.72	105	5	300
30	45	68.7	17.3	1.72	40	10	200
30	60	68.7	17.3	1.72	15	15	80
40	30	68.7	17.3	1.72	160	5	450
40	45	68.7	17.3	1.72	60	10	300
40	60	68.7	17.3	1.72	25	15	120
50	30	68.7	10.	1.72	145	5	400
50	45	68.7	10.	1.72	55	10	270
50	60	68.7	10.	1.72	20	15	110
60	30	120.	0.10	3.	5	9	15
60	45	120.	0.10	3.	2	18	8
60	60	120.	0.10	3.	2	27	4
70	30	150.	0.05	3.75	9	10	25
70	45	150.	0.05	3.75	3.5	20	17
70	60	150.	0.05	3.75	1.5	30	7

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TABLE IV

Same parameters as Table III, altering only the burst height and keeping time of penetration constant at 30 minutes after bomb detonation. Z = Burst height above target in thousands of feet

Z	h	y	S_2/S_1	t_b min	D min	t_b max	D max
0	20	68.7	17.3	1.72	75	5	220
1	20	68.7	10.	1.72	42	5	130
2	20	68.7	5.	1.72	22	5	65
5	20	0	0	0	0	0	0
0	30	68.7	17.3	1.72	105	5	300
1	30	68.7	10	1.72	60	5	175
2	30	68.7	5	1.72	30	5	90
5	30	0	0	0	0	0	0
0	40	68.7	17.3	1.72	160	5	450
1	40	68.7	10	1.72	95	5	270
2	40	68.7	5	1.72	45	5	130
5	40	0	0	0	0	0	0
0	50	68.7	17.3	1.72	145	5	400
1	50	68.7	10	1.72	87	5	240
2	50	68.7	5	1.72	4.5	5	120
5	50	0	0	0	0	0	0
0	60	120.	0.1	3	5	9	15
1	60	120.	0.5	3	25	9	75
2	60	120.	0.8	3	40	9	120
5	60	150.	1.0	3	50	10	170
0	70	150.	0.05	3.75	5	10	25
1	70	150.	0.05	3.75	50	10	250
2	70	150	0.80	3.75	80	10	400
5	70	150	1.00	3.75	100	10	500

* In the development of Equations 6 and 7, References 10 and 11 were consulted. However, our equations are limited only to values of ratios of total dosages accumulated in clouds, which simplifies the problem for us.

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22

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V. Contact Beta Hazard to Hands of Maintenance Personnel Handling Contaminated Engine Parts

a. During Operation GREENHOUSE (7) the beta-gamma ratio of fission products was found to be 157. According to Brennan (8) the contact beta-gamma ratio could be theoretically as high as 200. This applies to the case of fission products uniformly distributed over an infinite plane. Obviously, if the beta-gamma ratio is measured over a small object which has a relatively small surface area then the ratio would be increased considerably. It should be noted, however, that even though the beta-gamma ratio is thus increased, the beta contact hazard is decreased. Tersei (9) and the references in his report give a relation of the gamma dose rate reading at contact when fission products are spread over objects with different surface areas.

b. When an airplane goes through an atomic cloud, it becomes coated with fission products throughout the outer skin, and throughout the inside of the engines of the aircraft. As the airplane leaves the cloud, the air stream washes a considerable amount of contamination off the outer skin of the aircraft. However, those portions of the skin that are greasy or dirty will entrap larger amounts of fission products which may not be easily "airwashed" by the motion of the aircraft. In a similar fashion, fission products contaminate the oily and greasy engine parts which tend to retain these contaminants quite efficiently. Upon landing, if the aircraft is monitored by a gamma indicating device such as the T-1B (now called PDR39) then the gamma ray reading will be somewhat less than that from an infinite plane contamination, especially if the aircraft is small. However, most aircraft present quite a large surface area to the T-1B. It will be assumed that this surface area is approximately 100 square feet. If the T-1B is held three feet away from the surface, then the ratio of gamma reading on the surface of the aircraft, as compared to the instrument reading, would be three. If this reading is one roentgen per hour, then the beta contact dose could be theoretically as high as 600 beta rep per hour. However, there is no reason on earth why the T-1B could not be held one and a half feet from the aircraft's surface. If this is done, then the contact gamma reading would be only 1.3 times the instrument reading. This means the maximum contact beta rep reading would be 260. If the T-1B is held so that the center of the instrument chamber is nine to ten inches above the airplane's surface, then the gamma contact reading would be the same as the T-1B reading, hence, the maximum beta rep contact reading would be 200, if the T-1B indicates a dose rate of one roentgen per hour of gamma.

c. Actually, the human skin has a cutaneous layer of at least 0.1 millimeters (8) which absorbs a certain amount of the soft betas from fission products. Also, the oil and grease absorb a lot of the betas so that it is anticipated that this would reduce the beta-gamma

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ratio well below 200 on a large aircraft engine part. Brennan (8) found a maximum beta-gamma ratio of approximately 5 when he measured this ratio only four inches from the ground. It is our opinion that the beta-gamma ratio, when experimentally determined, during Operation TEAPOT in the Spring of 1955 (Project 2.8) would probably be less than 50 for operational aircraft. This is the beta-gamma ratio from an infinite plane where the surface under consideration is the greasy portions of the aircraft. For small engine parts of such aircraft the ratio would be increased in accordance with the relations given by Reference 9. Hence, if a small object is taken out of an aircraft engine part, the beta-gamma ratio would be as indicated in Table V. From an inspection of Table V, we see that if the contact dose is to be measured on a very small object, then a probe type radiac instrument would be best. It may even be better to develop an accurate beta-meter of the probe type. However, operationally it would be impractical to measure the beta contact dose on each and every small engine part in the field. First of all, to perform such a delicate operation, the suspected parts must be handled. If the small engine part is "dangerous" to handle, then in order to measure the beta contact hazard accurately, we expose the hands of our personnel to this danger <u>before</u> we find out whether it is dangerous. We may get around this by using tongs or remote handling equipment, but we can't imagine the employment of such a procedure operationally.

d. It is recommended that either the T-1B gamma indicating instrument or the PDR27 (gamma plus "beta") indicating instrument of the presently authorized Radiac Kit be employed to determine the beta contact hazard on the most contaminated engine parts of the aircraft as follows:

(1) As the airplane lands, monitor it with the T-1B instrument. If it is suspected that the airplane may have penetrated a young atomic cloud approximately sixteen hours ago, then if the T-1B reading is greater than one roentgen per hour, either the aircraft should be allowed to stand twenty-four hours and then handled with gloves or it should be decontaminated first before handling. If none of the above procedures are operationally practical in a given situation, maintenance crews should be asked to wear gloves and to wipe the grease off their hands repeatedly with rags and wash as soon as practical after finishing the maintenance work. The reasoning behind the above procedure is as follows: A study of Reference 23 shows that the highest internal concentration on engine parts is approximately ten to twenty times the outside contamination when the aircraft has penetrated a young atomic cloud. It is assumed that the beta-gamma ratio is approximately fifty for objects with large surface areas. If the T-1B is held one foot away from the

24

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TABLE V

Estimate of the Contact Beta Rep Dose Rate on Contaminated Objects of Various Cross-Sectional Areas when the Gamma Dose Rate Reading is 1r/hr at Various Distances from the Contaminated Object.

h	A	$\frac{ro}{rh}$	Max B rep	Mean B rep
3 feet	Infinitely lge	0.4	80	20
3 feet	100 sq ft	2.5	500	125
3 feet	10	15	3000	750
3 feet	1	100	20000	5000
3 feet	0.5	200	40000	10000
1 foot	(∞)	0.3	60	15
1 foot	100	1	200	50
1 foot	10	3	600	150
1 foot	1	15	3000	750
1 foot	0.5	27	5400	1350
1/2 ft	(∞)	0.2	40	10
1/2 ft	100	0.8	160	40
1/2 ft	10	1.5	300	75
1/2 ft	1	5	1000	250
1/2 ft	3.5	8	1600	400
1/6 ft	(∞)	0.05	10	2.5
1/6 ft	100	0.4	80	20
1/6 ft	10	0.8	160	40
1/6 ft	1	1.5	300	75
1/6 ft	0.5	2	400	100
*1/6 ft	(∞)	0.01	2	0.5
1/6 ft	100	0.1	20	5
1/6 ft	10	0.2	40	10
1/6 ft	1	0.3	60	15
1/6 ft	0.5	0.4	80	20

* refers to PDR27 Instrument with Beta Shield open. All other readings are for T-1B Instrument.

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TABLE IV Continued

Explanation of Symbols in Table V:

h = distance between contaminated object and Radiac Instrument.

A = Surface Area of Contaminated Object in square feet.

$\frac{r_0}{r_h}$ = Ratio of contact gamma reading to reading at vertical distance h above the object

Max B rep = The maximum contact Beta rep upon the object, assuming no shielding and no self absorption (i.e. assuming the Beta-gamma ratio has a value of 200 for a contaminated infinite plane).

Mean B rep = The contact Beta rep upon the contaminated object, assuming that shielding and self absorption reduce the theoretical Beta-gamma ratio by a factor of 4. (It is hoped that after TEAPOT, the experimental Beta-Gamma ratio on a contaminated aircraft engine will be obtained. It is our opinion that when this is done, it will be found that shielding and self absorption reduce the theoretical beta gamma ratio by a factor of 5 to 10. This means that here we are being conservative in assuming the above reduction to be only a factor of 4.)

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leading edges of the aircraft then the gamma reading on the T-1B would be the same as the contact gamma reading. Therefore, the maximum beta dose rep on the most contaminated engine part would be approximately 500 to 1000 times the indicated T-1B reading, provided the airplane lands on friendly territory at H + 16 hours. This means that for a T-1B reading of 1r/hr the most contaminated engine part would show a contact reading of 500 to 1000 beta rep per hour. If the airplane is allowed to stand twenty-four hours after it lands on friendly territory, the beta rep dose rate would be reduced from 1000 to 310 or from 599 to 120. If the mechanics' hands remain in contact with the engine parts for a period of one hour (after which he washes his hands) then the total contact beta dose to the hands would not be greater than that given by the following relation:

$$D_{t_1}^{t_2} = R\int_{t_1}^{t_2} t^{-1.2}\,dt \qquad \text{— Equation 10}$$

$$= 5R\left(t_1^{-0.2} - t_2^{-0.2}\right)$$

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When the proper values are substituted in Equation 10, we see that the beta rep dose is 440. This means that beta rep dose will be less than 440. At this time, we don't know how much less. We hope that after Operation TEAPOT we will have some quantitative data on this subject. It is assumed that 600 to 1000 beta rep is the skin erythema dose. Thus we see that even for the most contaminated engine part, the beta rep dose is less than the erythema dose. There is some evidence that the beta decay for fusion weapons follows a t^{-2} relation instead of the $t^{-1.2}$ decay used in Equation 10. If at future test operations this is found to be true, then the beta rep dose to the hands would be reduced significantly below the value of 440 reps given in the above example. As a matter of fact, calculation shows that if beta particles decay as t^{-2}, then in one hour the beta dose rep would be less than 10 reps. If there are contaminated engine parts laying around that are suspected of being contaminated, then the PDR27 should be used with the beta shield open, and the probe should be held as close to the contaminated object as possible. Under such circumstances, an inspection of Table V shows that the indicated PDR27 reading would be only 4/10 of the contact gamma reading, even though the surface area presented by the contaminated engine part is only half a square foot.

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VI. Military Counter-measures Against the Radioactive Hazards

Despite the fact that large areas in our country will be highly contaminated because of the radioactive fallout from atomic bombs, it is our opinion that adequate military counter-measures against this radiation hazard could be obtained by relatively simple methods. In general terms, the following sequence of events for proper counter-measures against the radioactive hazard are suggested:

a. Early Warning

It is possible to obtain some early warning of the probable area of fallout from the existing upper air winds. This would indicate whether or not the Air Base is in the downwind direction from a likely target area on a given day. This could easily be done by simply plotting the upper air winds in a radex or fallout plot form somewhat as indicated in Figures 1A, 1B, 2, 3, 4, 7 and 8. In Figure 1A, the winds are victorially plotted head to tail on, and the winds are weighted to show the relative amounts of time that each particle spends within a given layer in the atmosphere. The method of fallout plotting is given in much more detail in references 19 and 20 and in Section A of the Appendix. It is recommended that the radex plots be used as follows: Draw a circle with a radius of 300 miles around the Air Base, then plot the winds in all quadrants from any likely target area, and determine whether any or all of these radex plots show the Air Base to be in a downwind path. See Figure 11. If your Air Base is in the downwind path, then at least some warning could be had that there is a possibility of being subjected to radioactive fallout. This in itself should be of some help to the Commander. If it is desired to determine the exact fallout isodose lines before fallout begins, it would be necessary to know the exact location of the targets, the exact yields of the bombs and a very exact indication of the height of burst of the bomb above the target. It is obvious that such a large amount of information will probably not be available during combat operations. Even if all this information about the target, the yield, the height of burst, etc., is accurately known, there would be still quite a bit of uncertainty as to the exact area of fallout because of the inherent instability of the atmosphere. It should be remembered that a plot of the fallout area based on upper air winds is subject to many errors because of the many simplifying assumptions made. These assumptions are that the Stoke's Law of fallout is valid and that the winds remain constant in direction and speed throughout the fallout period which may last from half an hour to fifteen hours after bomb detonation. It also assumes that the wind direction and speed are the same throughout the downwind fallout area. An analysis of former Atomic Test Operations shows that for tower and surface shots the radex plot varies + 15 to 20 degrees from the position computed by the upper air winds at H-3 hours. For further discussion of this aspece refer to the Appendix.

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It is recommended that with the winds available at any Weather Station it is possible only to indicate the correct quadrant of fallout. It may even be possible to indicate within which half of a quadrant the fallout will occur. This means that we must use the fallout plot merely as an indication of the general area of the anticipated fallout. In view of this limitation, it is considered unwise to attempt to plot accurately the actual isodose lines of the contamination pattern within a given radex plot. Upon post analysis, when the winds aloft information is available throughout the fallout area, then it may be possible to accurately delineate the fallout area. It should be noted, however, that time and space variation of the winds must be taken into account and a time composite radex plot must be prepared which is very time consuming (see Appendix). Such accurate wind data is not available until after the event has occurred. Once the Commander is alerted to the possibility of fallout, he should have the radiation instruments available at various places within the Air Base to see whether the radioactive hazard acutally develops. As indicated above, it may easily pass north or south of the Air Base and miss the Air Base by as much as fifteen to twenty degrees. Once the fallout begins, it is immediately obvious whether the contamination will be excessive or not because the maximum dose rate is reached relatively fast after the start of fallout (See Figure 10). See Sections d and f below, Table VII, and Section d of Appendix for greater details in this matter.

b. Dispersal

By dispersal we mean the immediate evacuation of personnel and airplanes from the Air Base. This cannot be started after the fallout has begun. It is our opinion that preparations for immediate departure or dispersal of aircraft from a given Air Base must be started previous to the start of the radioactive fallout. This could easily be accomplished by the early warning net mentioned above. If the Air Base is under threat of radioactive fallout, then those aircraft and personnel that are to be immediately evacuated must be ready to go within a matter of minutes after the radiac instruments show the start of significant amounts of fallout. I would want to caution you at this point that if the dose rate is simply increased to a value of five to ten times background, or even 10,000 times background, there is no need for dispersal or evacuation to shelters. As a matter of fact, very large areas would normally receive such small amounts of radioactivity. For details on what intensities should be considered significant to cause dispersal or evacuation, one should refer to Table VII. As a rule, if radioactive fallout begins at approximately three to five hours after shot time and if the dose rate does not rise above 1r/hr, then it is not recommended that there be any dispersal or evacuation because the integrated dose to personnel at the Air Base probably would not exceed ten to thirty roentgens at the most. If the dose rate reaches a value greater than 100 r/hr (when fallout begins at

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29

H + 4 hours) then it is recommended that personnel be evacuated to shelters. If the fallout begins ten to fifteen hours after shot time, then personnel should not be evacuated unless the dose rate reaches a value significantly above 50 roentgens per hour. For further details consult Table VII. It may be necessary to evacuate to shelters those personnel that are not required for the immediate mission of the Air Base, even if the dose rate is significantly below those mentioned above, in order to keep to a minimum the total dosage received by all personnel within the Air Base. However, this again is a Command decision.

c. Shelters

Shelters against the radioactive hazard need not be expensive constructions nor do they have to be complicated or fancy. The shelter must provide three to five feet of dirt between the person and the source of radioactivity. This could be achieved by basements, sub-basements, fox-holes, and the like, which put a certain amount of dirt between the military person and the surface of the ground. It is recommended that people be shielded as much as possible in all directions including the vertical. There need not be air-conditioning, there need not be filters, nor air-tight seals to doors and windows of the shelters. There need not be cooking, messing or sanitary facilities within such shelters. There need not be storage of food in such shelters. In other words, it is our opinion that the shelters should be merely cells with a certain amount of dirt all around them to protect a person for a period of from six to twelve hours after fallout has begun. Six hours after fallout has begun a person may go upstairs and bring some food down. He may go upstairs for sanitary purposes for a short period of time without receiving excessive dosages provided he has waited approximately six hours after the start of fallout. Under no circumstances should such personnel be allowed to go out-of-doors during the active fallout period when the dose rate has the large values mentioned in Section b above. It is believed that active fallout may last from 5 to 12 hours.

d. Decontamination

Aircraft and airbase decontamination should be conducted after the acute dangers of the immediate fallout problem have been overcome. It is anticipated that this would occur twelve hours after fallout began under most circumstances. Mr. Louis Nees and Mr. Wang of AMC have recommended that perhaps decontamination of Air Bases could begin even before the fallout has started. This could be done by the use of sprinkling systems which may be put on Air Bases and which could be operated either automatically or manually. There is also the possibility of covering runways with canvas shields, etc. which would then be removed after fallout has been completed. Decontamination could also be effected by vacuuming of roofs. runways and other relatively smooth surfaces. It may also be possible to wash certain areas and to turn the ground over

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wherever this is possible, and to use many other common sense means of decontamination. It should be kept in mind that decontamination is nothing more or less than a good washing process. The dirt happens to be radioactive, but the only precaution we have to take because it is radioactive is to see to it that the decontaminating team does not receive excessive doses of radioactivity and we must also make an attempt to see that the drainage does not get into the water supply of the Air Base or the towns nearby. Aircraft decontamination could be effected by sweeping, vacuuming, washing, and other common sense methods. Normally, unless an aircraft flies through a young atomic cloud, there would be no contamination of any consequence within the engine parts and the cabins of the aircraft. If the aircraft catches the fallout while it is on an Air Base, then if the pilot can get to the aircraft and take off without receiving an excessive dose, the normal air washing due to flight would clean the aircraft automatically of large intensities of contamination. Under such circumstances, aircraft decontamination would not be necessary. However, if aircraft do fly through young atomic clouds, then they must either be decontaminated or allowed to stand for a period of time before they can be handled for normal maintenance purposes.

e. Evacuation

After personnel come out of their shelters and do whatever decontamination is necessary in order to go on with their normal military duties, it may be desirable to evacuate a certain portion of the airbase personnel to contamination free areas. It should be kept in mind, however, that the war situation may be such that there would not be any clear areas within reasonable reach of the Air Base. Figure 11 shows what would happen to this county when 100 to 110 atomic bombs of 15 MT are surface-detonated on the population centers and on the airbases of this country. It is very clear after looking at Figure 11 that there is no place to hide in this country, especially in the Eastern half of the United States. Under such an eventuality, it would be undesirable for the Commander of an Air Base to attempt evacuation or dispersal out of the Air Base. As a matter of fact, you can see that there is a distinct possibility of jumping from the frying pan into the fire, if dispersal is attempted without an accurate knowledge of the situation throughout the country.

f. Times of Entry into Contaminated Areas

Table VII indicates the dose accumulated in fallout areas assuming that the $t^{-1.2}$ decay law applies. It also shows the dosage accumulated taking into account the fact that personnel are subjected to radiation not only from the ground, but from an infinite volume of contaminated air during active fallout. See the appendix for greater details on the extra accumulation of dosage when people are caught

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TABLE VII

Accumulation of Dosage in Fallout Areas using the $t^{-1.2}$ decay tables, and a comparison of this to the total dosage accumulated when the "Volume-Effect" of Fallout is taken into account (See Section d of appendix for definition of Volume Fallout).

t_f	"Volume - Effect" of Fallout								$t^{-1.2}$ Decay							
	R_{max}	D_3	D_6	D_{12}	D_{24}	D_{36}	D_{48}	D^{∞}	R'_{max}	D'_3	D'_6	D'_{12}	D'_{24}	D'_{36}	D'_{48}	D'^{∞}
0.5	1380	485	500	490	535	570	573	720	230	172	234	265	305	331	343	575
1	600	275	330	360	410	440	450	625	100	97	150	195	235	256	270	500
2	258	96	190	242	298	330	340	545	43	34	86	131	170	192	205	435
3	142	0	115	185	236	270	285	500	27	0	52	100	135	158	171	400
4	114	0	62	137	197	230	247	475	19	0	28	74	113	135	148	380
5	84	0	29	107	178	205	220	452	14	0	13	58	102	120	132	362
6	72	0	0	81	147	185	200	437	12	0	0	44	84	107	120	350
7	60	0	0	63	129	162	179	425	10	0	0	34	74	95	107	340
8	50	0	0	46	105	147	167	412	8.4	0	0	25	60	86	100	330
9	43	0	0	31	100	135	154	400	7.2	0	0	17	57	79	92	322
10	38	0	0	19	87.5	123	142	395	6.3	0	0	10.5	50	72	85	315
11	34	0	0	7.5	77	112	132	385	5.7	0	0	4	44	66	79	309
12	30	0	0	0	68	102	122	380	5.1	0	0	0	39	60	73	304
13	27	0	0	0	60	94	113	375	4.6	0	0	0	34	55	69	300
14	25	0	0	0	52	89	108	370	4.2	0	0	0	30	52	65	295
15	24	0	0	0	47	80	100	363	3.9	0	0	0	27	47	60	291
24	13.2	0	0	0	0	38	59	330	2.2	0	0	0	0	22	35	265
36	8.2	0	0	0	0	0	22	305	1.4	0	0	0	0	0	13	244
48	5.7	0	0	0	0	0	0	290	1.0	0	0	0	0	0	0	230

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TABLE VII Continued [redacted]

Symbols of the Table have the following meaning:

t_f = Time of Start of Fallout in hours after bomb detonation. It may also be used as time of entry of personnel into fallout area.

R'_{max} = Maximum Dose Rate within fallout area assuming $t^{-1.2}$ decay (in roentgens per hour)

R_{max} = Maximum Dose Rate within fallout area taking into account "Volume - Effect" of fallout. Normally the maximum dose rate occurs 10 to 30 minutes after start of fallout in the downwind direction (r/hr)

Similarly, all primed symbols refer to $t^{-1.2}$ decay case, and all unprimed symbols refer to those values that are corrected for the "Volume- Effect" of fallout.

D_3 = Integrated Dose (in roentgens) accumulated within 3 hours after Bomb Detonation.

D_{12}, etc. refer to 12, 24, 36, and 48 hour integrated doses (roentgens).

D^{∞} = Integrated infinity dose. All values in the table are only within slide rule accuracy and even such values have been rounded out.

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in an area that is being subjected to active fallout. It is believed that people who are subjected to such "volume" fallout will receive less shielding from buildings above the ground, provided the shelters do not have three to five feet of dirt all around the person. Table VII has many uses. For example, it is possible to assume that t_f not only stands for time of start of fallout after bomb detonation, but also for time of entry of personnel into a contaminated area. Some illustrative examples will be given below for the proper use of Table VII:

(1) <u>Example 1</u>

Assume fallout starts at 3.75 hours after bomb detonation, and at H + 4 hours the maximum reading is 114 r/hr. Then by an inspection of the table we find that if personnel remain in the area two more hours, the accumulated dose would be 62 roentgens

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(at H + 6 hours); similarly the dosage would be 137 roentgens at H + 12; 197r at H + 24; 230r at H + 36; 247r at H + 48; and 475r at infinite time after bomb detonation. It should be noted that had we used the $t^{-1.2}$ decay tables, the integrated doses would have been 28r at H + 6; 74r at H + 12; 133r at H + 24; 135 at H + 36; 148 at H + 48 and 380r at infinite time.

It is also possible to determine in this same example what would happen if personnel were either evacuated for 6 hours or sent to adequate shelters (shelters with 3 to 5 feet of dirt all around for a period of six hours). Under such circumstances, the assumption is made that fallout starts at approximately H + 4 hours and personnel enter the area at H + 10 hours. An inspection of the table (reading the t_f = 10 hours row) shows that if people enter the area at H + 10 hours, then by H + 12 they would have accumulated 19 roentgens; by H + 24 they would have received 87.5r, and similarly by H + 36, 123r; by H + 48, 142r, and the life time dose (infinity dose) would have been approximately 395 roentgens.

(2) <u>Example 2</u>

Suppose at H + 4 hours the dose rate was not 114r/hr as in the table, but it was larger, say, it was 287r/hr, then the H + 6 hour dose would be found from the table as follows:

$$\frac{287}{114} \text{ x (H + 6 hour dose in the Table)}$$

which is

$$\frac{287}{114} \text{ x } (62r) = (2.51) \text{ x } (62r) = 155r.$$

(3) <u>Example 3</u>

If fallout started at H + 1.8 hours and personnel who remained in the contaminated area received 300 roentgens in four hours after the start of fallout, then if they remain in the area they would receive the following dosages for the times indicated:

(a) At <u>H + 6 hours</u> dose received is 300 roentgens.

(b) <u>At H + 12 hours</u>, dose received is:

$$\frac{300}{190} \text{ x } (242) = 382 \text{ roentgens}$$

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(c) At H + 24 hours,

$$\frac{300}{190} \times (298) = 470 \text{ roentgens}$$

It should be remembered that Table VII does not take into account any shielding due to roughness of terrain features or due to personnel being indoors, nor does it take into account the recovery of the body when the dose rate is relatively low.

g. Effects of Shielding and Dose Rate on Biological Damage

References 15 and 16 discuss the amount of reduction to be expected in the dose rate when the terrain is rough or rolling or has vegetation on it. These references also discuss the ability of the body to repair damaged tissue when the dose rate is quite low. In our report, it will be assumed that rolling countryside with vegetation reduces the dose rate by a small factor. It will also be assumed that for all practical purposes, dosage after 48 hours from time of bomb detonation can be neglected when we are computing the acute total body gamma dosage during combat conditions. For people indoors in the average air installations building at an airbase, the infinite plane dosage is probably reduced by 50% (due to terrain shielding and to shielding offered by the building). This means that for personnel indoors the dosage values of Table VII could be cut in half, and during combat, the integrated dosage beyond 48 hours can be neglected. Thus, the dose values of the examples cited above would have to be reduced by a factor of two, and dosages accumulated after 48 hours may be neglected.

h. Determining Fallout Areas after the Event

It is recommended that permanent installations of gamma indicating radiac instruments be made in several locations within an Air Base. These gamma indicating devices should preferably be self-recording in order to indicate time history of the fallout. If such instruments are available throughout all Air Bases in the country, then it would be possible to draw a contamination pattern throughout this nation immediately after this information is fed into a central headquarters. It is suggested that it would save lives of many Radiological Safety Monitors if permanent installation of gamma indicating devices are made on several buildings within an Air Base, thus preventing the necessity of surveying the Air Base during excessive fallout or when the intensity of radiation is high.

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VII. Offensive Uses of Radioactivity

a. Denial of an Area to the Enemy

During combat, it may be possible to deny a relatively large area to the enemy by exploding atomic bombs on the surface or underground. It is believed that if a 15 megaton bomb is contact burst or is buried 500 feet underground, then upon detonation of such a weapon an area of from 5000 to 10,000 square miles will be covered with such an amount of radioactivity as to make it impassable to the enemy for a period of from twelve to forty-eight hours. Of course, if such a weapon is to be employed by us, we must have quite accurate wind information at all levels of the atmosphere up to approximately 50,000 feet above sea level. We cannot determine the exact area of fallout, but we believe that we can determine the correct quadrant of fallout and even have a pretty good idea in which half of a given quadrant the fallout will occur. The shape of the area would normally be elliptical where the major axis would be from two to four times greater than the minor axis, depending upon the speed of the upper air winds. If there are no directional shears to the winds with altitude, then the fallout area will in fact be quite elliptical. However, if there are pronounced shears with height, then the area will deviate from an ellipse and will take a torturous path somewhat as indicated in the radex plots given in the appendix.

b. Relaxation of Missile CEP

In view of the fact that the lethal concentration of the radioactivity will cover approximately 30 to 50 times the blast or thermal damage area, it may be possible to relax the CEP of intercontinental missiles. As a matter of fact, it would be possible to wage atomic warfare using ballistic missiles which are intended merely to hit certain areas of the enemy country. In the case of Russia, it may be practical to develop missiles with an accuracy of plus or minus ten miles or even plus or minus fifty or 100 miles. This means that we have to forego the thermal and blast damage that we get from a bomb and use only the radiation damage parameter. If this is acceptable, then it may be possible to relax the stringent guidance problems that we have placed upon our "guided" missiles of the future. See Figure 11 for an illustration of the excessive contamination produced where 100 to 110 large bombs (15MT) are contact burst on this country.

c. Limitations to the Offensive uses of Radioactivity.

It should be noted that radiation damage from present atomic or thermonuclear weapons is a transitory one. At best, it will cover the enemy territory with lethal concentrations of radioactivity for a short period of time, but we know that the enemy can develop simple counter-measures against this hazard and survive such an

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attack. We have then merely succeeded in pinning the enemy's head down for a period of from twelve to forty-eight hours. He can come up after this time and fight back. However, it might be that under certain circumstances merely pinning down the enemy temporarily would produce a decisive effect. There are some other specialized uses of radioactivity. For example, if we do not want to destroy a city, and if we want to capture it intact, it may be possible to attack it with radiation only by exploding the bomb say 15 to 30 miles upwind of the city, thus covering the town with lethal doses of radioactivity. If the winds aloft on target are not known, several bombs must be detonated in the periphery of the target to be sure to catch one city in the downwind path. Under such circumstances, it may be possible for us to take the town without destroying it. If we are to use our atomic weapons for this type of radiological warfare it may be worthwhile to think of increasing the number of bombs in the stockpile because we would need more bombs, not less, to do the job. I say this despite the fact that the radiation damage area is fifty times more than the blast damage area. This is because the residual radioactivity decays rather rapidly with time. In 24 hours, the H + 1 hour activity is reduced by 45 and in approximately 13 days, the activity is reduced by 1000. This means that if bombs are to be used for radiological warfare, the attack must be repeated every 24 or 48 hours. Of course, the initial attack could be so timed that if there is a large probability that several contamination patterns will be superimposed upon a given airbase, then these contaminating events will not occur simultaneously. Reference is made to Figure 11. If the attacks in the California area or the New England area could be so timed that a given airbase or stockpile site receives contaminating fallout every three to six hours, then this would prolong the radiological hazard to a given area. On the other hand, if all bombs were dropped over the country at approximately the same time, a large portion of the gamma radiation would die down in one or two days. It would be best to attack the enemy nation with sufficient bombs to prevent retaliation in the first attack. In such an attack, every attempt should be made to destroy the enemy retaliatory power throughout the nation by hitting the targets, as much as possible, simultaneously. After this primary objective is achieved, however, subsequent raids could be so timed as to increase the radiation hazard to areas suspected of having a potential ability to counterattack. If the Russian stockpile sites are invulnerable to the thermal and blast damage produced by our multimegaton bombs, then it may be necessary to keep the stockpile sites and all approaches to it covered with such high doses of radioactivity as to make entry and exit into the area virtually impossible. Radiological contamination may also be used to advantage in areas where the exact location of the target is not known. Since one bomb of 15 Megaton yield produces excessive contamination, which covers 10,000 to 20,000 square miles, several such bombs should cover most of the area of a given state or region. On the other hand, the blast damage is permanent. It destroys buildings, it kills aircraft by shearing the wings off, it kills people by knocking them dead from flying debris, and otherwise it is a damage that cannot be repaired readily. In the case of radiation, if personnel are exposed to it in large doses, then it can kill just as surely as blast. However, if people take shelter where they have three to five feet of dirt between them and the radiation, they can remain underground safely for a period of from twelve to forty-eight hours and then come on out and fight. After forty-eight hours, most of the radiation intensity has been reduced to such a point where they will not get a lethal amount of radiation within short periods of time. So they can actually launch their missiles, warm up their aircraft and take off and resume the fighting. We must realize the limitations of radiological warfare. They are quite apparent. However, if the enemy is not forewarned and if the enemy is not ready with adequate shelters, then we can really produce excessive casualties in the enemy country by simply exploding our bombs on the ground. By this method, we lose practically none of the thermal and blast damage and in addition to this, we get the radioactive damage as a bonus. It seems that as we contemplate upon the offensive uses of radioactivity, the lesson we learn is that we must be ready to defend ourselves against the radioactive hazard. If we are ready with proper countermeasures, then we can blunt quite severely the horrible consequences of such a hazard. In other words, I believe that we, as a nation, can by realistically simple means protect ourselves against the radioactive hazards. No one can say that we can do this against the thermal and blast criteria of the bomb. Paradoxically, at this time, we have de-emphasized radiological safety within the Air Force. It is recommended that large numbers of enlisted and officer personnel of the Air Force be trained in Radiological Safety Operations. At the present time, this training has been stopped. It is recommended that a Radiological Safety AFSC be created within the Air Force. At the present time, this AFSC has been discontinued.

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APPENDIX

CONSTRUCTION OF FALLOUT PLOTS

A. Method of Plotting Fallout

The fallout plot or radex plot in its simplest form consists of plotting winds from the surface up to the height reached by the atomic cloud. The method of plotting is merely the vector addition of winds. The winds are weighted to account for the amount of time they spend through each layer of the atmosphere. It is assumed that the soil particles have a density of 2.5 gm/cm^3 and that rate of fall follows Stokes' Law:

$$V = \frac{2 g r^2 (\rho_2 - \rho_1)}{\eta} \qquad \text{---Equation 11}$$

where

V = rate of fall

r = radius of spherical particles

η = coefficient of viscosity of air

g = acceleration of gravity

ρ_2 = density of particles

ρ_1 = density of air

Although viscosity of air varies with temperature, for sake of simplicity, viscosity is usually assumed to be constant. Actually, an accurate use of viscosity in the Stokes' Equation is not justified, because the fallout particles are not all spherical, nor are they all of equal density. Errors introduced by these assumptions far outweigh a more rigid analysis of the change of viscosity of air with temperature. Also, the variation of winds aloft with time and space make it difficult if not impossible to determine with great enough accuracy the fallout area to justify the use of a more accurate rate of fall formula. Reference 16 uses different rates of fall formulas for different size particles. Although this may be justified for particles significantly larger than 100 microns and also for particles less than 10 microns, an inspection of Table XVIA shows that more than 50% of the total activity of a surface burst bomb is scavenged out by

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particles whose diameters are from 20 to 100 microns. In view of this, we neglect corrections to the simple Stokes' Law. The Air Weather Service Manual on Fallout and Radex plots (19) and Colonel George Taylor's method of Radex Plotting during Operation GREENHOUSE (20) describe the method quite adequately. For the following winds aloft information the simple radex plot is given in Figure 1A.

Altitude in Thousands of feet Above Mean Sea Level	Wind Direction	Wind Speed In Knots
0	90	5
5	120	8
10	150	10
15	160	15
20	180	20
25	230	25
30	270	30
35	270	40
40	290	45
45	330	50
50	70	25
55	80	20

A spherical particle of 70 micron diameter and a density of 3 gm/cm^3 will fall approximately at the rate of 6,000 ft/hr or at a rate of 1 knot. Hence, the trajectory plotted in Figure 1A shows the locus at sea level of 70 micron particles falling from different heights. In Figure 1A, the heights from which the particles have arrived is listed in thousands of feet. For example, the arrow line between points B and C of the figure represent fallout of 70 micron particles arriving from an altitude of 37,500 to 42,500 ft. above sea level. Since Stokes' Law indicates that the fall velocity of particles is proportional to the square of the particle radius, it is at once evident that 100 micron particles would fall at approximately double the speed of 70 micron particles and similarly 140 micron particles would fall four times as fast as 70 micron particles while 50 micron particles fall at approximately one half the speed of 70 micron particles. This means that from a given height, the smaller particles would fall further away from ground zero than the larger particles. For example, in Figure 1A, it is assumed that ground zero is at 0 and a 70 micron particle originating at 42,500 ft. will arrive at point C, hence 100 micron particles would fall at point D and 140 micron particles at E. By utilizing this method, it is possible to determine quite simply the complete fallout plot of any sized particle as indicated in Figure 1B. By the use of Stokes Law (Equation 11) it would be simple to find the times of fallout. For example, the fallout time at points C, D and E would be approximately 7, 3.5 and 1.75 hours respectively. For greater details consult subsequent sections of the appendix or references 19 and 20.

B. Detailed Study of Fallout from First Shot of CASTLE Test Operation

1. Existing Wind Distribution

In order to construct correct fallout plots, adequate winds aloft information is required before, during and after shot time. Unfortunately, during the first shot of CASTLE Test Operation (this was called BRAVO shot) there were no winds available from the shot island. The Navy (SS Curtiss) made some winds aloft measurements at a point south of ground zero. However, at Eniwetok, Kwajalein and Rongerik (See Figure 1, Reference Map, for locations of these islands) routine winds aloft information were taken.

2. Variation of Winds Aloft with Time and Space and its Effects on Radex Plotting

A study of such wind data indicates that although there was a time variation of the winds aloft soon after zero time, there was no significant space variation of the winds at a given latitude. This means that the Eniwetok, Curtiss and Rongerik winds all varied to approximately the same degree with time. In view of this, it was thought worthwhile to use average values of Eniwetok, Rongerik and Curtiss winds for H-hour and Eniwetok and Rongerik wind averages for times after H-hour. Because the correct winds aloft is the key to the proper analysis of CASTLE - BRAVO shot, this wind data is given in Tables VIII, IX, X and XI where the average H-hour, H + 2:15 hours; H + 8:15 and H + 14:15 hour winds are listed.

TABLE VIII

H-Hour Winds, Using the Average Values of Eniwetok, Rongerik and Curtiss Winds

Altitude in Thousands of Feet	Wind Direction In Degrees	Wind Speed In Knots
Surface	65	15
1	75	18
2	80	17.5
3	85	16
4	90	16
5	90	12
6	90	4
7	280	5
8	300	5
9	320	8
10	310	10
12	290	9
14	290	12
16	290	14
18	290	18
20	280	20
25	250	25
30	250	33
35	240	40
40	240	40
45	250	40
50	250	30
55	260	12
60	330	15
65	320	3
70	80	27
75	80	13
80	30	30
85	70	47
90	70	37
95	--	--
100	--	--

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TABLE IX

H + 2:15 Hour Winds using the Average Values of Eniwetok and Rongerik Winds

Altitude	Direction	Speed
Surface	70	17
1	80	18
2	70	18
3	80	17
4	80	15
5	80	13
6	60	5
7	300	5
8	270	7
9	320	9
10	310	10
12	270	11
14	290	8
16	300	15
18	300	13
20	300	17
25	300	25
30	255	33
35	240	42
40	255	38
45	250	37
50	260	30
55	300	13
60	Calm	Calm
65	Calm	Calm
70	80	13
75	80	18
80	80	36
85	80	13
90	—	—
95	—	—
100	—	—

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TABLE X

H + 8:15 Hour Winds using the Average Values of Eniwetok and Rongerik Winds

Altitude	Direction	Speed
Surface	70	15
1	80	15
2	90	14
3	90	14
4	100	12
5	100	7
6	180	5
7	180	6
8	320	5
9	280	7
10	290	13
12	300	13
14	290	10
16	310	10
18	290	15
20	290	20
25	260	25
30	260	30
35	260	39
40	250	40
45	260	40
50	270	15
55	260	7
60	Calm	Calm
65	Calm	Calm
70	—	—
75	—	—
80	—	—
85	—	—
90	—	—
95	—	—
100	—	—

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TABLE XI

H + 14:15 Hour Winds Using the Average Values of Eniwetok and Rongerik Winds

Altitude	Direction	Speed
Surface	80	13
1	90	13
2	100	15
3	100	12
4	100	10
5	90	10
6	100	6
7	Calm	Calm
8	50	5
9	280	8
10	280	10
12	300	10
14	330	8
16	320	10
18	320	12
20	300	23
25	270	25
30	260	30
35	250	30
40	240	40
25	260	35
50	280	27
55	280	7
60	90	6
65	270	3
70	Calm	Calm
75	90	20
80	90	32
85	90	42
90	90	46
95	90	46
100	90	54

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This wind information is also plotted in Figure 2 using simple radex plots or simple fallout plots of the winds for 50 micron diameter particles. An inspection of Figure 2 shows that the H-hour average wind plot goes approximately 20 miles NW and N of Rongelap and approximately 40 miles North of Rongerik. The H + 2:15 hour wind, however, shifts 35 to 40 miles south in the area of Ailinginae - Rongelap - Rongerik. The first temptation is to assume that if we use the H + 2:15 hour average winds in place of the H-Hour winds, we get a correct fallout picture, but this is not true since such a fallout plot does not properly account for the actual contamination that is shown in Figures 5 and 6. A detailed examination of Figures 2, 5, and 6 shows that the H + 2:15 hour fallout plot does not correctly take into account the distribution of contamination on Bikini, since according to Figure 2, the islands in the south sector of Bikini Atoll should all have about equal contamination, but Figure 6 shows that this is not true. Similarly, the contamination patterns at Ailinginae, Rongelap, Rongerik and Bikar cannot be justified by the wind pattern of H + 2:15 hours. Figures 5 and 6 were taken from Reference 12. It should be noted that the H + 8:15 and H + 14:15 hour average wind plots (See Figure 2) return to the north of the islands, and appear to parallel the H-hour wind plot more closely than the H + 2:15 hour plots. Figure 2 shows that the winds aloft simple radex plot ascillates considerably in eight hours. In view of such a rapidly changing meteorological situation it is not possible to prepare an adequate fallout plot utilizing one set of average winds for ground zero and assuming that this applies throughout the downwind area during the active fallout period. As indicated in Figure 2, there is a significant change in the winds aloft picture within two hours after shot time. Because of this it is mandatory to utilize a "Time Composite Radex Plot", which takes into account the change in wind direction and speed in the downwind direction. The composite analysis starts at the desired altitude and works the trajectory of a given particle to the ground. This merely identifies the given particle size reaching the surface from a given altitude. When such points are repeated for many particle sizes and from all elevations of the atomic cloud, we obtain the composite Radex Plots shown in Figure 3. Needless to say, such a procedure is time consuming and demands accurate and complete winds aloft information throughout the fallout area. Such information is not available before the fact for operational planning. Certainly, we can't expect forecast winds to be so accurate (± 5° and ± 2 Knots) within all altitudes. Hence, it is our opinion that although it may be worthwhile to use Composite Radex Plots for post analysis of a contaminating event, there is no operational need to perform such detailed analysis before the fact. What is required operationally is an indication of the correct quadrant of fallout, and a guess as to which half of the quadrant may receive the highest contamination. Figure 3 shows the composite fallout plot for 50, 70, 100 and 140 micron particles. It should be noted that this composite plot more nearly agrees with the actual

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contamination pattern shown in Figures 5 and 6. For sake of simplicity, the 50 micron composite fallout of Figure 3 is plotted separately in Figure 4. A comparison of Figure 4 with Figure 6 shows considerable agreement between the plotted and actual contamination as far as it is possible to do so with a one particle size analysis. In subsequent paragraphs, after we have taken into account the change of particle size with height within the atomic cloud, it will be shown that the Composite Radex Plot also accounts for the contamination pattern in the islands of Bikini Atoll.

3. Assumed Activity and Particle Size Distribution Within the Atomic Cloud at Time of Stabilization

A study of the downwind fallout from the tower shots at the Nevada Proving Grounds (T/S and U/K Test Operations) shows that as the weapon yield is increased from 12KT to 50KT, the mass median particle diameter of the active soil particles within the cloud aerosol appears to decrease from 90 microns to approximately 70 microns. This means that as the yield is increased (or the scaled height is decreased) the gross particle size of the cloud aerosol appears to decrease. However, it should be noted that the experimental evidence in this regard is very meager, hence we can't say with any degree of certainty that as the yield increases the atomic particle size decreases. An inspection of the actual contamination patterns when compared with winds aloft radex plots shows that the soil particles in the lower half of the atomic cloud stem appear to be significantly larger than the particles in the upper half of the stem, and the particles within the mushroom of the cloud are much smaller than the stem particles. In this analysis, we are referring to soil particles mixed into the fireball and sucked up into the cloud. These particles are assumed to be coated with fission products more or less uniformly. An analysis of Jangle-Surface fallout (See supplement to Reference 1) shows that the average particle size distribution within the bottom half of the cloud stem was approximately 140 microns. Because of the inverse "filtering" action of the air, it is assumed that the particle size within the cloud decreases with height. It is anticipated that if a certain amount of soil is tossed into the air, there would be a greater number of small particles at higher elevations as compared to the particle size in lower levels. In this study, it will be assumed that the particle size distribution within a 15 MT atomic cloud at time of stabilization is as indicated in Table XII.

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TABLE XII

Altitude Above Mean Sea Level in Thousands of Feet	Average particle Diameter in Microns	Number Distribution of Particle Sizes in Microns in Each Layer of a 15MT Atomic Cloud at Time of Stabilization (4 minutes)			
		10%	40%	40%	10%
h	(d mean)	d_{min}	d_1	d_2	d_{max}
0	140	110	130	150	170
5	130	100	120	140	160
10	120	90	110	130	150
15	110	80	100	120	140
20	100	70	90	110	130
25	90	60	80	100	120
30	80	50	70	90	110
35	70	40	60	80	100
40	60	40	50	70	90
45	50	35	45	65	85
50	50	30	40	60	80
55	50	30	40	60	80
60	45	25	35	55	75
65	45	25	35	55	75
70	40	20	30	50	70
75	30	15	20	40	60
80	20	10	15	35	50
85	10	5	7.5	25	35
90	10	5	5	20	30
95	10	5	5	10	15
100	10	5	5	10	15
110	10	5	5	10	15
120	10	5	5	10	15

The percentage activity in each layer of a 15 MT atomic cloud at time of stabilization (4 minutes after bomb detonation) may be expressed by the following relation:

$$PA = k\, d^{x}\, t^{-1.2} \quad \text{- - - - - - - - - - - - - - -Equation 12}$$

Where
PA = Residual radioactivity on a particle (Percentage)

d = diameter of particle

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t = time after bomb detonation

x = a variable which is a function of particle size. It has a maximum variation of 1 to 3. Assumed values of x are given in Table XIII.

The assumed average particle size and the percentage activity within each 5000 ft. layer of a 15 MT cloud is given in Table XIII. In this table we have shown only that radioactivity which is impregnated on relatively large particle sizes and which can readily fall-out due to the gravity of the particles. It does not take into account the small size particles (10μ or less) nor does it include the fall-out in and around the immediate area of ground zero.

TABLE XIII

Altitude Above Mean Sea Level in Thousands of Ft. h	Average Particle Diameter in Micron d mean	Value of x See Equation Number 12.	Percentage Activity Within a 15 MT Cloud Impregnated on Those Particles that are Large Enough to Fall readily out of the Cloud	
			PA	Cumulative PA
0	140	—	—	—
5	130	1.2	4	4
10	120	1.3	9	13
15	110	1.4	4.5	17.5
20	100	1.6	5.5	23
25	90	1.7	8	31
30	80	1.8	12	43
35	70	2.0	20	63
40	60	2.2	15	78
45	50	2.3	7	85
50	50	2.3	6	91
55	50	2.3	3	94
60	45	2.4	2	96
65	45	2.4	2	98
70	40	2.5	1	99
75	30	3	0.5	99.5
80	20	3	—	—
85	10	3	—	—
90	10	—	—	—

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Table XIV gives the total (scavengable and non scavengable) distribution of activity in a 15 MT cloud at time of stabilization:

TABLE XIV

Altitude above msl in Thousands of feet	Percentage Activity Held on Large Particles that readily fall-out		Percentage Activity on Particles too small to fall-out		Cumulative Total Percentage Activity
h	d_{mean}	PA	d_{mean}	PA	
0	140	—	—		—
5	130	3.3	—		3.3
10	120	7.5	—		10.8
15	110	3.8	—		14.6
20	100	4.7	—		19.3
25	90	6.8	—		26.1
30	80	10	—		36.1
35	70	17	—		53.1
40	60	12.8	—		65.9
45	50	6	—		71.9
50	50	5.1	—		77
55	50	2.5	—		79.5
60	45	1.7	—	1	81.2
65	45	1.7	<10	2	84.9
70	40	0.8	<10	2	87.7
75	30	0.4	<10	2	89.7
80	20	—	<10	2	91.7
90	10	—	<10	2	93.7
95	10	—	<10	2	95.7
100	10	—	<10	2	97.7
110	10	—	<10	2	99.7

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Using Equation 12, it is possible to find the assumed percentage activity of the minimum and maximum particle sizes arriving on the ground from a given altitude. When this is done we would have some value of the width of the fall-out area. This has been done and the values tabulated in Table XV:

TABLE XV

Assumed Percentage Activity in 15 MT Atomic Cloud at Time of Stabilization (4 minutes after bomb detonation)

	Minimum		Mean		Maximum		Non Scavengable Activity	Total Percentage Activity	
									Cumulative
h	d_{min}	PA	d_{mean}	PA	d_{max}	PA	PA	PA	PA
0	—	—	140	—	—	—	—	—	—
5	100	0.3	130	2.7	160	0.3	—	3.3	3.3
10	90	0.7	120	6.3	150	0.5	—	7.5	10.8
15	80	0.3	110	3.3	140	0.2	—	3.8	14.6
20	70	0.3	100	4.2	130	0.1	—	4.6	19.2
25	60	0.8	90	5.7	120	0.3	—	6.8	26.0
30	50	1.3	80	7.7	110	1.0	—	10.0	36.0
35	40	2.1	70	12.7	100	2.2	—	17.0	53.0
40	40	0.9	60	10.3	90	1.5	—	12.7	65.7
45	35	0.4	50	5.0	85	0.6	—	6.0	71.7
50	30	0.4	50	4.3	80	0.4	—	5.1	76.8
55	30	0.09	50	2.3	80	0.09	—	2.5	79.3
60	25	0.04	45	1.6	75	0.07	—	1.7	81.0
65	20	0.04	45	1.6	75	0.06	1	2.7	83.7
70	15	0.00	40	0.78	70	0.02	2	2.8	86.5
75	10	—	30	0.39	60	0.01	2	2.4	88.9
80	5	—	20	0	50	0	2	2.0	90.9
85	5	—	10	—	35	—	2	2.0	92.9
90	5	—	10	—	30	—	2	2.0	94.9
95	5	—	10	—	15	—	2	2.0	96.9
100	5	—	10	—	10	—	2	2.0	98.9
110	5	—	10	—	10	—	1	1.0	99.9

Although Table XV shows the assumed activity within the cloud (scavengable and non-scavengable), it does not show the large amount of activity that falls in and around ground zero within one-half to one hour after bomb detonation. This immediate fall-out is very large in particle size (100 to 10,000 microns and larger) and it is very massive in amount. It is doubtful whether Stokes Law of fall-out applies in this region. This appears to be large chuncks of debris returning to and near ground zero more as a massive fall-out resembling the downpour of record breaking rainfall. This large particulate soil debris may shoot up to 50,000 to 70,000 ft msl for 15 MT surface burst bombs, but it falls

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down quite rapidly. The upper portions of this massive column fall out of the mushroom and upper stem within 10 to 30 minutes. At lower elevations this massive fall-out may continue for 30 to 60 minutes after detonation. To represent the assumed distribution within an atomic cloud of this massive fall-out together with the rest of the particulates, we have prepared Table XVI.

TABLE XVI

Total Percentage Activity Within a 15 MT Atomic Cloud at Time of Stabilization, taking into Account Massive Fall-out in and near Ground Zero, Scavengable Activity Falling out in the Downwind Path and Non-Scavengable Activity in very small Particle Sizes (Less Than 10 micron)

h	Massive FO Activity in and Near Ground Zero		Large Particle FO		Average Particle Scavengable Activity		Non-Scavengable Activity	Cumulative Activity
	$d_{massive}$	PA	d_{mean}	PA	d_{mean}	PA	PA	
0	1000	2	—	—	—	—	—	2
5	500	1	300	1	130	1.3	—	5.3
10	300	1	200	2	120	2.5		10.8
15	200		175	2	110	1.8		14.6
20	175		140	3	100	1.6		19.2
25	150		120	1	90	5.8		26.0
30	150		110	1	80	9.0		36.0
35	—		—		70	17.0		53.0
40	—		—		60	12.7		65.7
45	—		—		50	6.0		71.7
50	—		—		50	5.1		76.8
55	—		—		50	2.5		79.3
60	—		—		45	1.7		81.0
65	—		—		45	1.7	1	83.7
70	—		—		40	0.8	2	86.5
75	—		—		30	0.4	2	88.9
80	—		—		20	0	2	90.0
85	—		—		10	0	2	92.9
90	—		—		10	0	2	94.9
95	—		—		10	0	2	96.9
100	—		—		10	0	2	98.9
110	—		—		10	0	1	99.9

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By the use of information contained in Table XV and Figure 3, and by the use of Equation 12, it was possible to prepare a first estimate of the area covered by the downwind fallout. This downwind area is shown in Figure 7. It should be noted that fallout originating above 52,500 feet has been omitted for the sake of simplicity in the plotting since above this level the winds begin to turn back towards Bikini. Also, because of the extreme heights and because it is assumed that 80% of the activity is held below 55,000 feet, it is our contention that no fallout of military significance reaches the immediate downwind area from above 55,000 feet.

4. Measured Activity and Particle Size Distribution Within the Atomic Cloud.

A planimeter was used to measure the three areas shown in Figure 7. Then these areas, together with the percentage figures from Tables XV and XVI were used to obtain the dose rate (R/hr) and the accumulated dose values ($D^{48}_{t_f}$ and $D^{\infty}_{t_f}$) listed in Table XVII. An examination of Table XVII shows that the assumed contamination on the islands of Bikini Atoll are all large by a factor of 2 or 5, when compared with the actual values shown in Figures 5 and 6. This indicates that either the contaminated areas in the vicinity of Bikini shown in Figure 7 are too small or the assumed percentage activity in the lower half of the cloud stem (from surfact to 20,000 feet) is too high. We have decided to reduce the total percentage activity in the lower cloud stem (from sea level to 20,000 ft. above sea level) from 19.2% to 10%. This revises Table XVI. The revised table XVI is shown as Table XVI.A. Figure 8 shows the final fallout from first shot of CASTLE Test Operation. The isodose lines are in dosages accumulated in 48 hours using $t^{-1.2}$ extrapolation.

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TABLE XVII

Calculated Dosages in the Downwind Area Using the Fallout Plot Shown in Figure 7 and Utilizing Information in Tablex XV and XVI.

	A_1 = Central Area (Contaminated to the Greatest Degree										
h	A_n	t_1	t_2	t_3	$D_{t_1}^{4/8}$	$D_{t_2}^{4/9}$	$D_{t_3}^{4/8}$	$D_{t_1}^{\infty}$	$D_{t_2}^{\infty}$	$D_{t_3}^{\infty}$	R_1
0 - 17.5	24	--	0.75	--	--	50,000	--	--	100,000	--	18,000
20	60	--	1	--	--	4,300	--	--	8,000	--	1,600
25	240	--	2	--	--	2,050	--	--	4,350	--	1,000
30	270	--	3.3	--	--	3,250	--	--	7,850	--	2,000
35	760	--	5	--	--	1,775	--	--	5,000	--	1,350
40	1,930	--	7.5	--	--	410	--	--	1,350	--	400
45	430	--	12	--	--	625	--	--	2,520	--	835
50	670	--	135	--	--	31	--	--	134	--	46
				A_2 = Medium Contaminated Area							
0 - 17.5	50	0.42	--	0.16	51,500	--	6,900	83,500	--	100,000	14,000
20	70	1.6	--	0.5	2,500	--	3,800	5,000	--	6,300	1,100
25	132	3.2	--	1.2	3,500	--	5,300	8,350	--	10,000	2,100
30	625	7	--	2.2	670	--	1,240	2,100	--	2,670	625
35	1,790	10	--	3.5	520	--	725	1,440	--	1,780	455
40	4,200	12	--	5.5	100	--	177	440	--	575	145
45	380	14	--	6.5	210	--	370	1,000	--	1,122	327
50	4,300		--	9.2	25	--	45	138	--	160	50
					A_3 = Least Conaminated Area						
0 - 17.5	60	1	--	0.4	15,700	--	29,250	21,750	--	35,000	5,800
20	96	3.2	--	0.8	670	--	1,600	1,170	--	2,100	4,300
25	240	5.2	--	1.3	750	--	2,075	1,415	--	2,750	570
30	1,680	9.2	--	1.9	110	--	370	215	--	500	116
35	7,000	15.6	--	2.5	35	--	165	105	--	238	57
40	15,800	17.8	--	3.5	10	--	54	31	--	75	19
45	18,000	25	--	4.2	2.6	--	21	13	--	31	8
50	23,200	36	--	5.2	0.7	--	12	7	--	17	5

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TABLE XVII Continued

Explanation of Symbols.

h = Altitude above sea level in thousands of feet

A_n = Net area within a given isodose line

t_1 = Time of start of fallout for the small particles in hours after bomb detonation

t_2 = Time of fallout for average particles

t_3 = Time of fallout for large particles

D_t = Accumulated dose in roentgens from start of fallout to 48 hours after bomb detonation.

D_t = Infinity or life time dose

R_1 = Dose rate in roentgens per hour extrapolated to one hour after bomb detonation using the $t^{-1.2}$ relation.

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TABLE XVI A

h	Massive Particle	Percentage Activity in Massive F.O. in and near G.F.	Large Particle	Percentage Activity in Large Particle Fallout	Average Particle	Average Scavengable Activity	Non-Scavengable Activity	Cumulative Activity
h	d Massive	P.A. Massive	d large	P.A. large	d mean	P.A. Average Scavengable	P.A. Non-Scavengable	P.A. Cumulative
0	1,000	1	--	--	--	--	--	1
5	500	0.5	300	1	130	1.3	--	3.8
10	300	0.5	200	1	120	2.5	--	7.8
15	200	0.2	175	1	110	1.8	--	10.8
20	175	0.2	140	0.5	100	1.6	--	13.1
25	150	0.1	120	0.5	90	5.8	--	19.5
30			110	0.2	80	9.0	--	28.7
35					70	17.0	--	45.7
40					60	12.7	--	58.4
45					50	6.0	--	64.4
50					50	5.1	--	69.5
55					50	3.5	1	74.0
60					45	2.5	2	78.5
65					45	2.5	3	84.0
70					40	1	3	88
75					30	1	3	92
80					20	1	2	95
85					10	0	1	96
90					10	0	1	97
95					10	0	1	98
100					10	0	1	99
110					10	0	1	100

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C. Scaling of Radioactive Fallout to Different Yield Bombs Detonated at Various Heights Above the Target

From a study of the residual radioactive fallout of tower shots at Nevada (1) it appears reasonable to assume that the percentage activity within a given isodose line remains constant when the bomb yield and the wind speed are varied, provided the scaled height is kept constant. This assumption is contrary to the scaling proposed by Schorr and Gilfillan (21) who seem to think that as the horizontal mean wind speed increases, the percentage fallout within a given isodose contour also increases. R. K. Laurino, etal (22) have shown from a study of HE test data that the area within a given isomass fallout area remains essentially constant despite different wind speeds. This agrees quite well with our analysis of near surface nuclear detonations (1) as mentioned above.

1. In the scaling process one of the most important parameters is the time of start of fallout of residual radioactivity in the different portions of the contaminated area. Unfortunately, very little actual information is available on this parameter. Times of fallout may be obtained from radex plots quite accurately provided there is a significant directional shear to the winds with altitude. For example, in Figure 1A there would be no doubt that the fallout at line FC came from the 22,500 to 27,500 ft. elevation. By superimposing a radex plot on the actual Jangle-Surface fallout (See Supplement to Reference 1) we were able to obtain some rough approximation of the particle size distribution within the Jangle-Surface cloud. Unfortunately, there were no large directional shears to the winds aloft during the surface shot of Jangle Test Operation, hence considerable doubt is cast on the calculated times of fallout shown in Table XX. This is especially true for the longer times of fallout.

2. In our scaling process, we do not use a "mean-wind". Unfortunately, many other organizations use such "mean-winds". It is our opinion that the use of "mean-winds" introduces such large errors, that if this approximation is used, then there is no point in determining the fallout direction and intensity with any accuracy. By "mean-wind", we refer to the resultant wind. For example, in Figure 1A, the direction of the mean wind is represented by the line OA, and the speed of the mean wind is 9 knots. If one were to assume that the fallout occurred in the direction of OA, he would make a large error, because the actual fallout follows not the resultant vector 'OA, but the radex plot. Hence, we see that the direction and extent of the fallout varies in a complicated manner which may in no way resemble the "mean" resultant wind.

3. The following equations are used in the scaling process:

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$$P = \frac{\Sigma AR}{kwt^{-1.2}} \qquad \text{----- Equation 13}$$

$$l = \frac{\Sigma AR'}{kw} \qquad \text{----- Equation 13a}$$

$$P = \frac{\Sigma AD}{5kwt^{-0.2}} \qquad \text{----- Equation 13b}$$

$$P = \frac{\Sigma AD'}{5kw} \qquad \text{----- Equation 13c}$$

where

P = Percentage of total residual activity within a given isodose line.

A = Area covered by the isodose contour in square miles.

R = Dose rate in r/hr at time of fallout.
R'= " " " " " one hour after bomb detonation.
D = Infinity dose

D'= Dose from one hour to infinity.

l = Constant = 12 over an infinite smooth plane.

w = Bomb yield in Kilotons.

t = Time of start of fallout in hours after bomb detonation.

In our scaling process, as a first approximation, we assume that the percentage activity within a given isodose or isorate line remains constant for two different yield bombs exploded at the same scaled height. Therefore, we set $P_1 = P_2$ and we obtain the following relations:

$$\Sigma A_2 R_2 = \Sigma A_1 R_1 \left(\frac{\omega_2}{\omega_1}\right)\left(\frac{t_1}{t_2}\right)^{1.2} \qquad \text{----- Equation 14}$$

$$\Sigma A_2 R_2' = \Sigma A_1 R_1' \left(\frac{\omega_2}{\omega_1}\right) \qquad \text{----- Equation 14a}$$

$$\Sigma A_2 D_2 = \Sigma A_1 D_1 \left(\frac{\omega_2}{\omega_1}\right)\left(\frac{t_1}{t_2}\right)^{0.2} \qquad \text{----- Equation 14b}$$

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$$\Sigma A_2 D_2' = \Sigma A_1 D_1' \left(\frac{\omega_2}{\omega_1}\right)$$ ----- Equation 14c

For any element of area, the following relations apply for the conditions indicated:

$$A_2 = A_1 \left(\frac{\omega_2}{\omega_1}\right)\left(\frac{t_1}{t_2}\right)^{1.2} \text{ provided } R_1 = R_2$$ ----- Equation 15

$$A_2 = A_1 \left(\frac{\omega_2}{\omega_1}\right)\left(\frac{t_1}{t_2}\right)^{0.2} \text{ provided } D_1 = D_2$$ ----- Equation 15a

$$A_2 = A_1 \left(\frac{\omega_2}{\omega_1}\right) \quad \begin{matrix} \text{Provided } R_1' = R_2' \\ \text{and} \\ \text{Provided } D_1' = D_2' \end{matrix}$$ ----- Equation 15b

$$R_2 = R_1 \left(\frac{\omega_2}{\omega_1}\right)\left(\frac{t_1}{t_2}\right)^{1.2} \text{ Provided } A_2 = A_1$$ ---- Equation 15c

$$R_2' = R_1' \left(\frac{\omega_2}{\omega_1}\right) \text{ provided } A_2 = A_1$$ ---- Equation 15d

$$D_2 = D_1 \left(\frac{\omega_2}{\omega_1}\right)\left(\frac{t_1}{t_2}\right)^{0.2} \text{ Provided } A_2 = A_1$$ ---- Equation 15e

$$D_2' = D_1' \left(\frac{\omega_2}{\omega_1}\right) \text{ Provided } A_2 = A_1$$ ----- Equation 15f

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4. As indicated in paragraph C.1, above, one of the most important parameters in the scaling process is the time of start of fallout. As a first approximatation, it will be assumed that for a given scaled height, regardless of yield, the normalized times of fall from different cloud heights are constant. Under this assumption areas would scale as follows:

$$A_2 = A_1\left(\frac{W_2}{W_1}\right)\left(\frac{t_1}{t_2}\right)^{1.2} \text{ Provided } R_1 = R_2 \text{ ----- Equation 15}$$

But $t \sim W^{1/3}$, therefore

$$A_2 = A_1\left(\frac{W_2}{W_1}\right)\left(\frac{W_1}{W_2}\right)^{0.4} = A_1\left(\frac{W_2}{W_1}\right)^{0.60} \text{ ----- Equation 16}$$

It should be noted that References 22 and 15 assume $A_2 = A_1\left(\frac{W_2}{W_1}\right)^{0.667}$ The area scaling formula (Equation 16) is valid for a given scaled height, provided the yield is not varied by more than a factor of 2 or 3. This means that the 15MT Surface burst bomb of CASTLE Bravo Shot may be scaled in accordance with Equation 16 for Surface burst weapons of 5 MT to 45 MT without introducing large errors. However, for yields much greater or smaller than this, it is presumed that Equation 16 does not apply. To illustrate this point, Jangle-Surface (1.15 KT) fallout is extrapolated to the CASTLE BRAVO yield of [redacted] by the following equation:

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$$A_2 = A_1\left(\frac{W_2}{W_1}\right)^{0.933} \text{ Provided } D_2 = D_1 \text{ ----- Equation 16A}$$

Equation 16A was obtained from Equation 15a, and by assuming that $t \sim W^{1/4}$. The actual Jangle-Surface measured fallout data is given in Table XVIII. This is then extrapolated to the CASTLE BRAVO case by using Equation 16A. The results are tabulated in Table XIX, which compares such extrapolated data with the measured CASTLE BRAVO data obtained from Table XX. An inspection of Figure 13 and Table XIX shows that the extrapolation from J-S (1.15KT) to CASTLE BRAVO [redacted] using Equation 16A underestimates the contaminated area by a factor of [redacted] for the heavily contaminated areas, by a factor [redacted] for the medium contaminated areas, and by a factor of [redacted] for the light contamination areas.

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TABLE XVIII

JANGLE-SURFACE FALL OUT DATA

$D^{\infty}_{t_f}$	A_n	A_c	P_n	P_c	h	t_f	d mean
5850	0.05	0.05	2.41	2.41	2000	0.05	225
2880	0.10	0.15	2.25	4.66	2800	0.0835	180
1000	0.40	0.55	3.51	8.17	3800	0.133	160
345	0.75	1.2	2.41	10.58	3800	0.20	140
100	1.06	2.3	1.0	11.6	—	0.25	100
23	0.92	3.2	0.2	11.82	--	0.25	70
31.5	47	50	17	28.8	5450	0.6	70
10	58	108	10.3	39.1	6000	2	50
4.7	100	208	8.1	47.2	7500	3.9	40
2.7	160	368	7.7	55	7500	5.1	35
1	210	578	4.1	59	7500	7	30
0.35	83	661	0.7	59.7	7500	10	25
4.5	96	757	7.8	67.4	6000	6.25	27
1.2	243	1000	6.3	73.7	8000	8.8	25
0.4	192	1192	1.6	75.3	9000	13.5	22
0.12	600	1792	1.6	76.8	9000	17.5	19.3
0.09	300	2090	0.23	77.1	9500	21	18

TABLE XIX

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TABLE XI

Measured CASTLE BRAVO Fallout Data

$D_{t_f}^{\infty}$	$D_{t_f}^{47}$	$D_{t_f}^{48}$ Using Volume Effect	A_n	A_c	P_n	P_c	t_f
27,500	10,000	16,200	60	60	2.74	2.74	1
16,500	8,000	13,000	60	120	1.64	4.40	1
8,800	5,000	8,330	840	960	15.30	19.7	3
5,000	2,000	3,330	1,200	2,160	10	29.7	4
2,500	833	1,400	4,920	7,080	30	59.7	6
367	107	180	2,200	9,780	2.5	62.2	8
325	75	125	6,200	15,980	5.3	67.5	10
105	20	33	10,000	25,980	3	70.5	15

It is believed that this is because we have assumed that fallout time is proportional to the third power of the yield. This may be a valid assumption provided the yield range is not too large. We may be justified in extrapolating a 1KT to the case of a 100 KT, but certainly, we are not justified in going any further than this. Similarly, we may extrapolate a 15,000KT to 5,000KT and to 45,000Kt, but we certainly are not justified in stretching the 15MT model from 300,000KT to 1KT. The main error in the simple extrapolation factor is the assumption that time of fall is proportional to the third power of the yield. The filtering action of the air appears to be proportional to some factor of the particle radius. A study of the tower shots during past test operations seems to indicate that the distribution of particle size in a given cloud is more nearly proportional to absolute height above the target rather than being proportional to scaled height. The data in this regard is not sufficient for proper analysis. However, it is sufficient to indicate at least the order of magnitude effect. In other words, for a 100MT shot, areas would not scale in accordance with Equations 16 or 16A. It is anticipated that the highly contaminated areas may be considerably over that obtained by Equation 16. This is because, regardless of the maximum height reached by the atomic cloud, it is believed that the majority of the large (and therefore more active) particles will be confined to an altitude below 60,000 ft. msl due to the filtering action of the air. Since we only have two models of surface burst bombs, we will use them to extrapolate to other yield bombs as follows:

$$A_2 = K A_1 \left(\frac{W_2}{W_1}\right)^{0.6} \quad \text{- - - - - - -} \quad \text{Equation 17}$$

where

K is evaluated for different yield surface burst bombs in Table XXI.

Equation 17 is used in conjunction with Table XX to obtain the contaminated areas from different yield surface burst bombs. These values are listed in Table XXII. In Figures 9A, 9B and 9C are plotted the fallout from 15,000 KT, 60,000 Kt and 100 KT bombs surface burst on dry land. The yields are assumed to be fusion yields. The wind distribution and the average particle size distribution with height within the atomic cloud is given in Table XXIII. The values from Table XXIII were used to prepare the radex plot or the general direction of fallout. After this, the areas and dosages from Table XXII were used to determine the intensity of fallout shown in Figure 9. As we contemplate on the large areas of contamination shown in Figure 9, and in Table XXII, we wonder just how large is our country and also what is the area of the Soviet Union? By merely looking in any Atlas or Almanac, we note that the total area of the U.S. is 3,000,000 square miles and that of Russia is 8,708,000 square miles (or used to be). This means that 100 bombs of the 60MT variety would cover this country with lethal concentrations of radioactivity, and for Russia, the number of bombs required is 300. Obviously, unless we prepare adequate shelters now, more than half the people in this country would become radiation casualties if the Russians can surface detonate on us from 200 to 500 bombs of the 60 MT variety. Figures 9 and the values of Table XXII may be altered to take into account any variation in height of burst by utilizing the information contained in Table II. For example, if a 15 MT bomb is detonated at 1,000 feet above target (instead of on the surface) then the radiation dosage figures in Figure 9A would be reduced by one half. If the same bomb is detonated at 5,000 feet above target, then the fallout downwind would be practically zero. Certainly, there would be no fallout of any military importance. By using the equation and the percentage fallout given in Table II, similar calculations may be made for any yield bomb detonated at any height above target.

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TABLE XXI

Values of k listed for different yield surface burst weapons in various intensities of contamination

$D_{t_f}^{\infty}$ (Roentgens)	DELETED										
	1.75	10	100	500	1000	5000	15,000	45,000	60,000	100,000	225,000
5,000	0.12	0.2	0.34	0.47	0.55	0.8	1	1.3	1.38	1.52	1.82
1,000	0.27	0.355	0.5	0.62	0.69	0.85	1	1.18	1.20	1.30	1.47
500	0.36	0.46	0.58	0.69	0.75	0.88	1	1.13	1.14	1.21	1.32
100	0.43	0.52	0.63	0.73	0.78	0.9	1	1.10	1.12	1.18	1.285

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TABLE XXII

Contaminated Areas from different Yield Surface Burst
Bombs

DELETED

$D_{t_f}^{*}$ Roentgens	$D_{t_f}^{48}(t^{-1.2})$ ROENTGENS	$D_{t_f}^{48}(V-E)$ ROENTGENS	Areas in square miles for the following yield (KT) surface burst bombs										
			1.75	10	100	500	1,000	5,000	15,000	45,000	60,000	100,000	225,000
>10,000	8,000	13,000	0.018	0.22	3.18	25	44	288	1,000	3,620	5,030	8,900	22,600
5,000	2,000	3,330	0.042	0.47	6.9	53	95	620	2,160	7,820	11,000	19,200	48,800
1,000	400	670	0.42	4	47	258	560	3,060	10,000	33,000	43,600	76,000	183,000
500	150	250	0.84	7.5	81.4	430	900	4,750	15,000	47,200	62,200	106,000	246,000
100	20	33	1.75	14.5	147	750	1,560	8,100	25,000	76,500	100,000	173,000	400,000

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TABLE XXIII

Winds Aloft and Particle Size Distribution for the Idealized Fallout Plots Shown in Figures 9A, 9B and 9C
for map scale where 1 inch = 32 n - miles

h	d mean	Weighting Factor	Wind Direction In Degrees	Wind Speed In Knots
0	1,000	0.004	310	10
5	500	0.016	310	20
10	200	0.1	300	20
15	150	0.2	300	30
20	125	0.25	290	40
25	100	0.41	270	45
30	85	0.5	250	45
35	70	0.67	250	50
40	60	0.93	240	50
45	50	1.33	270	60
50	50	1.33	270	35
55	50	1.33	200	30
60	45	1.67	200	50

D. Accumulation of Dosage in Fallout Areas.

An inspection of past atomic test operations shows that during the period of fallout, more dosage is accumulated within the contaminated area than can be accounted for by the $t^{-1.2}$ decay law. This is shown in Figure 10 and in Table XXIV. An inspection of the table and the figure shows that active fallout lasts from 5 to 10 hours after it has first started. It is difficult to explain why the actual dosage is greater than the calculated $t^{-1.2}$ value. It cannot be a change in the decay law, because this effect appears to be independent of the time after bomb detonation. It appears to be related to a certain time interval after start of fallout. In view of this, it might be a "volume-effect". That is, personnel within the active fallout area are not only subjected to radiation that has already fallen on the ground, but such personnel are also completely surrounded by radiation in all directions including the vertical. By this we mean to say that during active fallout, personnel are completely enveloped in an air mass that has fission products in it.

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Another way of looking at this is to assume that the radioactive cloud covers the fallout area and extends 5,000 to 10,000 feet above it. In most atomic test operations, in order to keep dosage to monitors to a minimum, no one is allowed to remain in fallout areas during active fallout. The practice is to enter contaminated areas after a time when decay has rendered the area "safe". This means that most of the residual radioactive data is extrapolated from 6 to 12 hours after bomb detonation back to assumed time of start of fallout. For example, in Figure 10, a radiological monitor would enter the radioactive contaminated area at H + 7 hours (Point A) at which time the gamma dose rate would be approximately 0.03r/hr. This dose rate would then be extrapolated back to start of fallout (H + 1.7 hour by the $t^{-1.2}$ relation. By this procedure it can be shown that at H + 2 hours the dose rate should have been approximately 0.135r/hr. However, we see in Figure 10 that at F + 2 hours the actual dose rate was 0.80r/hr. Thus we see that such an indiscriminate use of the $t^{-1.2}$ relation can lead to errors of 500% or more. On the other hand, if the $t^{-1.2}$ law is used at H + 2 hours, then the extrapolated reading for H + 7 comes to 0.18r/hr. This should caution all of us in the indiscriminate use of the $t^{-1.2}$ relation. We cannot give a quantitative explanation of this "Volume-Effect" of fallout at this time. However, what is important is that this effect is observed and well-documented on numerous occasions, and there is no doubt about its validity; therefore, we must take it into account in our calculations. An explanation of just why this "Volume-Effect" occurs is secondary to our problem at the present time. Table VII in Section VI of this report compares the integrated dosage accumulated if the $t^{-1.2}$ relation is employed to extrapolate back to time of fallout. For those people who like to have curves of decay expressed as exponentials, it can be shown that for a period of approximately one hour after fallout has started the decay curve follows a $t^{-5.2}$ parameter; between 1 hr and 6 hrs after fallout this changes to a $t^{-1.8}$ and from 6 hrs to many weeks, the decay finally settles to a $t^{-1.2}$ relation. However, this should not be construed to mean that the gamma decay does not follow $t^{-1.2}$ decay. It is our opinion that the gross fission product gamma decay from atomic or thermonuclear weapons follows $t^{-1.2}$ relation. The beta particle decay, however, follows $t^{-1.2}$ relation for fission bombs and t^{-2} for thermonuclear bombs. Figure 10 was taken from Reference 17.

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TABLE XXIV

Ratio of Actual Dose Rate and Integrated Dose to that Calculated from the $t^{-1.2}$ Relation at Lincoln Mine, Nevada, Which was in the Downwind Fallout Path of Shot #5, TUMBLER/SNAPPER, Test Operation in 1951. Fallout first began at H + 1.5 hours.

Time in Hours After Bomb Detonation t_4	Ratio of Actual Dose Rate to that Computed from $t^{-1.2}$ $\frac{(R)}{(R')}$	Ratio of Actual Integrated Dose to that Calculated from $t^{-1.2}$ $\frac{(D)}{(D')}$
1	—	—
2	6.2	3.43
3	1.88	2.82
4	1.5	2.46
5	1.5	2.32
6	1.33	2.22
7	1.07	2.15
8	1	2.08
9	1	2.00
10	1	1.93
11	1	1.89
12	1	1.85
24	1	1.75
36	1	1.71
48	1	1.67
	1	1.25

Similarly, during Shot #2 of UPSHOT-KNOTHOLE Test Operation (1953) the 12 and 24 hour integrated dosage ratios were 1.17 and 1.105 respectively at Lincoln Mine. During Shot #9 of UPSHOT-KNOTHOLE, the fallout at St. George, Utah began at H + 4 hours and the 12 and 24 hour dose ratios were 1.5 and 1.3 respectively.

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E. World-Wide Radioactive Contamination

1. In a number of papers dealing with the world-wide contamination problem there is an upper limit given to the number of bombs that we can use before the planet becomes contaminated beyond a certain tolerance level. One such "guesstimate" is a total of 25,000 megatons. This means that if approximately the equivalent of 0.125KT of fission products ($3 \times 10^{8} t^{-1.2}$ curies) are spread over one square mile, we would have reached the tolerance level. There is considerable doubt as to the order of magnitude of the 25,000 megaton value mentioned above. However, we must assume that there is an upper limit and that this upper limit may well be between 25,000 to 250,000 megatons. This limitation has military significance. For example, if 25,000 megatons is chosen as the upper limit, then we are allowed only one hundred bombs of 250 megatons each. If the American and Russian stockpile were composed of 250 megaton bombs, then the two nations together could not use more than 100 bombs between them. However, if the stockpile is composed of 25 megaton bombs then one thousand such bombs could be exploded. Therefore we must either limit the yield of our nuclear weapons, or design our thermonuclear weapons so as to minimize the fission yield from U238, and yet to increase the fusion yield to the desired megaton level. If this could be accomplished, it is believed that we can increase the yield of our thermonuclear weapons to 100 megatons without seriously concerning ourselves with the world-wide contamination problem. It had been assumed until recently that Strontium 90 was the main culprit in the world-wide contamination. However, a recent report by Dudley (Report on Project Gabriel, of the Division of Biology and Medicine of the U. S. Atomic Energy, July 1954, Secret, RD) shows that Iodine-131 must also be taken into account in our computations.

2. If we want to minimize the world-wide contamination level, we must detonate our megaton weapons either on the surface or underground. By contact bursting a nuclear weapon on the ground we are sure that 85 to 90% of the total residual activity is deposited on the enemy nation, thus leaving 10 to 15% for slow deposition throughout the world. This makes the contact fuze for multimegaton weapons almost mandatory.

3. If it is decided to increase the radioactivity of the bomb by Cobalt or other agents, we would increase the danger of world-wide contamination. Cobalt-60 will tend to contaminate the world because of its long half life. If such seeding agents must be used, we must concentrate on those isotopes whose half life is less than 3 to 5 days, so that the majority of the activity would die down before it reaches our hemisphere in 10 to 15 days. A cobalt device (and not a cobalt bomb that must be carried by aircraft) may be the most efficient contaminating agent if the device is large enough, and if it is buried deep enough to assure that more than 95% of the activity will fall on the enemy nation.

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4. It should be noted that if the equivalent of 0.125 KT of fission products is spread over one square mile of the earth's surface, then this would be equivalent to the fallout on the surface from a uniform distribution of 25,000 MT of fission products throughout the atmosphere. Therefore, assuming no fractionation of radionuclides, if an area is covered with an infinity isodose line (D_c^{∞}) of 550 roentgens or a 48 hour integrated dose (D_c^{48}) of 200 roentgens, that area has sufficient Strontium 90 in it to be a possible hazard. This means that every time we detonate a 15 MT bomb on the surface over enemy territory, we render approximately 15,000 square miles of that country useless for agriculture (assuming 25,000 MT is the limiting value). If 250,000 MT is the limiting value, then each 15 MT bomb would render useless 1,500 square miles of enemy territory. Of course, we can avoid this by detonating our bombs in the air. If we do this, however, we increase the world-wide contamination. It is a question of either contaminating excessively the enemy country (and later have to feed him) or getting the rest of the world contaminated.

5. According to Dr. W. F. Libby (see Rand Reports: R-251-AEC, "World-Wide Effects of Atomic Weapons, Project Sunshine", and RM-1280-AEC) stillborn Chicago babies by January 1954 showed 1/6 Sunshine Units of Sr 90 uptake. It is assumed that 1000 Sunshine Units is the minimum permissable concentration of Sr 90 in the skeleton (1000 S.U. = 1 μc or 5×10^{-3} μgm of Sr 90 per man). According to Sunshine estimates, 25,000MT may bring the population to the minimum permissable concentration. By January 1954, approximately 10MT (fission yield) had probably been exploded throughout the world. The majority of this was exploded on the surface (IVY-MIKE). This means that 85% of the 10MT yield is in the Pacific Ocean within 300 to 500 downwind of ground zero. Hence only a total of 1.5 to 2MT of fission products were available for world-wide contamination by January 1954. 1/6 Sunshine Unit found by Dr. Libby in Chicago babies represents the equivalent of approximately 4.2MT of fission products distributed throughout the world according to Sunshine estimates. However, if our estimate of fallout is correct, the concentration of Sr 90 in Chicago babies came from only 2MT. This means that perhaps the original Sunshine estimate of 25,000 MT limiting value is high by a factor of 2. If the Libby experiment is repeated, and if it accounts for the CASTLE shots as well as it did for the IVY-MIKE Shot, then we must re-evaluate the world-wide contamination problem. Conversation with Dr. Western and Dr. Dudley of AEC Division of Biology and Medicine has brought out the fact that the Sr 90 may have entered the human biological cycle directly from external deposits of fission products that fell out on leafy vegetables and the like.

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IX. RECOMMENDATIONS [redacted]

1. The Air Force should reactivate extensive training in Radiological Operations. Such training should stress the use of realistic, military tolerance doses for radiation as compared to the existing civilian tolerances. The former radiological engineer AFSC should be reactivated in order to attract competent personnel into this field.

2. Provisions should be made now for simple military countermeasures against the extensive radioactive fallout menace. Such countermeasures should include the construction of adequate shelters, decontamination procedures, and as much as possible, an automatic recording net of the radioactive contamination throughout a given region of the country.

a. Shelters must have 3 to 5 feet of dirt or sand or cement around them, but they need not be fancy. For example, there is no need for sanitary facilities if such shelters are in the basement of air installation buildings, since personnel could leave the shelters for short periods of time. Similiarly no provision need be made for cooking or messing facilities. There is no need for air conditioning or for air tight seals to doors and windows.

b. Decontamination should be as automatic as possible. Perhaps runways could be washed as the fallout begins. The problem is similar to snow removal where under certain circumstances, it may be best to start removal while there is active fallout. Washing, vacuuming and other common sense methods may also be employed. Runways may be covered with canvass or other materials, which can be rolled out, thus decontaminating a sufficiently large area in the runway to load bombs and to get ready for take-off. If a circular area of 100 to 150 feet radius is cleared of radioactivity, a man in the center of such an area would be safe, even if the area outside this circle is contaminated to high levels.

c. The use of radiological monitors should be minimized in an Air Base in order to keep radiation casualties to a minimum. In place of airmen carrying portable radiac instruments (and walking throughout the airbase or riding a jeep) to delineate the fallout, we need instead permanent installations of radiological instruments in selected spots on and around the Air Base. It is believed that with the advent of multimegaton weapons, the probability is high that the fallout pattern would cover all of the Air Base more or less uniformly. (See Figures 11 and 12). In the past, the fallout pattern from 70 to 100 KT weapons were considered. Under such circumstances one portion of the Air Base may be highly contaminated while another area may be relatively clear of contamination. Now,

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however, because of the fact that lethal concentrations of radioactivity may cover five to ten thousand square miles from one bomb alone, it would be unwise to perform a needlessly detailed radiological survey of the Air Base. In the event that the Air Base Commander desires a detailed contamination pattern, he can accomplish this by installing in all four quadrants fixed radiological instruments with provisions for continuous recording. It may be desirable to locate several of these instruments outside the Air Base in the event that the Air Defense Command may want a look at the continental fallout pattern. If radiological instruments are placed outside the weapon radius (5 to 15 miles) of our larger bombs then even if the Air Base is demolished a central Headquarters may still get the continental contamination pattern. Although presently authorized portable radiac meters cannot accurately indicate a dose rate above 50 r/hr, it would be relatively simple to construct permanent installations of radiological instruments that can indicate 500 r/hr of gamma. If each Air Base is equipped with such permanent radiological instrumentation, it would be relatively simple to place this information on an established communication net such as the Weather Net, etc. for use by agencies responsible for the defense of this country.

3. An analysis of this report brings out the fact that in the absence of countermeasures, the fallout from one bomb (15 MT) could endanger the populations of Washington, D. C., Baltimore, Philadelphia, and New York City (See Figures 11 and 12). This means that an unprepared and an uninformed nation will suffer horrible casualties from radiation. The report also points out, however, that by relatively simple means (proper education, early warning, shelters, etc.) it may be possible to reduce significantly the radiation casualties throughout the nation. Certainly there is no such "cheap" method of protecting our Cities and our population against the blast damage from nuclear weapons. For this reason the best national interest would be served if the military and civilian population are advised of the proper countermeasures against the radioactive hazard.

4. It is recommended that all multimegaton weapons be surface detonated on the enemy country in order to reduce the worldwide contamination. It is believed that 80 to 90% of the total residual activity of a bomb is deposited on the enemy country if the bomb is surface burst, thus leaving only 5 to 10% for contaminating the rest of the world. If weapon yields in excess of 100 MT are required, it is suggested that we start now looking into the possibility of building TN weapons without the use of large amounts of U238. In other words, the yield of our TN weapons should be mainly from fusion, rather than fission, in order to minimize the possibility of contaminating our planet beyond a certain tolerance level of residual radiation.

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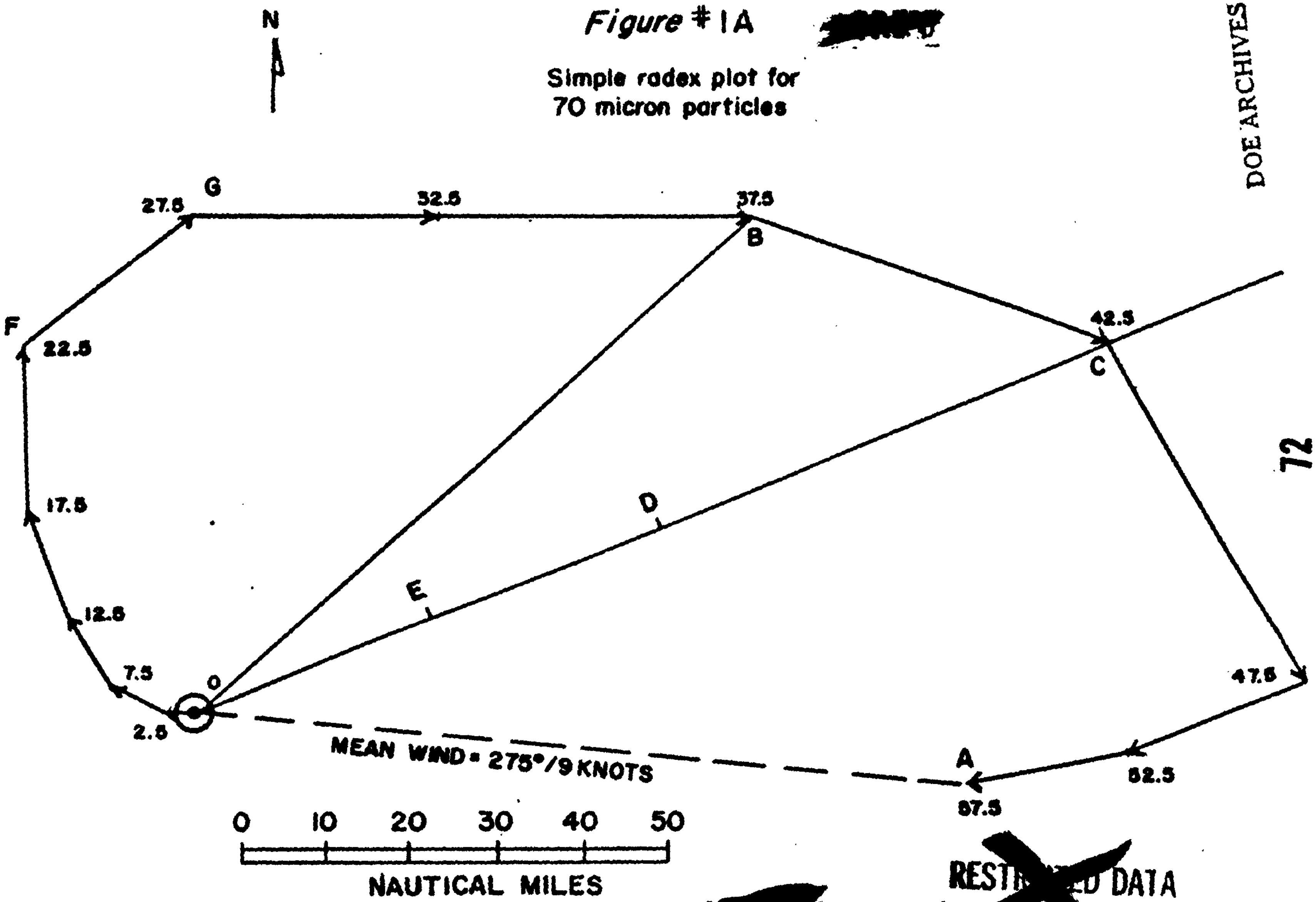
Figure # 1A [redacted]

Simple radex plot for 70 micron particles



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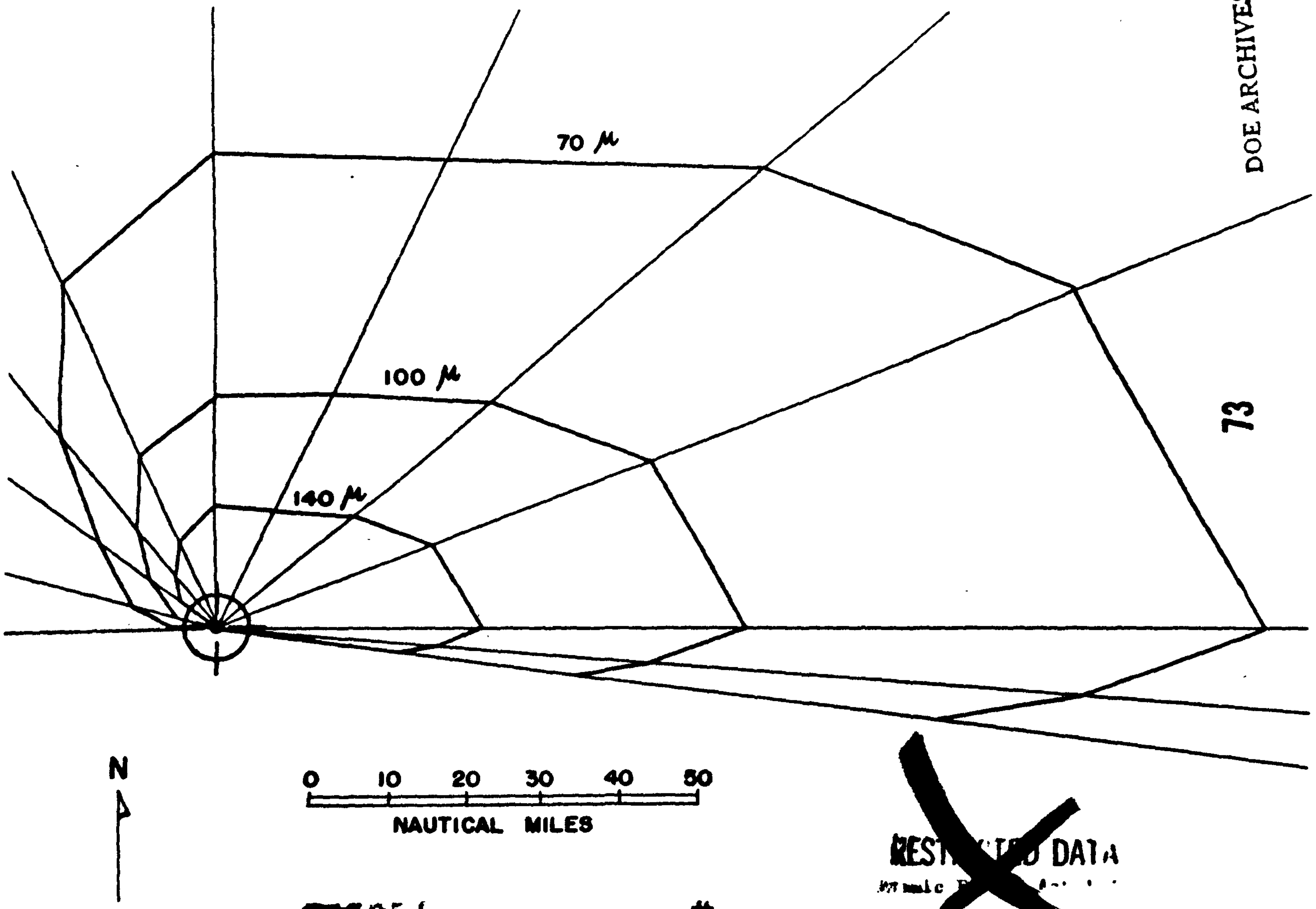

[redacted] Figure #1B

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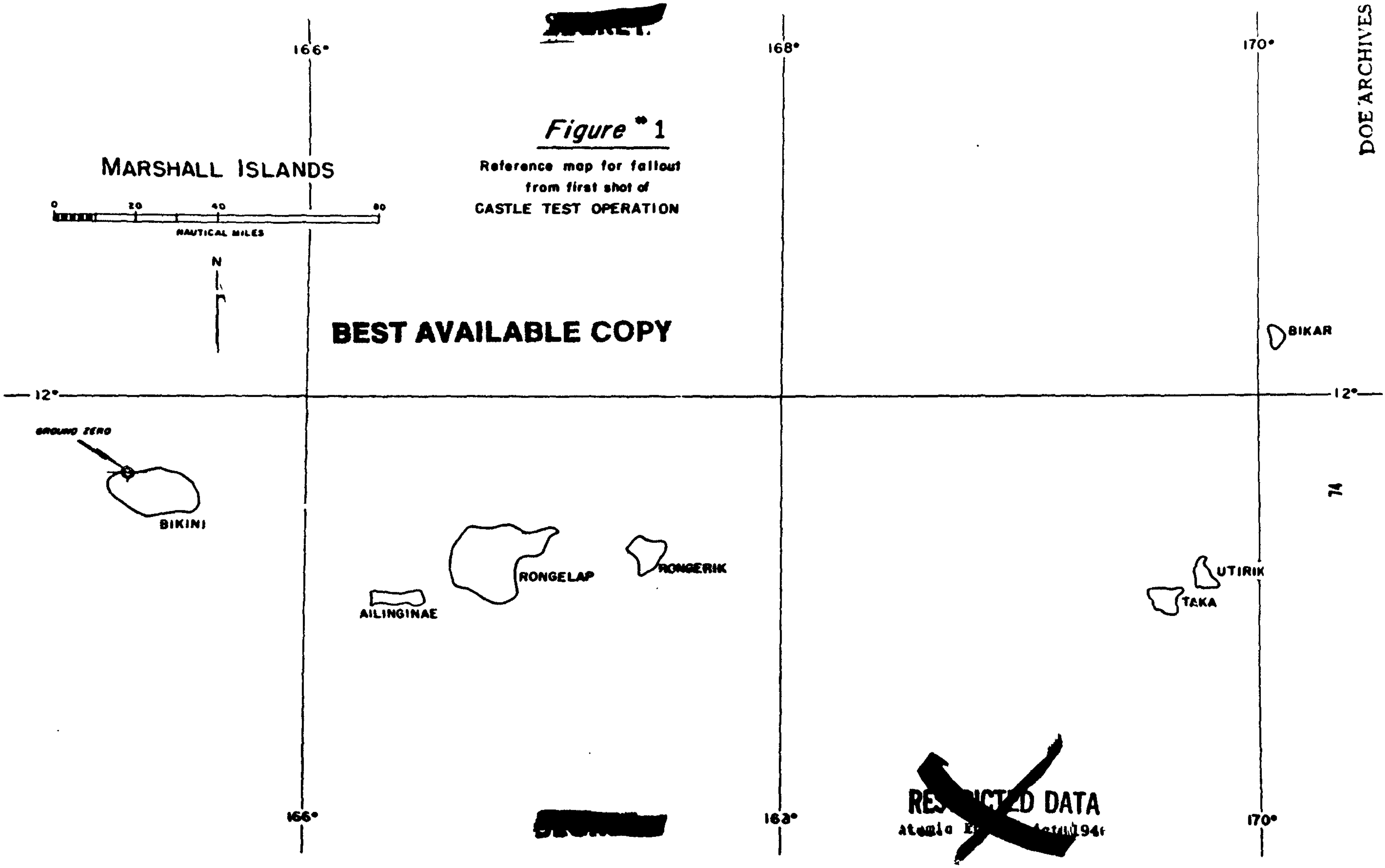

Figure # 1

Reference map for fallout
from first shot of
CASTLE TEST OPERATION

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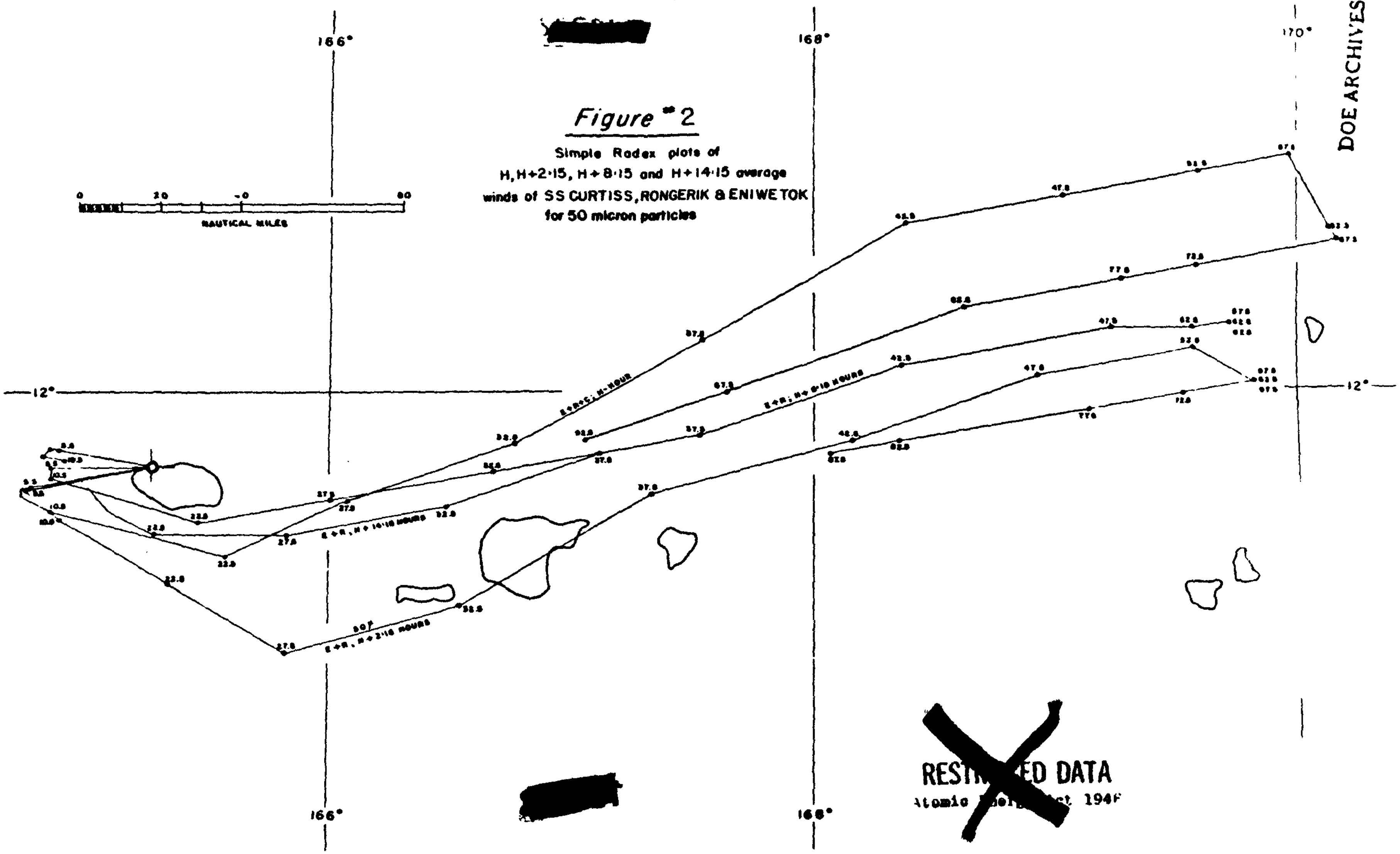

Figure # 2

Simple Radex plots of H, H+2·15, H+8·15 and H+14·15 average winds of SS CURTISS, RONGERIK & ENIWETOK for 50 micron particles

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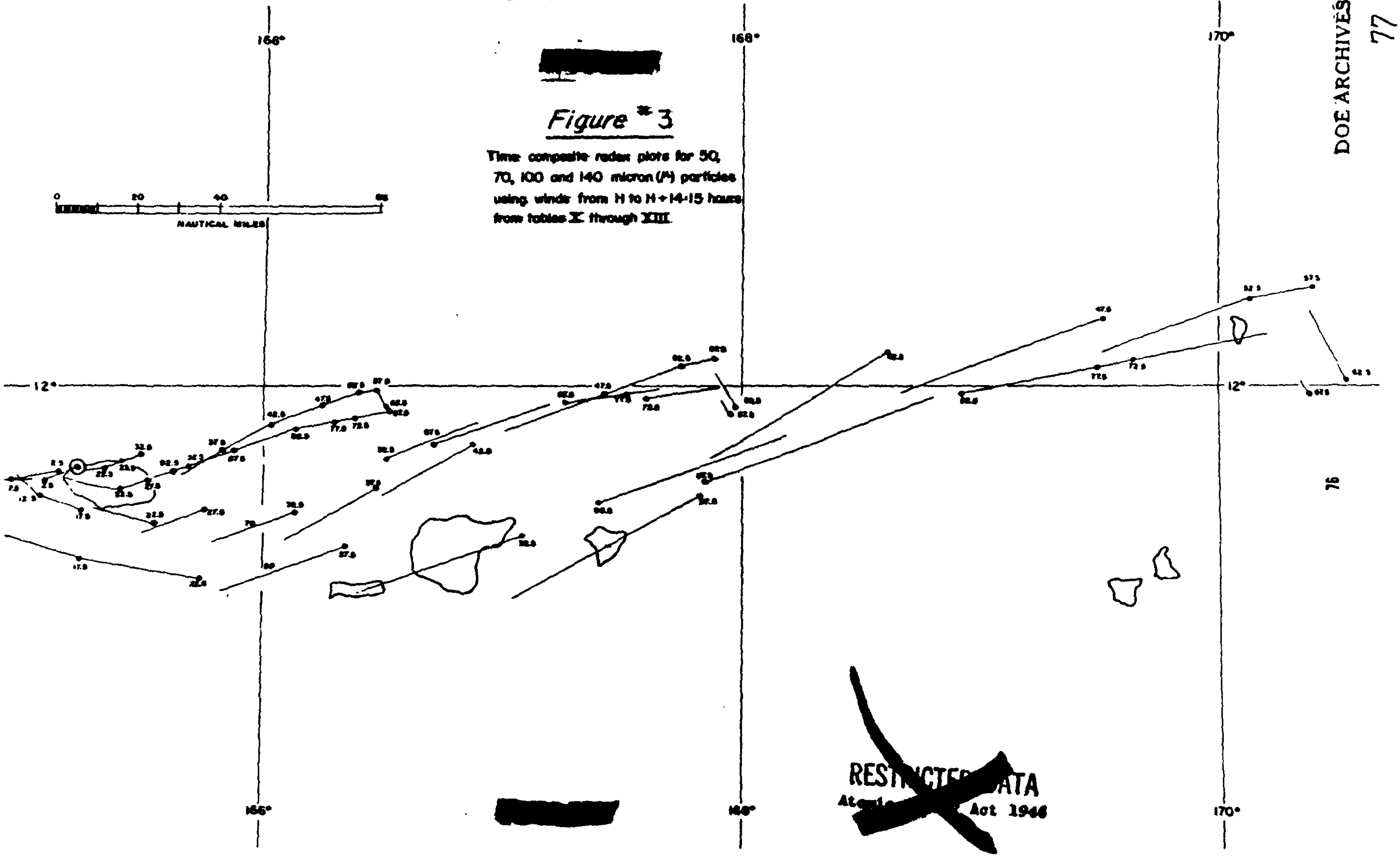

Figure # 3

Time composite radex plots for 50, 70, 100 and 140 micron (μ) particles using winds from H to H+14-15 hours from tables X through XIII.

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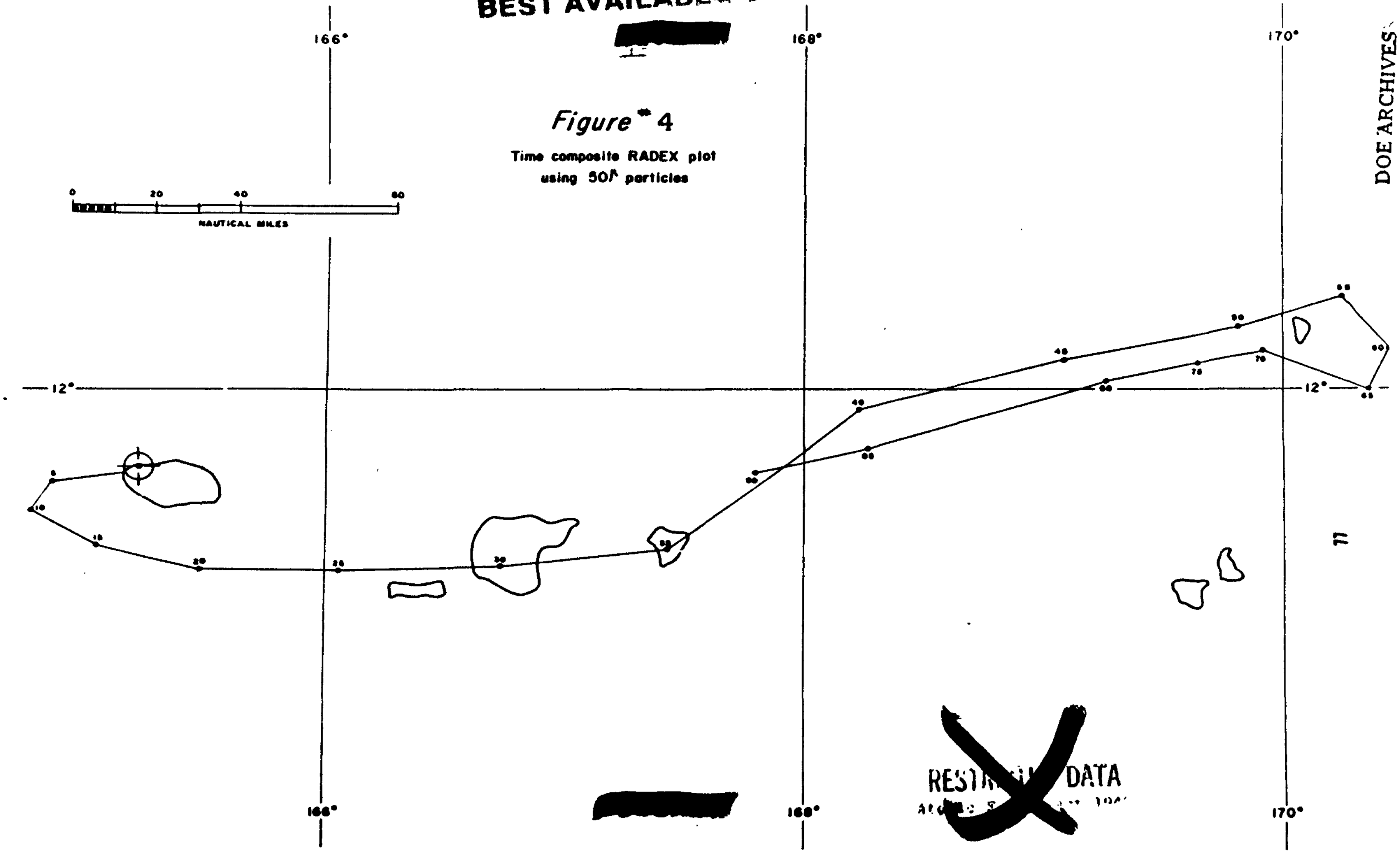
Figure 4

Time composite RADEX plot using 50μ particles



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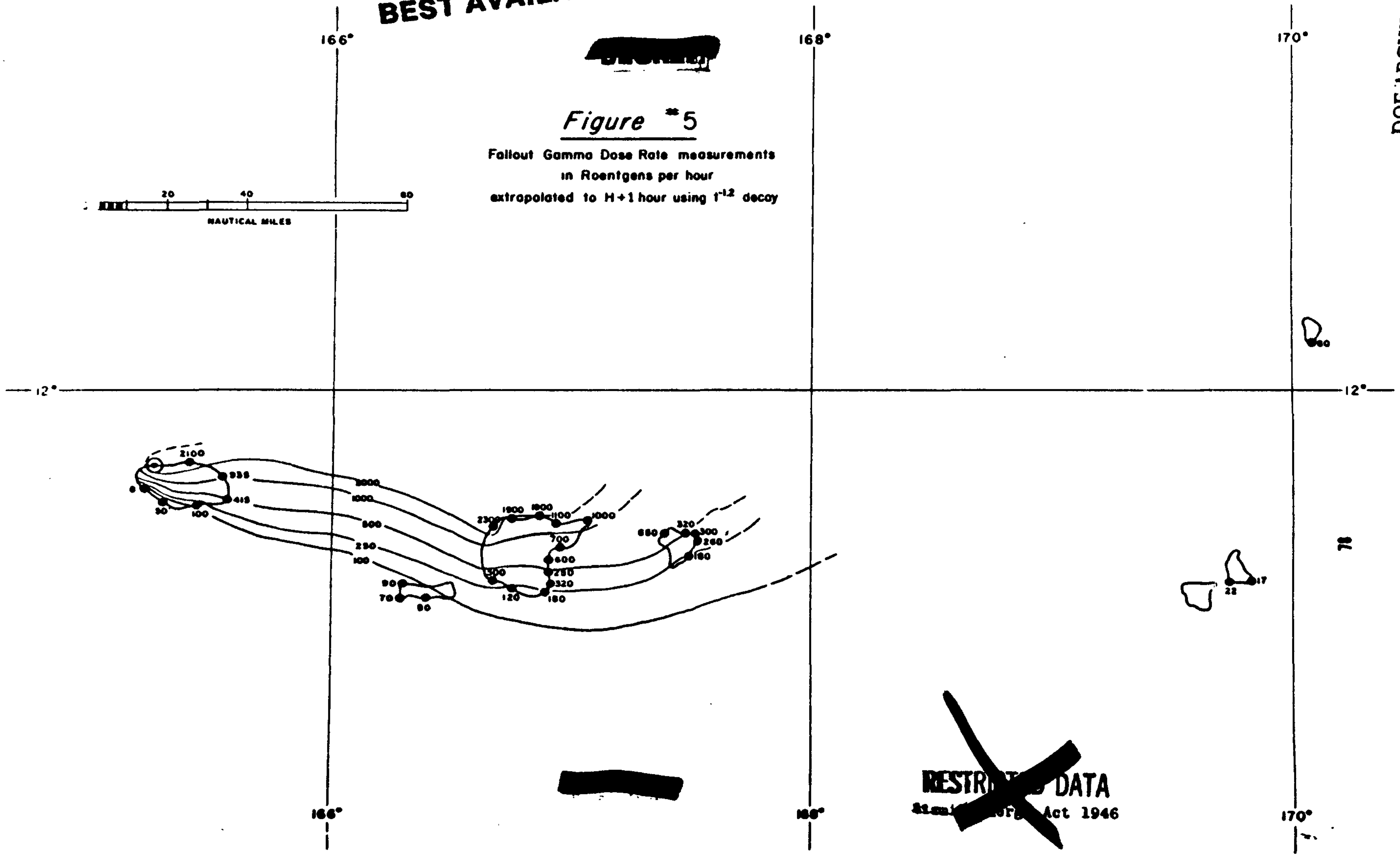

Figure #5

Fallout Gamma Dose Rate measurements
in Roentgens per hour
extrapolated to H+1 hour using $t^{-1.2}$ decay

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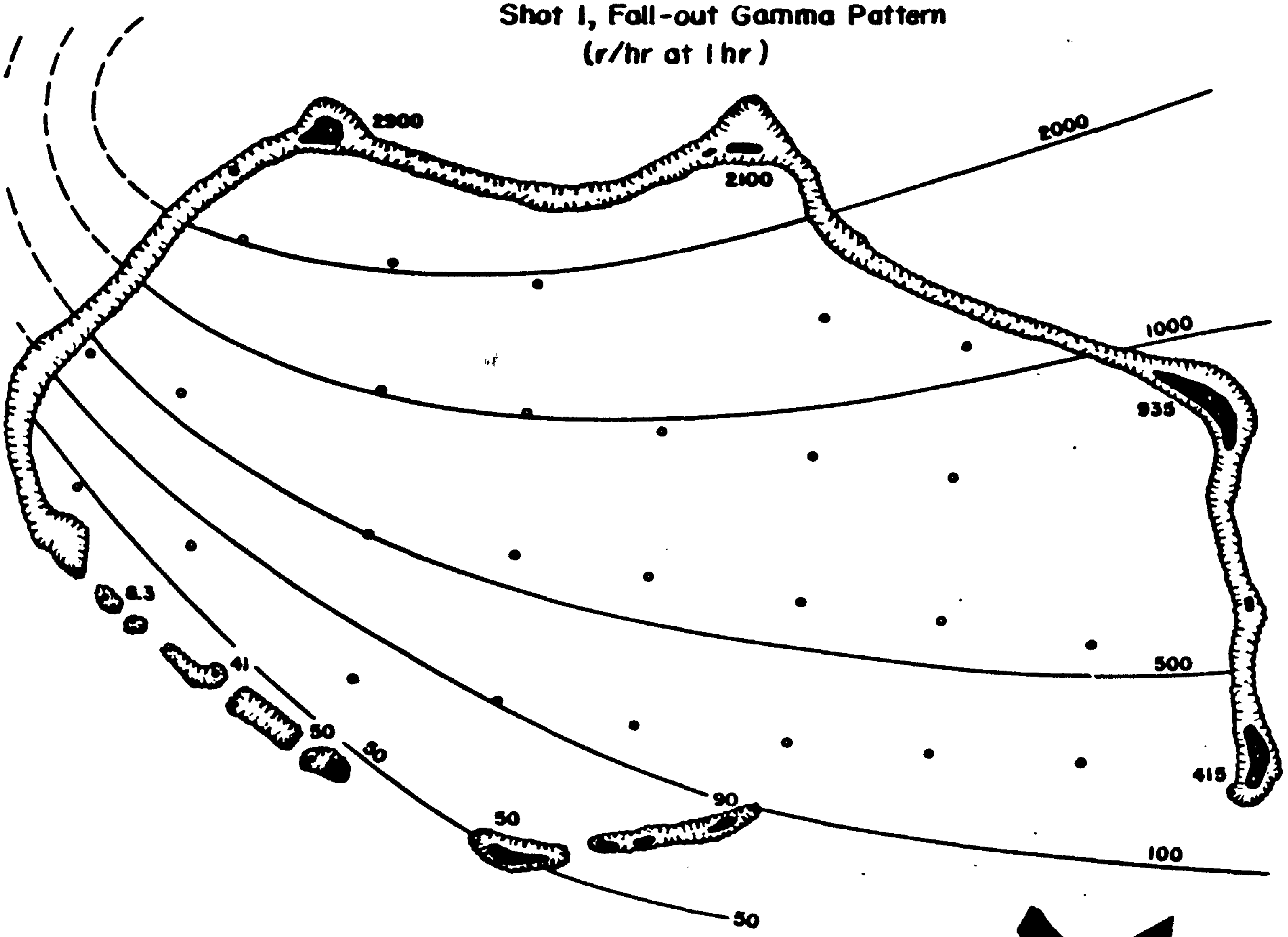
Shot I, Fall-out Gamma Pattern
(r/hr at I hr)



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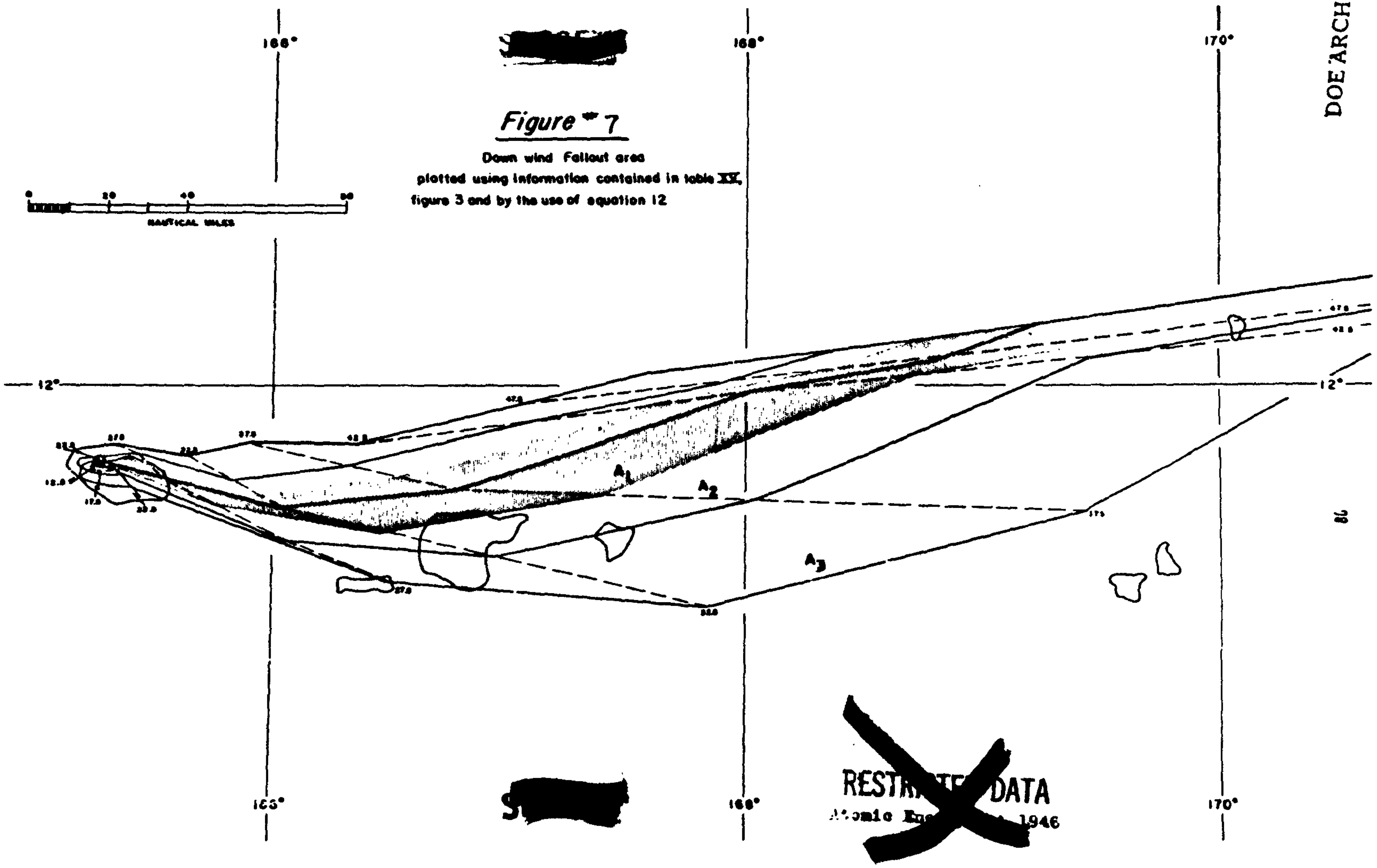

Figure # 7

Down wind Fallout area
plotted using information contained in table XX,
figure 3 and by the use of equation 12

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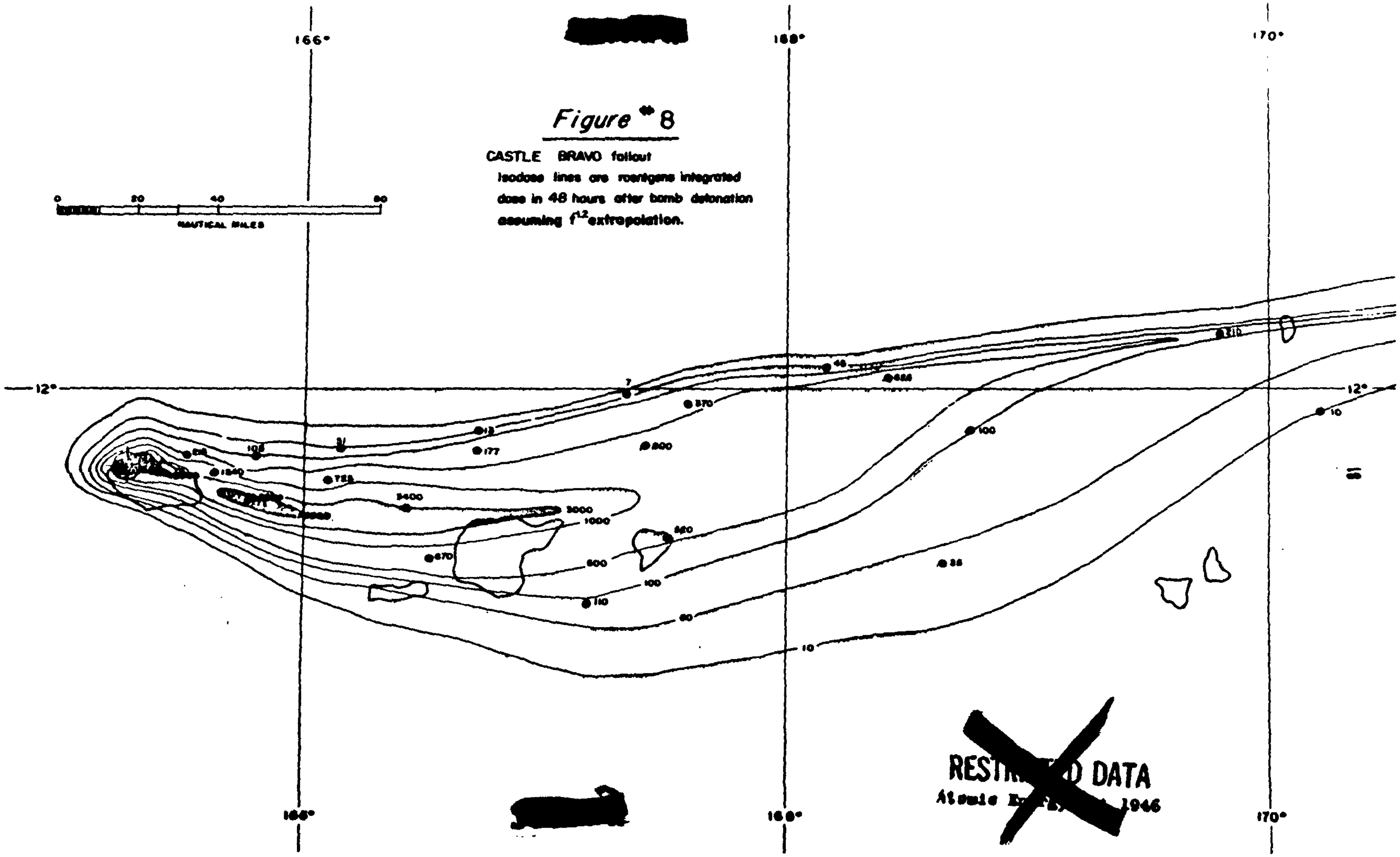

Figure # 8

CASTLE BRAVO fallout
Isodose lines are roentgens integrated dose in 48 hours after bomb detonation assuming $t^{1.2}$ extrapolation.

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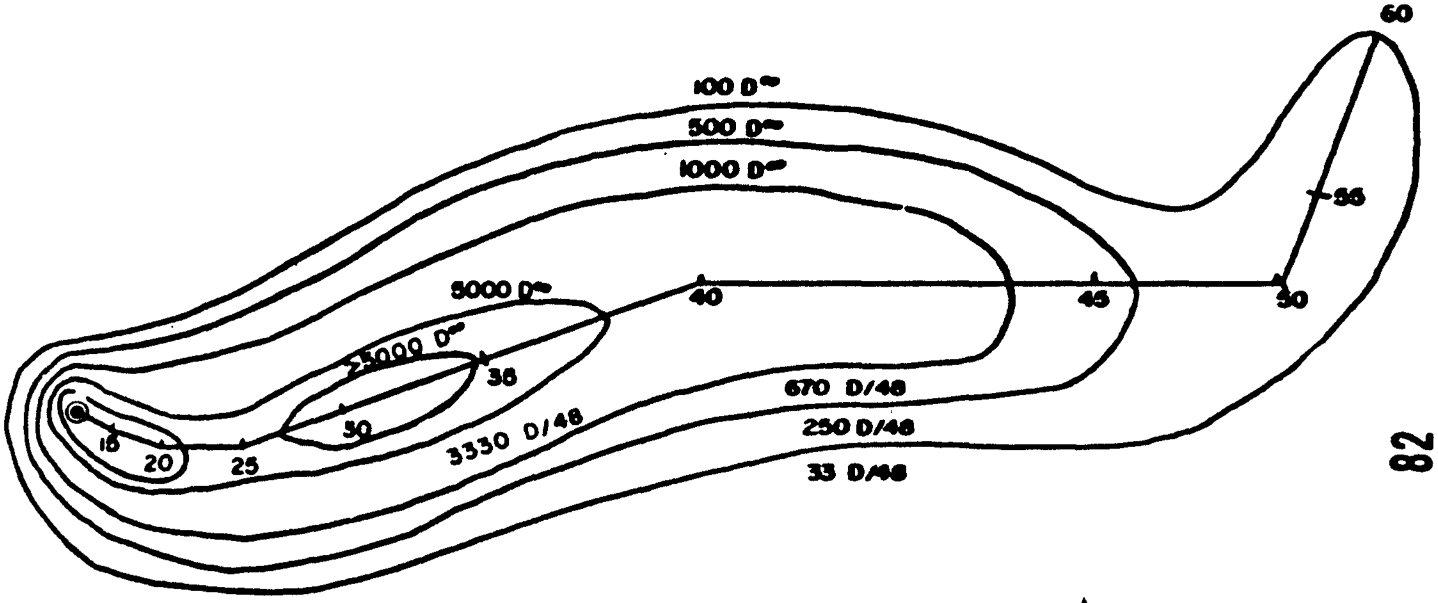
Figure # 9A

Idealized fallout from 15000KT surface burst weapon. Isodose lines in roentgens infinity dose and roentgens 48 hour dose



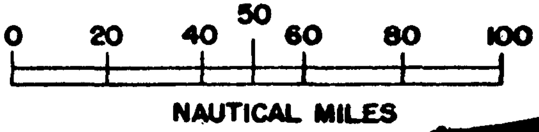


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Figure # 9B
60,000 kt Fallout
Surface Burst

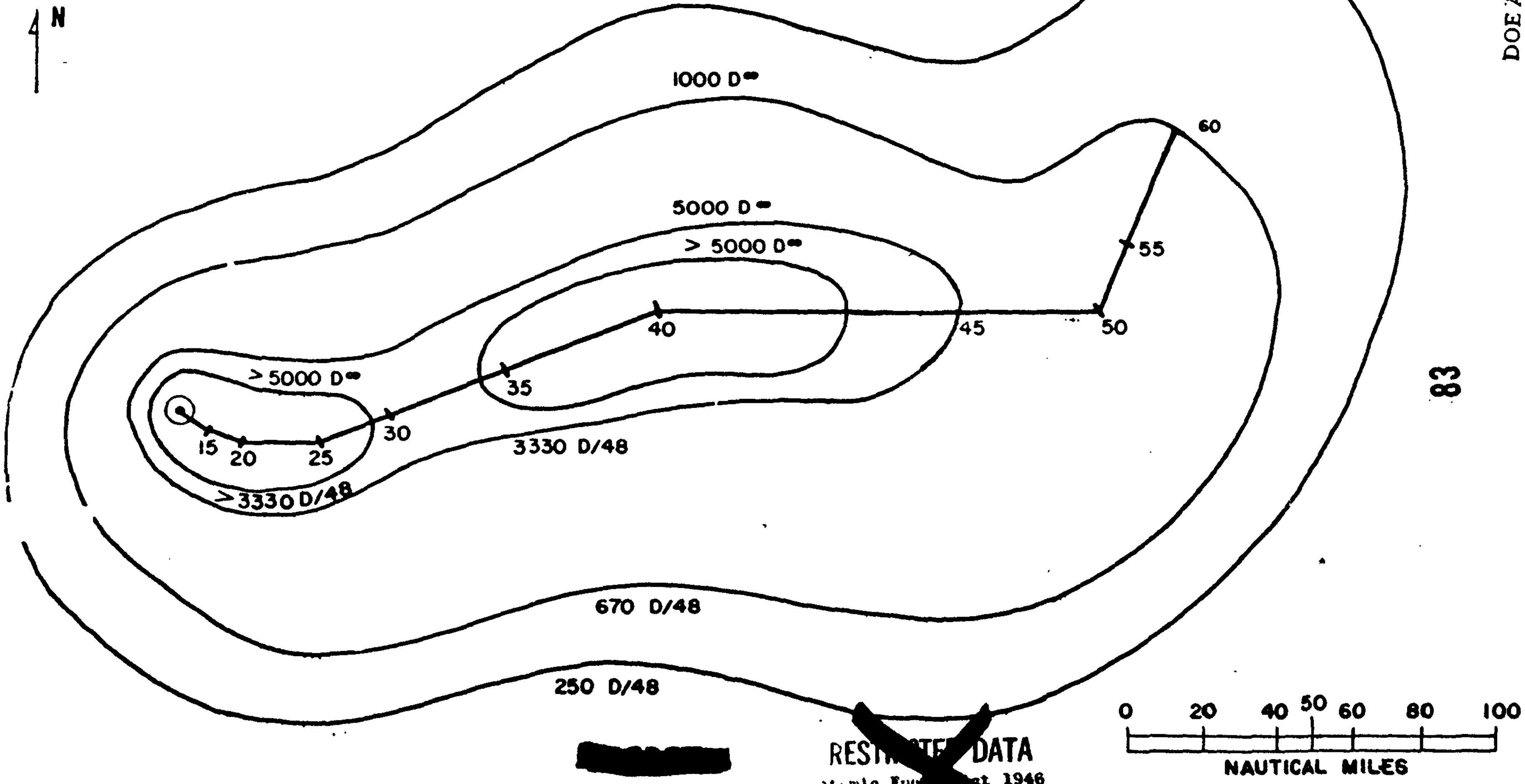

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Figure * 9C

Fallout from 100 KT surface burst

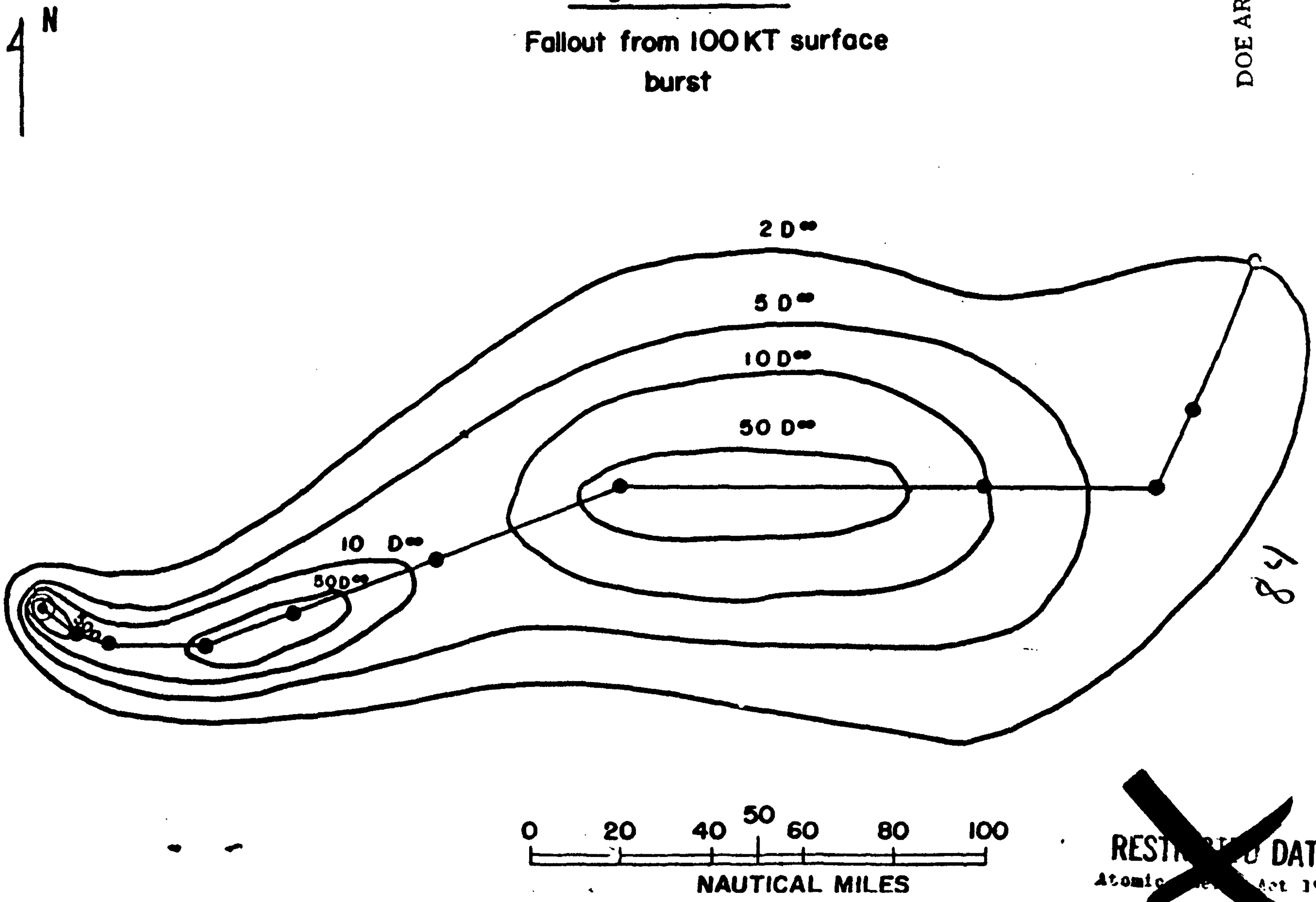

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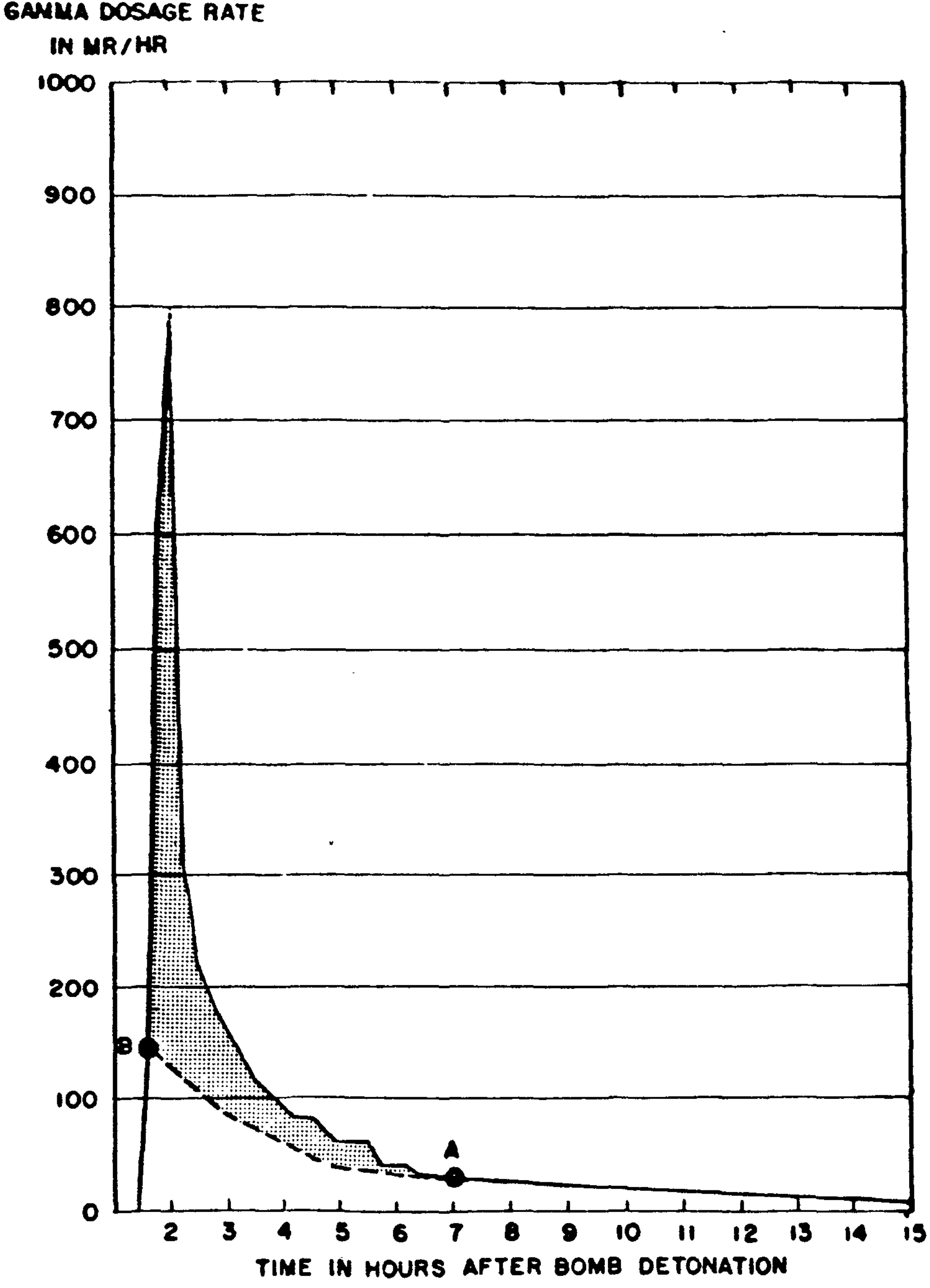
Figure # 10

Fallout at lincoln mine, Nevada from shot 5 of tumbler/snapper test operation in 1952.



Shaded portion shows fallout in excess of the $t^{-1.2}$ RELATION

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Explanation of Figure 11

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The figure represents the idealized contamination patterns over this country, if 111 nuclear weapons of 15 MT yield are contact burst over target. The targets consist of the 106 cities of this country whose population is 100,000 or more, and five selected airbases. Each fallout plot consists of two areas. The small inner area covers 12,500 square miles and represents an average infinity dose of 2,700 roentgens, which is equivalent to a 48 hour integrated dose of 1,420 roentgens and a 24 hour dose of 1,140 roentgens. The large outer area covers 25,000 square miles and it represents an infinity dose of 190 roentgens and a 48 hour dose of 75 roentgens. The dosages are computed on a "Volume-Effect" basis rather than on a $t^{-1.2}$ relation (See Section d of Appendix for details on Volume-Effect). The areas were obtained by averaging the values given in Table XX and in Figure 12. An inspection of Figure 11 shows that each contamination pattern is alike no matter where the bomb is exploded over the country. At first glance this may seem to the reader an unwarranted simplification. However, in an earlier report (see Reference 6) the same analysis was made using the actual winds aloft over each target. This was a very time-consuming and tedious analysis. Some of the contamination patterns were long and thin, others short and wide, some were elliptical, others more tortuous patterns. However, the net total effect was the same as in Figure 11 of this report. That is, both analyses showed that there was no place to hide in the Eastern part of the U. S. and the North Eastern U.S. was contaminated over and over again. The primary purpose of Figure 11 is to illustrate that during atomic warfare dispersal of aircraft and evacuation of personnel cannot be relied upon as military countermeasures. On the contrary, a Commander may lose more of his forces by evacuation and dispersal.

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Figure #11

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Figure #12

Fallout from first shot of CASTLE TEST OPERATION superimposed upon North-Eastern United States. Isodose lines are in roentgens accumulated during 48 hours

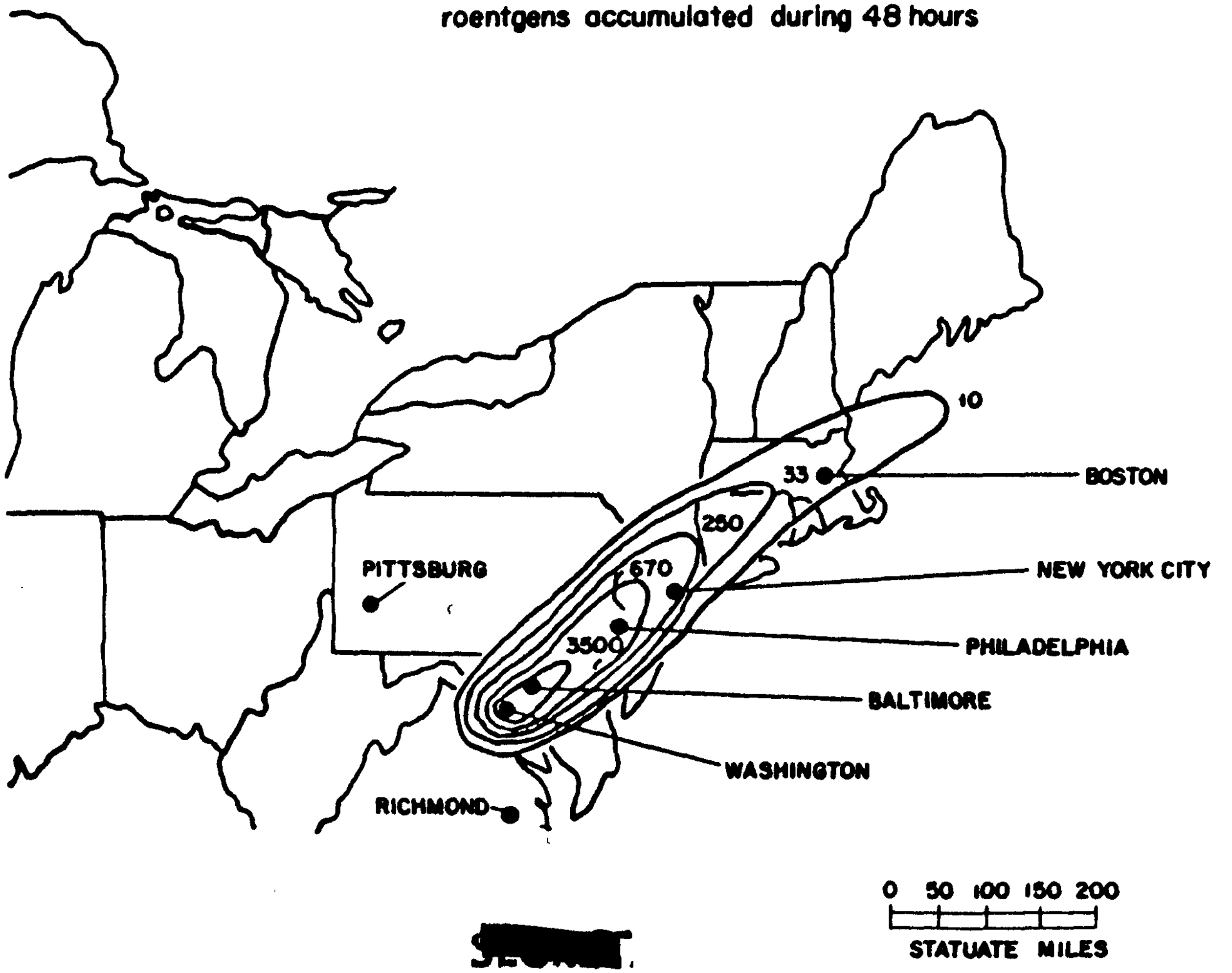

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Figure #13

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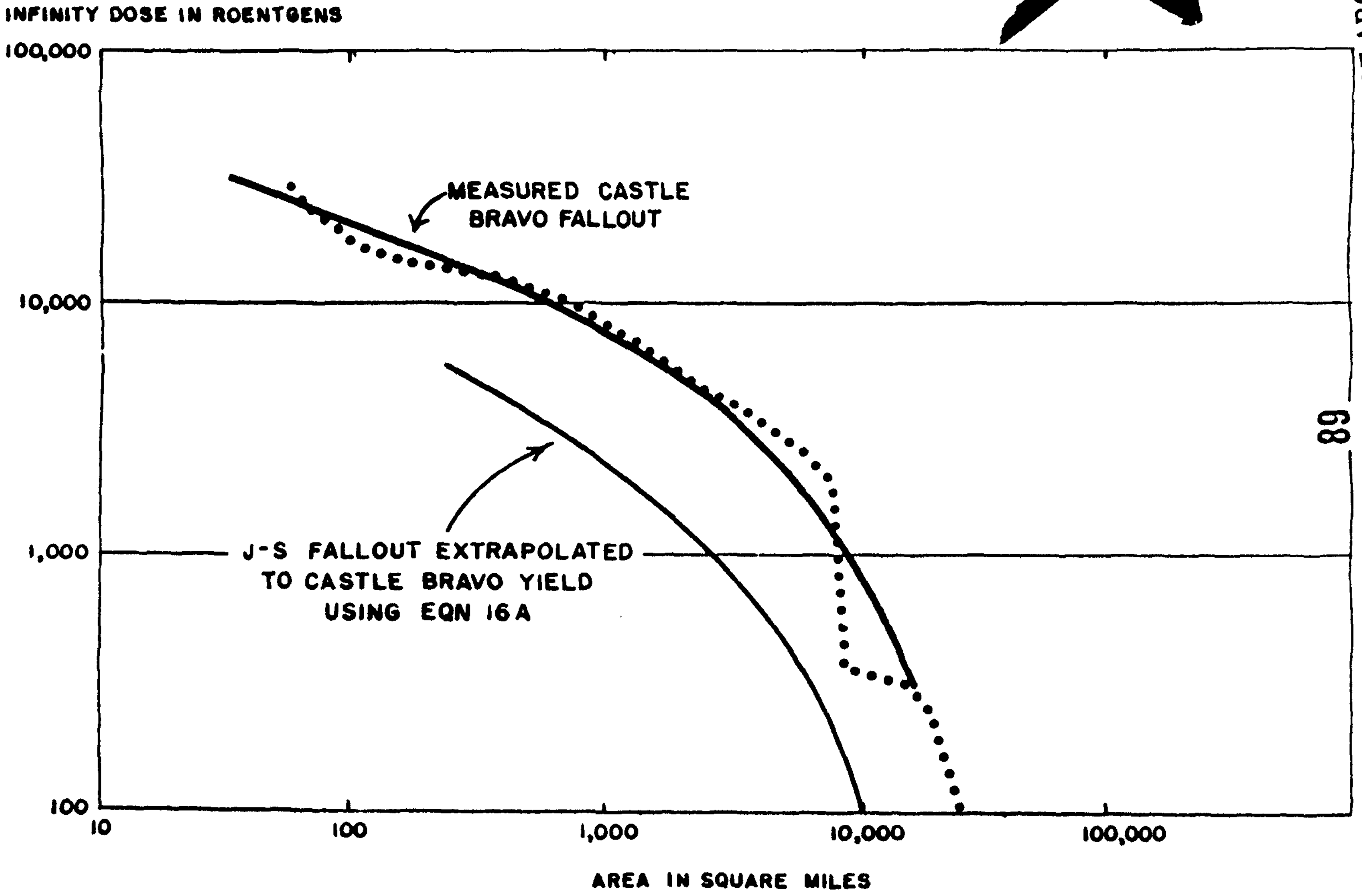

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REFERENCES:

1. "Radioactive Fall-out from Atomic Bombs", Hq ARDC C3-36417, Nov 1953 (S-RD) and Supplement, by Lieutenant Colonel N. M. Lulejian.

2. UPSHOT-KNOTHOLE, Project 4.1, "The Radiation Hazards to Personnel within An Atomic Cloud", S-RD

3. Personal Communication with Col Houghton and Capt Steel of AFSWC

4. Operation U/K, WT-705, "Activities of the Special Weather Advisory Service", C-RD

5. Operation CASTLE, "Project 9.1, Cloud Photography", S-RD

6. "Radioactive Fall-out from Contact Burst Megaton Bombs", Hq ARDC C4-18098, S-RD by Lt Col Lulejian

7. Operation GREENHOUSE, Scientific Test Directors Report WT-26, Annex 6.5 Aug 1951, S-RD

8. Operation U/K, Project 4.7, "Beta-Gamma Skin Hazard in the Post Shot Contaminated Area," WT-746, C-RD

9. USNRDL-383, "Beta-Contact Hazards Associated with Gamma Radiation Measurements of Mixed Fission Products", by J. D. Teresi

10. Rand Report R-139, "The Radiation Hazard from an Atomic Bomb Cloud", 1949 (S-RD) by Cohen and Plesset

11. USNRDL-379, "Radiation Hazards to Aircrews Exposed to the Atomic Cloud of an Atomic Detonation" by Teresi

12. Preliminary Report on Operation CASTLE Project 2.5a, "Distribution and Intensity of Fall-out" ITR-915 (S-RD)

13. Preliminary Report, Operation CASTLE, Project 4.1, "Study of Response of Human Beings Accidentally Exposed to Significant Fall-out Radiation", ITR 923, S-RD

14. Operation JANGLE, Project 2.7, "Biological Injury from Particle Inhalation", by Falconer Smith, June 1952, WT-396, S-RD

15. AFSWP Report 507, Radioactive Fall-out Hazards from Surfact Bursts of Very High Yield Nuclear Weapons S-RD

16. Rand Report R-265-AEC "Transport and Early Deposition of Radioactive Debris from Atomic Explosions"

17. TUMBLER-SNAPPER Report on Radiological Safety, WT-558, Dec 52, S-RD

[redacted]

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91

[redacted]

18. Operation UPSHOT-KNOTHOLE Report on Radiological Safety

19. "Radioactive Fall-out and Radex Plots" Air Weather Service Manual 105-3, Unclassified

20. "Meteorological Technical Report of Operation GREENHOUSE", by Cmdr Pate and Col George Taylor, Joint Task Force 3, Sept 1951, Secret

21. Schorr, M. G. and Gilfillan, E. S., "Predicted Scaling of Radiological Effects to Operational Weapons". JANGLE Project 2.0 (15 Jun 52) S-RD

22. R. K. Laurino, LJP Minvielle, E. T. Sheffield, R. F. Johnson, "Effects of Surface and Underground Nuclear Explosions", USNRDL PAD-10, WP 311.4, 30 Jun 52, Secret

23. "Consideration of Radioactive Contamination in the Major Overhaul of Aircraft Turbo-Jet Engines," USNRDL Report # 355, 1 May 1952, by H.A. Myers et al.

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