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Project 7.5
Dispersion of Gaseous Debris from Nuclear Explosions

P. W. Allen
Headquarters United States Air Force
Washington, DC

November 1952

NOTICE:
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19. ABSTRACT (*Continue on reverse if necessary and identify by block number*)

This project was designed to provide information for the solution of two problems: (1) dispersion of gaseous debris; and (2) initial cloud dimensions.

Observations that were made indicated that the major portion of the Mike cloud entered the stratosphere--the cloud top reached 120,000 feet with the mushroom base at about 67,000 feet. The tropopause height at the time of the detonation was about 58,000 feet. The top of the King cloud reached about 74,000 feet with the mushroom base at about 40,000 feet.

Samples for the measurement of the world-wide distribution of induced gaseous activity (tritium and carbon-14) were taken at widely separated geographical positions, including both northern and southern hemisphere points. These samples were periodically collected at each location over a period of six months following the detonations.

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OPERATION IVY—PROJECT 7.5

Report to the Scientific Director

DISPERSION OF GASEOUS DEBRIS FROM NUCLEAR EXPLOSIONS

Philip W. Allen

Headquarters United States Air Force

Washington, D.C.

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.

ABSTRACT

Observations were made to determine the approximate initial vertical distribution of visible debris from the Mike and King detonations. The major portion of the Mike cloud entered the stratosphere—the cloud top reached about 120,000 feet with the mushroom base at about 67,000 feet. The tropopause height at the time of detonation was about 58,000 feet. The top of the King cloud reached about 74,000 feet with the mushroom base at about 40,000 feet.

Samples for the measurement of the world-wide distribution of induced gaseous activity (tritium and carbon-14) were taken at widely separated geographical positions, including both northern and southern hemisphere points. These samples were periodically collected at each location over a period of six months following the detonations. The results of this sampling produced no worthwhile information as to the world-wide distribution of the gaseous debris.

PREFACE

This report is intended to present the information obtained from this project's participation in Operation Ivy. Emphasis is placed on data presentation in this report.

CONTENTS

Chapter I
INTRODUCTION

1.1 OBJECTIVE

This project was designed to provide information for the solution of two problems encountered by the United States Air Force.

1.1.1 Dispersion of Gaseous Debris. The design of a network for surface (or near surface) collection of gaseous debris from a foreign thermonuclear explosion depends upon the time required for the gases to diffuse down to the earth's surface from the major portion of the cloud. The primary objective of this project was to locate approximately the initial incidence and maximum surface concentrations of gaseous debris from the explosion.

1.1.2 Initial Cloud Dimensions. The initial altitude of the gaseous debris from a thermonuclear explosion probably determines to a great extent the subsequent surface concentrations of the gases and their point of incidence at the surface. The secondary objective of this project was to determine the approximate vertical distribution of debris.

1.2 DISCUSSION

1.2.1 Theory of Cloud Rise. The fireball of an atomic device exploded on or near the surface of the earth is composed of vaporized bomb components and earth or water, or both, depending upon the surface over which detonated. Although these are at extremely high temperature in the fireball, they cool very rapidly by radiation and expansion, probably condensing to liquid or even reaching solid form soon after the cloud starts rising. Evidence for this is that the gaseous ball loses its initial brilliance after a few seconds, becomes reddish in color, and in a few more seconds a smoky dark envelope—probably solid particles and condensed moisture—obscures the hot, inner material. At this time the buoyancy is not then due to low-density debris gases, but is due to the heated air in which the debris is carried. Being air, further expansional cooling should follow approximately the dry adiabatic lapse rate for air changing to a moist adiabatic lapse rate when condensation of moisture begins. (It is possible that the heat released by the cooling particles may tend somewhat to retard the cooling of the mass of air in which the debris is carried—this retarded cooling effect may more than offset the cooling due to mixing with entrained cool air.)

It would appear highly improbable that any meteorological feature of the atmosphere could have an appreciable effect upon the rise of the debris cloud during the period when the latter's temperature greatly exceeds the ambient air temperature. As the temperature

of the debris cloud approaches the ambient air temperature, it is possible that the energy of the atmosphere could have a marked effect upon the further development of the debris cloud. The cloud should continue to rise until its density reaches that of the surrounding atmosphere. The one factor which apparently contributes greatest to the maximum height reached by the debris cloud is the yield of the device. Greater yields produce more heat and larger fireballs which require longer to mix into the air and more expansion to cool and, therefore, reach greater heights before coming to equilibrium with the atmosphere.

1.2.2 Dispersion of Gaseous Debris. The detection and identification of a thermonuclear detonation might possibly be made through the presence of tritium and carbon-14—collectible as tritium-bearing water vapor or carbon dioxide containing carbon-14. The initial distribution of these gases in a nuclear debris cloud and the subsequent diffusion rate are very important considerations in the design of a net of stations for the collection of these products from such events. If these gases diffuse rapidly to the lower atmosphere or are present in large quantity in the lower cloud stem, samples of them may be obtained easily as soon as the air in which they are carried comes within the reach of U.S. aircraft. If, however, these gaseous products are initially confined to the upper levels and diffuse downward quite slowly, collection of these gases would be possible only after considerable time and at probably great distances from the point of detonation. In this case it would be necessary to place collecting stations, or sampling flights, at great distances from the test areas, and possibly, even to locate stations at intervals over an appreciable portion of the earth's surface to ensure collection.

The thermostability that characterizes the lower part of the stratosphere is responsible for a rather general belief that little or no vertical mixing occurs in this region. This concept is countered by observations which suggest the presence of turbulence at these altitudes. For example, the constant-level balloons flown by General Mills, Inc., and New York University have shown vertical oscillations of 1,000 feet or more over a period of minutes. Also, the gustsondes parachuted from balloons at altitudes over 70,000 feet by the National Advisory Committee for Aeronautics constantly recorded moderate turbulence in the stratosphere. Whether these indications are real turbulence or are indications of wave motion rather than mixing is not clear.

Under any circumstance, it is considered essential that samples of any gaseous products be obtained as soon as possible after detonation.

Chapter 2
PROCEDURE

2.1 CLOUD HEIGHT MEASUREMENTS

Three surface vessels and three aircraft were used as platforms for making cloud-height measurements. Observers aboard these vehicles used navigation sextants to measure the elevation angles to the tops of the clouds and other prominent cloud features, and to get the angular width of the cloud. Radar on the surface vessels was used to make some height measurements and measurements of distance between the vessels and ground zero.

2.2 LONG-RANGE MEASUREMENTS OF GAS DIFFUSION

2.2.1 Procedure. The only long-lived radioactive gaseous isotopes which would be released or induced in large quantity by the Mike device (which are not already present in the atmosphere in large quantity) are tritium and carbon-14.

It was expected that tritium would be present in atmospheric moisture; as such it would be carried down and reduced by rainfall. The approach to sampling, therefore, was to obtain samples of atmospheric moisture as it reached the earth's surface.

Carbon-14, existing as carbon dioxide or monoxide, would be subject to scavenging by vegetation and to dilution by animals, combustion and manufacturing processes. Hence, sampling for carbon-14 was accomplished by collecting samples of free air at altitudes of about 18,000 feet.

Sampling programs were set up to obtain data designed to show any appreciable change in the concentrations of these two isotopes in the atmosphere over a period of months following the Mike detonation.

2.2.2 Collection Devices and Locations. Tritium Samples. For tritium samples atmospheric moisture was collected either by direct rainfall or by small dehumidifiers in areas where rainfall might be infrequent during critical winter months.

Approximately one-gallon samples of atmospheric water were collected using Carrier Corporation Model 53 F-2 dehumidifying units. This type of dehumidifier utilizes a freon cooling coil for removal of moisture from the air. From 6 to 20 hours were required to collect a sample of this size dependent on the meteorological conditions at the particular location. These dehumidifiers (called "humidry" units) were placed in operation at the following sites where rainfall is normally infrequent during winter months

Hickam AFB, Hawaii; and Anderson AFB, Guam.

Samples of natural rain water, utilizing a standard rain gage as a collector, were collected at

The stations at Hawaii and Guam collected samples daily for a period of two weeks following the Mike detonation. All of the others started background sampling on or about

1 October 1952, and continued collecting one sample per week for six months following the Mike shot.

Carbon-14 Samples. Free air samples for carbon-14 measurements were obtained by aircraft operating from six Air Force Bases at various points in the northern hemisphere. To collect the air samples, aircraft were equipped with an inlet duct located on the forward section of the fuselage, an internal installation consisting of a Quincy compressor and five standard Air Force low-pressure oxygen bottles, and the necessary transfer plumbing and fittings to complete the system. Whole air samples of approximately 600 cubic feet stored at 200 - 250 psi were collected by this method in approximately one hour of operation and shipped to the laboratory without transfer from the original collection containers. Samples were collected at the rate of two samples (five bottles constitute one sample) per month per location for a period of several months. Whole air samples were collected by aircraft operating from the following locations: ; Anderson AFB, Guam, Eielson AFB, Alaska; Hickam AFB, Hawaii; and McClellan AFB, California.

Chapter 3
RESULTS

3.1 HEIGHTS OF RADIOACTIVE CLOUDS

It was not the purpose of this project to document accurately the rise and development of the clouds, but rather to obtain certainly and quickly the cloud height with an accuracy of about ±10 percent. It was believed that this could be accomplished reasonably well by several observers at different positions, each utilizing simple equipment. Results proved that a height value could be obtained quickly, since cloud-height values were received in Washington, D.C. within 12 hours after the explosion. However, the variety of cloud heights obtained by the different observers surely indicates that the desired ±10 percent maximum probable error in the results was not accomplished.

3.1.1 Mike Cloud. Height observations were made from three surface vessels and two aircraft. In addition, some cloud-width observations were taken by one of the observers aboard a surface vessel and by an observer in a third aircraft. Data recorded by the individual observers and their positions are as listed in Tables 3.1 through 3.6, inclusive.

Unfortunately, the cloud spread out very rapidly and the top was hidden from the surface observers before it stopped rising. The airborne observers were in the best position for making measurements, but large errors are probable in the calculation of the cloud height from the uncertainties in the base line distance to the cloud at the time of the observation. Of all observations made, those from Aircraft No. Mike 1 (Table 3.1) must be considered most reliable. Aircraft No. Mike 1 was at the greatest distance from the cloud—about 70 miles—and was in a position to see the actual cloud top until it stabilized. Also, the aircraft position at the time of each observation was fairly closely defined.

A rough estimate of the true cloud height may be obtained from the surface observation by subtracting a quantity R sin A, where R is the radius of the cloud at the time of the observation and A is the elevation angle to this apparent cloud top, from the base-line distance from the point of detonation to the observation position. Corrections of this nature bring the surface and aerial measurements toward better agreement but still do not provide satisfactory results. No corrections were made for cloud drift, because the cloud reached 80,000 feet within two minutes and the winds above that height were nearly calm. High-altitude wind data just prior to the Mike detonation are tabulated in Table 3.7.

Radar measurements of cloud heights were completely unsatisfactory because it was impossible to determine the portion of the cloud producing the reflection. However, the radar did provide reliable information on the distance of the observer from the detonation point.

The height of the base of the mushroom cloud ranges from 31,200 feet to 77,500 feet, as computed from the measurements recorded by different observers. The measurement by the observer from Aircraft No. Mike 1 of 67,000 feet is probably a valid figure, in that he reported observing the junction point of the cloud stem and the main upper portion and used that point for the measurements. This figure agrees well with photographs of the cloud at 10 minutes, which shows the mushroom body of the cloud to amount to about half of the total height. It is possible that surface observers may have measured either a

lower-shear layer (at 27,000 feet as reported by Aircraft No. Mike 1) or the far edge of the mushroom base. Corrections applied, considering the latter possibility as a source of error, bring the observations made from the U.S.S. Estes and the U.S.S. Curtiss up to between 60,000 and 70,000 feet.

Several observations were made of the width of the mushroom cloud between 10 minutes and 55 minutes after detonation. A determination of cloud width at 30 minutes may be deduced from recorded observations. The edge of the cloud arrived directly overhead of the U.S.S. Estes at 30 minutes when its position was 26 nautical miles southeast of ground zero. At this time an observer aboard an aircraft positioned to the east of the cloud reported that it appeared the cloud had shifted southward so that about 10 percent more of the cloud lay south of ground zero than to the north. Making this correction to the position of the U.S.S. Estes at 30 minutes, a cloud radius of about 23 nautical miles at 30 minutes is obtained.

3.1.2 King Cloud. The same technique was used for observing the height of this cloud. Two aircraft and two surface vessels were used as observation platforms. Cloud-width observations were made by the observer aboard the U.S.S. Oak Hill. Data recorded by the observers are reported in Tables 3.8 through 3.12 inclusive.

Aircraft No. King 1 was positioned south of the detonation point at an altitude of 10,700 feet. Aircraft No. King 2 was positioned to the north at an altitude of 42,000 feet. The U.S.S. Rendova was about 16 nautical miles south-southeast of ground zero, and the U.S.S. Oak Hill was 15 to 17 nautical miles northeast of ground zero.

The main part of the cloud moved west-southwest at a mean speed of 14 knots, as observed by radar aboard the U.S.S. Oak Hill. This is in agreement with the observed winds aloft at the time (see Table 3.13). Because of the relative positions of Aircraft No. King 1 and the U.S.S. Rendova to the direction of cloud drift, correction for the cloud drift in the calculation of cloud height from these two positions is minor. Cloud-drift corrections from the other two positions are almost exactly the drift of the cloud. The observer aboard the U.S.S. Oak Hill reported the cloud still rising after 10 minutes, while the other observers reported the cloud stabilized. This may be explained by a plume which started forming at 7 minutes and probably reached to nearly 75,000 feet where the winds shifted to west-southwest. This wind shift would have carried the plume toward the U.S.S. Oak Hill and shortened the base line, and hence, give a false indication that the cloud was still rising.

The heights obtained from the data reported from the U.S.S. Rendova are considerably greater than those from the other positions. The other observers report the cloud leaning more toward the south, in the direction of the U.S.S. Rendova, than would be expected from the winds or the radar observations. This would account for the greater heights reported from the U.S.S. Rendova. Also, a projection toward the south was reported by the other observers at 8 minutes and fading out a few minutes later. This projection may account for the series of 90,000-foot readings from 7 minutes to 8½ minutes from the U.S.S. Rendova.

The average of the mean heights obtained from the four observers between 9 minutes and 13 minutes gives 74,000 feet for the cloud height.

The base of the mushroom was measured as about 40,000 feet from the U.S.S. Oak Hill at 5½ minutes. A measurement of 43,000 feet was obtained from the U.S.S. Rendova, and Aircraft No. King 2 estimated the base at 35,000 feet. These values are not in sufficient disagreement, considering the raggedness of the base, to justify attempts at greater accuracy. The approximate height of the base of the mushroom cloud is taken as 40,000 feet.

The mushroom cloud diameter for the King shot was observed from the U.S.S. Oak

Hill. The cloud grew in a very consistent manner and reached a stabilized diameter of about 16 miles in 13 minutes. Cloud-width observations are tabulated in Table 3.12.

3.2 DISPERSION OF GASEOUS DEBRIS

Due to the time interval between initiation of a program for the measurement of dispersion of gaseous debris from nuclear detonations and Operation Ivy, it was necessary to proceed with the collection of samples before the sampling techniques were proven valid or the cost of sample processing determined. The initial selection of samples for processing was made to give, as closely as possible, a general cross section of time and space which would be the basis for determining if the program offered a reasonable chance of providing positive data. When results of the analysis of these selected samples showed that the program was not yielding desired results, further sampling was discontinued. The high cost of sample analysis did not warrant analysis of the samples remaining on hand.

Later efforts in the study of debris from nuclear devices shows that both carbon-14 and tritium can be collected in whole air samples, if the samples are collected at altitudes comparable to the height of the main debris cloud (stabilized cloud), collection is made within a few weeks after detonation, and specific precautions are made to prevent the introduction of superfluous carbon dioxide (or monoxide) and moisture into the sample. Gaseous debris from large-scale nuclear detonations does not diffuse down to low altitudes sufficiently rapidly nor in sufficient concentrations to allow the collection of the required sample at, or near, the earth's surface.

3.2.1 Atmospheric Moisture Samples. Moisture samples, in one-gallon containers, were shipped to Tracerlab, Inc., for processing and final laboratory assay. Processing included purification of the water sample by filtration and distillation, enrichment of the sample in tritium content by electrolysis, and conversion of water to hydrogen using a magnesium furnace at 600°C. Assay of the reduced hydrogen fraction for tritium was accomplished by hydrogen gas counting with a mixture of argon and propylene gas.

Results from the atmospheric moisture samples are tabulated, by collection station, in Tables 3.14 through 3.23, inclusive. These results are expressed in terms of the number of tritium atoms per 10^{18} hydrogen atoms. The normal background ratio of tritium to hydrogen atoms has been observed to be approximately 1 to 2×10^{-18} in maritime air and 3 to 5×10^{-18} in continental air.

3.2.2 Whole Air Samples. Assays for carbon-14, present as $C^{14}O_2$, and for tritium present as H^3_2O, were made for eleven of the air samples collected. Results are expressed in terms of atoms per equivalent mole of air (EMA), where EMA is defined to be the quantity of air contained in one gram molecular volume at standard atmospheric temperature and pressure. The normal atmospheric concentration, as observed by AFOAT-1, is approximately $(2.1 \pm 0.4) \times 10^8$ atoms/EMA for carbon-14 and of the order of 5×10^5 atoms/EMA for tritium.

The data for these eleven air samples are tabulated in Table 3.24. Each sample was divided into two aliquots and designated as I and II. Analyses were made both by Tracerlab, Inc., and by the Argonne National Laboratory. Data from the latter laboratory are designated by the notation ANL following the reported value. In some cases, aliquots were further divided for assay by both laboratories.

Carbon-14. The carbon-14 activity is presented in the CO_2 fraction of a whole air sample as $C^{14}O_2$. The CO_2 fraction was removed by passing each sample, at reduced pressure, through a cold trap at −183°C. Purification of the CO_2 fraction was accomplished by

(Text Continued on Page 25.)

TABLE 3.1 MIKE CLOUD HEIGHT FROM AIRCRAFT NO. MIKE 1

Time After Detonation	Aircraft Position*		Distance to Ground Zero	Elev. Angle From Horiz.	Calculated Cloud Height**	Remarks
Minutes	Latitude	Longitude	Feet	Degrees	Feet	
0	10°36'N	161°47'E	416,000	-	-	
1.5	10°35'N	161°50'E	415,000	5.78	58,000	Top
2.66	10°35'N	161°52'E	412,000	12.83	110,000	Top
3.42	10°34'N	161°53'E	412,000	13.07	112,000	Top
4.42	10°34'N	161°55'E	411,000	13.55	115,000	Top
5.75	10°34'N	161°57'E	410,000	14.17	120,000	Top of main cloud
8.5	10°37'N	161°50'E	405,500	16.47	136,000	Top of plume
10.5	10°39'N	161°45'E	400,000	07.30	67,000	Base of mushroom
11.75	10°40'N	161°44'E	397,500	12.50	104,000	Right side of top
13.4	10°41'N	161°42'E	399,000	14.63	120,000	Top, main cloud
15.25	10°42'N	161°39'E	400,000	1.58	27,000	Shear layer
56	10°38'N	161°35'E	432,000	14.00	124,000	Top
57	10°38'N	161°33'E	440,000	13.92	125,000	Top
60	10°38'N	161°24'E	474,000	13.28	128,000	Top
63	10°34'N	161°29'E	472,000	16.58	156,000	Height of sun
65	10°32'N	161°31'E	475,000	12.17	118,000	Top

* Coordinates of Ground Zero: Approximately 11° 40.2'N 162° 11.7'E
** Contains corrections for aircraft altitude of 12,300 feet and 4,000 feet for earth curvature.

TABLE 3.2 MIKE CLOUD HEIGHT FROM AIRCRAFT NO. MIKE 2

Time After Detonation	Aircraft Altitude	Distance to Ground Zero	Elev. Angle From Horiz.		Tangent of Angle		Cloud Height	
			Top	Base	Top	Base	Top	Base
Minutes	Feet	Feet	Deg.	Deg.			Feet	Feet
0.67	36,060	-	0	-	-	-	36,000	-
5.0	36,060	308,000	10	-2	0.176	0.0349	90,000	25,000
20.0	41,800	328,000	6	-2	0.105	0.0349	76,000*	30,000
25.0	41,800	243,000	17	-1	0.305	0.0175	116,000	38,000
60.0	41,950	182,500	18	-1	0.324	0.0175	101,000	38,000

* Height of middle of mushroom.

TABLE 3.3 MIKE CLOUD HEIGHT FROM U.S.S. RENDOVA

Time After Detonation	Elev. Angle from Horiz. to:		Distance to Ground Zero	Distance to Ground Zero Corrected by R sin A	Tangent of Angle		Cloud Height	
	Top	Base			Top	Base	Top*	Base
Minutes	Deg.	Deg.	Feet	Feet			Feet	Feet
2.0	-	-	179,400	-	-	-	48,000**	
2.5	-	-	179,400	-	-	-	50,000**	
3.0	33.4	-	179,500	137,700	0.659	-	91,000	
4.0	35.1	-	179,500	132,700	0.703	-	93,000	
5.0	-	23.3	179,600			0.431		77,500
10.0	51.2	-	177,600	100,100	1.244	-	124,500	
11.0	52.4	-	176,900	95,900	1.298	-	124,500	
11.5	52.8	-	176,500	94,400	1.317	-	124,000	
12.0	53.1	-	176,200	93,000	1.332	-	124,000	
12.5	53.3	-	175,800	91,500	1.342	-	123,000	
13.0	53.4	-	175,500	90,100	1.346	-	121,000	

* With correction R sin A applied.
** Height obtained by radar. After 2.5 minutes the cloud was too high for radar.

TABLE 3.4 MIKE CLOUD HEIGHT FROM U.S.S. ESTES

Time After Detonation	Elev. Angle from Horiz. to:		Distance to Ground Zero	Distance to Ground Zero Corrected by R sin A	Tangent of Angle		Cloud Height	
	Top	Base			Top	Base	Top*	Base
Minutes	Deg.	Deg.	Feet	Feet			Feet	Feet
3.5	35.75	14.08	181,600	135,600	0.720	0.251	97,500	45,500
4.0	36.65	12.13	181,400	132,600	0.744	0.215	98,500	39,000
5.0	38.10	11.25	180,700	127,700	0.784	0.199	100,000	36,000
5.5	40.23	11.53	180,400	124,000	0.846	0.204	105,000	37,000
6.0	42.61	12.30	180,100	120,400	0.920	0.218	111,000	39,500
6.5	45.20	-	179,800	116,200	1.007	-	117,000	-
7.0	47.46	-	179,500	112,500	1.090	-	123,000	-
7.5	48.99	-	179,200	109,500	1.150	-	126,000	-
8.0	50.43	-	178,800	106,400	1.210	-	129,000	-
8.5	52.75	-	178,500	102,800	1.315	-	135,000	-
9.0	54.03	13.82	178,300	99,800	1.378	0.246	137,000	44,000
9.5	55.29	13.25	178,300	97,300	1.444	0.235	141,000	42,000
10.0	56.31	-	178,300	95,500	1.500	-	143,000	-
10.5	57.17	-	178,000	94,000	1.550	-	146,000	-
11.5	57.42	-	177,400	90,300	1.567	-	142,000	-
12.0	57.77	14.26	177,000	88,800	1.586	0.254	141,000	45,000
12.5	58.28	14.52	176,400	87,000	1.618	0.259	140,000	45,500
13.0	58.75	14.72	175.8	85,200	1.648	0.262	140,000	46,000

* With correction R sin A applied.

TABLE 3.5 MIKE CLOUD HEIGHT FROM U.S.S. CURTISS

Time After Detonation	Elev. Angle from Horiz. to:		Distance to Ground Zero	Distance to Ground Zero Corrected by R sin A	Tangent of Angle		Cloud Height	
	Top	Base			Top	Base	Top*	Base
Minutes	Deg.	Deg.	Feet	Feet			Feet	Feet
1.0	14.78	12.47	213,000	205,300	0.264	0.221	54,000	47,000
2.0	24.57	12.03	212,000	183,000	0.457	0.213	83,500	45,000
3.0	30.95	12.97	211,200	172,000	0.600	0.230	103,000	48,500
4.0	32.82	10.98	210,100	166,000	0.645	0.194	107,000	41,000
5.0	33.97	11.37	209,200	161,700	0.674	0.201	109,000	42,000
6.0	37.75	11.00	208,300	153,900	0.774	0.194	119,000	40,500
7.0	36.00	11.00	207,200	153,900	0.727	0.194	112,000	40,000
8.0	38.28	12.55	206,500	148,500	0.789	0.223	117,000	46,000
9.0	39.00	10.07	205,300	144,500	0.810	0.177	117,000	36,500
10.0	39.90	10.00	204,500	140,500	0.836	0.176	117,500	36,000
11.0	40.25	10.12	203,500	137,800	0.846	0.178	116,500	36,000
12.0	40.10	11.65	202,500	135,600	0.842	0.206	114,000	41,500
13.0	39.75	11.58	201,500	133,400	0.832	0.205	111,000	41,500

* With correction R sin A applied.

TABLE 3.6 MIKE CLOUD RADIUS FROM U.S.S. ESTES

Time After Detonation	Angle Width of Mushroom	$\tan \frac{\text{Angle Width}}{2}$	Distance to Cloud	Cloud Radius
Minutes	Degrees		Naut.mi.	Naut.mi.
10.0	68.87	0.686	29.3	20.1
10.5	68.40	0.680	29.2	19.9
11.0	70.14	0.702	29.2	20.5
16.5	82.53	0.877	28.3	24.8
17.5	84.05	0.901	28.2	25.4
	MIKE CLOUD RADIUS FROM AIRCRAFT #3			
25				22
45				28
55				30.5
	DEDUCED CLOUD RADIUS			
30				23

TABLE 3.7 WIND DATA FROM ENIWETOK PRIOR TO MIKE

0300 GCT 30 Nov. 1952			1300 GCT Nov. 1952		
Height Feet	Wind Degrees	Knots	Height Feet	Wind Degrees	Knots
Surface	050	14	Surface	110	12
2,000	030	16	2,000	110	15
4,000	030	14	4,000	120	15
6,000	040	08	6,000	130	14
8,000	070	07	8,000	130	17
10,000	090	06	10,000	130	14
12,000	120	05	12,000	130	08
14,000	050	05	14,000	140	09
16,000	080	06	16,000	150	10
18,000	070	03	18,000	160	11
20,000	030	05	20,000	160	10
25,000	290	17	25,000	250	17
30,000	290	13	30,000	240	24
35,000	320	I0	35,000	240	14
40,000	360	14	40,000	250	15
45,000	020	27	45,000	330	18
50,000	360	15	50,000	350	15
55,000	060	20	55,000	040	08
60,000	050	22	60,000	070	34
65,000	100	38	65,000	070	36
70,000	100	27	70,000	080	20
75,000	100	12	75,000	100	19
80,000	100	08	80,000	080	07
85,000	100	06	85,000	010	06
90,000	Calm		90,000	090	04
95,000	Calm				
100,000	Calm				
105,000	Calm				
110,000	240	10			
115,000	270	16			

TABLE 3.8 KING CLOUD HEIGHT FROM AIRCRAFT NO. KING 1

Time After Detonation	Distance from Ground Zero	Elev. Angle to Horizontal	Correction for Earth Curvature	Cloud* Height	Remarks
Minutes	Feet	Degrees	Feet	Feet	
1.0	185,500	3.12	1,000	18,500	
2.0	192,700	3.50	1,050	20,000	Ice cap forming
2.5	192,700	11.53	1,050	51,000	
2.75	192,700	12.7	1,050	55,000	
3.0	201,000	13.07	1,100	58,000	
Unknown	201,000	14.17	1,100	63,000	
4.0	209,500	17.15	1,250	76,000	Max.hgt.observed
6.0	214,300	15.51	1,300	71,000	
7.0	217,300	14.83	1,300	69,500	
9.0	228,300	16.08	1,400	78,000	Plane at bad angle
10.0	227,700	14.92	1,400	73,000	
11.0	227,700	14.93	1,400	73,000	
14.0	237,500	15.47	1,500	78,000	Cloud dissipating
20.0	276,500	12.70	2,000	75,000	

* Correction for earth curvature and aircraft altitude (10,700 ft.) applied.

TABLE 3.9 KING CLOUD HEIGHT FROM AIRCRAFT NO. KING 2

Time After Detonation	Horizontal Radar Distance to Column	Elev. Angle from Horiz.	Cloud* Height	Remarks
Minutes	Feet	Degrees	Feet	
1.8	-	0	42,000	
3.0	188,500	-	-	
4.0	188,500	4.33	56,000	Cloud base estimated 35,000 ft.
8.0	158,000	6.00	58,500	
10.0	146,000	9.42	66,000	Cloud base estimated 35,000 ft.
13.0	109,500	13.50	68,000	

* Corrected for aircraft altitude (42,000 feet). No correction for earth's curvature made.

TABLE 3.10 KING CLOUD HEIGHT FROM U.S.S. RENDOVA

Time After Detonation	Elev. Angle from Horiz. to:		Distance to Ground Zero	Distance to Ground Zero Corrected by R sin A	Tangent of Angle to		Corrected Cloud Height	
	Top	Base			Top	Base	Top	Base
Minutes	Deg.	Deg.	Feet	Feet			Feet	Feet
2.0	27.2	15.9	97,500	92,900	0.513	0.285	47,600	27,800
2.5	28.7	20.0	97,400	91,500	0.549	0.364	50,000	35,400
3.0	34.0	21.6	97,300	89,500	0.675	0.396	60,400	38,500
3.5	37.3	23.2	97,200	87,500	0.761	0.425	66,700	41,300
4.0	40.0	23.8	97,000	85,500	0.839	0.440	71,600	42,700
4.5	42.2	24.0	96,800	83,600	0.908	0.445	75,800	43,000
5.0	44.3	-	96,700	81,900	0.976	-	79,900	-
5.5	45.7	23.1	96,500	80,000	1.025	0.425	82,000	41,000
6.0	46.1	23.2	96,300	78,600	1.04	0.429	81,800	41,200
6.5	47.0	23.5	96,100	77,000	1.072	0.435	82,600	41,800
7.0	50.3	23.7	96,000	74,800	1.204	0.440	90,300	42,200
7.5	52.0	23.1	96,000	73,000	1.28	0.406	93,500	39,000
8.0	53.1	23.6	95,900	71,400	1.33	0.438	95,000	42,000
8.5	54.1	23.1	95,800	70,000	1.38	0.426	96,800	40,800
9.0	-	23.0	95,800	-	-	0.425	-	40,700
9.5	48.8	22.9	95,900	70,100	1.145	0.422	80,400	40,500
10.0	50.3	22.9	96,000	68,900	1.205	0.422	83,000	40,500
10.5	-	22.8	96,200	-	-	0.420	-	40,400
11.0	-	-	96,400	-	-	-	-	-
11.5	50.5	22.5	96,600	66,800	1.213	0.414	81,000	39,900
12.0	51.5	22.2	96,800	65,200	1.257	0.408	82,000	39,500
12.5	-	22.0	96,900	-	-	0.403	-	39,000
13.0	51.5	21.8	97,000	64,700	1.257	0.400	81,000	38,800

TABLE 3.11 KING CLOUD HEIGHT FROM U.S.S. OAK HILL

Time After Detonation	Elev. Angle from Horiz. to:		Distance to Ground Zero	Distance to Ground Zero Corrected by R sin A	Tangent of Angle to		Corrected Cloud Height	
	Top	Base			Top	Base	Top	Base
Minutes	Deg.	Deg.	Feet	Feet			Feet	Feet
1.0	22.88	11.05	92,400	90,000	0.422	0.195	38,000	18,000
1.5	23.50	14.85	93,600	90,600	0.435	0.265	39,400	24,800
2.0	29.33	-	95,400	90,600	0.562	-	50,900	-
2.5	33.45	12.52	96,700	89,400	0.661	0.222	59,200	21,500
3.0	33.98	13.50	97,900	88,800	0.674	0.240	59,800	23,500
3.5	34.92	21.65	99,100	88,800	0.698	0.397	62,000	39,400
4.0	35.97	21.53	100,300	90,000	0.726	0.395	65,500	39,600
4.5	35.72	21.07	101,000	89,400	0.719	0.385	64,300	39,000
5.0	36.80	20.18	102,800	88,800	0.748	0.368	66,500	37,800
5.5	36.92	21.20	104,000	88,200	0.751	0.388	66,300	40,300
6.0	37.43	21.37	105,200	89,400	0.765	0.391	68,500	41,200
6.5	37.53	18.35	106,400	89,400	0.768	0.332	68,600	35,400
7.0	37.95	14.98	107,000	88,200	0.780	0.268	68,800	28,600
7.5	38.05	14.78	108,200	88,800	0.783	0.264	69,500	28,600
8.0	38.07	14.42	109,500	88,200	0.783	0.257	69,100	28,100
8.5	39.72	15.03	110,700	88,200	0.831	0.269	73,300	29,800
9.0	39.15	14.13	111,900	88,200	0.814	0.252	71,800	28,200
9.5	39.83	14.08	113,100	88,200	0.834	0.251	73,500	28,400
10.0	40.52	13.62	113,700	87,500	0.855	0.242	75,000	27,500
10.5	38.35	12.98	114,900	88,800	0.791	0.231	70,200	26,500
11.0	41.45	12.92	116,800	88,200	0.883	0.229	78,000	26,700
11.5	41.75	12.42	118,000	88,200	0.893	0.220	78,700	26,000
12.0	41.87	12.20	118,600	87,000	0.896	0.216	78,000	25,600
12.5	42.30	12.15	119,800	87,500	0.910	0.215	79,600	25,700
13.0	42.52	11.90	120,400	88,200	0.917	0.211	81,000	25,400

TABLE 3.12 KING CLOUD RADIUS FROM U.S.S. OAK HILL

Time After Detonation	Angle Width of Mushroom	tan $\frac{\text{Angle Width}}{2}$	Distance* to Cloud	Cloud Radius
Minutes	Degrees		Naut. mi.	Naut. mi.
0.5	4.00	0.035	15.1	0.53
1.0	7.07	0.062	15.2	0.94
1.5	9.32	0.081	15.45	1.25
2.0	12.03	0.105	15.7	1.65
2.5	15.33	0.135	15.9	2.15
3.0	19.48	0.172	16.1	2.77
3.5	20.40	0.180	16.3	2.93
4.0	20.37	0.180	16.5	2.97
4.5	23.17	0.205	16.7	3.42
5.0	25.92	0.230	16.9	3.89
5.5	27.67	0.246	17.1	4.21
6.0	28.83	0.257	17.3	4.45
6.5	31.08	0.278	17.5	4.86
7.0	33.67	0.303	17.6	5.33
7.5	34.27	0.308	17.8	5.48
8.0	35.90	0.323	18.0	5.81
8.5	37.43	0.339	18.2	6.17
9.0	38.75	0.352	18.4	6.48
9.5	40.20	0.367	18.6	6.83
10.0	41.33	0.377	18.7	7.05
10.5	42.57	0.390	18.9	7.37
11.0	43.30	0.397	19.2	7.62
11.5	44.40	0.408	19.4	7.92
12.0	46.58	0.431	19.5	8.40
12.5	47.07	0.436	19.7	8.59
13.0	46.88	0.433	19.8	8.58

* Corrections applied for cloud drift.

TABLE 3.13 WIND DATA FROM ENIWETOK PRIOR TO KING

2100 GCT, 15 November 1952

Height Feet	Wind	
	Degrees	Knots
Surface	070	17
2,000	080	22
4,000	090	26
6,000	090	25
8,000	100	21
10,000	070	20
12,000	070	18
14,000	060	13
16,000	060	14
18,000	080	19
20,000	080	30
25,000	050	26
30,000	030	08
35,000	340	29
40,000	330	41
45,000	340	38
50,000	170	07
55,000	070	05
60,000	060	22
65,000	070	22
70,000	020	07
75,000	240	14
80,000	240	11
85,000	230	13
90,000	230	14

TABLE 3.14 HUMIDRY DATA

Time-wise, it is possible for the activity collected on 16 November to have been influenced by the Mike detonation. Activity above the specified background figure is noted on 5 October 1952 prior to the occurrence of the Mike shot. It cannot be ruled out that these activities, if real, may be the result of an accidental release of H^3 at the Test Site or in production within the United States.

Sample Number	Collection Data			Atoms $H^3/10^{18}$ Atoms H
	Date	Duration of Collection		
		Hours	Minutes	
5	5 Oct 52	6	10	18.4 $\pm$ 0.4
8	26 Oct 52	6	40	0.0 $\pm$ 0.4
10	9 Nov 52	6	50	2.9 $\pm$ 0.3
11	16 Nov 52	7	00	17.8 $\pm$ 0.81
12	23 Nov 52	8	20	1.5 $\pm$ 0.4
13	30 Nov 52	9	25	4.4 $\pm$ 0.68
24	16 Feb 53	9	45	0.73 $\pm$ 0.27

TABLE 3.15 HUMIDRY DATA

No activity, within the limited number of samples analyzed from this station, can be attributed to Mike. If the activity reported on 1 October is real, the source must be assigned to other than Mike.

Sample Number	Collection Data			Atoms $H^3/10^{18}$ Atoms H
	Date	Duration of Collection		
		Hours	Minutes	
1	1 Oct 52	11	30	50.4 ± 1.2
2	8 Oct 52	11	30	2.7 ± 0.3
7	12 Nov 52	10	20	3.13
25	18 Mar 53	10	55	0.5 ± 0.3

TABLE 3.16 HUMIDRY DATA

Time-wise, the activity reported on 13 November could be from Mike — otherwise, all data appear as background.

Sample Number	Collection Data			Atoms $H^3/10^{18}$ Atoms H
	Date	Duration of Collection		
		Hours	Minutes	
8	30 Oct 52	12	30	-0.2 ± 0.3
9	6 Nov 52	13	00	-0.29 ± 0.79
10	13 Nov 52	11	15	77.0
12	27 Nov 52	14	00	0.1 ± 0.3
21	29 Jan 53	15	00	0.8 ± 0.2
22	5 Feb 53	15	10	0.4 ± 0.2
23	12 Feb 53	2	55	3.3 ± 0.2
29	26 Mar 53	19	00	0.2 ± 0.2

TABLE 3.17 HUMIDRY DATA

The activities reported for the two samples in November appear above background values. Time-wise it would be rather difficult to ascribe the 3 November sample as being influenced by Mike.

Sample Number	Collection Data			Atoms $H^3/10^{18}$ Atoms H
	Date	Duration of Collection		
		Hours	Minutes	
1	3 Nov 52	12	00	12.1
4	24 Nov 52	15	00	7.7
7	15 Dec 52	19	45	0.3 ± 0.3
16	16 Feb 53	16	00	1.6 ± 0.3
21	23 Mar 53	13	00	0.3 ± 0.3

TABLE 3.18 HICKAM HUMIDRY DATA

The first increase in activity which may be significant was noted on 6 November. Thereafter, fluctuations between this value and the background value continued for the remainder of the sampling period.

Sample Number	Collection Data			Atoms $H^3/10^{18}$ Atoms H
	Date	Duration of Collection		
		Hours	Minutes	
1	1 Nov 52	8	45	4.17
2	2 Nov 52	7	20	3.3
5	5 Nov 52	7	53	3.57
6	6 Nov 52	7	20	18.5
7	7 Nov 52	8	03	3.45
9	10 Nov 52	9	02	23.25
10	11 Nov 52	7	45	2.86 ± 11%
12	13 Nov 52	9	30	5.4
13	14 Nov 52	10	30	17.9
16	17 Nov 52	12	30	3.13
17	18 Nov 52	12	00	2.7 ± 10%
18	19 Nov 52	8	30	6.25
20	21 Nov 52	8	00	6.7
22	24 Nov 52	8	55	3.7 ± 0.3
25	26 Nov 52	11	10	0.59 ± 50%
29	30 Nov 52	11	55	5.15
30	1 Dec 52	9	15	1.1 ± 0.3

TABLE 3.19 GUAM HUMIDRY DATA

The results indicate that the activity rose to a value of about 200 times background 7 days after Mike and then decreased slowly to background in the following 10 days.

Sample Number	Collection Data			Atoms $H^3/10^{18}$ Atoms H
	Date	Duration of Collection		
		Hours	Minutes	
1	2 Nov 52	5	00	3.13
3	4 Nov 52	8	00	14.1
4	5 Nov 52	7	45	21.8
6	7 Nov 52	10	00	417
7	8 Nov 52	10	00	238
9	10 Nov 52	9	00	125
10	11 Nov 52	9	00	25.6
11	12 Nov 52	7	00	19.9 ± 0.4
12	13 Nov 52	7	00	25.65
14	15 Nov 52	8	00	14.3
15	16 Nov 52	7	00	17.2
16	17 Nov 52	6	55	9.1
17	18 Nov 52	7	25	11.9 ± 0.8
18	19 Nov 52	5	45	2.0
22	23 Nov 52	8	25	2.8 ± 0.2
24	25 Nov 52	6	30	2.8_6
25	26 Nov 52	6	45	5.1 ± 0.4
35	6 Dec 52	7	00	2.17
42	13 Dec 52	7	45	0.28_6

TABLE 3.20 RAIN WATER DATA

H^3 activity which may be from Mike appears observable in the samples collected on 17 November and 15 January.

Sample Number	Collection Data: Date	Duration of Collection: Hours	Minutes	Atoms $H^3/10^{18}$ Atoms H
40	6 Nov 52	6	20	2.86
42	17 Nov 52	4	15	33.4
43	26 Nov 52	4	50	1.2 ± 0.4
47	15 Jan 53	4	35	3.6 ± 0.4
50	18 Feb 53	9	55	0.1 ± 0.3
51	28 Feb 53	9	00	2.5 ± 0.6

TABLE 3.21 RAIN WATER DATA

Sample Number	Collection Data: Date		Duration of Collection	Atoms $H^3/10^{18}$ Atoms H
24	27 Nov 52	to	2 Dec 52	6.2 ± 0.3

TABLE 3.22 RAIN WATER DATA

The perturbations in the activity levels of these samples are well within the questionable area of significance.

Sample Number	Collection Data: Date		Duration of Collection	Atoms $H^3/10^{18}$ Atoms H
6	26 Oct 52	to	1 Nov 52	3.0
7	2 Nov 52	to	8 Nov 52	4.35
8	9 Nov 52	to	15 Nov 52	12.2
9	16 Nov 52	to	22 Nov 52	11.1 ± 0.3
10	23 Nov 52	to	29 Nov 52	7.7
17	9 Feb 53	to	16 Feb 53	2.5 ± 0.2
18	30 Mar 53	to	6 Apr 53	7.2 ± 0.2

TABLE 3.23 WATER DATA

Time-wise the activity recorded for the period 3-6 November could be influenced by Mike. All other activities appear at background.

Sample Number	Collection Data: Date		Duration of Collection	Atoms $H^3/10^{18}$ Atoms H
6	3 Nov 52	to	6 Nov 52	23.4 ± 0.3
7	11/12 Nov	26 hrs		1.96
9	24 Nov 52	to	1 Dec 52	$3.11 \pm 9\%$
10	1 Dec 52	to	4 Dec 52	2.4 ± 0.32
12	15 Dec 52	to	19 Dec 52	$0.625 \pm 60\%$
13	22 Dec 52	to	29 Dec 52	0.63 ± 0.37
16	10 Jan 53	to	12 Jan 53	2.0 ± 0.3
19	2 Feb 53	to	6 Feb 53	0.5 ± 0.3
23	3 Mar 53	to	5 Mar 53	1.6 ± 0.2

passing it through a CuO combustion furnace and then a cold trap maintained at a temperature of −78°C. Assay of the carbon-14 activity in this purified CO_2 fraction was made by low background gas proportional counters.

Inspection of the data indicates only one possible significant carbon-14 concentration—that reported for Sample Hi-12-II. Another carbon-14 result which is above background is for Sample El-38, however, this sample was subdivided for duplicate analysis by the other laboratory and the value was not corroborated. It is very doubtful if either of these

TABLE 3.24 WHOLE AIR SAMPLES FROM 18,000 FEET

Sample Identification	Collection Data Place	Date	Atoms C^{14}/EMA	Atoms H^3/EMA
		16 Oct 52	$(2.69 \pm 0.28)10^{-8}$	$(-3.1 \pm 3.5)10^5$
- II		13 Nov 52	$(2.28 \pm 0.13)10^{-8}$	$(4.1 \pm 0.37)10^6$
GU - 11 - I	Guam	19 Nov 52	$(1.6 \pm 0.12)10^{-8}$	
		4 Nov 52		$(1.4 \pm 0.04)10^6$
		20 Nov 52	$(-2.3 \pm 5.2)10^{-8}$	
		15 Dec 52		$(-2.5 \pm 1.6)10^5$
EI - 36 - I	Eielson	16 Oct 52	$(1.38 \pm 0.67)10^{-8}$(ANL) $(2.7 \pm 0.14)10^{-8}$	$<1.1 \times 10^7$ (ANL)
- II			$(1.51 \pm 0.35)10^{-8}$(ANL) $(2.7 \pm 0.10)10^{-8}$	
*EI - 38	Eielson	13 Dec 52	$(5.17 \pm 0.22)10^{-8}$(ANL) $(2.5 \pm 0.21)10^{-8}$	$<9.2 \times 10^5$ (ANL)
HI - 12 - II	Hickam	20 Nov 52	$(3.4 \pm 0.11)10^{-8}$	
MC - 23 - I	McClellan	24 Nov 52	$(1.87 \pm 0.10)10^{-8}$(ANL) $(2.2 \pm 0.11)10^{-8}$	
MC - 24 - I	McClellan	3 Dec 52		$(-2.1 \pm 4.4)10^5$

*Sample not aliquoted.

values is more than statistical fluctuation, either in sampling or in laboratory measurement.

Tritium. Tritium is present in the oxidized state as H^3_2O in the whole air sample. The H^3_2O was removed by freezing all the moisture by passage of the whole air sample through a cold trap at −78°C. After purification by filtration and distillation, the water was reduced to hydrogen by a magnesium reduction furnace at 600°C. Assay of the tritium in the total hydrogen fraction was made by the same counters and techniques discussed in Section 3.2.1 above.

Inspection of the resultant data indicates that while some small contribution to the tritium activity may be present from Mike, the fluctuations in the results for samples where Mike could not have contributed are so large as to discredit the validity of making any quantitative interpretation of the results.

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