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Project Stemwinder

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Atmospheric Radioactivity Research Project
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The objective of Project Stemwinder was to probe and sample nuclear clouds as soon as possible after cloud stabilization in order to investigate the amount of radioactive debris which stabilizes in the troposphere and its distribution with height. Sampling was accomplished by the RB-57 aircraft. The detonations investigated were all air bursts over water during Operation Dominic I at Christmas Island. Some data for surface detonations obtained by sampling aircraft during Operation Redwing are used to compare with the Stemwinder data.

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FOREWORD

Classified material has been removed in order to make the information available on an unclassified, open publication basis, to any interested parties. The effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is either currently classified as Restricted Data or Formerly Restricted Data under the provisions of the Atomic Energy Act of 1954 (as amended), or is National Security Information, or has been determined to be critical military information which could reveal system or equipment vulnerabilities and is, therefore, not appropriate for open publication.

The Defense Nuclear Agency (DNA) believes that though all classified material has been deleted, the report accurately portrays the contents of the original. DNA also believes that the deleted material is of little or no significance to studies into the amounts, or types, of radiation received by any individuals during the atmospheric nuclear test program.

FINAL REPORT
OPERATION DOMINIC I
PROJECT STEMWINDER

By

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Atmospheric Radioactivity Research Project
U. S. Weather Bureau, Washington, D. C.
May 1964

For

Fallout Studies Branch
Division of Biology and Medicine
U. S. Atomic Energy Commission

CONTENTS

PROJECT STEMWINDER

I. Introduction

The objective of Project Stemwinder was to probe and sample nuclear clouds as soon as possible after cloud stabilization in order to investigate the amount of radioactive debris which stabilizes in the troposphere and its distribution with height. Sampling was accomplished by the RB-57 aircraft of the 1211th Test Squadron under the scientific direction of the Atmospheric Radioactivity Research Project, U. S. Weather Bureau and sponsored by the Division of Biology and Medicine, U. S. Atomic Energy Commission. The detonations investigated were all air bursts over water during Operation Dominic I at Christmas Island. Some data for surface detonations obtained by sampling aircraft during Operation Redwing are used to compare with the Stemwinder data.

The project was conceived as an attempt to utilize available sampling aircraft (on a non-interference basis with respect to their primary mission) to narrow the area of uncertainty involved in two related problems. First, there was the operational need for prediction of the possible local hazard due to rainout of radioactive debris from a portion of a nuclear cloud which might pass over Christmas Island shortly after an airburst. Since the tops of rain clouds in the Christmas Island area were generally below 20,000 feet, and often below 10,000 ft., the amount and distribution of debris in the stem of the mushroom cloud was of primary concern. In the absence of any data, the possibility could not be ruled out that one percent, or more, of the fission products produced might remain in the stem region below 20,000 feet. Since predictions of the rainout of this amount of debris could, under certain circumstances, indicate unacceptable levels of contamination at the ground, thus causing the postponement of scheduled detonations, there was an immediate need for data on radioactivity in the stem cloud.

The second problem concerns the partition of radioactive fission products between the stratosphere and the troposphere as a function of the nuclear yield, the height of the tropopause, the height of detonation, and possibly other factors. This has been an important consideration in estimating the long-range fallout from nuclear tests since fission products have a mean residence time of several weeks in the troposphere (intermediate fallout), as opposed to many months or years in the stratosphere (world-wide fallout), depending on the latitude and altitude of injection. The fraction of the debris which remains in the troposphere may be particularly important in considering the possible hazard from relatively short-lived isotopes, such as I-131, since the stratospheric portion will usually decay to insignificant amounts before it can return to the surface of the earth .

It must be emphasized that the above remarks apply only to the very small particles which contribute to the intermediate and world-wide fallout. In the case of surface detonations, much of the radioactivity is associated with relatively large particles which comprise the local fallout. These large particles are not affected by the tropopause and will appear in the "local" fallout regardless of whether they are initially injected into the troposphere or the stratosphere.

II. Cloud Heights of Air Bursts in a Tropical Atmosphere

Dominic shot data, including yield, height of burst, cloud top and base and tropopause height, are listed in Table I of the Appendix. The cloud top data are plotted as a function of total yield in figure 1. The two low yield Dominic detonations (Tanana and Petit) are included in Table I, but not in figure 1. Since there was no scientific program to document cloud heights, a "best guess" was arrived at for each cloud by evaluating estimates made by observers at the ground and in the sampling aircraft in the light of the dose rates reported at the various sampling altitudes. Some of the aircraft had a maximum altitude of about 60,000 feet and on most detonations at least one of the aircraft flew at an altitude within a few thousand feet of the cloud top. The error in the estimated cloud height is believed to be less than 10 percent. Variations in the height of burst did not appear to have any consistent effect on the cloud heights. Evidently, the effect of the burst altitude was masked by the influence of meteorological factors and/or the errors in the cloud height estimates.

To aid in drawing the mean curve and the estimated range of cloud heights (indicated by the dashed lines in figure 1), selected data were added from other Pacific test series. Almost all the detonations in past U.S. tests in the Pacific were surface bursts and the documentation of nuclear cloud dimensions was generally poor. Perhaps the most reliable cloud top measurements were those obtained by aerial photography on a few of the Redwing detonations. These data are plotted in figure 1 along with all available data for yields greater than 10 megatons (1). The curves are intended to be valid only for "air bursts" in a tropical atmosphere and for heights of burst (HOB) less than about 15 percent of the expected cloud top height. For this purpose, an "airburst" may be defined as a detonation at an altitude equal to or greater than $180Y^{0.4}$ where Y is the total yield in kilotons. Only surface burst data are available for yields above 5 MT, and it is assumed that in this yield range the data are applicable to airbursts as well. However, it must be emphasized that there are no <u>reliable</u> cloud top data for yields greater than about 5 megatons and the extrapolation of the curves beyond this point represents little more than an educated guess. Indeed, over the entire range of yields shown in figure 1, the dashed curves indicate only the expected range of cloud heights for the stated conditions and should not be interpreted as representing absolute limits.

III. <u>Stem Cloud Penetrations</u>

An RB-57 aircraft was available for stem penetration missions immediately following seven of the Dominic detonations. The navigator was provided with an Eberline E-500B dose-rate meter with a range from 0.01 to 2000 mr/hr and instructed to record the dose rate as the pilot penetrated the stem cloud at specified altitudes. The dose rates measured in the cockpit were then used to estimate the amount of activity in the cloud in the following manner:

The relation between cloud concentration and dose rate in a uniform infinite cloud (2) is given by

$$C = \frac{D\,\rho}{\rho_o} \; \frac{84\,\rho_o}{(3.7 \times 10^4)\,(1.6 \times 10^{-6})E} \qquad (1)$$

C = cloud concentration in microcuries/cm^3

D = dose rate in Roentgens/second

ρ_o = standard density of air at sea level = 1.293×10^{-3} g/cm^3

ρ = density of air at sampling altitude in g/cm^3

E = average gamma energy in Mev

84 = energy absorbed per roentgen in ergs per gram of air
1.6×10^{-6} = ergs per Mev
3.7×10^{4} = disintegrations per second per microcurie

Converting the unit of dose rate to roentgens per hour, and the concentration to megacuries/(mile*)^3, we have

$$C = 2.1 \frac{\rho}{\rho_o} \frac{D}{E} \qquad (2)$$

For stem penetrations within an hour after burst time, E was assumed to be 1 Mev. For the sampling missions between 2 and 5 hours after burst, a value of 0.86 Mev was used (3). Figure 2 gives the value of ρ/ρ_o as a function of altitude for a typical tropical atmosphere (4). Using appropriate values for E and ρ/ρ_o in equation 2, the dose rates recorded during stem penetration were converted to cloud concentrations. An estimate of the stem diameter was then used to estimate the total volume of cloud in a layer 1000 feet thick. Multiplying the concentration by the volume the total amount of activity in the layer and the fraction of the bomb represented by that activity was determined.

The stem penetration data and computed results are given in table II of the Appendix. The results are also shown in figure 3 as a plot of the fraction of the bomb present in a 1000 foot slice of the stem cloud versus height (indicated as percent of the total stem height). The three highest Dominic data points are derived from the extended sampling missions described in Section IV. The Redwing data is discussed in Section V. The curve is intended to represent a conservative estimate (for safety considerations) of the activity as a function of height in the stem for air bursts.

The rather large scatter in the data may be attributed to several factors. It appears that the stem visibility may be the most important of these. Most of the higher activity readings occurred during penetrations when the stem cloud was visible to the pilot. The relatively low readings were obtained when the cloud was not visible or, when it is not known whether the cloud was visible. It is quite possible that the aircraft did not actually penetrate the stem on these occasions. The dose rates measured inside the aircraft may have been due to "shine" from the stem cloud or to diffuse material outside of the stem core.

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* Statute miles are used throughout this paper.

In those cases where the stem was not visible and several passes were made at the same altitude, only the highest reading has been plotted.

It is unfortunate that for the lower 80 percent of the stem, virtually all the data for the larger detonations (Arkansas, Questa, Encino) are questionable due to the stem visibility problem. Therefore, it is impossible to say whether the low values obtained for these shots may indicate a real decrease in the fraction of activity in the lower stem with increasing nuclear yield.

Additional factors which contribute to the uncertainty in the results are the following:

1) Stem volume estimates

In order to determine the total activity present in a 1000 foot layer, the stem diameter at the penetration altitude must be estimated. The estimates used in the computations are given in Table II of the appendix. These values are based on visual estimates made by ground observers, visual estimates by the airborne samplers or, where necessary, estimates from other detonations in the same yield range. The estimated diameter could be in error by as much as a factor of two in some cases.

2) Stem Height Estimates

The stem was considered to extend from sea level to the base of the cloud, regardless of the height of burst. The cloud bases in Table I are based on visual observations from the ground and from sampling aircraft and verified, where possible, by radiation readings reported by sampling aircraft. The uncertainty in the height of the cloud base (stem height) is about ten percent.

3) Representativeness of Dose Rate Readings

The measured dose rates are assumed to represent those in a uniform, infinite cloud. The assumption appears to be reasonably valid for those penetrations where the stem was visible. The aircraft required 20 seconds or more to traverse the cloud at a speed of about 7 miles/minute while the mean free path of gamma radiation in air is on the order of a few hundred feet. The navigator reported that the dose rate would rise sharply on entering the cloud, remain fairly steady (within a factor of two) during penetration and then drop sharply. It would be advantageous to use automatic time-intensity recorders in future operations.

The effect of aircraft "shielding" on the dose rate in the cockpit is also uncertain. Tests made at the ground, using a point source outside the aircraft, indicated that there was no appreciable shielding effect on gamma radiation due to the aircraft skin. However, equation (2) assumes that the receptor is completely surrounded by a uniform radiation field. Actually, of course, the receptor was surrounded by a "blank space" equivalent to the volume of the aircraft. No attempt has been made to correct for this. However, the effect should be small, probably less than a factor of two, since the mean free path of the gamma radiation is large compared to the dimensions of the aircraft. Experimental determination of the correction factor should be planned in connection with any future operation of this type.

IV. Aircraft Sampling in the Vicinity of the Cloud Base

Aircraft equipped with Los Alamos Scientific Laboratory (LASL) air filter tanks were available for five Dominic detonations. Approximately one-hour sampling missions were flown at altitudes from 35,000 to 48,000 feet from 2 to 5 hours after detonation. The two sampling tanks were opened simultaneously when contact with the cloud was made and remained open for the entire sampling period. As the sampling pattern was flown, dose rate readings in the cockpit were made at one-minute intervals with a hand-held AN/PDR-27J Radiacmeter with a range from 0.01 to 500 mr/hr. Sampling missions were successful on four of the five detonations and the radio-chemical analysis of the samples are reported elsewhere (5).

The dose rate readings obtained during three of the sampling missions, one for Bluestone and two for Bighorn, were sufficient to estimate the distribution and amount of activity in the cloud at sampling altitude. The results are included in figure 3 and Table II (Appendix).

Bluestone

The Bluestone cloud was sampled at an altitude of 45,000 feet at approximately 3 to 4 hours after detonation. The base of the cloud was reported to be at about 45,000 feet.

The shot-time wind data and the position of the cloud, both indicate cloud travel toward the ESE at about 15 knots. To correct for the movement of the cloud during the sampling period, the reported aircraft positions were adjusted to the sampling mid-time of 3-1/3 hours after detonation. The resulting radiation field and the actual sampling track (unadjusted) are shown in figure 4. Assuming a decay exponent of -1.2, integration of the pattern yields 520 R/HR-(miles)^3 at one hour in a 1000 foot layer. From equation (2) this is equivalent to 270 megacuries or of the total fission products produced by the detonation. The cloud covers an area of 5200 square miles at this altitude.

The sampling track appears to have covered the cloud quite well. However, the pilot reported "shine" from higher portions of the cloud during the last few minutes of sampling when he was outside of the visible cloud. The readings due to "shine" were about 100 mr/hr. It is therefore possible that a significant fraction of the in-cloud readings may also have been due to shine from the upper portions of the cloud and the estimate of the amount of activity at 45,000 feet may be high.

Bighorn

Sampling missions were flown at altitudes of 43,000 feet and 48,000 feet from 4 to 5 hours after the detonation. The base of the cloud was estimated to be at about 50,000 feet. The cloud movement was toward the southeast at about 11 knots at 43,000 feet and toward the south-southeast at the same speed at 48,000 feet. The data was adjusted to a mid-time of 4-1/3 hours at 43,000 feet and 4-2/3 hours at 48,000 feet. The actual sampling tracks (unadjusted) and radiation patterns are shown in figures 5 and 6. Integration of the pattern at 43,000 feet yields 250 R/HR-(miles)^3 at one hour in a 1000 foot layer. This is equivalent to 140 megacuries or of the device. The cloud covers an area of 6000 square miles. Integration of the pattern at 48,000 feet yields 500 R/HR-(miles)^3 at one hour in a 1000 foot layer. This is equivalent to 230 megacuries or of the fission products produced by the detonation. The cloud covers an area of 9000 square miles at this altitude.

Although the crews were not aware of any problem with "shine" on these missions, the possibility that radiation readings may have been influenced by shine from higher portions of the cloud can not be ruled out.

V. Comparison With Radiochemistry Results

The radiochemical analysis of the samples obtained on the Bluestone and Bighorn missions provides a check on the method of calculating the amount of debris present from the dose rate readings in the cloud. Tracerlab (6) has determined the total number of fissions collected in each sample, based on the number of atoms of Mo^{99} present, corrected for the fission yield of Mo^{99} for thermal fission of U^{235}. Given the total volume of air passing through the sampling tank and the average dose rate along the sampling path, we can estimate the fissions per sample by the same method that was used to estimate the fraction of the bomb in a 1000-foot layer. The volume sampled is determined from the altitude, temperature of the air, the speed of the aircraft, sampling time and the characteristics of the sampling tank and filter paper (7). The average dose rate is determined from the readings taken in the cockpit at one-minute intervals during the sampling period. From equation (2) we can calculate the gamma megacuries in the sample. Assuming that one kiloton of fission (1.4×10^{23} fissions) is equivalent to 550 gamma megacuries at one hour, we will use the conversion factor:

$$1 \text{ megacurie } (H + 1) = 2.64 \times 10^{20} \text{ fissions}$$

Table I gives the pertinent data and the fissions/sample as calculated from the dose rate readings and as determined from radiochemical analysis of the sample.

TABLE I

Comparison of Calculated and Analyzed Fissions/Sample

Shot	Altitude (Feet)	Sample Volume $(\text{Feet})^3$	Av'g Dose-Rate (MR/HR At H+1)	Calculated Fissions/Sample	Fissions/Sample (Rad Chem Analysis)
Bighorn	43,000	1.06×10^6	190	1.9×10^{14}	3.3×10^{14}
Bighorn	48,000	1.11×10^6	270	2.3×10^{14}	4.9×10^{14}
Bluestone	45,000	1.10×10^6	560	5.6×10^{14}	5.8×10^{14}

The agreement between the calculated values and the results of the sample analysis is remarkably good, considering the uncertainties due to the possibility of "shine" from other portions of the cloud, aircraft "shielding" and aircraft contamination. The calculated values for the Bighorn samples are low by about a factor of two, possibly due to the effect of the "blank space" mentioned in section III. The calculated value for Bluestone is in almost perfect agreement with the results of the sample analysis. As mentioned above, there was reason to suspect a "shine" contribution to the dose rates on this mission which may have compensated for the "blank space" effect. Additional experimental data is needed to evaluate these factors but the results indicate that the method employed on these missions is a practical and promising way to obtain the distribution of activity in a nuclear cloud.

VI. Redwing In-cloud Dose Rate Data

Redwing Project 2.66a (8) investigated the doses and dose rates experienced at various altitudes in aircraft penetrations of several nuclear clouds, all but one resulting from surface bursts. Some of these penetrations were complete traverses through the cloud. Since the altitude, the mean speed of the aircraft (7 miles per minute), the time in cloud and average dose rate are reported, these data can be utilized in the same manner as the Dominic stem penetrations to compute the fraction of the device at the penetration altitudes. The pertinent data and computed quantities are given in Table III of the Appendix. The computed device fractions are plotted in figure 3 for comparison with the Dominic data.

Several interesting features may be noted. It appears that the fraction of activity in the upper half of the stem is greater for surface bursts than for air bursts and the difference increases with altitude. The largest gradient of activity with altitude appears at about 70-80 percent of the stem height which implies that, for surface bursts, the radioactive base lies below the visual cloud base. However, this inference may not be warranted since the high activities encountered below the base may be due to the descent of fallout particles from above.

The values computed for the lower portion of the mushroom indicate about 1 to 2 percent of the total fission products per 1000 feet. Since the mushroom portion of the clouds investigated averaged about 30,000 feet in vertical extent the average activity in the mushroom must have been about 3 percent per 1000 feet. Thus, we have some basis for believing that this admittedly crude method can give at least the right order of magnitude for the activity at a given altitude even when using the average dose rate on a single pass through the cloud.

Finally, we note that the one Redwing data point for an airburst (Cherokee) gives about five times the activity indicated by the curve estimated from the Dominic data. This might be attributed to the fact that the detonation took place at a lower scaled height than any of the Dominic air bursts. The burst height was somewhat below the minimum altitude for a true air burst according to our definition ($HOB \geq 180Y^{0.4}$) and the activity distribution might be expected to be intermediate between those for air bursts and surface bursts. Although the close-in fallout measured after the Cherokee detonation was very light it was considerably more than that found after any Dominic shot. However, only one surface vessel was available for fallout measurements during the Dominic tests.

Shipboard dose rate levels never exceeded 0.1 milliroentgens/hour but the very limited number of measurements obtained do not permit us to draw firm conclusions. (These measurements, obtained at the request of the Hazards Evaluation Branch, have not been published.)

VII. Results and Conclusions

A. Activity in the Stem Cloud for Air Bursts

Although the Dominic stem penetration data leave a good deal to be desired in defining the distribution of activity in the stem, the curve in figure 3 represents a "best estimate" based on our interpretation of these data. A major uncertainty lies in the assumption that the distribution in the stem does not vary with yield. As mentioned in Section III, this curve may overestimate the activity in the lower part of the stem for the larger yields (above about 200 KT).

B. Cumulative Activity with Height in the Nuclear Cloud for Airbursts

Using the stem activity curve in figure 3, an estimate of the cumulative activity with height in the nuclear cloud was derived. The solid portion of the curve in figure 7 was obtained from the stem activity curve using an average stem height of 40,000 feet and assuming the height of the top of the stem (or visual cloud base) to be 63 percent of the cloud top height (the average for the Dominic series). Since the entire stem appears to contain less than 1 percent of the total activity, it is obvious that the activity must increase rapidly with height at or above the base of the cloud. The dashed portion of the curve represents a subjective estimate, based, in part, on the Redwing data for surface detonations, of the distribution of activity in the mushroom portion of the cloud. The activity in the mushroom is assumed to be distributed as follows:

Layer (Percent of Cloud Top Height)	Fraction of total Activity (Percent)
65-70	0.6
70-75	14
75-80	25
80-85	25
85-90	15
90-95	15
95-100	5

In sum, it appears reasonably certain that for airbursts less than 1 percent of the total activity is present in the stem and less than 0.1 percent stabilizes between the earth's surface and one-half of the cloud top altitude. The fraction of activity per unit altitude increases with height throughout the stem and the region of maximum vertical gradient, which might be termed the radiological base of the cloud, probably occurs somewhat above the visual cloud base. The peak activity per unit altitude is assumed to occur between 75 and 85 percent of the distance from the surface to the cloud top. The assumption has also been made that, for airbursts, the distribution of activity relative to the cloud top height does not vary with the nuclear yield, burst height or atmospheric conditions.

Actually the interaction of these factors must exert some influence on the activity distribution. The estimated tops and bases of the Dominic clouds indicate that the ratio of base height to top height has a tendency to decrease with increasing yield. However, the variation among detonations of about the same yield is almost as great as that for the range of yields from The mean ratio is 63 percent with individual clouds varying from 53 to 73 percent. Some of the variation may be due to errors in the estimated bases and tops, but part of the variation is undoubtedly real. There is a similar uncertainty in the height of the radiological base.

C. Partition of Activity Between Stratosphere and Troposphere

The height of the tropopause, the boundary between the stratosphere above and the troposphere below; varies with latitude, season, and daily atmospheric changes. The daily and seasonal variations are less in tropical latitudes than elsewhere. The tropopause height averaged about 54,000 feet above sea level for the Dominic tests and varied between 50,000 and 58,000 feet on individual shot days. This behavior is representative of the tropical tropopause.

Using the activity distribution in figure 7, a mean tropopause height of 54,000 feet and the mean cloud height curve in figure 1, a "typical" curve of the percent of the total debris in the troposphere as a function of yield has been calculated. The curve, shown in figure 8, is intended to be valid at time of cloud stabilization for air bursts in a tropical atmosphere. Another curve has been drawn to indicate the likely maximum tropospheric fraction assuming a high tropopause (58,000 ft.) and low cloud heights (using the lower curve in figure 1). This does not represent an absolute maximum since higher tropopauses and lower clouds may occur occasionally. In addition, the uncertainties in the activity - height curve (figure 7) make it impossible to define a meaningful and useful absolute upper limit to the tropospheric fraction. No attempt has been made to estimate the minimum tropospheric fraction, but in the megaton yield range it could be several orders of magnitude below the "typical" fraction.

The most critical uncertainty in the estimates occurs in the range from about 700 KT to about 5 megatons, where the radiological cloud base may lie in the vicinity of the tropopause. For yields less than 700 KT, the tropospheric fraction (at cloud stabilization) can be estimated within a factor of two or less. For yields above about 5 MT, the fraction in the troposphere becomes very small, although we can not yet determine precisely how small it may be.

Estimates of the tropospheric fraction for each Dominic detonation are also plotted in figure 8. These estimates were made using the activity height curve in figure 7 and the estimated cloud top and tropopause height for each shot (Table I in the Appendix).

Finally, an estimate of the kiloton equivalent of fission products stabilized in the troposphere as a function of total yield for air bursts is shown in figure 9. The "typical" and "maximum" curves were derived from the curves in figure 8, assuming the yield to be entirely due to fission. For thermo-nuclear devices, the amount in the troposphere should be multiplied by the fission fraction of the device. Several interesting features may be noted. The maximum tropospheric contamination is produced by bursts in the low megaton range (assuming 100 percent fission yield). With typical cloud heights and an average tropopause height of 54,000 feet the maximum tropospheric contamination is about 500 KT for yields between about 800 KT and 2 megatons. As the yield increases the tropospheric debris decreases rapidly and then levels off at about 5 kilotons of fission equivalent for yields from 10 MT to 100 MT. The maximum curve, based on a high tropopause and low cloud heights is quite similar, with a maximum tropospheric contamination of about 1.5 megatons for yields between 2 and 3 megatons, all fission. This curve also decreases rapidly and then levels off at about 12 kilotons of tropospheric debris for yields between 15 MT and 100 MT. It should be recalled here that these curves are based on the activity-height curve in figure 7 and are subject to the same uncertainties.

D. Dominic Debris in the Troposphere

Using the estimated tropospheric fraction (figure 8) and the fission yield (Table I, Appendix) for the individual Christmas Island detonations, it is estimated that of the total radioactivity, initially stabilized in the troposphere. The uncertainty in this figure is less than Since a half-residence time of one month is generally accepted for tropospheric debris (9), one might expect to find somewhat more than equivalent of debris deposited at the surface, mostly in tropical latitudes, within a month of the conclusion of the test series. A rough integration (10) of the activity collected by the USAEC, Health and Safety Laboratory Monthly Fallout Deposition collections, indicated that only about was deposited in the latitude band from 30°N to 30°S through August 1962. This result is not inconsistent, considering the uncertainties in the tropospheric fraction and deposition estimates. However, there are several reasons for believing that the amount deposited in the latitude band was actually less than half the tropospheric fraction.

First, some of the debris which initially stabilized below the tropopause may have ascended into the stratosphere in convective cells or as a result of thermally induced direct circulation.

Second, some debris was transported to mid-latitudes at altitudes below the tropical tropopause. Since there is a polar tropopause in mid-latitudes, generally between 30,000 and 40,000 feet, the debris which was transported away from the equatorial region at altitudes from about 40,000 to 55,000 feet would become incorporated into the mid-latitude stratosphere. An interesting example of this is provided by the interception of the Questa cloud by sampling aircraft over the western United States (11). In addition, the lower stratosphere over the United States appears to have contained fresh debris from the Christmas Island tests during most of the month of May, 1962 (11).

Finally, the evidence for a half-residence time of one month for tropospheric debris may actually apply only to debris below the polar tropopause. The residence time for debris in the troposphere, above 40,000 feet, in tropical latitudes has not been established. Only a very small fraction of the debris from the Christmas Island tests stabilized below 40,000 feet. The fraction was much smaller than that for previous Pacific test series which consisted primarily of surface bursts.

In any case, it has become increasingly evident that the potential hazard due to short-lived fission products, is not attributable solely to the portion initially injected in the troposphere. The tropopause is not an impermeable membrane; there is an exchange of air between the stratosphere and troposphere. Therefore, the three-dimensional trajectory of the debris-laden air would have to be considered in determining the fate of a particular debris cloud.

It has also been shown (11) that severe thunderstorms which penetrate the lower stratosphere provide an effective mechanism for bringing stratospheric debris directly to the ground. It appears that the thunderstorm scavenging of stratospheric debris from the Christmas Island tests accounted for most of the Iodine-131 found in milk in the midwestern United States in May 1962.

VIII. <u>Recommendations for Future Work</u>

Project Stemwinder has shown in-cloud dose rate monitoring by aircraft to be a relatively simple and economical way to obtain useful information on the distribution of radioactive debris in nuclear clouds. Tentative answers have been found for the questions which prompted the effort, but large uncertainties still exist. The experience gained with Project Stemwinder indicates that the lower stem should be monitored soon after cloud stabilization, while it is still visible, and that several penetrations should be made at each altitude to insure that representative readings are obtained. Additional data is particularly needed for yields in the megaton range.

An obvious limitation of Project Stemwinder was the aircraft ceiling of 50,000 feet. The determination of the amount of debris initially stabilized in the troposphere requires sampling to an altitude of 60,000 feet. Aircraft with this capability have been used for cloud sampling but were not available to the Stemwinder project.

The following recommendations are offered for the conduct of future operations should the opportunity present itself.

A. A continuous recording gamma intensity instrument package with a range from 1 mr/hr to 1000 R/hr should be used for aircraft cloud penetrations.

B. Experimental determination of the dose rate reduction due to the aircraft should be attempted.

C. The extended sampling missions near the base of the cloud were limited to one-hour sampling time for Project Stemwinder. This limit should be extended to two hours where radiation safety considerations permit.

D. Missions should be flexible and there should be voice contact between the project director and the aircraft during the entire mission. The project director should follow the track of the aircraft on radar. The pilot can report his visual observations of the cloud, dose rates he is encountering and any other information which might aid in obtaining complete coverage of the cloud at the chosen altitude.

E. The project personnel should debrief the pilot and navigator immediately upon termination of the mission to record their impressions and discuss any questions concerning the information obtained on the mission.

F. If the opportunity presents itself, an attempt should be made to monitor the entire cloud from a low or intermediate-yield detonation. Thus, the distribution of activity throughout the entire cloud can be ascertained and the total computed activity can be compared with the fission yield of the device as a check on the method.

Acknowledgments

Project Stemwinder was originally conceived and coordinated by Joshua Holland, Chief, Fallout Studies Branch, Division of Biology and Medicine, USAEC, whose vigorous efforts brought the project into being in the space of a few weeks prior to the start of Operation Dominic.

The ideas and efforts of the late A. Vay Shelton of the Lawrence Radiation Laboratory (Chief of the Hazards Evaluation Branch for Dominic I) and Robert J. List, Kosta Telegadas and Jerome L. Heffter of the Atmospheric Radioactivity Research Project, U. S. Weather Bureau, were instrumental in planning and carrying out the project.

The excellent cooperation and high skill of Paul Guthals (Los Alamos Scientific Laboratory) and Harry Hicks and Dr. E. Fleming (Lawrence Radiation Laboratory) in directing and controlling the sampling aircraft contributed much to the success of the project.

Our thanks are also due to Col. Templeton Walker, Commander, 9th Weather Recon Wing, and to all the members of the 1211th Test squadron who displayed great enthusiasm and a high degree of professional competence in carrying out the sampling missions.

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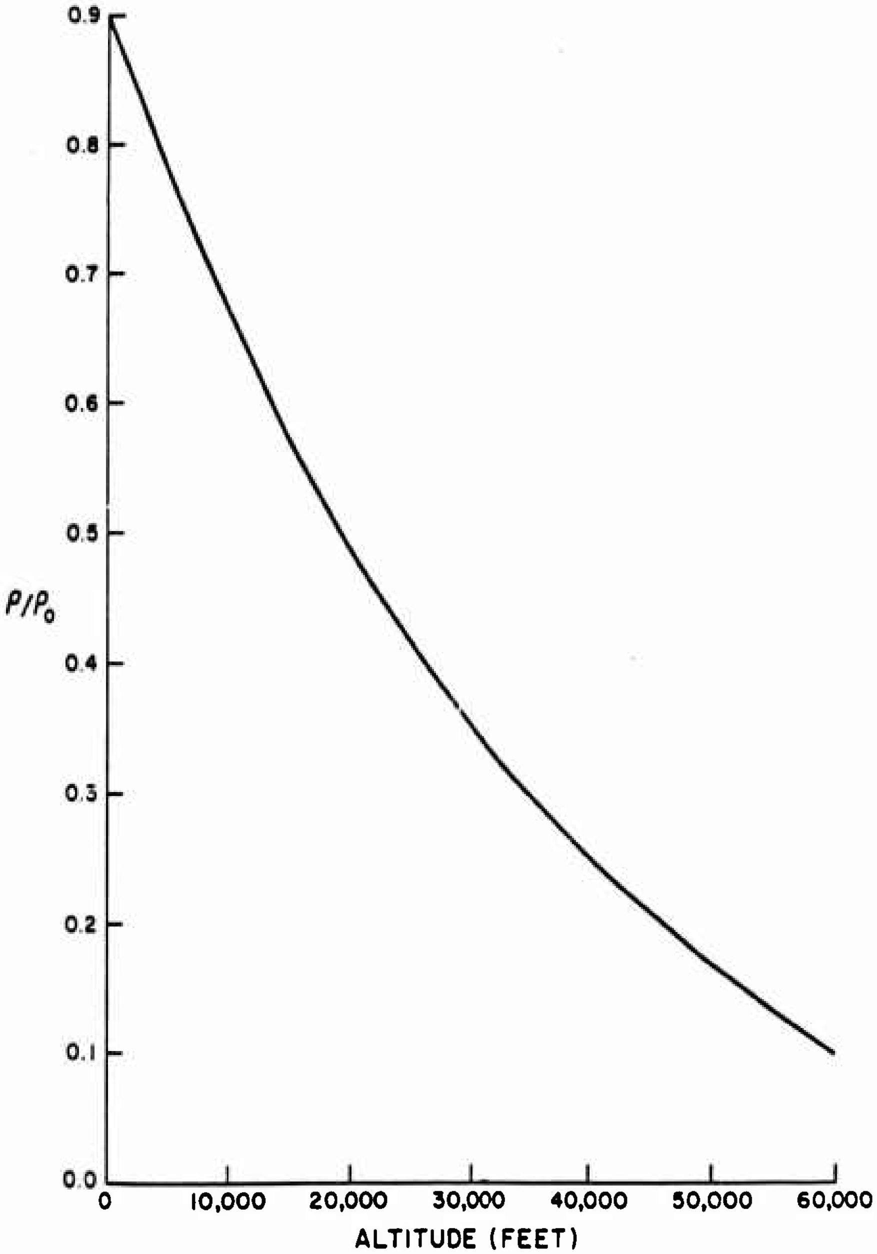

Fig. 2 Ratio of air density (ρ) to standard sea level air density (ρ_o = 1.293 x 10^{-3} g/cm^3) as a function of altitude.

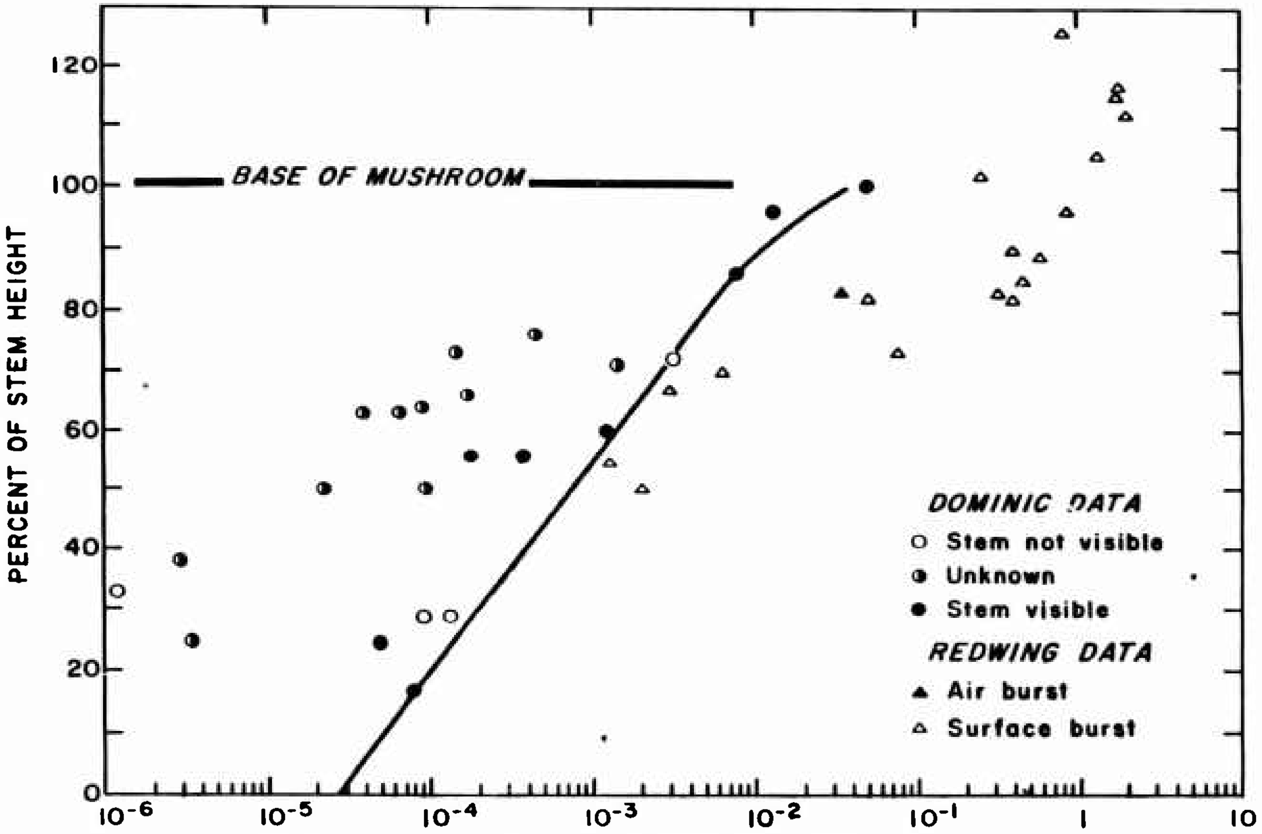

Fig. 3 The variation with height of the percent of the total activity residing in a 1000-foot horizontal layer of the cloud.

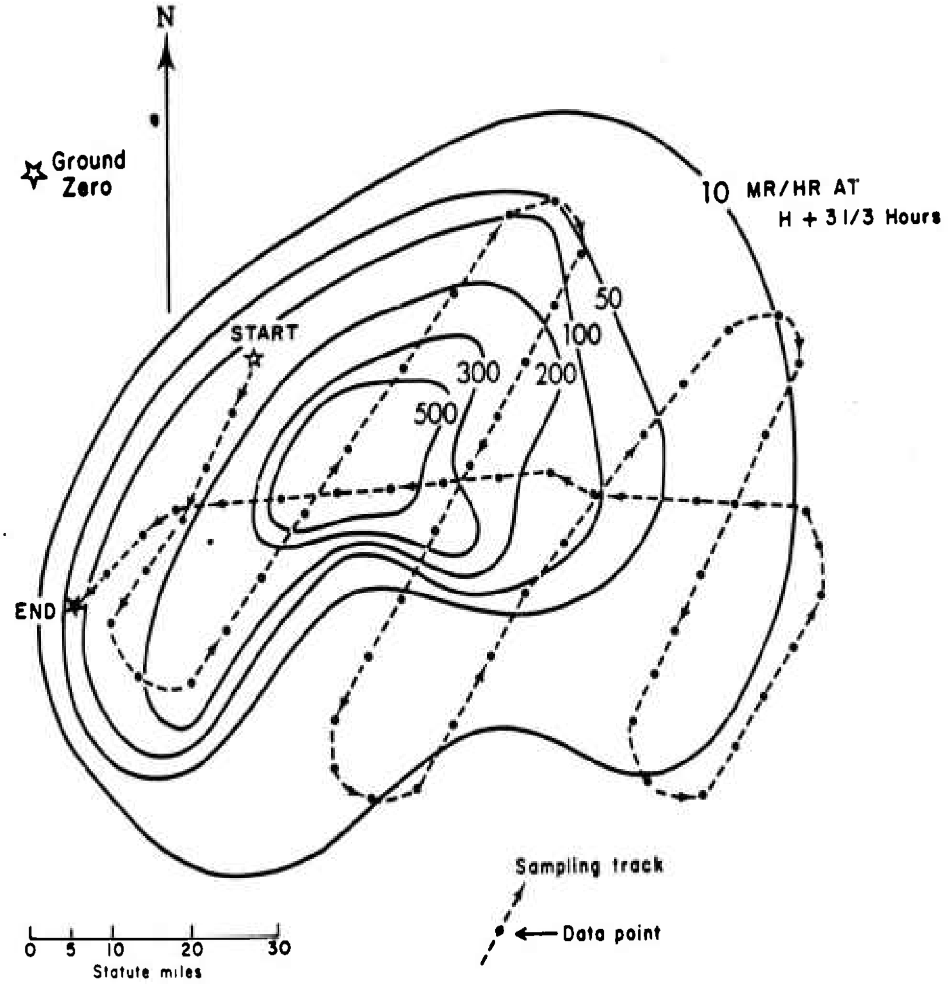

Fig. 4 Sampling track and radiation pattern in the Bluestone cloud at 45,000 feet.

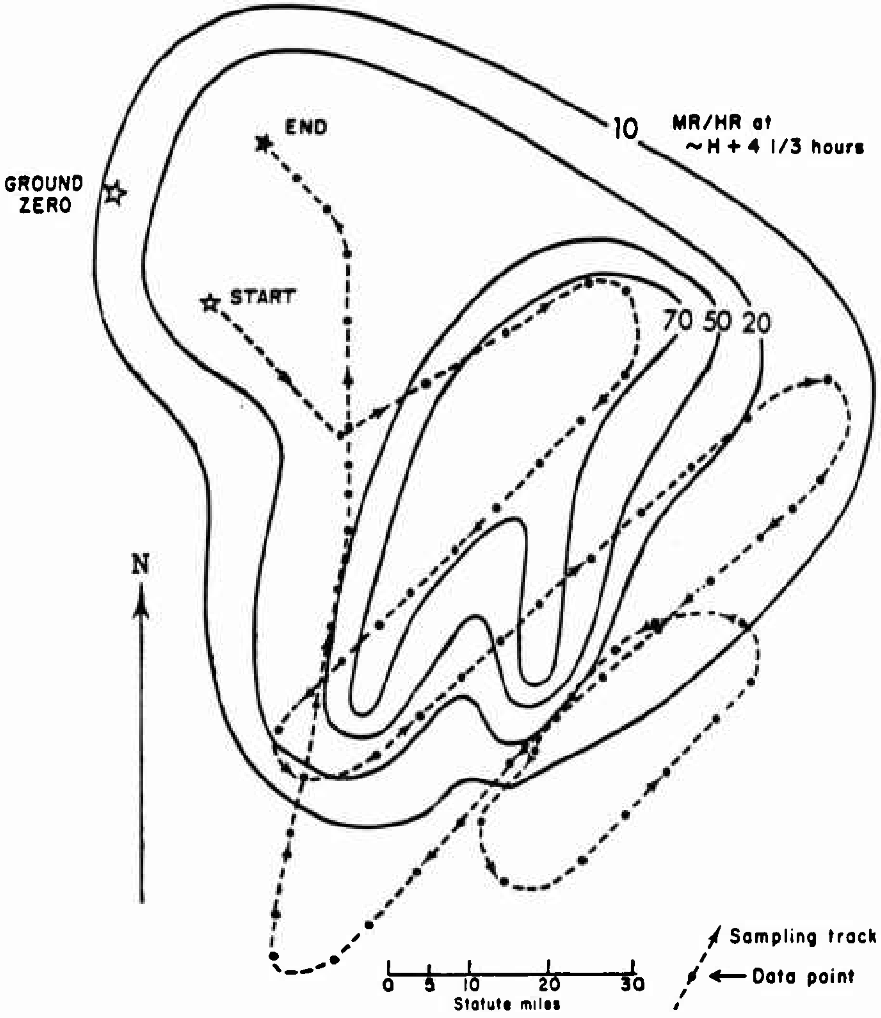

Fig. 5 Sampling track and radiation pattern in the Bighorn cloud at 43,000 feet.

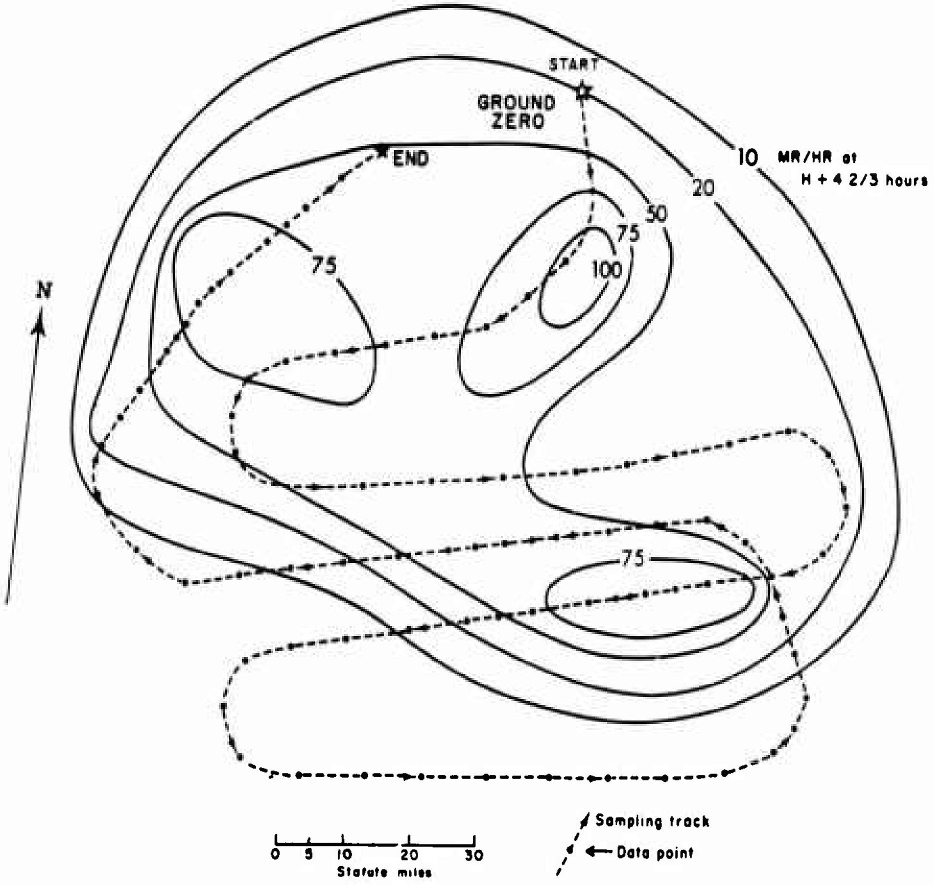

Fig. 6 Sampling track and radiation pattern in the Bighorn cloud at 48,000 feet.

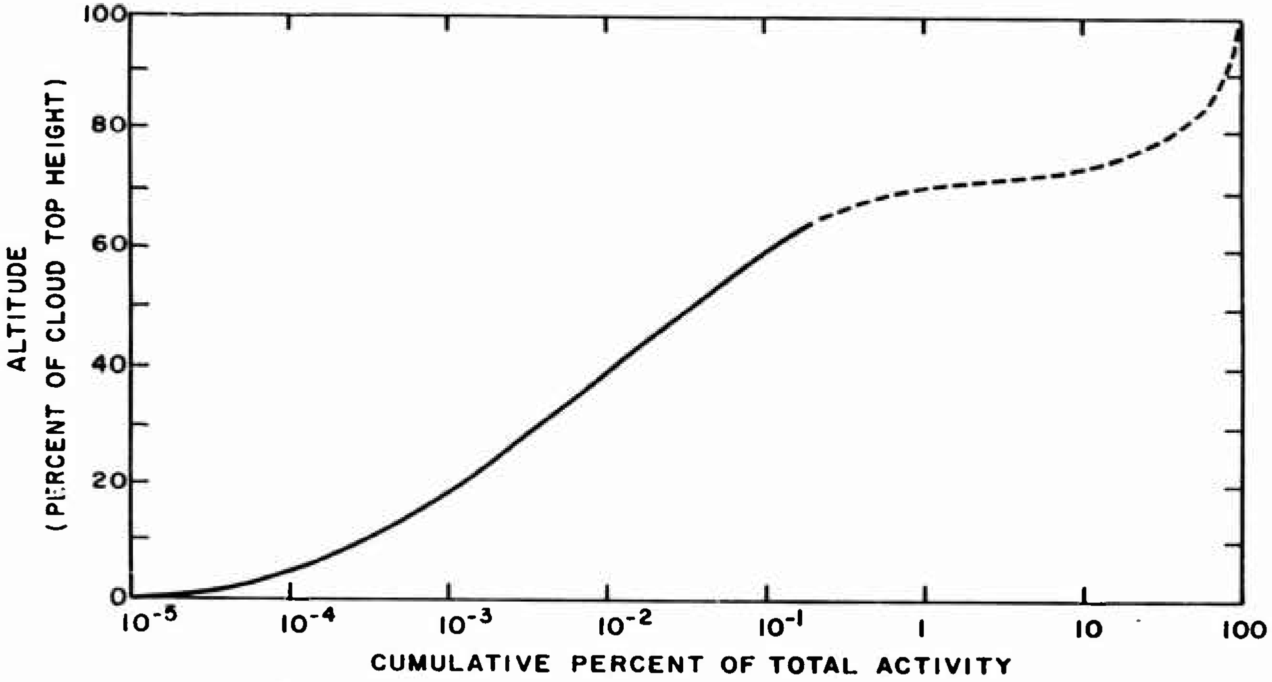

Fig. 7 Cumulative activity as a function of height in the nuclear cloud for air bursts.

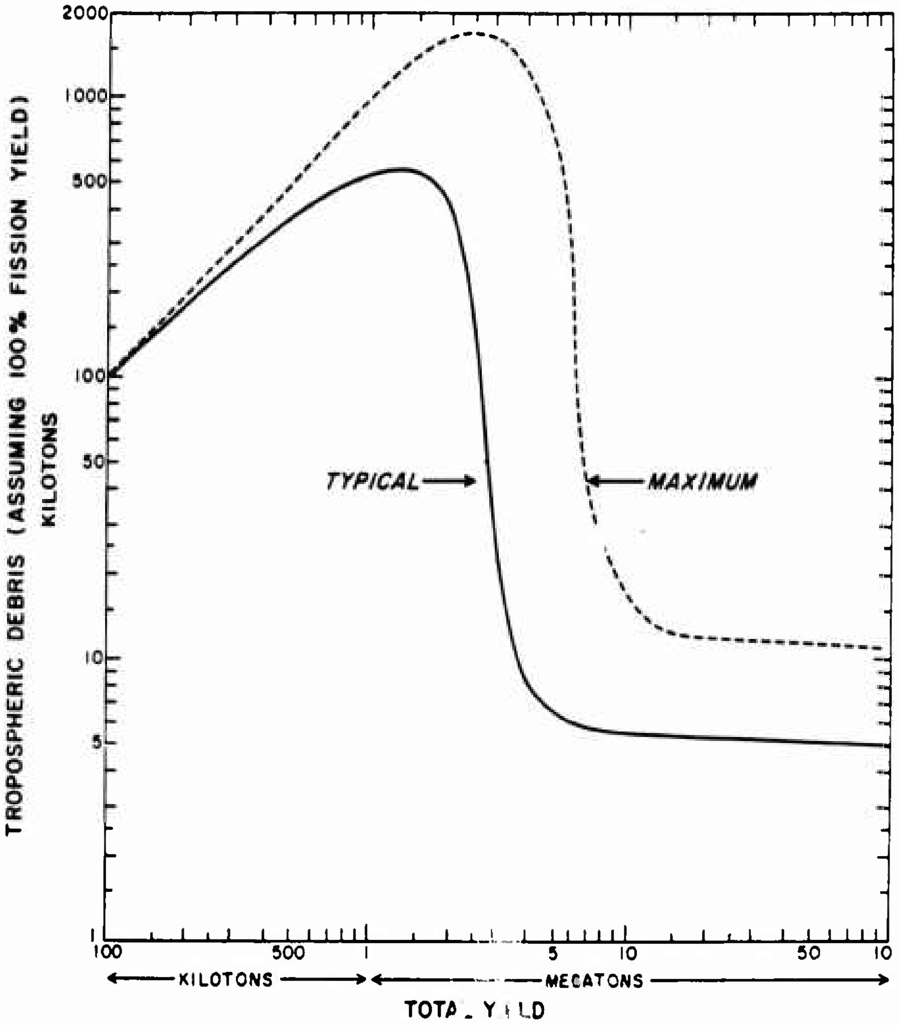

Fig. 9 Amount of debris (kilotons equivalent) initially injected in the troposphere as a function of total yield for air bursts in a tropical atmosphere.

Appendix

NOTES ON TABLE I

1. Johnston Island detonations are not included.
2. Yields and Height of Burst are approximate and subject to revision. (Obtained from Division of Operational Safety, AEC, December 1963.)
3. Cloud Tops and Bases are estimates based on visual observations and In-cloud dose rates (See Section II).
4. ( ) Indicates data estimated from past detonations. No observations available.
5. * Frigate Bird detonated at ~ 4°50'N 149°25'W

TABLE I

DOMINIC I - CHRISTMAS ISLAND SHOT DATA

Name	Date (1962)	Total Yield (KT)	Fission Yield (KT)	Cloud Top	Cloud Base	Height of Burst	Tropopause Height
				(Thousands of Feet)			
ADOBE	Apr 25			55	35	2.7	56
AZTEC	Apr 27			62.5	35	2.8	54
ARKANSAS	May 2			62	45	5.3	54
QUESTA	May 4			62	40	5.4	56
FRIGATE BIRD*	May 6			62	40	11.0	56
YUKON	May 8			57	35	2.8	57
MESILLA	May 9			55	36	2.5	55
MUSKEGON	May 11			52	30	3.0	52
ENCINO	May 12			62.5	40	5.4	53
SWANEE	May 14			58	35	2.7	56
CHETCO	May 19			55	36	6.9	58
TANANA	May 25			23	18	9.0	58
NAMSE	May 27			60	40	7.1	55
ALMA	Jun 8			65	40	8.9	54
TRUCKEE	Jun 9			60	40	7.0	54
YESO	Jun 10			79	45	8.8	53
HARLEM	Jun 12			65	45	13.6	51
RINCONADA	Jun 15			65	40	9.1	50
DULCE	Jun 17			57	35	9.1	53
PETIT	Jun 19			24	20	15.0	54
OTOWI	Jun 22			57	40	9.0	53
BIGHORN	Jun 27			(94)	50	12.2	53
BLUESTONE	Jun 30			(65)	45	4.8	52
SUNSET	Jul 10			(65)	40	5.6	54
PAMLICO	Jul 11			(82)	(45)	14.0	53

NOTES ON TABLE II

COLUMN	COMMENT
1	The unclassified code name for the detonation .
2	Fission yields are approximate. Obtained from Division of Operational Safety, AEC in December, 1963.
3	Altitude at which aircraft penetrated the cloud.
4	Penetration altitude expressed as a percent of the altitude of the base of the mushroom cloud.
5	Indicates whether the stem was visible to the pilot at the penetration altitude. (?) indicates visibility is not known.
6	Values given are rough estimates of the stem diameter at the time and altitude of penetration. In a few cases, visual observations and aircraft "time-in-cloud" data were available. Bighorn and Bluestone diameters were estimated from figures 4-6. In other cases estimates are based on observations at other altitudes and/or other detonations of similar yield.
7	Represents the volume of a 1000-foot deep layer of the stem, centered at the penetration altitude, computed from the diameter given in column 6.
8	The time, after detonation, of the aircraft penetration.
9	The dose rate measured during penetration with a hand-held instrument in the rear seat of the aircraft.

TABLE II (Continued)

COLUMN	COMMENT
10	A decay exponent of -1.2 was used to convert dose rates to one hour after detonation.
11	Relative air density at penetration altitude obtained from figure 2.
12	The one hour dose-rate (column 10) was converted to activity concentration in megacuries/(mile)^3 using equation 2, page 4.
13	The data in columns 7 and 12 were used to determine the amount of activity in a 1000-foot layer centered at the penetration altitude.
14	It is assumed that 1 KT of fission produces 550 gamma megacuries at one hour after detonation (Glasstone, Effects of Nuclear Weapons, April 1962.)
15	The activity per 1000-foot layer (column 13) is expressed as a percent of the total activity produced by the detonation (column 14).

TABLE II

STEM-INDER DATA

(1) Shot Name	(2) Fission Yield (KT)	(3) Penetration Altitude (FT)	(4) Percent of Stem Height	(5) Stem Visibility	(6) Stem Diameter (Statute Miles)	(7) Layer Volume (Miles^3/1000 Ft)	(8) Time (Minutes)	(9) Dose-rate (MR/HR)	(10) Dose-rate (MR/HR at H+1)	(11) Relative Air Density (ρ/ρ_o)	(12) Activity Concentration (Mc/Mile^3)	(13) Activity in layer (Mc/1000 Ft)	(14) Total Activity in Device (Mc at H+1)	(15) Percent of Total Activity in layer (% Per 1000 Ft)
ARKANSAS		15,000	33	No	3	1.35	29	6	2.5	0.57	.0030	.0040		
		15,000	33	No	3	1.35	32	3	1.5	0.57	.0018	.0025		
		15,000	33	No	3	1.35	37	6	3.5	0.57	.0042	.0057		
		25,000	56	Yes	6	5.4	50	250	200	0.41	.17	.94		
		25,000	56	Yes	6	5.4	57	400	400	0.41	.35	1.9		
QUESTA		10,000	25	?	2	0.6	18	50	11	0.67	.016	.010		
		10,000	25	?	2	0.6	25	12	4	0.67	.006	.0036		
		15,000	38	?	3	1.35	30	9	4	0.57	.005	.0067		
		15,000	38	?	3	1.35	33	10	5	0.57	.006	.0081		
		20,000	50	?	3	1.35	38	80	45	0.48	.046	.062		
		20,000	50	?	3	1.35	42	40	27	0.48	.027	.037		
		25,000	63	?	4	2.4	50	70	53	0.41	.046	.11		
		29,000	73	?	5	3.75	55	170	140	0.36	.11	.41		
		30,500	76	?	5	3.75	65	200	220	0.34	.16	.60		
		30,500	76	?	5	3.75	69	400	470	0.34	.34	1.27		
YUKON		10,000	29	No	2	0.6	18	50	12	0.67	.017	.010		
		10,000	29	No	2	0.6	20	150	36	0.67	.051	.031		
		10,000	29	No	2	0.6	22	180	55	0.67	.078	.047		
		10,000	29	No	2	0.6	26	170	60	0.67	.085	.051		
		25,000	72	No	3	1.35	33	1800	900	0.41	.78	1.1		
		25,000	72	No	3	1.35	39	> 2000	>1200	0.41	>1.0	>1.4		
		25,000	72	No	3	1.35	47	> 2000	>1500	0.41	>1.3	>1.8		
		25,000	72	No	3	1.35	51	1800	1500	0.41	1.3	1.8		
		21,000	60	Yes	3	1.35	54	600	520	0.47	.52	.70		
ENCINO		25,000	63	?	4	2.4	32	100	46	0.41	.040	.096		
		25,500	64	?	4	2.4	37	120	62	0.41	.054	.13		
		26,500	66	?	4	2.4	44	180	130	0.39	.11	.25		
		28,500	71	?	4	2.4	49	1400	1100	0.37	.86	2.10		
ALMA		20,000	50	?	3	1.35	15	1300	240	0.48	.25	.33		
TRUCKEE		10,000	25	Yes	2	0.6	10	500	55	0.67	.078	.047		
		7,000	17	Yes	2	0.6	14	500	85	0.74	.13	.078		
DULCE		10,000	29	No	2	0.6	20	150	40	0.67	.057	.034		
		10,000	29	No	2	0.6	24	4	1.4	0.67	.0020	.0012		
		10,000	29	No	2	0.6	26	5	1.7	0.67	.0024	.0014		
		10,000	29	No	2	0.6	27	30	11	0.67	.016	.010		
BIGHORN		43,000	86	Yes	85		260			0.22		140.0		
		48,000	96	Yes	100		280			0.18		230.0		
BLUESTONE		45,000	100	Yes	80		200			0.21		270.0		

TABLE III

REDWING CLOUD PENETRATION DATA*

(1) Shot Name	(2) Total Yield (KT)	(3) Fission Yield (KT)	(4) Burst Height (FT)	(5) Cloud Top (FT)	(6) Cloud Base (FT)	(7) Diameter (St. Miles)	(8) Penetration Altitude (FT)	(9) Percent of Stem Height	(10) Dose Rate (R/HR)	(11) Time (Min)	(12) Percent of Total Activity (% Per 1000 Ft)
FLATHEAD			Surface	65,000	35,000	12	44,000	126	130	58	
CHEROKEE			4300	80,000	52,000	34	43,000	83	3.6	75	
DAKOTA			Surface	77,000	50,000	9	35,000	70	6.0	28	
						26	41,000	82	6.0	34	
						23	45,000	90	60	38	
						25	48,000	96	120	42	
APACHE			Surface	69,000	40,000	2.4	20,000	50	18	53	
						25	33,000	83	36	45	
						29	41,000	102	75	20	
						56	42,000	105	42	44	
						40	45,000	112	180	34	
						42	46,000	115	180	28	
						40	47,000	117	180	35	
NAVAJO			Surface	85,000	55,000	6	30,000	55	0.9	33	
						8	37,000	67	1.8	27	
						27	40,000	73	6.0	22	
						32	45,000	82	21	25	
						32	47,000	85	25	27	
						39	47,000	89	15	38	

* This table is based on data reported in reference 6.

Notes:

COLUMN	COMMENT
7	The diameter of the cloud at the time and altitude of penetration was estimated from the reported time-in-cloud and the reported aircraft speed of 7 miles per minute.
9	Penetration altitude is expressed as a percent of the stem height. Altitudes above the base of the cloud are indicated by values over 100 percent.
12	These values were computed in the same manner as those in column 15 of Table II.

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