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HEADQUARTERS
JOINT TASK FORCE SEVEN
WASHINGTON 25, D.C.

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SUBJECT: A Study of Certain Operational Weather Considerations Involving The Tests and Delivery of High Yield Weapons

TO: Dr. Alvin C. Graves
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Reference request contained in your message cite J-18659, inclosed is a copy of the Study of Certain Operational Weather Considerations Involving The Tests and Delivery of High Yield Weapons, prepared by CDR Elbert W. Pate, USN, and Clarence E. Palmer, Professor of Geophysics, University of California at Los Angeles.

FOR THE COMMANDER:

1 Incl:
Report - Subj as above
Dtd 30 June 1953

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A STUDY OF CERTAIN OPERATIONAL WEATHER CONSIDERATIONS INFLUENCING THE TEST AND DELIVERY OF HIGH YIELD WEAPONS.

JOINT TASK FORCE SEVEN

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A STUDY OF CERTAIN OPERATIONAL WEATHER CONSIDERATIONS INVOLVING THE TEST AND DELIVERY OF HIGH YIELD WEAPONS

By

COMMANDER ELBERT W. PATE, USN
Staff Weather Officer
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University of California at Los Angeles

30 June 1953

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A Report to the Commander, Joint Task Force SEVEN

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INDEX

ABSTRACT AND CONCLUSIONS

With Respect to Weather in the Marshall Islands:

1. *The behavior of the tropical atmosphere is little understood by the professional meteorologist and therefore, not surprisingly, by the majority of military and civilian staff officers at all levels. Seasonal variability of the important weather elements does not conform to the calendar. Casual statistical analysis of available weather records lead more often than not to erroneous operational conclusions.* (and yet operations seem to get done.)
(Pages 1 - 9)

2. *Operational weather requirements have been imposed in overseas test operations which are inherently inconsistent, almost mutually exclusive, and capable of realization only for short periods separated by long intervals.* ?
(Pages 8 and 9)

With Respect to the Dynamics of Bomb Clouds:

1. *The bomb cloud is not a disorderly mixing of environmental air in the wake of a bubble of heated gas, but is part of a logical and ordered motion forming a complete system.*
(Pages 10 - 13)

2. *It is entirely possible that a high yield detonation can "trigger" a self-sustaining circulation which will derive its energy through the condensation process.*
(Page 13)

3. *Analysis of bomb cloud dynamics points to the reason for the inadequacy of present techniques in high yield cloud sampling: during the early stage of cloud formation, much bomb material is available at lower altitudes, but severe turbulence forms an insurmountable obstacle to the use of manned aircraft; at later states, when turbulence has subsided, continued development of the torus ring structure of the cloud has forced the bulk of the bomb material into the stratosphere.* ?
(Pages 14 and 15)

With Respect to Evidence From High Yield Detonations:

1. *Both MIKE and KING produced clouds which closely followed the torus ring model. Both demonstrated marked streamline and condensation effects.*
(Pages 17, 19 and 20)

2. *The detonation of MIKE and KING induced spectacular and widespread weather changes which persisted for several hours.*
(Pages 19 and 21)
(Note that the proposal to detonate King on the original K day also produced widespread and unpredictable weather changes.)

3. *Any comparison of bomb yield to the energy liberated in a tropical storm is not an issue. The bomb, by establishing a definite vertical and horizontal circulation, "triggers" the atmosphere, and the energy liberated through the condensation process dwarfs that originally released by the bomb itself.*

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With Respect to Low Yield Detonations

1. *Analysis of smoke-puff photographs from the Tumbler No. 3 test demonstrates ~~that a near-idealized torus ring circulation~~ is established with relatively low bomb yields.*

(Section IV) I agree but this observation is not new

With Respect to Certain Operational Problems

1. *Present sampling techniques for high yield devices are not adequate for the reason that the bulk of the bomb debris is deposited in the stratosphere beyond the altitude capability of presently available aircraft.*

(Sections II and III)

2. *The dimensions and structure of the bomb cloud formed by the detonation of high yield weapons introduce several serious operational considerations bearing on the delivery problem. Among these are:*

   a. Extreme turbulence within the bomb cloud which would probably preclude aircraft operation below the stratosphere in the same area for a considerable time following detonation, even if the factor of radiological contamination is ignored.

   (Page 22)

   b. Assuming delivery to a location in the high latitudes with a low stratosphere, such as Russia during winter, the size and thickness of the generated cloud would probably produce a large obscured area on the radar scope of any following aircraft engaged in the destruction of the same or an adjacent target.

   (Page 23)

Is this conclusion on a high latitude, low stratosphere continental, winter situation based on our tropical high stratosphere, mid ocean, fall situation? Suggest that author reread page 1 of report.

I. WEATHER OVER THE MARSHALL ISLANDS

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1. "Wet" and "Dry" Seasons:

Our knowledge of weather and wind in the Central Pacific is still surprisingly meager. The region lies far from the chief trade routes of the Pacific, so that we do not possess the abundance of marine records, dating back to the days of the full-rigged ship, that give us so much information on surface conditions in higher oceanic latitudes and along the coasts of Asia and America. In spite of long occupation, first by Germany, then Japan, and in spite of the location of recent weapon tests by the United States Armed Forces, the Marshall Islands are among the least known, from a meteorological point of view, of the archipelagos of the Central Pacific. The reason lies partly in the short observational record, but more importantly, perhaps, in certain preconceived ideas, held alike by many professional meteorologists and by operational commanders acting on their advice, that have tended to obscure the issues.

Historically, explorers, soldiers, sailors, and scientists of the Atlantic community first learned about tropical weather in, and in the neighborhood of, the great continents: Asia, America, and Africa. With few exceptions the torrid parts of these regions are subject to pronounced seasonal variation in wind and weather. In some regions the seasons are spoken of as monsoons, in others, as the wet and dry seasons. At all events, the tendency of rainfall in these places, to be associated with a specific wind direction and to occur mostly in one season of the year, has been known to laymen for centuries. The peoples of high latitudes in Europe and America have found nothing surprising in this: living also on continents, they have been used to far greater seasonal extremes, particularly in temperature, than any found in monsoon countries. So there has grown up, in the minds of both scientists and laymen, the expectation that all tropical regions, even those far from any large land mass, display well-marked seasonal variations in wind and weather.

In the Central Pacific, especially east of the 180th meridian, it is very difficult to find, in the data that we have so far, very reliable traces of this supposed universal seasonal variation. There is a great variability in weather, it is true, but this seems to occur with little relation to the time of the year. In fact, the region overlapping the equator and about the longitudes of the Hawaiian Islands is a zone with probably the most highly variable rainfall on the whole globe. The Marshall Islands, lying as they do closer to Australia than the Central Pacific atolls, come remotely under the influence of that continent, and consequently show some seasonal variation in cloud and rainfall. But this is overshadowed by a greater aperiodic variability of the type found in the Central Pacific. In the southern Marshalls this aperiodic type of variation extends

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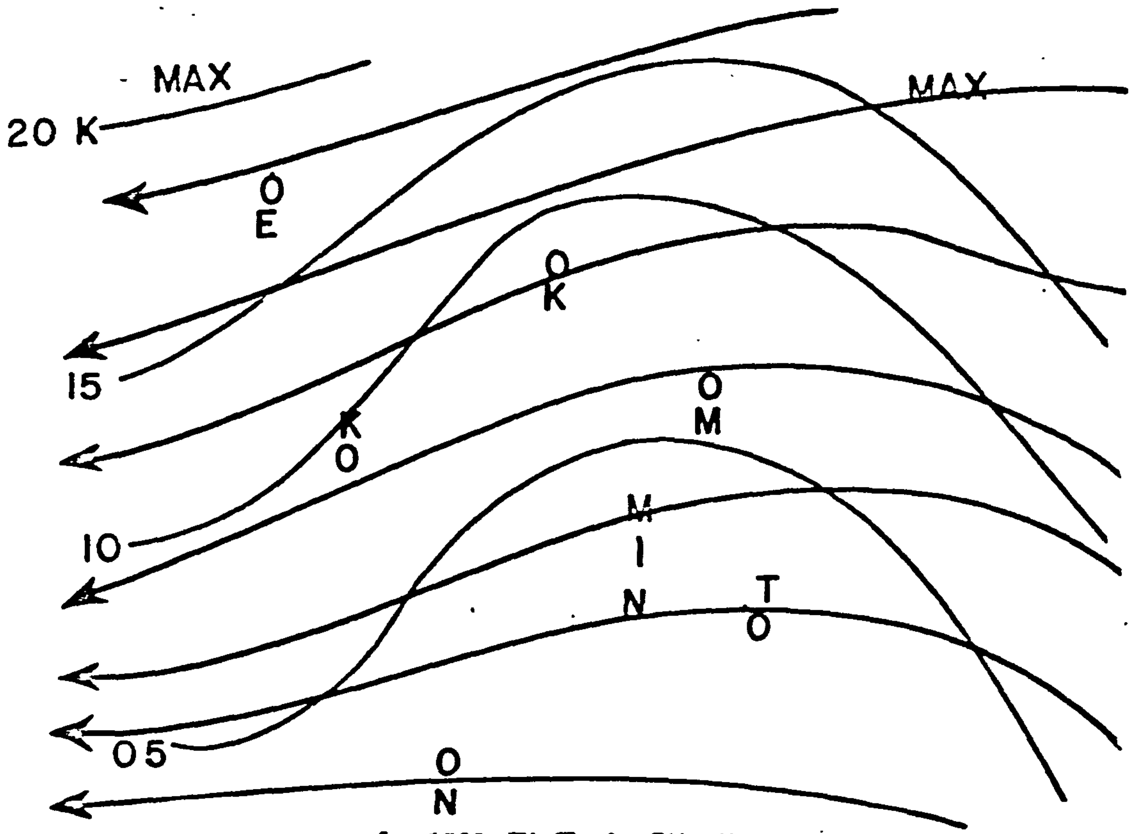
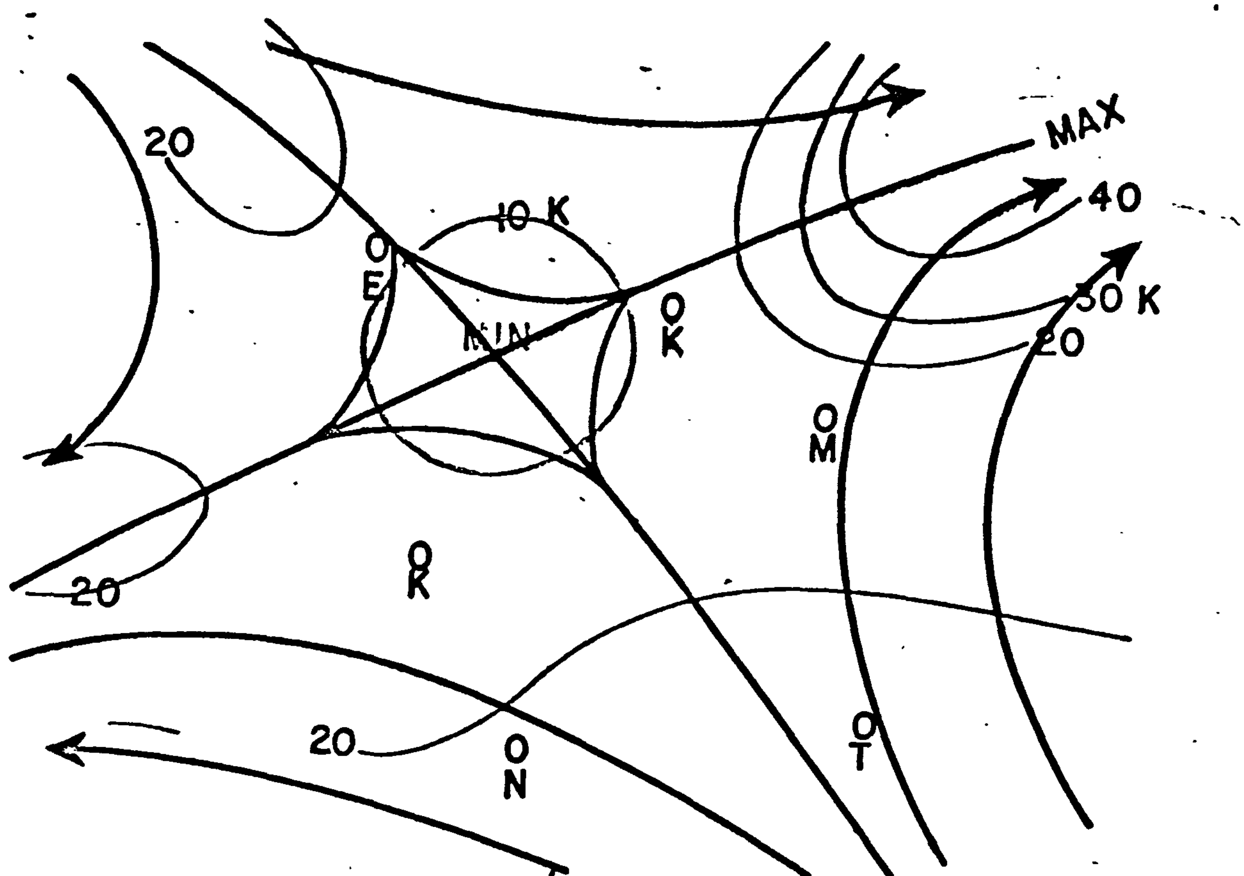
even to the winds. For example, at Ocean Island, south of the Marshalls, west winds sometimes replace the more usual east winds for several days, but the change is only slightly connected with season and it is incalculable in its occurrence from year to year. Since 1900 there have been years in which westerlies prevailed at Ocean Island on as few as 2 and as many as 167 days. One could not, in other words, count on the seasonal occurrence of west winds at that island in any one year, nor plan any military operation there on a statistical presumption.

2. *Three Typical Weather Situations:*

In the oceanic tropics, as in high latitudes, cloud systems have been found associated with specific types of wind systems. However, the connection between the wind systems and the clouds is much more obscure and requires for its discovery more detailed research. At first sight the surface wind in the Marshall Islands, particularly in the north near Bikini and Eniwetok, appears to undergo very minor variations, whereas the clouds may change greatly in form, amount and height from day to day. Nevertheless, recent research, based on high level observations taken during the series of atomic tests between 1946 and 1952, has revealed that the cloud is correlated with major wind systems, and that the general weather situations from day to day fall into three fairly well-marked classes.



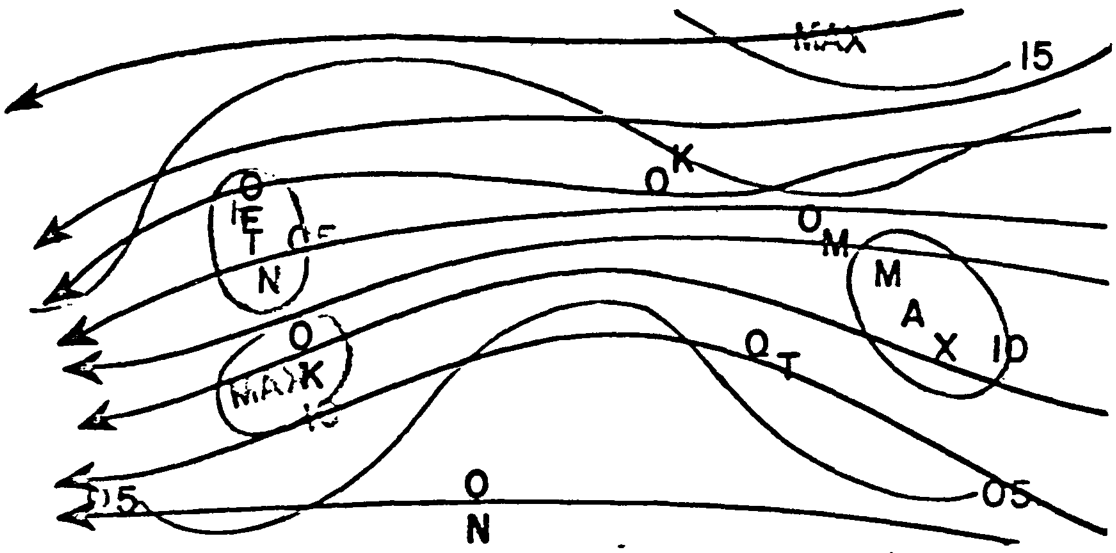
I. 1500 Ft Trade Situation



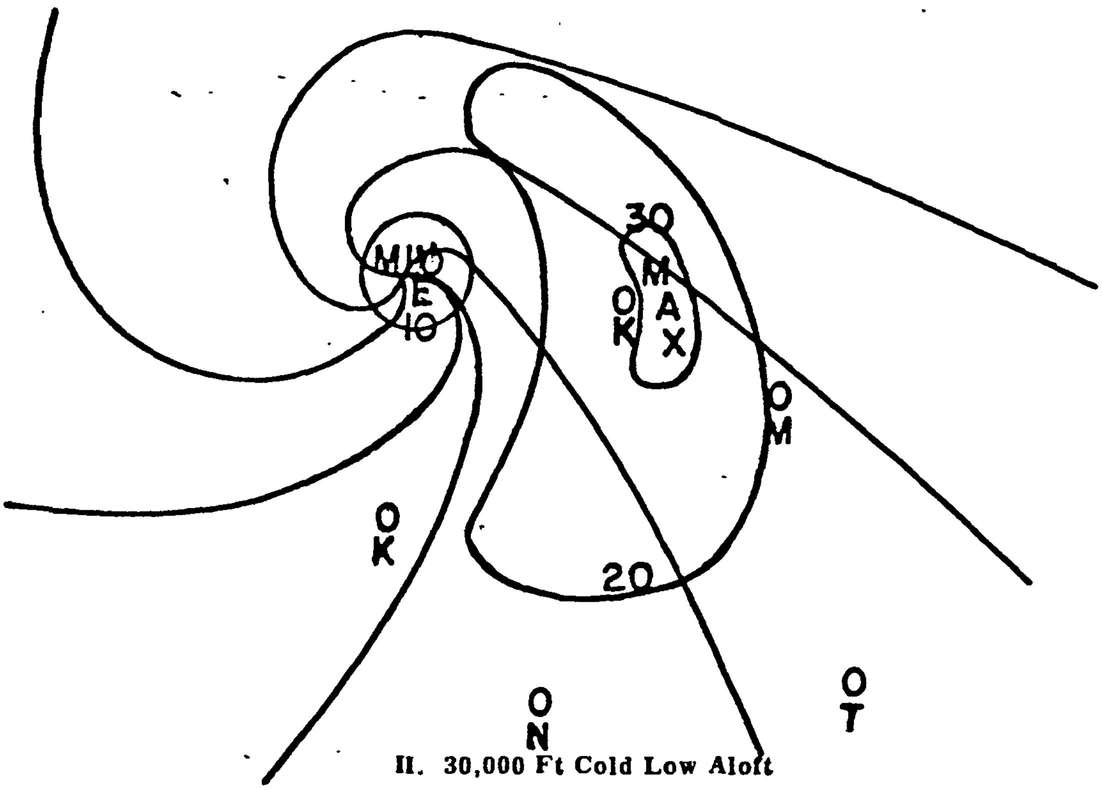
I. 30,000' Trade Situation

The first weather situation may be called the "trade" situation. Over the Marshall Islands, north of 5° N, east-north-east to northeast winds prevail in the lower levels of the atmosphere; the wind speeds range between 5 and 10 knots from the equator to 10° N, increasing to as much as 20 knots in the region between Eniwetok and Wake. Small amounts of cumulus clouds (usually about 5/10 coverage) are found in this current and the clouds do not extend much above 8,000 feet in the north nor above 12,000 feet in the southern Marshalls. Rain sometimes falls from some of these clouds, particularly in the south, but it is usually in the form of light showers. No extensive middle or upper cloud decks are found. Although the lower winds are northeasterly and quite fresh, as one ascends in the atmosphere over the northern Marshalls, one finds that the winds turn more westerly with elevation, until at about 20,000 feet they lie between northwest and southwest. The westerlies then extend upwards to the tropopause, increasing in speed to about 35 knots at 45,000 feet. If the upper winds in the region should be mainly southwesterly, rain from the trade cumulus is likely and the amount of cloud may increase from time to time to as much as 8/10. On the other hand, if the upper winds are chiefly northwesterly in direction, cumulus cloud may decrease to as little as 2 or 3/10 and showers are less likely. The variation between northwest and southwest is controlled by an upper level pressure trough which tends to be located during trade weather just west of Eniwetok. The difficulties of forecasting variations in trade weather, then, are associated with small movements of the trough line to and fro across the northern Marshalls.

The second type of weather situation is very easily confused with the first, especially if an adequate upper air observational network is not established. In the lower atmosphere the winds are, as in the trade situation between east-north-east and northeast. However, the fluctuations in speed, in time, and space may be quite large and the winds do not vary latitudinally in the regular manner that is typical of the trades. For a period of two or three days, for example, although the winds remain in the northeast, almost the entire Marshall Islands may show wind speeds less than 10 knots. The cloud cover, instead of being recorded as 5/10 trade cumulus may consist over most of the area of only 2 to 4/10 of small cumulus below 4,000 feet. Here and there, a more or less stationary line of large cumulo-nimbus with heavy showers, or on occasion thunderstorms, may be observed from aircraft or lie across individual atolls. The greatest difference, however, lies not in the lower cloud but in the middle and upper regions. A very extensive sheet of alto-stratus breaking here and there to alto-cumulus will blanket the southern Marshalls and extend from time to time to the Eniwetok - Bikini area. From this sheet, wherever it is thick, will fall a continuous and often heavy rain. Cirrus cloud is much more extensive than normal and in the south may form continuous overcasts lying above and sometimes fusing with the alto-stratus decks. Cloud and weather make aircraft operations above 20,000 feet difficult and occasionally hazardous.



II. 1500 Ft Eniwetok Winds Under Cold Low Aloft



II. 30,000 Ft Cold Low Aloft

The difference between this situation and trade weather, as far as winds are concerned, is most marked in the atmosphere above 30,000 feet. The lower easterlies turn as before to westerlies, but these westerlies are stronger and form part of a very large cyclonic circulation which lies more or less stationary between Eniwetok - Bikini and Wake Island. The circulatory system is known as an upper level tropical cyclone. Winds as high as 100 knots at 45,000 feet have been reported over the northern Marshalls during such situations. Once established, an upper level cyclone may remain in situ for 10 days before moving out into higher latitudes. Even though there may be temporary clearance for a day or two at some stations, the weather remains generally unsettled as long as the cyclone lies between Eniwetok and Wake. There may be a very general deterioration in the weather as the stationary cyclonic circulation intensifies and reaches lower and lower levels. Following the movement of the upper level cyclone into higher latitudes, the trade situation will become re-established; this re-establishment is often accompanied by a sudden and dramatic improvement in the weather.

The third type of situation is characterized by winds in the lower atmosphere which fluctuate between northeast and southeast in the northern Marshalls and between

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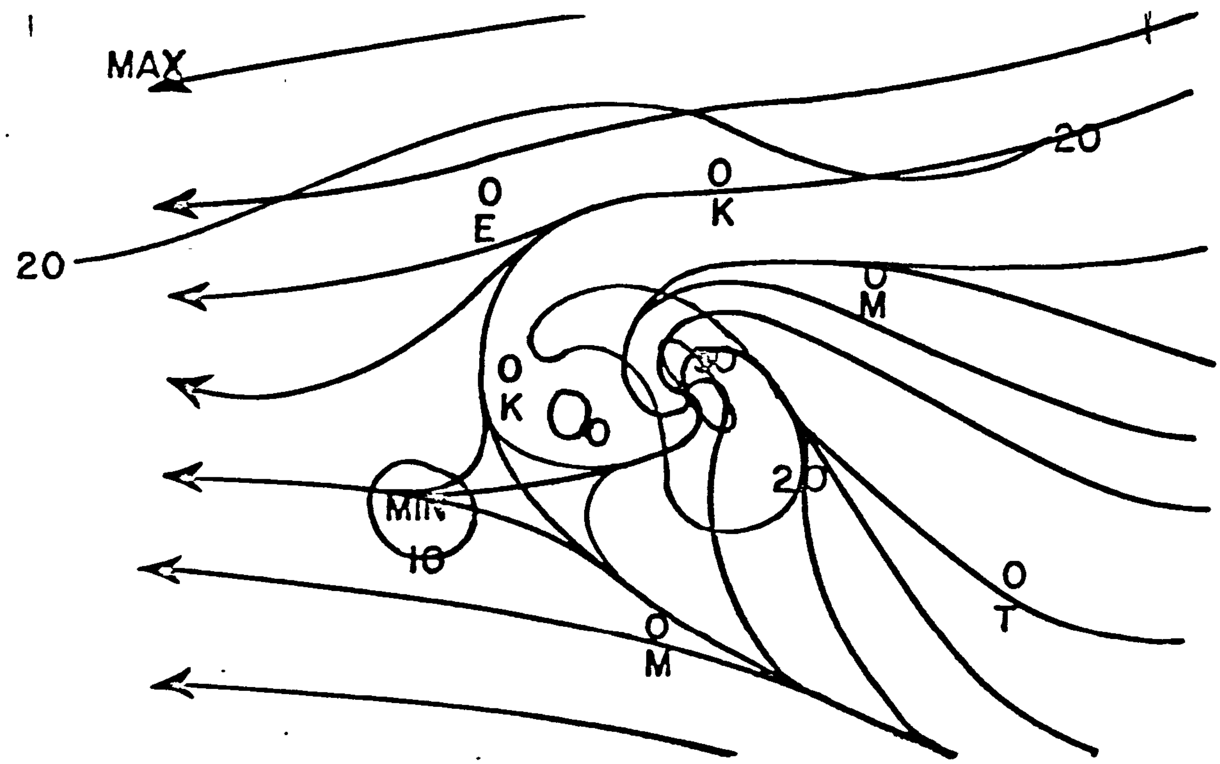
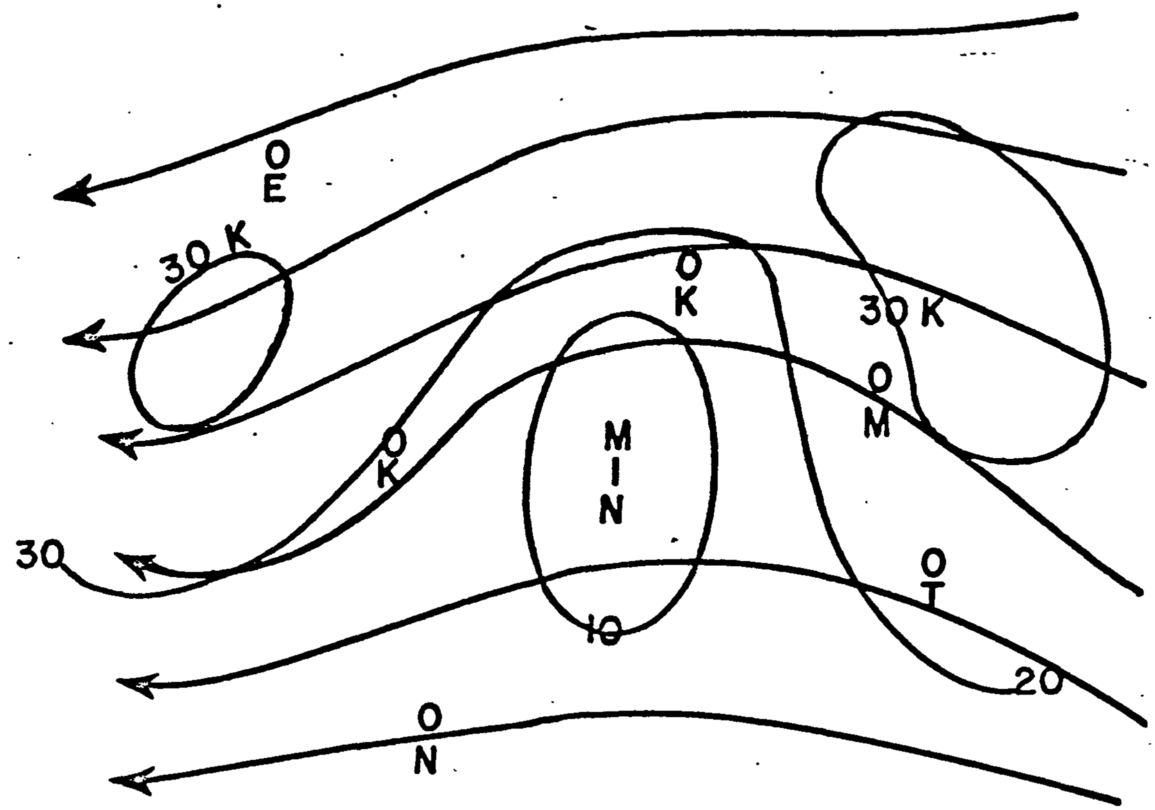
east and west in the southern Marshalls. The easterly winds extend to great heights, reaching in some instances from the surface to 60,000 feet. Fluctuations in the easterlies are due to the passage of atmospheric waves traveling from east to west at approximately 12 knots. Thus the eastern Marshalls are affected by the wind shifts before the western Marshalls. Some of these waves become transformed into cyclonic circulations which show up on wind maps as vortices or eddies, similar, though on a larger scale, to the eddies seen on the surface of rivers. The transformation from wave into vortex occurs first in the lower atmosphere and gradually extends upward, in contrast with the situation previously described, where the cyclones have their origin in the high atmosphere. In general, bad weather is associated with the west-southwest and southeast winds accompanying the rear portions of the vortex. This is also true of the waves from which the vortices originate. The worst weather is associated with the southeast winds. There is a tendency for this weather to occur in the form of long lines of cumulo-nimbus cloud, bearing striking resemblance to the cold fronts of high latitudes, but they are more numerous than the latter within an equivalent area. Many vortices are quite weak, that is to say, maximum wind speeds, usually found in the southeasterlies, do not exceed 30 knots. But there is always a likelihood of a vortex intensifying suddenly to become a typhoon. The best known examples are the typhoons "Georgia" and "Joan" which intensified over the Marshall Islands during Operation Greenhouse. Though typhoons are small in area in these longitudes, they can be extremely violent and can cause as much damage as the great typhoons of the western Pacific. The damage is more restricted in area, usually being confined to one or more atolls unfortunate enough to lie directly in the track of the storm



III. 1500 Ft Low Level Warm Core Low



III. 30,000 Ft Warm Core Low Aloft

A vortex that is intensifying affects the winds up to 40,000 feet and above, and if a vortex should happen to form south of Majuro and move to a position south of Eniwetok while intensifying, very bad weather accompanied by cumulo-nimbus and extensive decks of alto-stratus and cirro-stratus clouds may be expected in the test area. Several examples of this situation occurred during Operation Ivy. A good rule of thumb states that the right semi-circle of the storm is the most dangerous, both for air and sea transportation and for the fixed installations. Bikini and Eniwetok are situated just north of the usual summer tracks for the vortices, so that test operations in the period August to October are subject to hazard.

As mentioned earlier, there is a slight seasonal tendency in the weather of the Marshall Islands and this we are now in a position to evaluate. The three classes of weather situations can occur in any one month of the year and any one may succeed any other. However, the low level cyclone situation tends to be more frequent between the months of July and November than during the rest of the year. ("Georgia" was an exception that shows how unreliable this rule is.) Similarly, the trade situation, while it can occur at any time of the year, is to be expected more frequently during winter months. January, February, and March are probably the months of greatest expectation. The upper level cyclone situation appears to have little, if any, dependence on season. Because of its persistence (up to 10 days), it must always be taken into account in planning any operation in the northern Marshalls. Thus, although Operation Ivy was planned for the fall when low level cyclones were expected, the last part of October was dominated by high level cyclones and one time it appeared as if this weather situation would seriously hamper the plans of Task Force 132.

3. Meteorological Incompatability in Relation to Weapon Testing

It is probably safe in planning future weapon tests in the Marshall Islands to assume that each of the three situations described in the previous section will occur at least once during a period longer than one month. As already stated, there will be a tendency for low level cyclones to be more frequent in summer and fall, while the trade situation should be expected at highest frequency in winter and spring. In the past there has been a tendency in planning the more complicated operations to assume that the wind systems aloft are associated only at random with cloud and weather. For example, there have been requirements in past operations that the winds over the Marshall Islands up to 40,000 feet be, in the period following a detonation, from the southeast or south. At the same time, concomitant air operations have been predicated on the assumption that trade cumulus without middle or upper cloud would prevail over an area including Kwajalein and Eniwetok. Obviously, this is asking for an incompatible distribution of the weather elements. It is true that such conditions may occur at long intervals of time and for short periods; however, they will represent a transition from one typical situation to another and cannot be counted upon for a sufficient length of time to ensure the success of a complicated weapon test. Other meteorological incompatibilities would be the association on strong westerly winds (above 50 knots), above 20,000 feet in the Eniwetok - Bikini region, and cloud conditions appropriate for photography on the ground and in the air. Undoubtedly such conditions have existed on past operations, notably on Sandstone, but they can be regarded as lucky accidents, of short duration. The occurrence of such accidents, and the ability of meteorologists to forecast them, cannot be counted on in planning operations.

with low speed westerly above 20M HJD

Finally, it should be emphasized that the most that can be done, in the present state of knowledge of tropical meteorology, is to forecast broad-scale situations, involving, in the most general terms, the association of wind systems with average cloud cover and precipitation. It is not possible to say that an individual cumulus cloud will be located in such and such a spot at such and such a time, 24 hours ahead. The average lifetime of a tropical cumulus of any magnitude is only 45 minutes; its rate of movement depends only partly on the wind speed and direction. Its shape and the height to which it will reach, the amount of overhang, the rate of dissipation of the tops, will all depend on the micro-structure of the air - a problem in turbulence theory which is beyond the power of any aerodynamist or meteorologist to forecast 24 hours before the event. Precipitation in the form of showers, likewise, depends upon complicated physical processes *occurring within individual clouds. While it is possible to state something about the likelihood of precipitation of this type in a given area, it is not possible to say whether rain will fall on one or another of the islets of an atoll, nor to state the exact time of beginning and ending of individual showers. An experienced meteorologist, who has spent a long time studying cloud forms in the tropics, might make forecasts of these elements as much as an hour in advance. To expect more than this is to expect the impossible.*

In summary, God did not design the tropical atmosphere to AEC specifications. ?

?? Who could ask for anything more!

II. THE DYNAMICS OF BOMB CLOUDS

No attempt is made in the following notes to arrive at quantitative results. However, enough data exist, especially in the form of photographs of the clouds that form as a result of nuclear explosions, to enable a qualitative hypothesis to be constructed. The hypothesis will be concerned with the manner in which the fireball is transformed into the familiar mushroom cloud of past atomic tests. This topic has not been the subject of recent extended researches, and the principles upon which it is usually discussed seem to be inadequate to explain the meteorological concomitants of the initiation and growth of the cloud. It appears that the fireball has been treated as if it were a bubble of heated gas, which it indeed is, and that the events subsequent to its formation can be accounted for by the rise of the ball, much cooled, but still as a bubble, moving upward under buoyancy forces with little change in shape. Changes in shape actually observed have been attributed to atmospheric turbulence resulting in "entrainment" of outside air, in the form of a wake stream. The speculations advanced here arise from the observation that the formation and movement of the cloud and the circulation within it are much too regular, especially under conditions of little wind shear, for the phenomena to be entirely accounted for by turbulence theory. With the larger bombs, the integrity of the atmospheric circulations over time intervals of many minutes suggests that there are present regular streamline motions dynamically independent of and only slightly distorted by small scale atmospheric turbulence.

The conditions with which these speculations begin are those following a detonation at some distance above ground and after the resulting fireball has reached its maximum expansion. Within the region limited by the wavefront of the shock wave, the isobaric surfaces may be considered, except in the immediate vicinity of the mass of heated gas, to have returned to approximately their normal atmospheric orientation, that is, quasi-horizontal. In standard meteorological texts an expression may be found which gives the acceleration of the circulation around any atmospheric path due to the so-called solenoidal field. Consider the vertical paths through the fireball residual and the surrounding atmosphere, shown in Figure 1.*

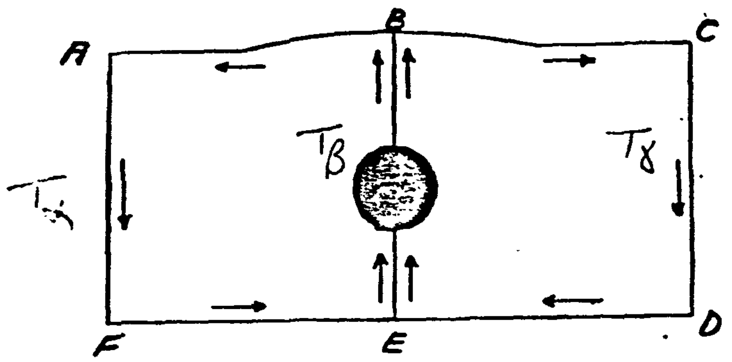


Figure 1: Acceleration of circulation

**Haurwitz, B. Dynamic Meteorology. McGraw-Hill, New York, 1941.*

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ABC and DEF are isobars whose values are, respectively, P_1 and P_o and such that $P_o > P_1$; AF, BE and CD are verticals, directed toward the center of the earth. If C represents the circulation around any path, R is the gas constant for dry air and T_α, T_β, T_γ represent the mean temperatures along the verticals AF, BE and CD, respectively, then, neglecting the effect of the earth's rotation:

$$\left(\frac{dc}{dt}\right)_{ABEF} = R(\bar{T}_\beta - \bar{T}_\alpha) \log \frac{P_o}{P_1}$$

$\bar{T}$ ≡ Mean temp. c = velocity

$$\left(\frac{dc}{dt}\right)_{BCDE} = R(\bar{T}_\gamma - \bar{T}_\beta) \log \frac{P_o}{P_1}$$

(?)

It is clear that $\bar{T}_\beta > \bar{T}_\alpha$ and $\bar{T}_\beta > \bar{T}_\gamma$. The direction of the acceleration of the circulation around these paths is therefore indicated by the arrows in Figure 1. In the absence of wind, complete symmetry will exist, so that after a short time interval, a field of motion will be set up corresponding to Figure 2, and the heated gases and environmental air will ascend together as a vortex ring.

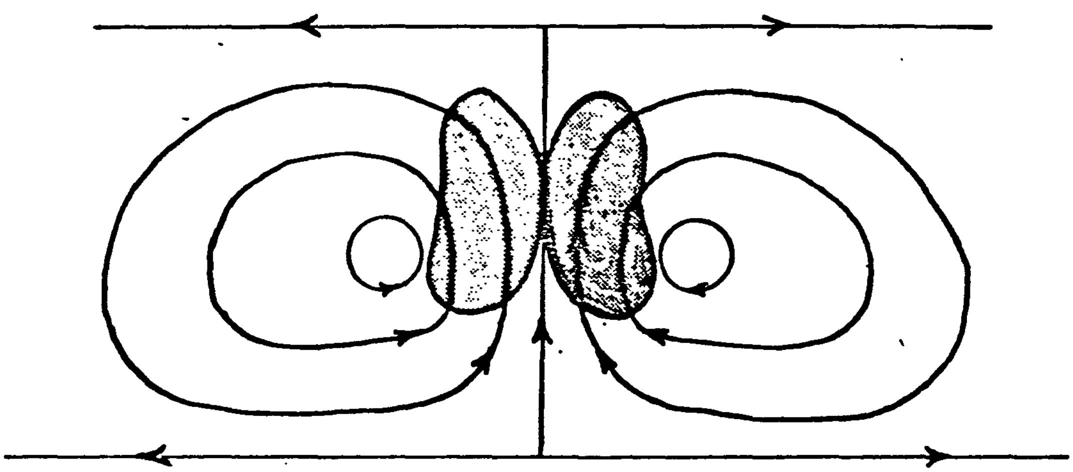


Figure 2

"Entrainment" is thus seen to be, not a disorderly mixing of environmental air in the wake of a bubble of heated gas, but rather, part of an ordered motion in which the gases and the atmosphere form a complete system (see Figure 3). Theoretically, this system should extend laterally behind the shock wave to infinite distances; actually, losses of energy restrict its lateral extent, while cooling due to adiabatic expansion and radiation limit its vertical extent. Turbulence, also, will in time destroy the symmetry of the system and its strict torus form; shear in the wind, both horizontal and vertical, will deform and ultimately destroy the circulation. However, during the early stages of cloud formation, there is surprisingly little deformation, especially with the larger detonations.

1. The stem should be a secondary effect, that is, it will be located in approximately the position of the axial streamline that ends at the ground and passes through the center of the ring. Radioactive material, naturally, can be carried into it as a result of the circuitous motion of the bomb material around the vortex ring during its ascent; there will also be some fall-out of larger particles. However, if the explosion is sufficiently high in the atmosphere, the visible stem material when it is stirred up from the ground and not the result of condensation in a moist atmosphere, may not reach the central portions of the ring. On the other hand, with some low level detonations, the stem may pass completely through the ring and be visible as a plume protruding through it. In a moist atmosphere, as in the Marshall Islands, these appearances are not to be expected, since condensation will occur on all trajectories that pass upward through the condensation level. The stem in these cases will consist partly of bomb material, partly of surface material, but largely of condensed water. With very large bombs, where turbulence cannot have any immediate large-scale effect on the form of the stem, this structure should consist of smooth laminations corresponding to the differences in water vapor distribution along the vertical in the environment. The stems of large bombs should appear different in structure from those of small ones.

2. The stems should in many cases show spiral markings, especially in their lower portions. This is due to the convergence induced in the lower atmosphere by the vertical circulations. The direction of rotation of the spiral will depend on the sign of the vertical component of vorticity in the lower atmosphere: if the horizontal wind shear at the time of explosion is cyclonic, the stem should show a twist in the positive sense (cyclonic as seen from above); the opposite circulation should be observed under anti-cyclonic shear conditions. This deduction is based on simplifying assumptions. First, Coriolis' force has been neglected; if the horizontal winds set up after the explosion are large in magnitude as they probably are, the effect will be to produce only cyclonic twists in the stem, the anti-cyclonic being damped. Second, the horizontal variation in vertical velocity and the vertical shear in the winds have been neglected; these, if large, could produce complicated rotations in the stem which, without empirical data, it is not possible to evaluate.

3. During ascent of the vortex ring air should be moving some distance ahead of the ring (see Figure 3). The effect of this movement should sometimes be visible, more especially if a stable moist layer lies in the higher atmosphere. Then a cap cloud similar to the pileus seen on many tropical cumulus, should be visible close to but moving ahead of the vortex ring.

4. *Other things being equal, the higher the temperature of the fireball and the greater its size, the greater will be the horizontal extent of the circulation. With the larger bombs, provided they are exploded in an atmosphere with pronounced cyclonic shear, a cyclonic system of approximately the size and intensity of the weaker tropical depressions of the Marshall Islands could be set up. Whether such a system could ever become self-perpetuating, through the supply of energy set free by condensation, is a matter about which it is impossible to reach definite conclusions as yet; at the same time, it must be said that the triggering of such a self-sustaining circulation is not at all impossible. The energy for the circulation would be derived, not from that initially released in the fireball, but from the atmosphere, the energy source of tropical depressions and typhoons. Comparison of the relative energy release of typhoons and nuclear (or thermonuclear) devices is therefore irrelevant.*

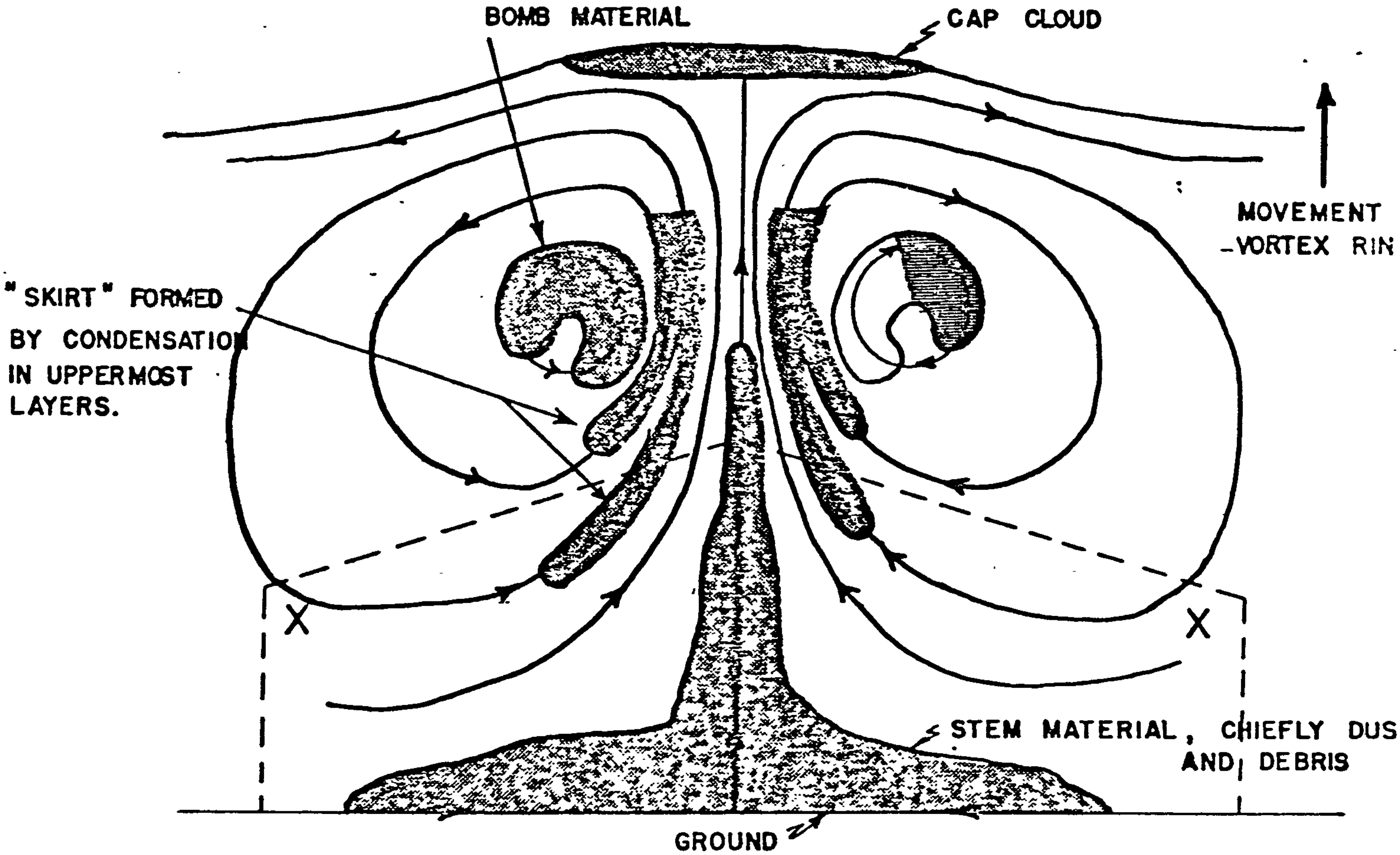
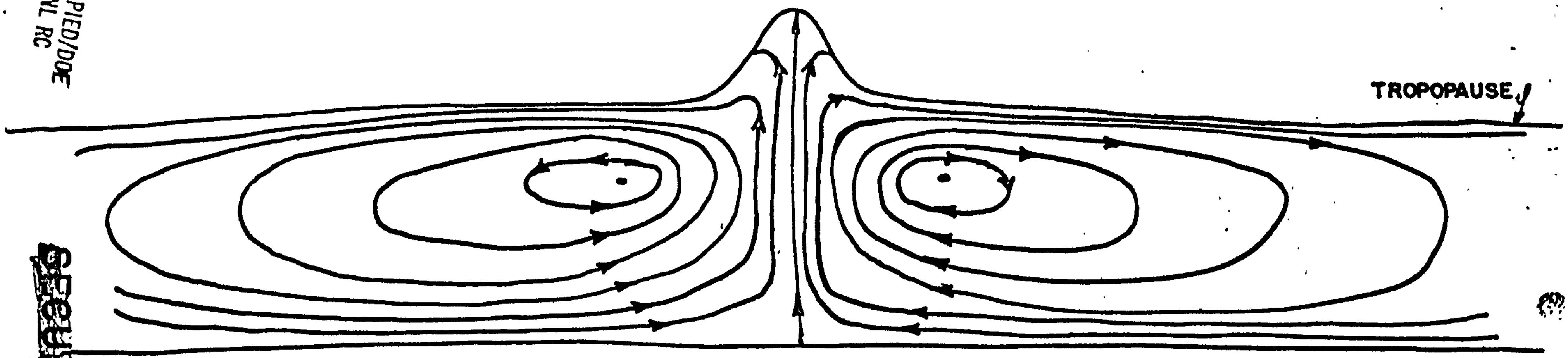


Figure 3: Cross-section showing morphology of a high level cloud during ascent through an atmosphere relatively dry in the lower layers.

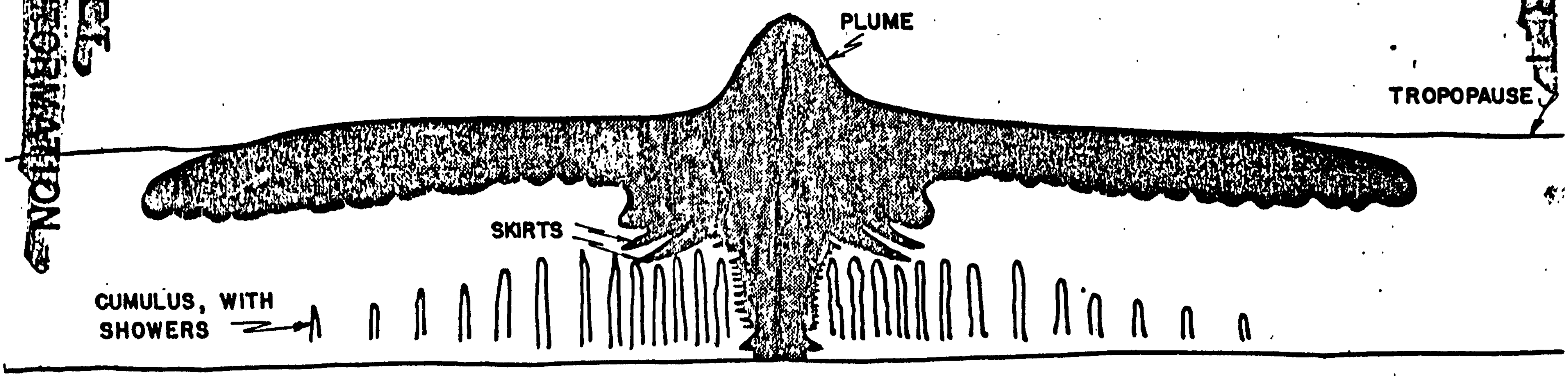
5. In a moist atmosphere and with large bombs the whole of the region marked X in Figure 3 up to and including the stem, should fill with many cumulus clouds soon after the vortex ring has begun to ascend.

6. The cloud will ascend until it reaches a height at which the atmospheric stability is such as to act as a "lid" through which the vortex ring as a whole cannot ascend; in general this level will be at or slightly above the tropopause. On reaching this stable level, the vortex ring and its attendant cloud will expand laterally and in the absence of other sources of energy, the circulation will decelerate and be destroyed eventually by turbulence. Roughly speaking, it may be estimated that the destructive effect of mixing will be greatest when the winds just below the tropopause have strong horizontal and vertical shear.

7. The vertical velocities will reach a maximum along the axial streamline at the time just before the ring reaches its maximum height and at the point on that streamline where it is cut by the plane of the vortex ring (Figure 4). With large bombs this vertical velocity ought to reach very large values. If the "lid" is a very stable layer, such as the lower tropical stratosphere, the central fast moving stem together with much bomb material may be carried up considerable distances into the stratosphere as a narrow "plume" before decelerating to zero vertical velocity (see Figure 4).



A: Streamline pattern at maximum development. Plume may continue upward after remainder of circulation is decelerating.



B: Cloud consisting of bomb material, debris, condensed steam and condensed atmospheric water vapor corresponding to streamline pattern above in A.

Figure 4: Large Yield, Maximum Development

III. EVIDENCE FROM HIGH YIELD DETONATIONS

*1. The Eniwetok Atmosphere, MIKE Day**

The general susceptibility of the atmosphere to convection is illustrated by the reports of cumulus and towering cumulus clouds at both Eniwetok and Kwajalein, as well as by reports of showers and lightning.

Some of the rising air was thoroughly mixed with the environment in the conditionally unstable layers just below 10,000, 19,000, and 29,000 feet. In the lowest of these layers, this mixture maintained high humidity; a layer of clouds was observed near 10,000 feet, trapped below a relatively stable layer. The clouds reported at this level show some of the effects of the low stability (altocumulus characteristics) and some of the effects of being trapped at a level (altostratus characteristics). One of the cloud types reported at Kwajalein indicated altocumulus spreading from the upper portion of cumulus clouds.

Similar mixing of the rising air with the environment in the unstable layer from 13,000 to 19,000 feet undoubtedly occurred. There was no layer immediately above, however, that was stable with respect to saturated air, so that the mixture would be free to break through to higher levels instead of spreading at this altitude.

Also, in the unstable layer from 25,000 to 29,000 feet, the rising air was most likely subject to mixing with the environment. In the region from 22,000 to 29,000 feet, the ratio of wind shear to stability showed a maximum for the sounding.

This region, similar to the one at 10,000 feet, was topped by a stable layer. This means that some of the rising air mixed with the environment of the unstable layer and spread laterally below the stable layer. Here, however, the process did not lead to extensive cloudiness since the environment was quite dry and the mixture unsaturated. Any fragments of the cumulus clouds that broke away from primary convection cells at this altitude quickly evaporated.

The air rising from the surface in the convection cells which attained great height would have reached an equilibrium level near 40,000 to 42,000 feet had it not been for environmental mixing as the rising sample passed through the layers favorable to mixing. Because of this mixing, the equilibrium level was reduced somewhat. The presence of cirrus and cirrostratus clouds at 35,000 to 36,000 feet in the reports from both Eniwetok and Kwajalein can be taken

* *Extract from an analysis made by LCDR William J. Kotsch, USN, attached to JTF 132 Weather Central during MIKE*

as evidence of this fact, since they likely derived from the spreading out of the upper portion of cumulonimbus formations.

2. **MIKE Weather in vicinity of Zero, 0640 - 0700 (L)***

"The personnel in the WB-29 informed me that there were only scattered low clouds in the vicinity of the atoll, whose bases were estimated near 1800 feet and whose average tops were estimated to be near 4,000 feet. I was also informed that "one or two" low clouds to the southwest of the atoll extended to an estimated maximum height of about 7 or 8,000 feet. I was further informed that only a few scattered middle clouds were observed in the vicinity of the atoll and also as far as the personnel aboard the aircraft could see from an altitude of 1,500 feet.

On at least four different transmissions, I was advised that there were no showers between "Point IP" and "Point X" or in the general vicinity of the atoll. The wind at 1,500 feet was reported to be 110 degrees, 12 or 14 knots. On several occasions, the terminology "practically clear" was used by the personnel aboard the aircraft."

3. **MIKE Cloud and Effects****

The detonation occurred at 0715 M, 1 November 1952, as scheduled. It was observed from the flag bridge of the USS Estes (AGC-12) at a distance of 31 miles on a line bearing approximately 155° from the shot island.

The initial aspect of the explosion, seen through density goggles, consisted of an immense fireball which appeared on the horizon like the sun when half-risen; however, the angle subtended by the half-disk at maximum was at least twice that of the sun. A rough estimate indicates that its diameter at this time was between 3 and 4 miles. The fireball was not homogenous but consisted of a bright inner core of approximately two-thirds the total diameter surrounded by a thin, relatively dark shell (orange in color as seen through the goggles), the whole being enclosed in an outer, very bright shell which was the limiting region of the fireball.

The fireball seemed to ascend very rapidly after an initial hover time whose duration cannot be estimated, but which seemed to be shorter than those occurring with weapons tested during Greenhouse.

* *Extract from radio report of voice transmissions between weather observer in WB-29 aircraft and forecaster in JTF 132 Weather Central aboard USS ESTES.*

** *Extracts from a report by Professor C. E. Palmer to CJTF 132 (eyewitness description recorded shortly after event).*

During its rapid initial ascent the ball contracted horizontally and became transformed into a fiery and exceedingly turbulent columnar cloud, losing its quasi-spherical form soon after the ascent began. I thought I saw a small secondary explosion in the fiery column at this time, but other observers do not confirm this. I removed the goggles immediately after this secondary detonation.

The "doughnut" or smoke ring was then formed, without much slackening in the rate of ascent. I estimated that the mushroom cloud reached the tropopause within H plus 3 minutes. Its vertical deceleration after 2 minutes was very rapid and was accompanied by a tremendous lateral spreading many times faster than that seen in A-bomb clouds. It appeared as if the cloud "splashed" against the tropopause.

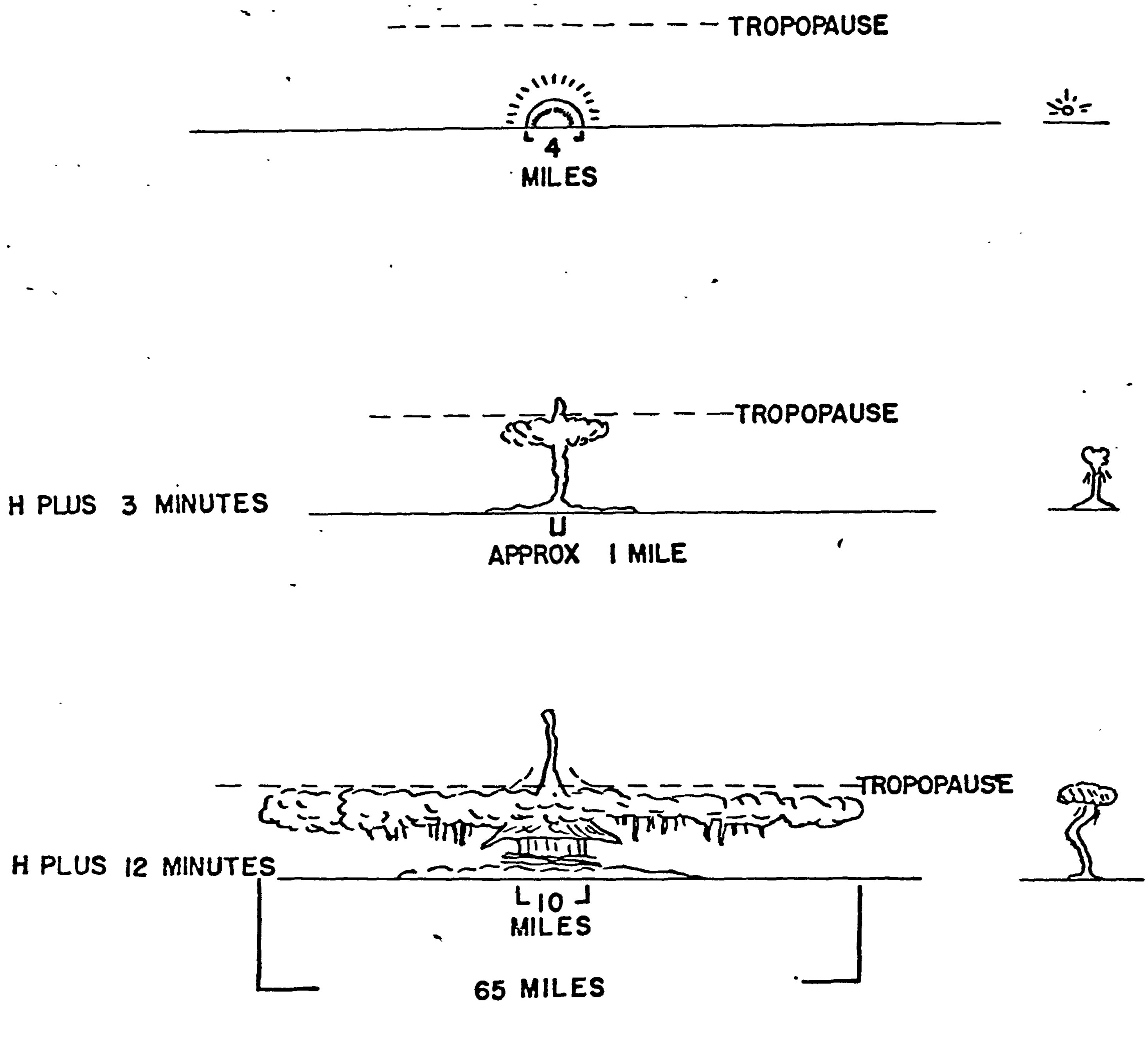
The stem passed into the head of the cloud and moved upward with it from the time the latter was first formed. At first the stem was relatively narrow, being not more than 1 mile in diameter and perfectly vertical. It seemed to be very turbulent but was not marked spirally as are some A-bomb stems. The turbulent appearance soon vanished and the stem expanded laterally to a diameter of 10 miles. At maximum and before deformation, it presented a very smooth appearance like a pile of inverted saucers of different diameters, stacked one upon the other. The only natural cloud resembling the stem at this time is the vertically stacked altocumulus lenticularis seen over and near high mountains during foehn periods. I have seen clouds like the stem over the Sierras in California, and the Southern Alps in New Zealand and I have seen photographs taken in Sardinia of similar structures associated with the Alps. There is no doubt in my mind that the smooth stem is a surround formed about the narrow turbulent initial stem by condensation in outside air taking part in the vortex-ring circulation. The smooth outlines indicate that this part of the circulation is non-turbulent streamline motion and that the various "saucers" are the result of variations in moisture content in the atmospheric layers partaking in the motion upward through the middle of the vortex ring. It may be assumed that the rapid lateral extension of the initial stem is an index of the rate of entrainment of outside air into the vortex ring system; if so, the rate must be many orders of magnitude greater than that in any previous detonation. At the point where the stem joined the head several large skirts formed toward the end of the ascent. Their presence suggested a highly saturated atmospheric layer at about 30,000 feet.

In contrast to the broad stem, the head remained turbulent. It still presented a cumuliform structure at H plus 45 minutes. By this time however, parts of it were being transformed into altocumulus and other parts (at the same level but on the opposite side of this cloud) into cirrus. After comparing notes with other observers, I am convinced that the mushroom cloud remained below the tropopause throughout the period of its expansion and thereafter. This is not to say that the entire cloud was *limited by the tropopause but only the great bulk of it (consisting largely of condensation in entrained air, condensed steam from the sea surface and coral and other debris from the destroyed islands). There is indirect evidence that the initial central turbulent pillar pierced the tropopause at about H plus 3 minutes but its further ascent would be hidden by the great lateral development of the vortex ring (mushroom cloud). ((Development of plume was seen aboard LST 213 miles from zero)). This expansion seemed to be symmetrical and very rapid in its initial stages but began to diminish sensibly by H plus 10 minutes. By H plus 15 minutes, it had in all appearances ceased and the mushroom cloud at that time was 65 miles in diameter. In direct sunlight it was of a creamy white color but the shadows were intense orange. The first evidence of precipitation from the mushroom cloud occurred at H plus 6 minutes. Dark trails were seen descending from it in the vicinity of the stem. I suggest that these trails consisted largely of mud and rain. The first rainbow was seen below the top and to the left of the stem at H plus 7 minutes and rainbows were seen in various positions under the cloud as the ship maneuvered between H plus 30 minutes and H plus 45 minutes.*

After H plus 15 minutes, the intrinsic cloud motions having virtually ceased, the whole structure began to move and to be deformed by the winds near Eniwetok. Up to that time, however, it can be considered to be independent of the wind, the explosion having set up its own local symmetrical circulation over an area at least 65 miles in diameter. The mushroom cloud during the period of deformation was transformed into a dense sheet of altostratus topped by cirrus. Many cumulus shower clouds formed beneath it, penetrating it in places; rain also continued to fall from the altostratus but much of it was in the form of virga. The deterioration of the local weather prevented useful observation of the cloud after H plus 1 hour 30 minutes.

At sunset, the weather having improved considerably, opportunity again occurred of observing distant and high parts of the cloud. The sky color from 10 to 25 minutes after sunset was extraordinarily brilliant. Low in the west there appeared a chevron-shaped, brilliantly illuminated tenuous cloud which I suspect, since it was higher than natural cirrus in the vicinity, lay in the stratosphere. The tentative suggestion may be made that it was derived from a narrow filament that pierced the tropopause at H plus 3 minutes. Its position in the west suggests that it moved with the stratospheric winds between 60,000 and 80,000 feet.

MIKE


TROPOPAUSE
4
MILES
TROPOPAUSE
H PLUS 3 MINUTES
APPROX 1 MILE
TROPOPAUSE
H PLUS 12 MINUTES
10
MILES
65 MILES

4. KING Event

In several respects, atmospheric changes produced by the detonation of KING were more spectacular than those produced by MIKE.

a. Atmospheric Stability

While surface and lower level observations indicated great stability, a more detailed analysis of temperature, humidity and wind data aloft showed the great susceptibility of the KING atmosphere to convection. In fact, higher energy release through the condensation process was available during KING than MIKE, being on the order of 28 x 10^6 ergs per gram of air rising to the level of zero buoyancy.

b. Pre-shot Weather, Eniwetok Atoll

16 November was abnormally clear, with 2/10 - 3/10 flat cumulus, typical of a fresh trade outbreak. Visibility was quite high, pilot reports indicated no obstructions to visibility in any direction for hundreds of miles.

c. KING Detonation

KING was dropped on schedule and detonated over zero point (Runit Island) at approximately 1130 (M), 16 November.

One of the immediate results of the detonation was the rapid evaporation of cloud over a wide area at least seven miles in radius. This evaporation process was produced by thermal radiation from the fireball and not by pressure changes associated with passage of the blast wave.

An almost perfectly symmetrical torus ring formed in a short time and rose rapidly to the tropopause. As in the case of MIKE, the visual impression was that of a "splash", the canopy spread rapidly and, within about fifteen minutes, was estimated to be about thirty-five miles in diameter. The predominate cloud form visible on the bottom part of the canopy was mammato-cumulus indicating extreme turbulence within the mushroom. The bottom of the canopy eventually lowered as the induced circulation continued until there was a cirrus overcast at about 35,000 feet. Later this cloud deck continued to lower, producing virga trails, degenerating slowly as it lowered into altocumulus and altostratus, and eventually dissipated by late afternoon. The upper part of the cirrus deck persisted throughout the day.

KING was a spectacular producer of "home-made" weather. Although no rain showers were observed within a radius of at least one hundred miles of Eniwetok just prior to shot*, scattered showers were observed on the USS ESTES about ten minutes after observation and scattered precipitation was observed in all quadrants (especially to SE and SW) during the remainder of the day.

* WB-29, P2V, and ship observations

5. **Summary of Important Dimensions and Observations, MIKE and KING**

Considerable controversy has arisen concerning the phenomena observed during both of these high yield shots. All observations have an inherent weakness: the object observed was much too large to permit measurement from finite distances. For instance, the elevation angle on the MIKE canopy exceeded 90° within seven minutes. All conclusions, therefore, have a strong subjective element which cannot be eliminated. The following dimensions have been arrived at by discussion between experienced observers present during both detonations and verified to a reasonable extent by photo-interpretation. In the case of MIKE, the high altitude reached by the plume is verified to some extent by post-sunset observations of the cloud in the stratosphere. This same observation also appears to establish that the mushroom did not penetrate the stratosphere to any finite extent.

not so!! !!?

a. *Size of Cloud at Maximum Development*

	MIKE	KING
Diameter of Canopy	75 ~~miles~~	35 miles
Diameter of Stem, near base	10 miles	3 miles
Top of Canopy	60,000 ft	60,000 ft
Base of Canopy	$<$ 40,000 ft	$<$ 40,000 ft
Top of Plume	130,000 ft (?)	no evidence
Diameter of Plume	4 miles (?)	no evidence

b. *Dimension of Circulation Diameter in Upper Troposphere at Maximum Development*

MIKE, 80 miles

KING, 40 miles

c. *Evidence for Vortex Ring Circulation in Upper Troposphere*

(See photographs)

d. *Evidence for Altostratus Formation in Vicinity of Stem*

(See photographs)

e. *Evidence for Cumulus and Shower Formation*

Numerous eyewitness accounts from surface and airborne observers, numerous photographs.

f. *Evidence for Extreme Turbulence in Canopy*

Numerous observations of mammato-cumulus, persisting in the canopy for at least thirty minutes after formation.

g. *Evidence for Secondary Nature of Stem*

(See photographs)

h. Evidence of the Opacity to Radar Waves of the Stem and Mushroom

(1) The MIKE stem obscured all aircraft targets behind it.

(2) Experience with similar cloud of high water content and thickness indicates that a radar wave would have been unable to penetrate the canopy (or mushroom).

6. Photographs

Introduction:

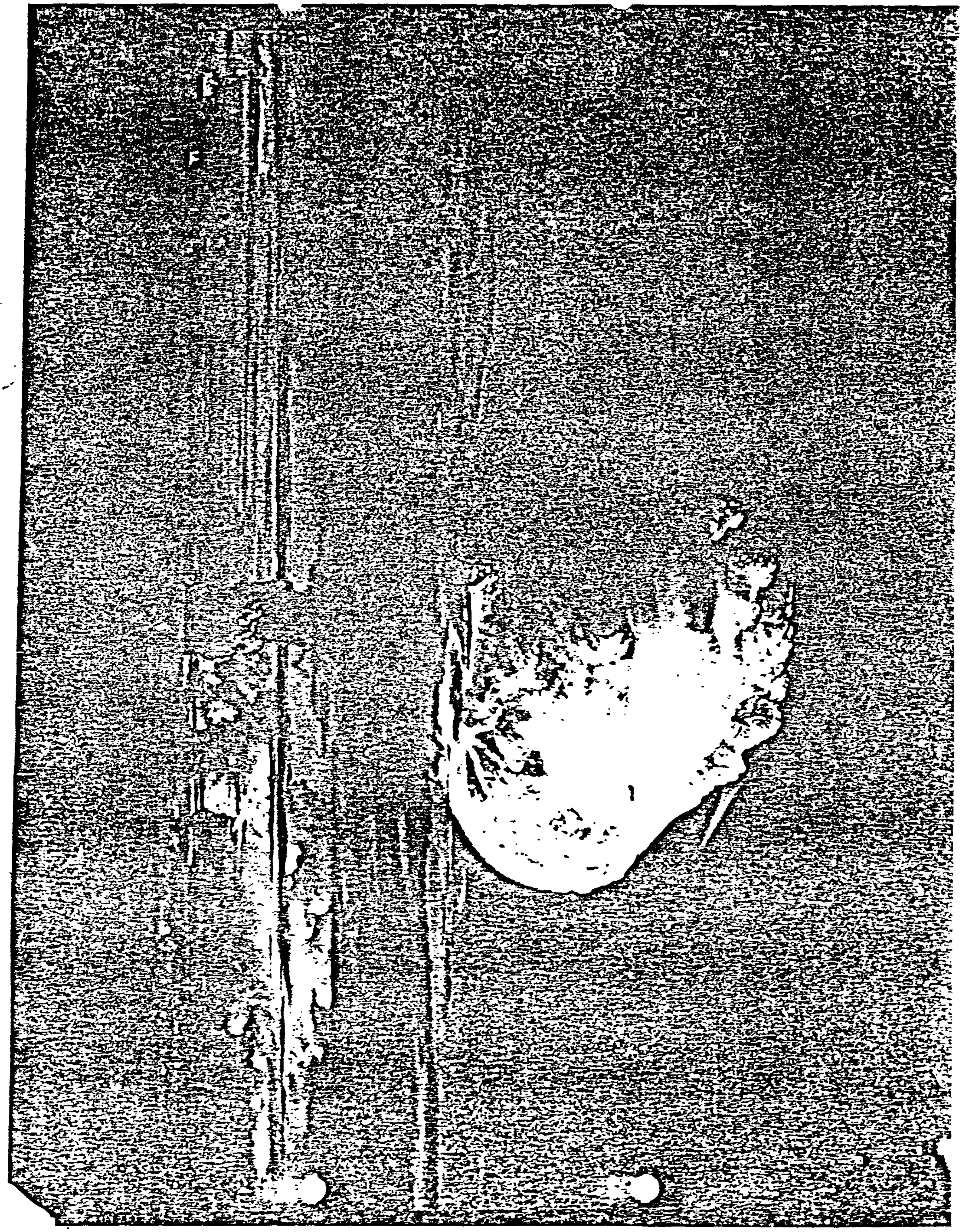
There are several important points which should be kept in mind in connection with the photographs appearing in this section of the report.

(1) The precise location of the aircraft is unknown. Best information indicates that all of the pictures concerning MIKE were taken from an altitude of 11,000 feet and at distances which varied from 50 to 70 miles.

(2) The time of each picture is also not known with precision.

(3) The size of the MIKE cloud precludes real appreciation for the dimensions and effects.

(4) Because of distances involved, optical convergence can result in erroneous conclusions with respect to cloud amounts. Interpretation of the photographs has considered, in addition to the visual evidence available in the picture, surface and aircraft weather reports from the vicinity.



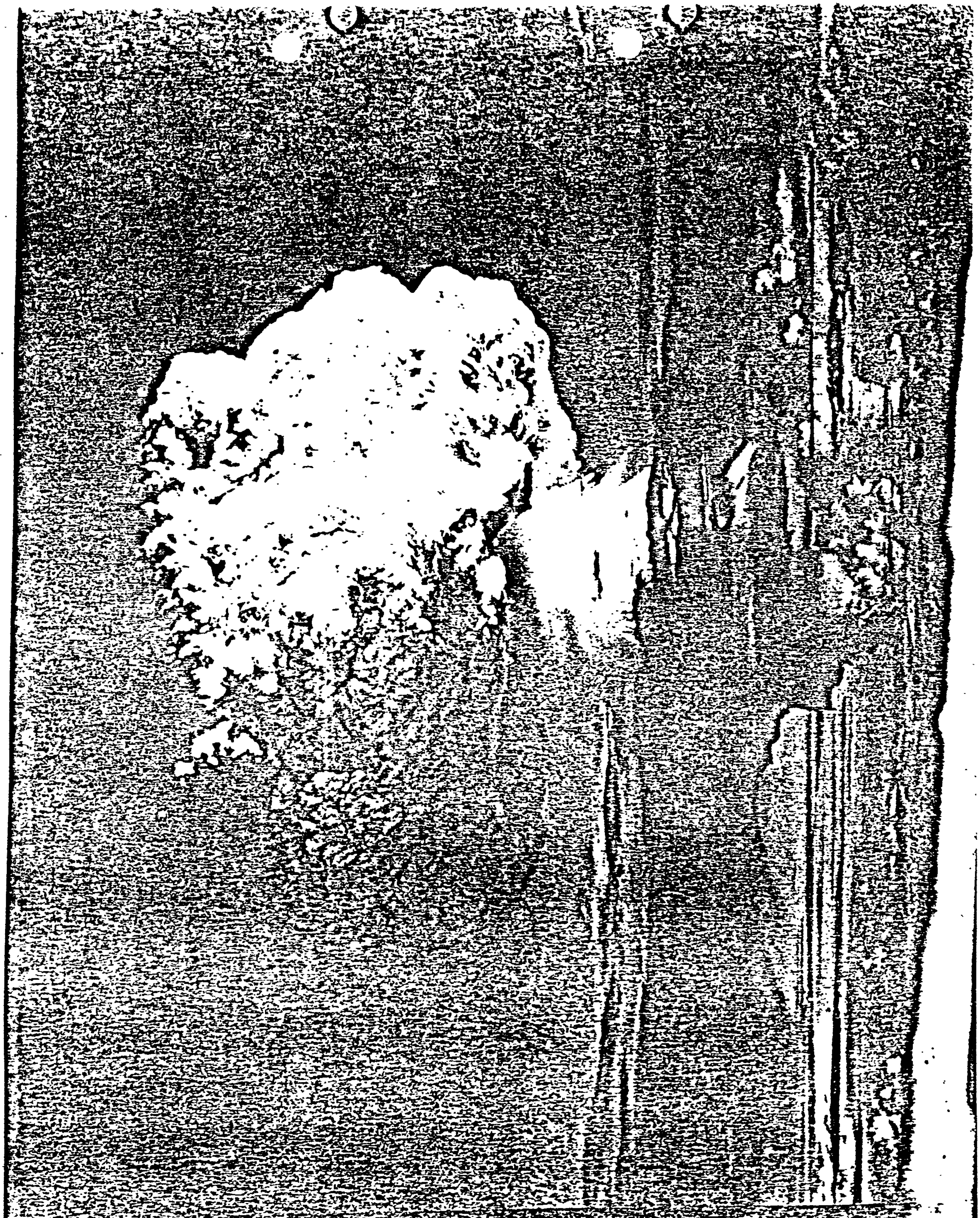
I MIKE CLOUD IN VERY EARLY STAGE.

Altitude 11,000 feet, distance about 60 miles. Scattered to broken stratus below aircraft at about 10,000 feet, intermediate cloud decks in foreground at about 17,000 feet from which light precipitation is beginning to fall. Formation of condensation "skirt" at base of mushroom shows high moisture content at this level. Outer portion of "skirt" is showing definite streamlines of torus ring circulation.

II CONTINUED DEVELOPMENT OF MIKE CLOUD

About twenty seconds after proceeding photograph, MIKE cloud has assumed a definite torus ring circulation, with condensation "skirt" lowering. Note steep slope of streamlines immediately below mushroom, compared to shallower slope at lower levels. Appearance of mammato cumulus in base of mushroom indicates extreme turbulence. Some growth in cumulus to right of stem has begun, and some dissipation of stratus deck in foreground is also apparent. Top of cloud has not yet reached the base of the stratosphere.

The mushroom is about twenty-five miles in diameter.



III CONTINUED DEVELOPMENT OF MIKE CLOUD

About thirty seconds after preceding photograph, MIKE cloud has almost reached the base of the stratosphere. Condensation "skirts" around stem have continued to build downward as increasing amounts of moisture have been drawn into the torus ring circulation. Mammato cumulus is clearly apparent beneath the mushroom; cumulus clouds in vicinity are building up and cloud decks in foreground have noticeably dissipated.

Mushroom is about thirty-five miles in diameter.

IV CONTINUED DEVELOPMENT OF MIKE CLOUD

MIKE cloud has "splashed" against the base of the stratosphere about six minutes after detonation. One of the most significant details in this photograph is the appearance of the "plume" above the laterally spreading canopy. Theoretical analysis of bomb clouds (see Section II) would indicate that most of the radioactive debris would be contained in this "plume". Results of the cloud sampling program would tend to establish this conclusion, and indicate a fundamental operational difficulty.

The canopy is now approaching its maximum dimension, some seventy to eighty miles in diameter. Stratus clouds in foreground are almost completely dissipated, and cumulus continues to increase in height under influence of the induced circulation.

V KING CLOUD

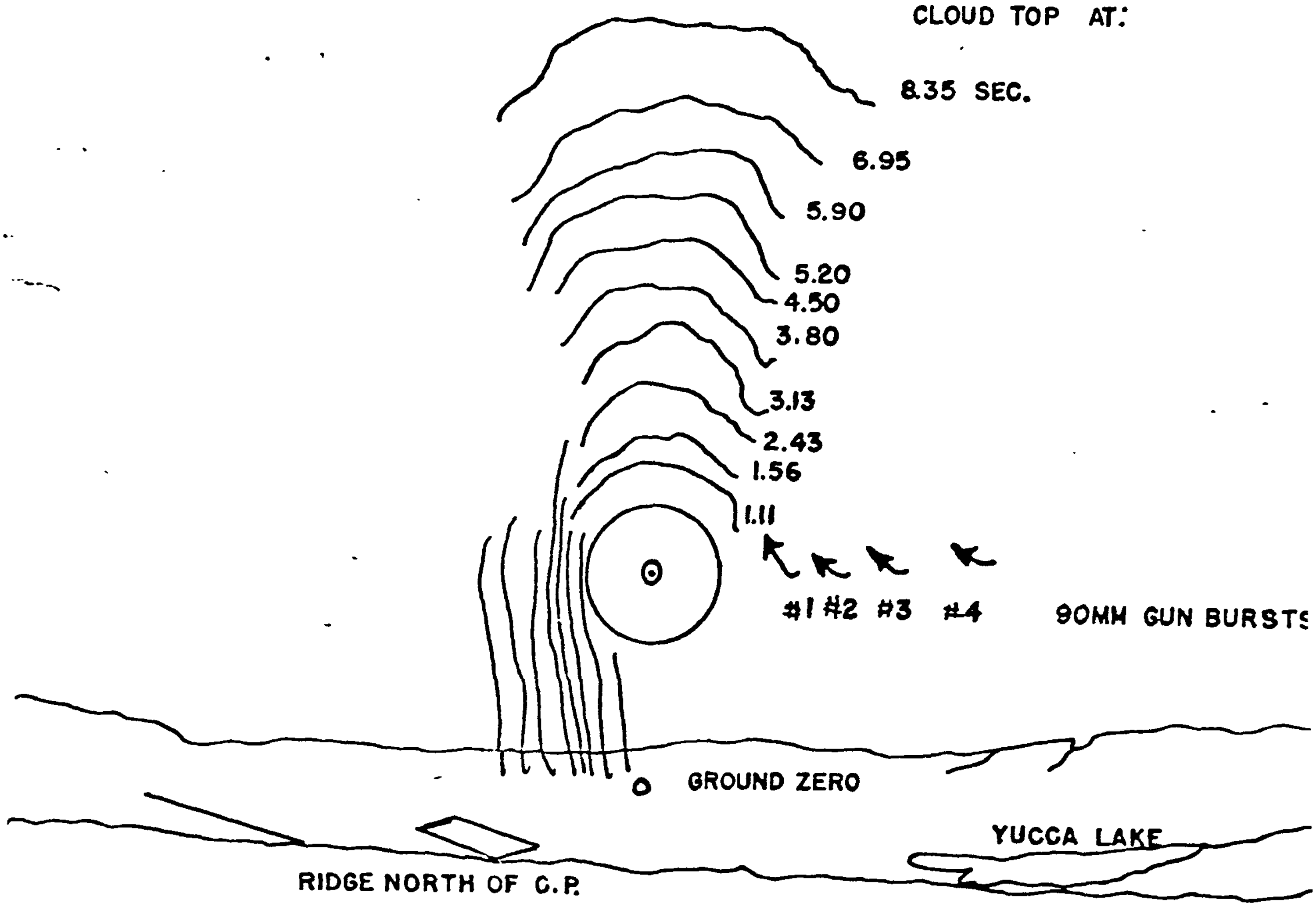
The ordered nature of the torus ring circulation is evident, as is the extreme turbulence present in the canopy.

IV. EVIDENCE FROM LOW YIELD DETONATION*

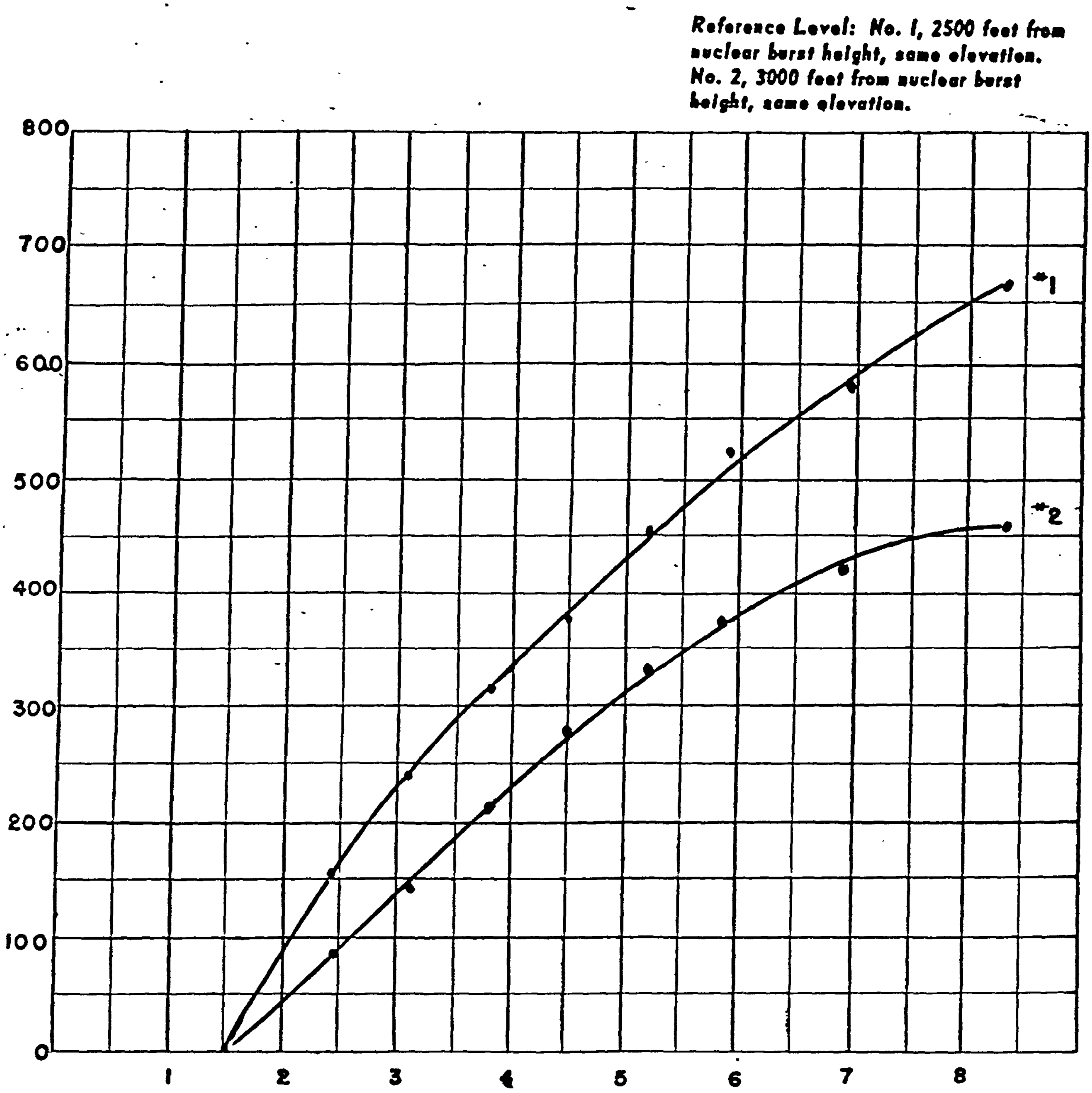
Following data including sketch and illustration were obtained by analysis of photographs of smoke puffs in connection with Tumbler 3. ...

Movement of the smoke puffs clearly traced the streamline motion in the surrounding air mass directly connected with the formation of the Torus Ring. Initial horizontal velocity of burst no. 1 was 200 feet per second with average velocity of 100 feet per second. The initial velocity of burst no. 2, which was at a greater horizontal distance from the detonation point, was 100 feet per second. The average velocity was 65 feet per second. The average velocity of the cloud top was 970 feet per second.

* *Extracts from a private communication from Daniel F. Seacord, Jr., Los Alamos Scientific Laboratory.*


CLOUD TOP AT:
8.35 SEC.
6.95
5.90
5.20
4.50
3.80
3.13
2.43
1.56
1.11
#1 #2 #3 #4
90MM GUN BURSTS
GROUND ZERO
YUCCA LAKE
RIDGE NORTH OF C.P.

Tumbler 3


Reference Level: No. 1, 2500 feet from nuclear burst height, same elevation. No. 2, 3000 feet from nuclear burst height, same elevation.
800
700
600
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200
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1
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7
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#1
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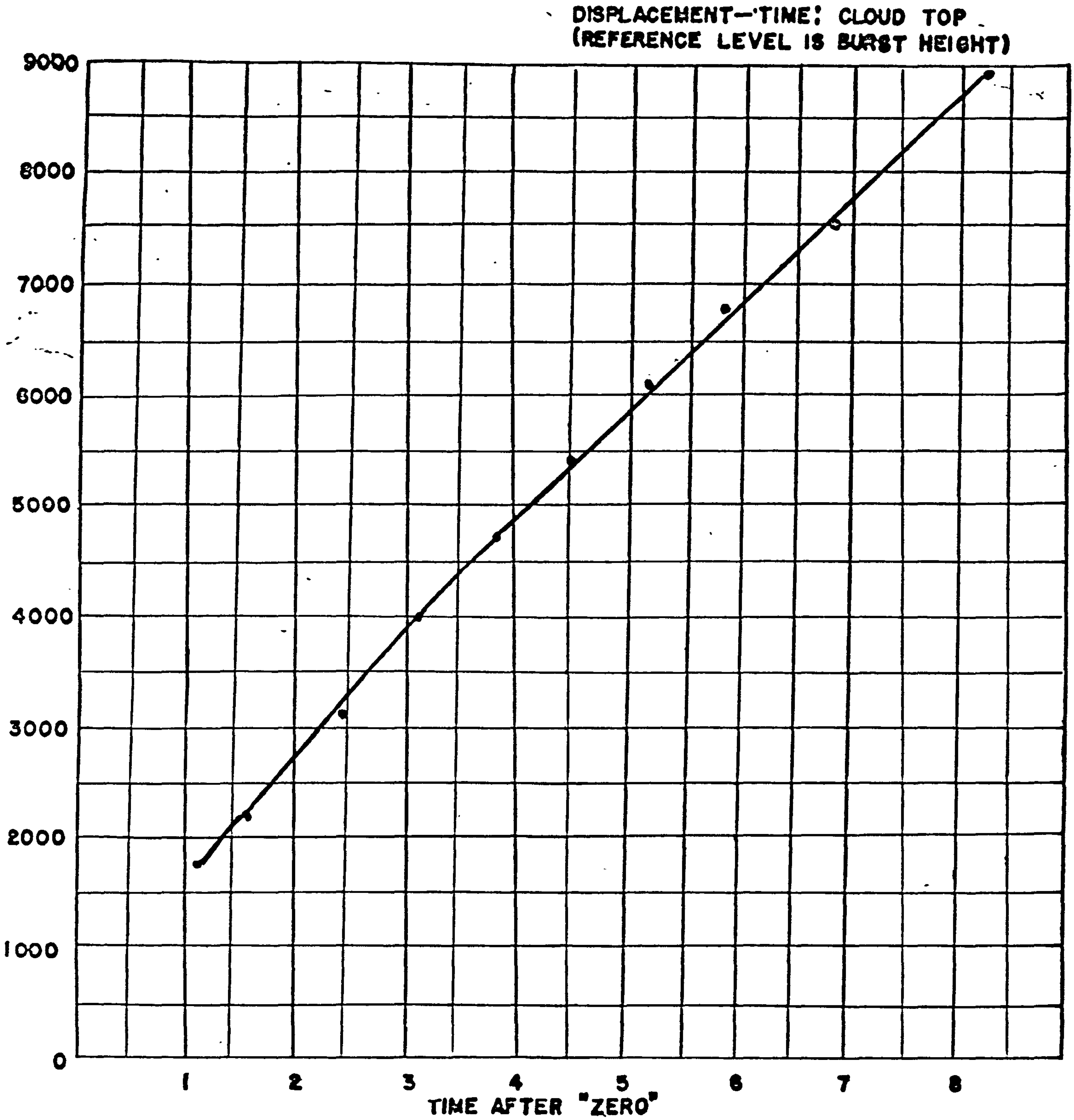
60


DISPLACEMENT—TIME; CLOUD TOP
(REFERENCE LEVEL IS BURST HEIGHT)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8
TIME AFTER "ZERO"