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WT-933
OPERATION CASTLE—PROJECT 9.1

Report to the Scientific Director

CLOUD PHOTOGRAPHY

DDC
MAR 23 1965

Staff of Edgerton, Germeshausen & Grier, Inc.
Boston, Massachusetts

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Defense Atomic Support Agency
Washington, D. C. 20301

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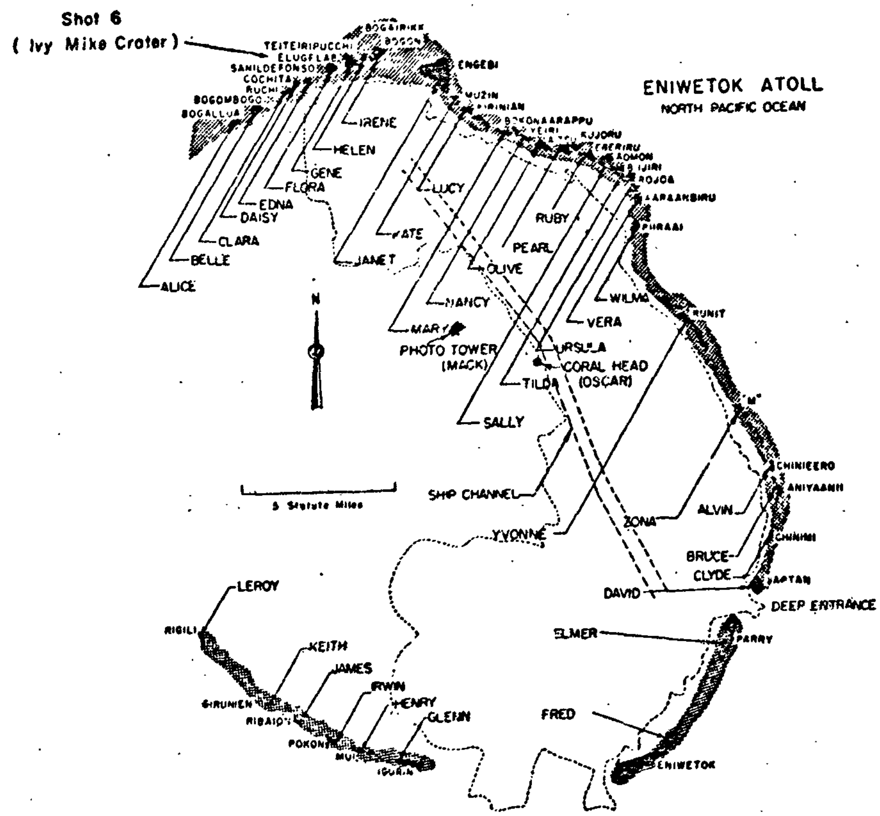
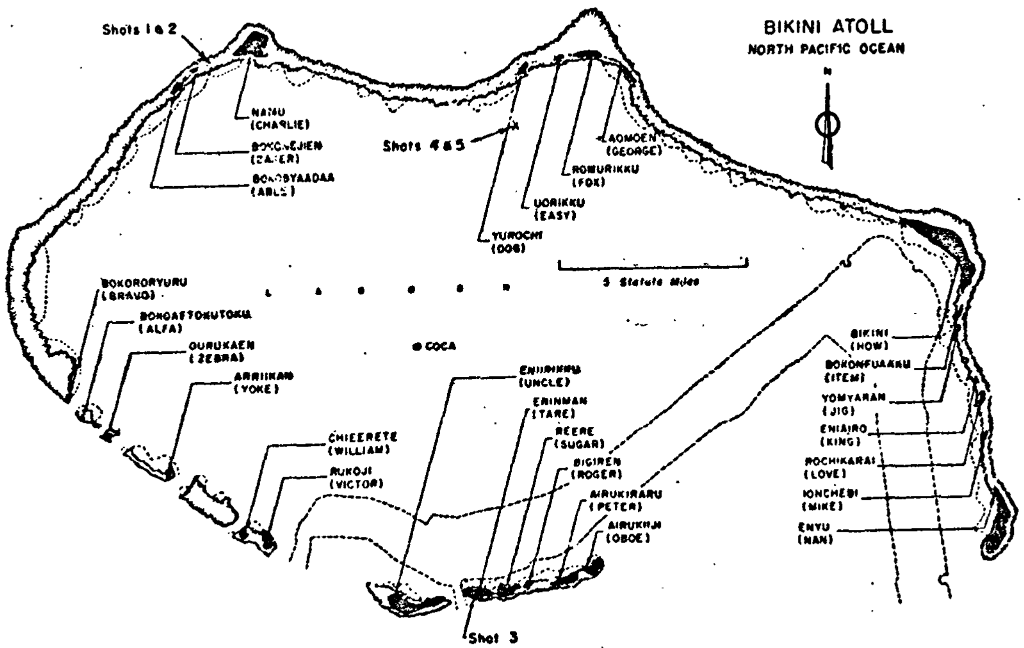
GENERAL SHOT INFORMATION

	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5	Shot 6
DATE	1 March	27 March	7 April	26 April	5 May	14 May
CODE NAME (Unclassified)	Bravo	Romeo	Koon	Union	Yankee	Nectar
TIME*	06:40	06:25	06:15	06:05	06:05	06:15
LOCATION	Bikini, West of Charlie (Namu) on Reef	Bikini, Shot 1 Crater	Bikini, Tare (Eninman)	Bikini, on Barge at Intersection of Arcs with Radii of 6900' from Dog (Yurochi) and 3 Statute Miles from Fox (Aomoen).		Eniwetok, IVY Mike Crater, Flora (Elugelab)
TYPE	Land	Barge	Land	Barge	Barge	Barge
HOLMES & NARVER COORDINATES	N 170,617.17 E 76,163.98	N 170,635.05 E 75,950.46	N 100,154.50 E 109,799.00	N 161,698.83 E 116,800 27	N 161,424 43 E 116,688,15	N 147,750.00 E 67,790.00

* APPROXIMATE


Shot 6
(Ivy Mike Crater)
ENIWETOK ATOLL
NORTH PACIFIC OCEAN
ENGEBI
IRENE
HELEN
GENE
FLORA
EDNA
DAISY
CLARA
BELLE
ALICE
LUCY
JANET
RUBY
PEARL
OLIVE
NANCY
MARY
PHOTO TOWER
(MACK)
URSULA
CORAL HEAD
(OSCAR)
TILDA
SALLY
WILMA
VERA
RUNIT
N
5 Statute Miles
SHIP CHANNEL
YVONNE
ZONA
ALVIN
BRUCE
CLYDE
DAVID
DEEP ENTRANCE
LEROY
RIGILI
KEITH
JAMES
IRWIN
HENRY
GLENN
ELMER
PARRY
FRED
ENIWETOK


Shots 1 & 2
BIKINI ATOLL
NORTH PACIFIC OCEAN
N
NAMU
(CHARLIE)
BOKONEJIEN
(BAKER)
BOKOBYAADAA
(ABLE)
Shots 4 & 5
AOMOEN
(GEORGE)
ROMURIKKU
(FOX)
UORIKKU
(EASY)
YUROCHI
(DOG)
5 Statute Miles
BOKORORYURU
(BRAVO)
BOKOAETOKUTOKA
(ALFA)
OURUKAEN
(ZEBRA)
ARRIIKAN
(YOKE)
L A G O O N
COCA
ENIIRIKKU
(UNCLE)
ENINMAN
(TARE)
REERE
(SUGAR)
BIGIREN
(ROGER)
AIRUKIRARU
(PETER)
AIRUKIJI
(OBOE)
CHIEERETE
(WILLIAM)
RUKOJI
(VICTOR)
BIKINI
(HOW)
BOKONFUAAKU
(ITEM)
YOMYARAN
(JIG)
ENIAIRO
(KING)
ROCHIKARAI
(LOVE)
IONCHEBI
(MIKE)
ENYU
(NAN)
Shot 3

FOREWORD

This report is one of the reports presenting the results of the 34 projects participating in the Military Effects Tests Program of Operation Castle, which included six test detonations. For readers interested in other pertinent test information, reference is made to WT–934, Summary of Weapons Effects Tests, Military Effects Program. This summary report includes the following information of possible general interest: (1) an overall description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the six shots; (2) discussion of all project results; (3) a summary of each project, including objectives and results; and (4) a complete listing of all reports covering the Military Effects Tests Program.

ABSTRACT

Project 9.1 was organized to document the cloud-rise phenomena during Operation Castle by means of photographs exposed from aircraft. This supplements Program 13.2, a Los Alamos Scientific Laboratory study of the early cloud-rise by means of ground-based cameras.

Four aircraft were used: One RB–36 operating at 40,000 feet, and three C–54's working at 10,000 to 14,000 feet. The planes were 40 to 100 miles from ground zero, usually at the 50-mile range at H-hour. Aerial cameras were installed on A–28 Stabilized Mounts and operated by the Lookout Mountain Laboratory, U.S. Air Force. Photographs were taken of the visible cloud, from several directions, as a function of time. Supporting data were photographed automatically, and the aircraft furnished navigation logs to document their position at every instant. These logs were rather less complete and less accurate than had been expected; this is attributed primarily to the difficulties in flying under unaccustomed conditions.

All four aircraft flew on every shot. Of the 24 missions, six were spoiled because of interference by natural clouds. Four of these were on Shot 3, which was fired under such bad weather conditions that good photography from the ground or from the air was impossible.

The data obtained are more complete and more accurate than any obtained during previous operations. Good measurements of cloud height and diameter over a 10-minute interval were obtained for the five shots which were photographed. It has been found possible to apply suitable corrections for the effects of earth curvature and atmospheric refraction, the slight tilt of the camera platform, and the altitude of the plane. The resulting data agree well from one plane to the other, and it has been possible to assign smaller uncertainty to the results than had been anticipated. With a few exceptions, it has

not been possible to evaluate the few data taken more than 10 minutes after detonation. The results fit well with those obtained during Operation Ivy.

A number of ways to improve the procedure became apparent as the tests continued which should lead to a better job on future operations. Several specific recommendations are presented.

The results of the Castle measurements are summarized in tabular form below, and Ivy results are included for comparison.

SUMMARY OF CLOUD PARAMETERS

Shot	Height to Top (thousands of feet)		Diameter (thousands of feet)	
	Max.	at 1 min.	1 min.	10 min.
Castle				
1	114	47	38	370
2	110	44	33	316
4	94	35	26	125
5	110	44	34	270
6	72	25	19	147
Ivy				
Mike	98	39	30	200
King	76	28	11	90

No data were obtained for Shot 3.

Supplementary data on cloud phenomenology such as dimensions of condensation rings, ice caps, and "bells" and "skirts" surrounding the main stem are presented in Chapter 6. Also included are several approximations of the diameter of the stem at high altitudes (35,000 to 50,000 feet) at relatively late (30-minute) times.

CONTENTS

Chapter I

INTRODUCTION

The purpose of this experiment was the determination of the dimensions and altitude of each nuclear cloud as functions of time. Primary interest lies in the early stage during which the cloud rises to maximum altitude. Secondary interest lies in the intermediate interval during which the cloud extends to its maximum diameter at the stabilized altitude. The late stages during which the cloud begins to disperse and to drift with the several wind layers are important, receive attention but to a lesser extent than the first two mentioned above.

The results are vital to strategists, who need assurance whether a delivering aircraft can or cannot safely avoid the uprushing maelstrom. They are also important to the groups concerned with cloud-sampling operations, and are of potential utility in devising methods of estimating energy release. They are of more than academic interest to practicing and theoretical meteorologists.

The photographic method of recording these phenomena was chosen in view of its ability to record permanently, and for ready analysis, every visible detail of the cloud at any desired time. The anticipated large dimensions of the Castle clouds dictated the placement of the cameras at considerable distances. The use of aircraft as camera platforms was decided in view of the paucity of suitable atolls, and of the probability of natural cloud cover. Several such aircraft were needed, for the purposes of triangulating on the cloud to determine its position, and to provide insurance against failure of any one station to procure satisfactory data.

Chapter 2

BACKGROUND AND THEORY

Cloud phenomena have been studied photographically on most of the test operations in the past. These studies have been carried out by Edgerton, Germeshausen and Grier, Inc. (EG&G), under the auspices of the Los Alamos Scientific Laboratory (LASL) on Operations Greenhouse (References 1, 2); Buster (References 3, 4); Tumbler–Snapper (References 5, 6); Ivy (References 7, 8, 9); and Upshot–Knothole (Reference 10). The Greenhouse measurements were taken for analysis by groups at the USAF Cambridge Research Center and Rand Corporation, who reported those results in detail. All of these programs were carried out with rather limited objectives.

All measurements were taken with ground-based cameras until Ivy, when the first attempt at aerial documentation was made. These data were far from perfect but provided invaluable experience in planning the Castle program. As it turns out, the same statement can be made concerning the Castle results: The data are incomplete, although they are the best yet obtained; the experience shows many ways in which they could have been improved.

2.1 PLAN FOR CASTLE

At the request of the Armed Forces Special Weapons Project, a technical proposal (Reference 11) for the Castle cloud-study program was submitted, and was followed by a detailed technical plan (Reference 12). This plan recommended the use of several aircraft, at 30,000 to 40,000 feet, together with ground-based stations. The aircraft were to be placed 75 to 100 miles from ground zero in different directions but in the two western quadrants to photograph the silhouette of the cloud against the dawn sky light. Wide-angle lenses were to be used to keep the entire cloud within the field of view for upwards of an hour. The cameras were to be mounted on automatically stabilized platforms to control the tilt, and the aiming direction of the camera was to be recorded automatically from a gyro repeater. Accurate navigation logs were needed to keep track of the aircraft position throughtout the run. As will be seen, these requirements were not entirely met; it is clear now that they are all truly necessary and cannot be compromised if all of the objectives of the program are to be satisfied.

During a meeting of Program Directors at LASL, in June, 1953, a decision was reached to separate the airborne and land-based photographic programs. The land-based portion was reduced in scope, placed under LASL Project 13.2, and carried out entirely by EG&G., Inc. The airborne portion was placed under AFSWP Project 9.1; the photographic work was assigned to the Lookout Mountain Laboratory, USAF, while EG&G., Inc. furnished advice and consultation in planning the program, analyzing the films, and reporting the results.

2.2 THEORY

Since Project 9.1 was concerned with observing the cloud phenomena and not with explaining them, the theoretical background is extremely simple. The size of a given object, H, is related to the size of the image, h, by the simple relation

$$H = D_{oa}\, h/f$$

where f is the effective focal length of the lens, and D_{oa} is the distance along the optic axis, from the lens to the plane (perpendicular to the optic axis) containing the object. The focal length is calibrated accurately for each lens. The image size and optic-axis distances, however, may both be poorly known. Assuming the distance to ground zero is accurately known, it is not known how far away a given part of the cloud is (for example, the near edge), nor is it known how high that part is if ground zero or the horizon is obscured by clouds. Thus the gross cloud diameter may be determined more easily and reliably than the heights and positions of specified portions.

It was to overcome these difficulties that use was made of the stabilized platform. With this table the angle of tilt in aiming the camera is at least known, and film measurements can be made to fiducial or other artificial reference points where no natural reference appears in the photograph. Measurements of this sort have been carried out successfully for objects lying near the ground-zero plane. To investigate such objects as the near edge of the cloud, more information is required: for example, a second picture taken from another location. If the object can be clearly identified in both pictures and if the camera aiming angles are accuragely known, the position of the object can be computed by triangulation. This endeavor has failed for Castle, since the angles and positions are too poorly known and since two different views of most cloud irregularities are quite difficult to identify positively. It appears that two views from nearly the same position are needed, not more than 15 degree separation, and that the aiming angles must be measured with a higher order of precision than appears justified.

2.3 CORRECTIONS TO OBSERVED DATA

The practical difficulties and limitations in the experiment are considerable, necessitating the evaluation of suitable corrections to the direct measurements. For example, a correction must be made for the curvature of the earth and for refraction of the light path through the atmosphere. This is a relatively straight-forward calculation, involving the altitude of the plane and its distance from the object, and is treated thoroughly in many works (References 13, 14). It is employed whenever artificial reference points are used in measuring the film.

A similar calculation is concerned with the position of the apparent horizon in the ground-zero plane. This horizon is used as the measurement reference wherever it is clearly visible. Since it usually lies behind the detonation point, it appears to be at some (easily calculable) altitude above ground zero.

A more-serious correction is needed in determining the location of the top of the cloud, which may be obscured by other portions of the cloud closer to the camera. It is clearly impossible to photograph the top of a wide-spread object unless the camera can be placed above it. This correction necessarily involves personal judgment based on detailed examination of a series of pictures taken at different directions and times. A feeling is developed for the probable shape at the top, and the data are corrected accordingly.

Additional corrections are required to compensate for the variations in tilt of the stabilized platform. These variations are small, except when the plane banks and throws the table into the stops. Nevertheless the correction is significant even for the small variations and is considered as a separate step in the computations whenever artificial reference must be used.

Chapter 3

INSTRUMENTATION and OPERATIONS

3.1 INSTALLATIONS

For the purposes of Project 9.1, two cameras were installed and operated in each of four airplanes by the Lookout Mountain Laboratory. Each plane was equipped with a Type A–28 Automatic Stabilized Mount, which carried one modified K–17C camera and one 35-mm Eclair motion-picture camera. The 35-mm cameras were intended to operate at about one frame per second, to document the rapid rise of the cloud during the first five minutes. They were equipped with timing clocks. The K–17C cameras were provided with special shutters to permit long exposures under dim lighting conditions and were planned to take three photographs every minute during the early stages and to drop back to a slower schedule later on. The K–17C cameras were provided with data recording chambers to record: (1) the time at which each frame was exposed, (2) aiming of the camera by means of a gyro-controlled compass card, and (3) tilt of the stabilized platform by means of a bubble-level.

One installation was placed in the RB–36 aircraft, which was flown at about 40,000 feet on every shot. This plane was available to Project 9.1 for only the first 10 minutes after detonation; it then performed duties for Program 11 and Task Unit 9 to the exclusion of Project 9.1 interests.

Similar installations were made in three C–54 aircraft, which flew at 10,000 to 14,000 feet for each shot. These planes were available for an hour or more and were shared with Task Unit 9.

The original plan called for placement of all planes in the two western quadrants to permit photography of the cloud silhouette against the dimly illuminated eastern sky. Distances and lenses were specified to cover a field of view approximately 150,000 feet high and 350,000 feet across in the vertical plane at ground zero. This requirement was based on observations taken during Operation Ivy.

The ship's navigator was requested to supply information as to the distance and bearing to ground zero every minute, together with supplementary data on the plane's heading, course and speed.

Although the schedule was tight, all equipment was installed and trial runs were made before leaving the United States. These runs were apparently satisfactory. Trial runs were also made in the forward area, with the primary object the determination of the pre-dawn sky light-levels. It was found that the available light was marginally weak but still exceeded pessimistic expectations.

3.2 OPERATIONS

The plan of operation was relatively simple in principle, but success depended upon good luck as well, as on proper functioning of individuals and equipment. Serious loss of data or even complete failure of the mission could result from the failure of a single link in the chain. For example, incomplete navigation data can spoil an otherwise perfect set of films. On the other hand, failure of a clock or of a shutter or of a power source is equally ruinous. Natural cloud cover can kill the mission completely.

The results of these cloud-rise studies are easily the best obtained to date. However, the basic plan fell short of complete fulfillment in several important respects.

3.2.1 Equipment Failures. The most-serious failures were those of the special shutters in the modified K-17C cameras. This is presumably caused by the low-temperature operation and was not encountered before the operation because of the closeness of the schedule. The failures manifest themselves in double exposures, under- and over-exposures occurring in a sequence of properly exposed photos and in the shutter remaining open during film transport. The resulting photographs sometimes give partial information but result more frequently in gaps in the data. Fortunately, these gaps are sometimes filled by cameras in the other planes. This difficulty became less serious as the operation proceeded.

The data-recording chambers in these cameras were usually well exposed and legible. On two occasions when the camera was operated at runaway speed (1.5 second picture interval versus the prescribed 20 second) the vibration caused complete loss of the chamber data. This difficulty was eliminated.

The compass card in the recording chamber sometimes gave data which are obviously in error. (The plane's course swings around a 60 degree arc, but the card shows an angular change in aiming of only 25 degrees.) It is understood that lack of time prevented the coupling of this card to a gyro-repeater and that the settings were put in manually.

Owing to the pressure of time, the prescribed short-focal-length lenses were not used on the motion-picture cameras. The use of long lenses, together with the too-close positioning of the aircraft, limited the field of view to about a third of the prescribed dimensions. As a result, the cloud invariably ran out of field in two minutes or less.

There were two cases of failure of the clocks in the Eclair cameras, owing to low-temperature operation. The difficulty was remedied satisfactorily.

3.2.2 Failures Due to Aircraft Location. The aircraft were much too close to the point of detonation, for the purposes of Project 9.1, because of compromises with other experimenters using the same planes.

The RB-36 plane was needed by Project 11 to begin sampling operations after the first 10 minutes. This requirement pulled the plane in to a range of 50 nautical miles on every shot and resulted in too small a field of view for the cameras. The cloud went out-of-frame in the K-17C cameras at 4 minutes (Shot 1) to $7\frac{1}{2}$ minutes (Shot 4) and in the Eclairs at 1.5 to 3.7 minutes. An accompanying difficulty arose from the Program 11 wish to have the plane in the southeast quadrant—there was not enough light once the fireball dimmed, so that exposure-times up to 4 seconds had to be used. The platform was not steady enough for such long exposures, and the pictures are blurred and difficult to read.

The C-54 planes were shared with Task Unit 9, which wanted to be as close as possible to the burst. The compromises adopted were certainly unsatisfactory to them as well as to Project 9.1. The ships were placed in the right directions but were only 40 to 60 nautical miles from ground zero—so close that the useful period of observation was limited to 10 minutes or less. There were two exceptions on Shot 5, when the planes were at 90 and 100 miles and procured good photographs to 15 and 20 minutes respectively.

3.2.3 Failures Due to Navigation Errors. The position data supplied by the aircraft navigators are not as good as had been expected. Undoubtedly EG&G did not appreciate all of the problems involved and assumed the job to be easier than it actually was. As a result, the specification of data requirements may have been inadequate. The other groups concerned also assumed the job to be routine, and as a result, everyone was inadequately briefed.

The disappointing data from the first shot pointed up the problem and led to corrective measures. Two planes furnished sketchy information, starting after the useful photography was completed, and the other two sets of data contained obvious errors and inconsistencies. Some of the navigators performed consistently better than others thereafter, although the data still contain obvious gross errors: one log had the plane remaining in the same position for 3 minutes; in other cases the aircraft backed up, went sideways, or ran at 700 miles per hour. It is believed that the navigators did the best job they could, adequate for the routine running of the plane, but that the added requirements of this program led to the sort of human errors that everyone can make when working under extreme stress.

On the last two shots, supporting navigational data were furnished by the Air Operation Center aboard the USS Estes. Comparison of these results with those logged by the aircraft navigators shows that the probable uncertainty in distance is of the order of ±2 nautical miles, and in angular bearing of the order of ±4 degrees. (Extreme discrepancies of 26 miles and 14 degrees were actually reported.)

It is believed that the data are generally good as regards distance from plane to ground zero but that the bearings are too poorly known to give any accuracy in triangulating on the cloud. This conclusion, together with the limited photography coverage, restricts the interval of measurement to about the first 10 minutes, before wind drift becomes appreciable. Thus the third, and least important, objective of the program was not satisfied, with the exception of several measurements of stem diameter at about 30 minutes. The two major objectives, however, were met with reasonable precision.

Chapter 4

METHODS AND ANALYSIS

The photographic study of cloud-rise phenomena differs in several important respects from the customary aerial survey or photogrammetric mapping problem. It is not enough simply to establish accurate scale factors for distance. Customary mapping procedures always reduce the three spatial dimensions to two by employing a system of contours to represent the relatively slight variations in the third. Here refuge cannot be taken in such a device; the three spatial dimensions, and also time, must be considered as four separate, independent, and irreducible variables. A complete analysis of all phases of this problem would be laborious and unjustifiably expensive; even a limited study, however, requires accurate and complete control of all four variables for every photograph exposed. In addition, it requires experience and judgment on the part of the analyst to: (1) interpret the series of pictures, (2) identify irregularities in the poorly defined and sometimes nebulous cloud surface, (3) evaluate the relative importances of prominences in the cloud, and (4) estimate probable features which are hidden from the camera.

4.1 SPATIAL CONTROL

It is necessary to know the following for each photograph: (1) horizontal distance from ground zero, (2) altitude of the camera platform, (3) horizontal aiming angle (bearing), (4) vertical aiming angle (tilt), (5) focal length of the lens, (6) distortion characteristics of the camera, (7) location of the optic-axis on the film (fiducial marks), and (8) earth curvature and atmospheric refraction.

In addition to the above, it is desired to make sure that the field of view of the camera is large enough. A photograph in which cloud-cover, perspective difficulties and curvature-refraction effects are all minimized is preferred. These are contradictory effects, and the optimum distance for multimegaton bombs is of the order 75 to 150 miles.

In practice, Items 2, 4, 5, 7, and 8 are usually quite well known. Item 6 is neglected; Item 1 is known to about ±2 percent; but Item 3 is too poorly known (± 4 degrees or so) to permit any true three-dimensional analysis. Lack of this information requires that the cloud phenomena be evaluated in the vertical plane through ground zero. The loss of any of these data, for any given photograph, seriously impairs the value of that picture to the study.

Data regarding camera position for the Castle detonations were derived from the navigation logs furnished from the field. The given data were plotted for each mission as a series of arrows originating at the given position and terminating at the expected position 1 minute later. Since the terminus almost invariably differs from the actual position given by the log for that time, by 1 to 10 miles, it must be concluded that the data are not internally consistent. Therefore, a smoothed curve is drawn through the data to represent the probable course of the ship. An adjusted time scale is constructed along this curve, with equal increments of distance to take account of the nearly constant velocity and with minimum deviation from the logged time scale. This curve is felt good to ±2 percent as regards distance to ground zero, and to ±4 degrees as regards angular bearing.

4.2 TIMING CONTROL

It is necessary to know the time, relative to detonation, at which each photograph is exposed. This problem was solved in principle by photographing a clock, mounted within the camera, at the same time each exposure is made. The remaining problem is one of synchronization. In most cases the clock was set to within a second or two, and the clock error was noted. However, in two cases the clock ran slow because of low temperatures. In another case, in which clock error is not noted but is of the order of 3 minutes, the only way to ascertain the time is to work backward from the best data obtained from other cameras.

4.3 MEASUREMENTS FROM THE FILMS

It is impossible to specify an exact measurement procedure, since each photograph differs importantly from all others. The analyst takes advantage of every feature that can aid him, primarily in the matter of establishing a gound-reference level. Many such references are possible; sometimes all of them are available and sometimes none. The best reference would be a clearly defined ground zero, such as may be derived from the ellipse representing the water-shock intersection. Other possible references are the horizon, a well-defined condensation ring or skirt surrounding the stem, the edge of the film frame, or the fiducial references in the camera film-plane. Frequently these fiducial marks are missing, because they require sky light to shadow them on the film; artificial illumination would be much more reliable. Having chosen the reference for a given photo, measurements are taken to tie them all together, i.e., horizon to fiducials, shock-wave to condensation ring, and so on. Such data, obtained from a few pictures, may be invaluable for making measurements from other photos in the same series. Thus, measurements may be made from the shock circle for the first few pictures, from a prominent skirt later on, and finally, from the fiducials when they reappear.

Measurements are taken from the best reference for the particular picture to the several interesting cloud features. Careful notes are kept explaining the references used and the portions of the cloud to which measurements were taken. These notes are used later in resolving the discrepancies between readings from several cameras.

The 35-mm films are read by means of a Hauser microscope comparator or by means of a magnifier and scale on an illuminated table. The comparator provides more precision than is required (±0.0002 inch on the film) and is rather time consuming, in view of the careful set-up required. The magnifier and scale permit readings to an estimated ±0.001 inch, which is more than adequate for these measurements. The choice of instrument is usually made in view of the particular features of the given film.

The K-17C films are read by means of a scale on an illuminated table, which is good to ±0.01 inch. This is more than adequate for these purposes, since the edge of the irregular cloud usually cannot be defined to better than 0.10 inch on these films.

4.4 CALCULATIONS

Scale factors are derived for each film as a function of time from the smoothed airplane position curve and from the calibrated focal length. Then the appropriate corrections are derived, also as functions of time. These corrections (for earth curvature and refraction, position of the apparent horizon, altitude of a particular skirt used as the measurement reference, and tilt of the camera platform) depend upon the altitude of the plane and its distance from ground zero, the reference chosen for the particular measurement, the measurements relating the several references, and the position of the bubble level showing platform tilt. The corrections are applied to the film measurements with appropriate scale factors to derive the final readings of cloud diameter or height as functions of time.

The data from the cameras are plotted for comparison and almost always show a gratifying agreement during the rise of the cloud to maximum altitude. This agreement shows the analysis to have been correct. The diameter readings and height to bottom always continue to agree well, but the height-to-top readings usually begin to spread apart after stabilization, disagreeing sometimes by as much as 20 percent.

When discrepancies appear, the films and the measurement notes are re-examined to determine the cause. Usually it is a matter of judgment as to which portion of the image truly represents the top of the cloud. Sometimes it can be shown that the cloud must have moved enough to upset the scale factors; in such a case the average of two readings from opposite directions is better than either alone. A "best curve" is agreed upon, and estimates of error are derived from the scatter in the figures and from the known uncertainties in the supporting data.

Chapter 5

RESULTS

The measurements and calculations are presented and discussed, shot by shot, in the succeeding paragraphs. Data are given concerning the diameter and heights to top and bottom of the cloud proper, as functions of time for a maximum of 10 minutes. Few data were obtained at later times and, with the exception noted in Chapter 6, are omitted in view of uncertainty as to motion of the cloud with the wind.

In general, the diameter data are considered the most accurate while the height to the top of the cloud is least reliable. This follows from the fact that the cloud towers high above the camera and the top cannot be seen.

For the purposes of this report, the top of the cloud is measured at the top during the rise and near the edge after stabilization. Whenever a thunderhead (a small wisp of material going to higher altitudes than the cloud proper) is observed, the data are also given. The bottom of the cloud is sometimes poorly defined, because of the massive stem, but roughly represents the cloud level about halfway from stem to edge.

5.1 SHOT 1

Data from this detonation are less complete than from succeeding shots. Two of the planes furnished adequate navigation data, and also usable films; fortunately, the worst camera failures occurred in the aircraft whose positions were unknown. Table 5.1 lists all of the films exposed for cloud Projects 9.1 and 13.2, together with an evaluation of their utility for these purposes.

The results, given in Figure 5.1, are based on measurements from three aerial films (two from K–17C cameras and one from an Eclair) and are tied into the 13.2 data from ground-based cameras, which cover only the first 0.6 minute. The diameter curve is believed to be good to ±3 percent for the first 5 minutes; after this the photographs are poor and only two measurements could be taken. The height-to-top figures are good to ±3 percent for 4 minutes. Then they become increasingly uncertain; at 6 minutes the given data could be in error by ±10 percent, and thereafter the prominent thunderhead provides the only reliable measurements. Height to bottom is probably good to ±5 percent out to 10 minutes.

Experience on this first shot led to corrective measures designed to improve the quality of the data on succeeding shots.

5.2 SHOT 2

Three of the aircraft furnished good navigation data (an estimated probable curve was derived for the fourth) and five of the eight films exposed are quite good. Table 5.2 lists all of the films exposed for Projects 9.1 and 13.2, together with evaluation as to their utility for cloud study.

The results, given in Figure 5.2, are based on measurements from four K–17C and three Eclair films, and are tied into the 13.2 data from ground-based cameras. The diameter curve is felt to be good to ±3 percent for 7 minutes, and only slightly poorer thereafter. The height-to-top data are good for nearly 4 minutes and then become poor as the cloud spreads out and obscures the top. The thunderhead and height-to-bottom data are considered good.

The K-17C film exposed in the RB-36 plane is a particularly good record of the growth during the first 45 seconds. The shock wave is visible in the air for about 7 seconds,

TABLE 5.1 FILMS EXPOSED, SHOT 1

Film EG&G	Number LML	Location	Nav. Data	Comments
24067	117D	RB36	OK	Poor timing, read 1.5 minute
24068	117C	RB36	OK	Poor timing, read 1.3 minute
24069	117A	5615	OK	OK to 3.1 minutes
24070	117B	5482	None	Photos OK, not read
24071	ALD12	RB36	Fair	Read 4.2 minutes
24072	ALD9	5561	Poor	Camera failure
24073	ALD10	5615	Fair	Photos fair, read 9 minutes
24074	ALD11	5482	None	Camera failure
24050		HOW		No timing marks
24051		HOW		Fogged, radiation
24052		NAN		OK 30 seconds
24053		NAN		OK 48 seconds
24054		TARE		OK 44 seconds
24055		TARE		OK 37 seconds
24056		HOW		Fogged, radiation
24057		NAN		Fogged, radiation
24058		TARE		Fogged, radiation
24063		HOW		Fogged, radiation
24064		NAN		Fogged, radiation
24065		HOW		Fogged, radiation
24066		NAN		Fogged, radiation

and its intersection with the water surface can be measured for 45 seconds. Its radius increased at a constant rate of 1.31×10^3 feet/seconds to a radius of 69,000 feet by 45 seconds. The intersection circle provides an unusually good reference for the measurement

TABLE 5.2 FILMS EXPOSED, SHOT 2

Film EG&G	Number LML	Location	Nav. Data	Comments
24567	121E	RB36	OK	Poor, timing errors
24568	121C	5561	OK	OK 1.3 minute
24569	121B	5615	OK	OK 2.0 minutes
24570	121A	5482	None	Poor, not read
24571	ALD21	RB36	Fair	OK 6.5 minutes
24572	ALD18	5615	OK	Poor, read 10 minutes
24573	ALD19	5482	Poor	OK 10 minutes
24574	ALD20	5561	OK	OK 7.3 minutes
24552		NAN		OK 20 seconds
24553		NAN		OK 36 seconds
24554		TARE		OK 25 seconds
24555		TARE		OK 35 seconds
24559		TARE		Poor
24562		PARRY		OK 46 minutes

of cloud heights. The later pictures from this camera are quite poor owing to the long exposures required.

5.3 SHOT 3

Because of heavy cloud cover and local rain squalls, no photographs were obtained for this shot, from the air or from the ground.

5.4 SHOT 4

The navigation data were good from one plane, fair from two, and poor from the fourth. Three films were good, four were poor, and one camera jammed. As indicated

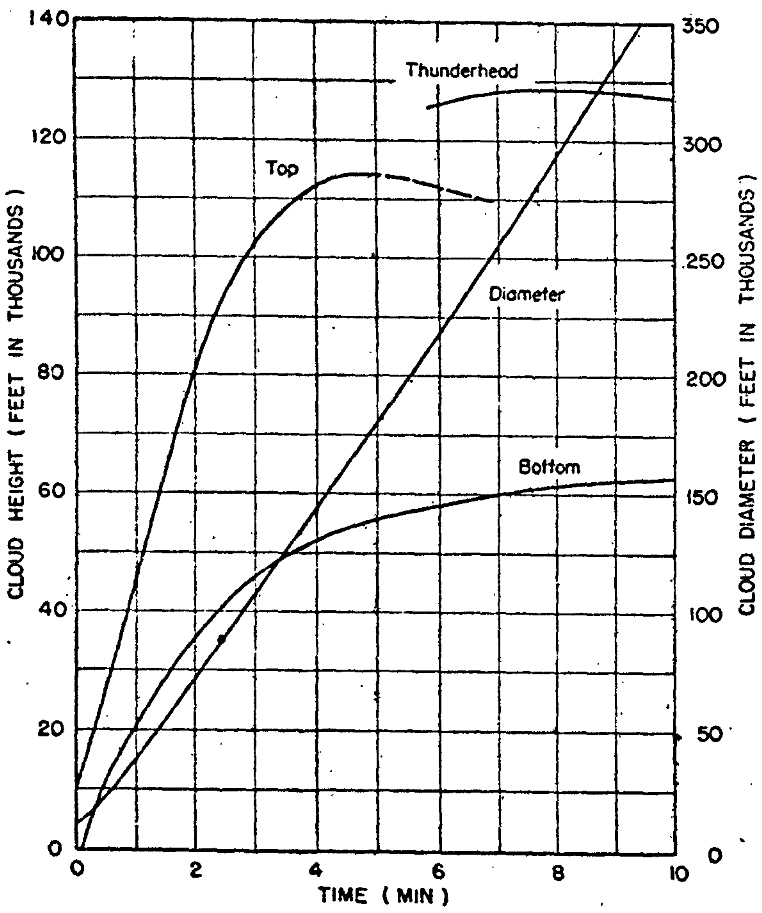


Figure 5.1 Cloud dimensions: Shot 1.

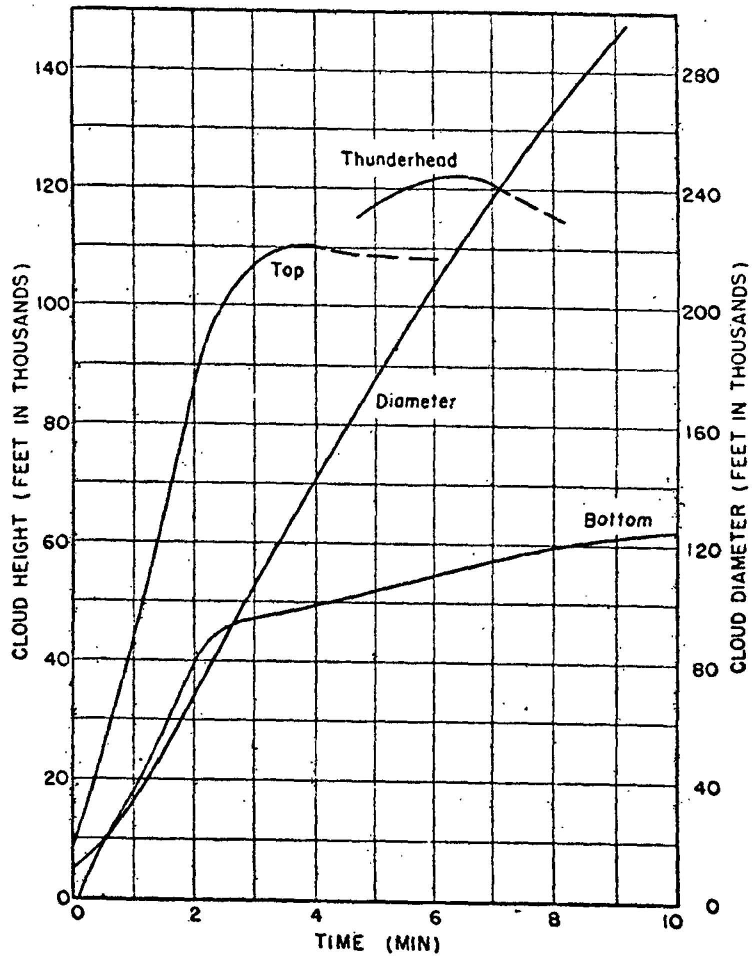


Figure 5.2 Cloud dimensions: Shot 2.

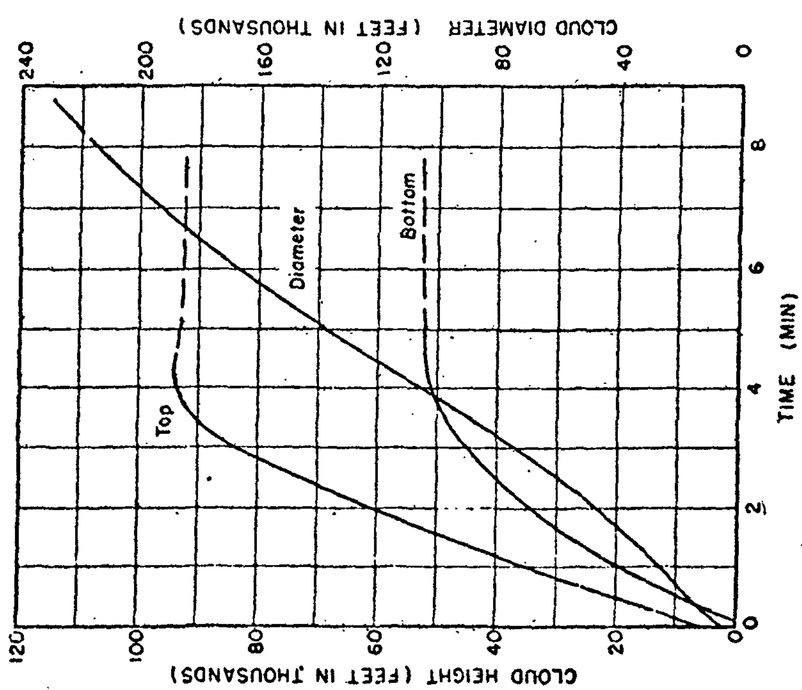


Figure 5.3 Cloud dimensions: Shot 4.

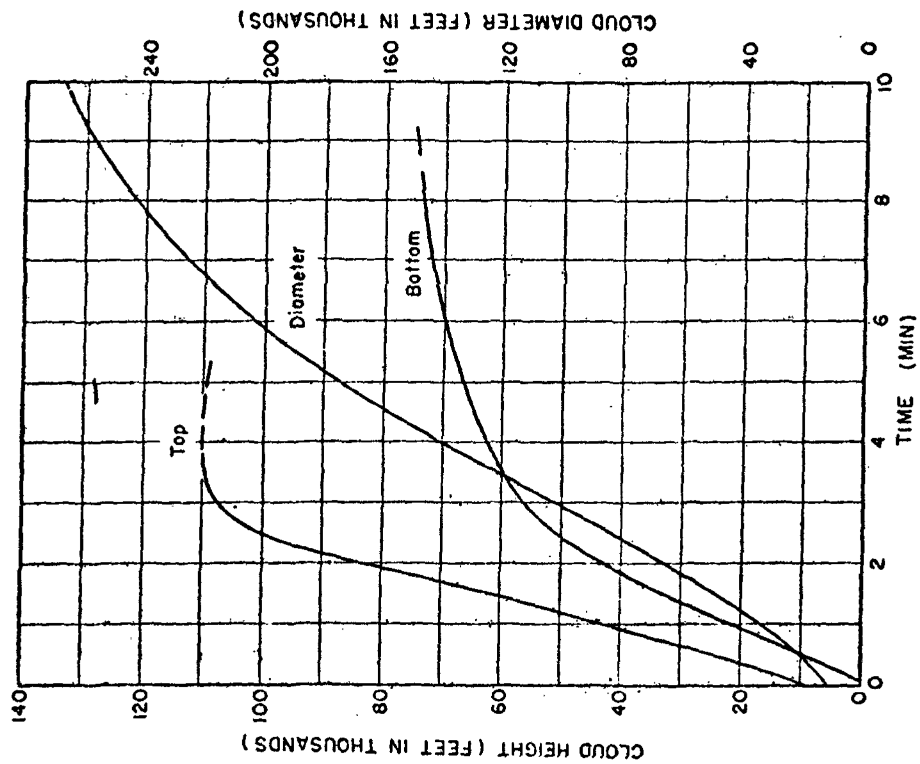


Figure 5.4 Cloud dimensions: Shot 5.

in Table 5.3, some data were obtained from two K-17C cameras and from two Eclairs. The measurements from these films agree fairly well with each other and tie in with the results from the 13.2 ground-based cameras. Figure 5.3 is the graph of the data.

All three curves are good to ±3 percent for 4 minutes and become poorer thereafter. By 8 minutes the probable error is estimated to be of the order of ±8 percent.

This device, of lower yield than those used for Shots 1 and 2, went to a lower ultimate altitude and did not have the thunderhead observed in prior shots.

5.5 SHOT 5

Three aircraft furnished good navigational data, and the Air Operations Center aboard the USS Estes supplied information of the fourth, as well as checking two of the

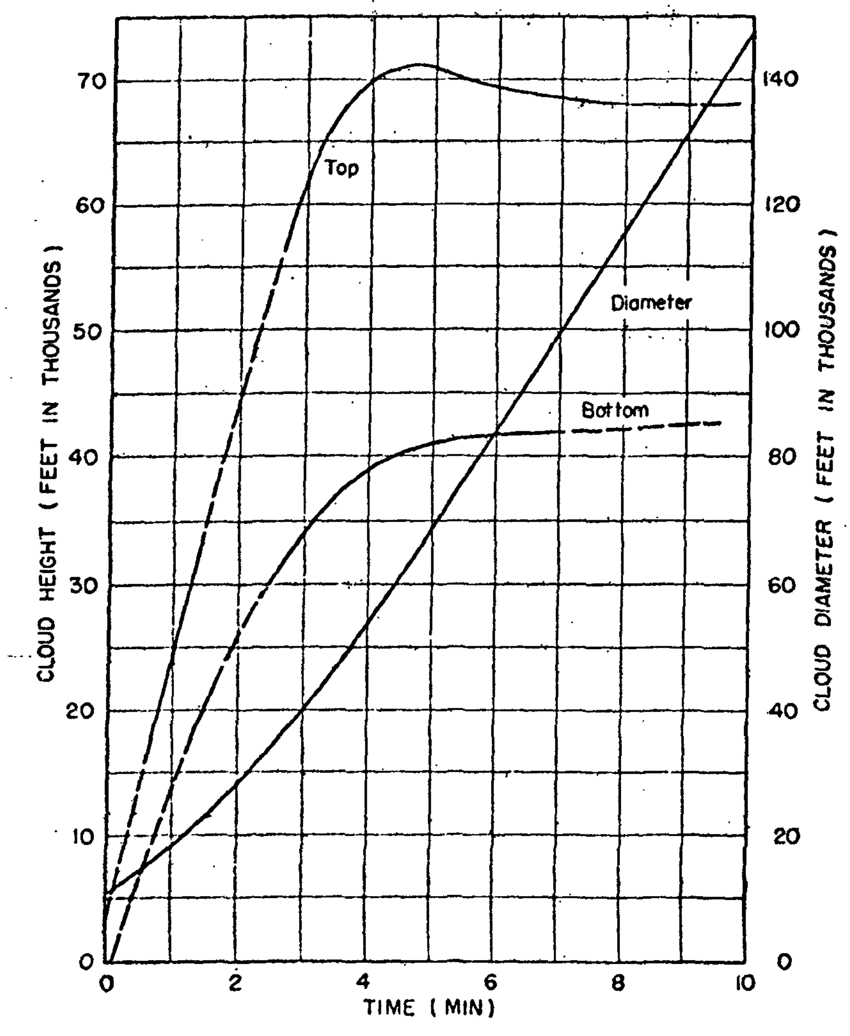


Figure 5.5 Cloud dimensions: Shot 6.

other ships. The checks were not perfect as regards the angular bearings of the ships from ground zero but were quite good as to distance. All eight cameras obtained good photographs, although one had a bad timing error. This shot is the best documented in the entire program.

Table 5.4 describes all cameras operated for cloud study projects, and the results are plotted in Figure 5.4. All three curves are good to ±2 percent for the first 2 minutes, deteriorating thereafter to an estimated ±7 percent at 10 minutes.

Two of the aircraft were moved out to the 75-to-100-mile range for this shot and obtained good photographs to 15 to 20 minutes. Unfortunately no position data are available after 12 minutes for one ship, and the other plane used the camera with the timing error. Thus no attempt has been made to obtain later-stage information by triangulation methods.

TABLE 5.3 FILMS EXPOSED, SHOT 4

Film EG&G	Number LML	Location	Nav. Data	Comments
24167	125C	RB36	OK	OK 3.7 minutes
24168	132B	5561	OK	Poor, not read
24169		5615	Fair	Camera jammed
24170	130B	5482	Poor	Underexposure, read 5.2 minutes
24171	ALD28	RB36	OK	OK 7.5 minutes
24172	ALD33	5615	Fair	OK 11.4 minutes
24173	ALD31	5482	None	Poor, not read
24174	ALD34	5561	OK	NG, not read
24150		HOW		OK 30 seconds
24153		NAN		OK 36 seconds
24156		HOW		Fogged
24157		NAN		NG
24162		PARRY		Fair 40 minutes
24163		HOW		Fogged
24164		NAN		OK 3 minutes
24165		NAN		OK 1 minute

5.6 SHOT 6

Cloud cover was heavy at shot time. For a while, two planes saw the nuclear cloud between layers of natural clouds. The photographs are of poor pictorial quality, but they yield surprisingly good measurements. The other two planes and all ground cameras were obscured by clouds and obtained no pictures. Table 5.5 summarizes the films.

TABLE 5.4 FILMS EXPOSED, SHOT 5

Film EG&G	Number LML	Location	Nav. Data	Comments
24267	125C2	RB36	OK	OK 2.8 minutes
24268	132B2	5561	OK	OK 5.1 minutes
24269	132C2	5615	OK	OK 1.5 minutes
24270	125D	5482	AOC	OK 3.4 minutes
24271	ALD37	RB36	OK	OK 6.0 minutes
24272	ALD35	5615	Fair	OK 7.1 minutes
24273	ALD41	5482	AOC	OK 15 minutes
24274	ALD36	5561	OK	Timing ? read 10 minutes
24250		HOW		OK 36 seconds
24253		NAN		OK 45 seconds
24256		HOW		Fogged
24257		NAN		Fogged
24263		HOW		Fogged
24264		NAN		Fogged
24265		NAN		Fogged

One of the successful planes furnished good navigational data in close agreement with the Air Operation Center (AOC) figures; the other plane disagreed drastically with AOC.

Study of the photographs forces the conclusion that AOC was in error, and that the ship's own data are correct. Use of the AOC data leads to an apparent maximum cloud height of 52,000 feet, in disagreement with other results and with all past experience with bombs in this range of yields. The navigator's data lead to the eminently reasonable figure of 70,000 feet, in exact agreement with the data from the other plane.

The results are given in Figure 5.5. The dashed lines represent intervals during which the particular feature was hidden by natural cloud and are thus reasonable interpolations. It is felt that a ±5 percent uncertainty applies for the entire 10-minute interval. It should be noted that the height-to-top measurements are reliable in spite of the poor photographic quality, because the cloud height was less and the camera distance greater than usual.

TABLE 5.5 FILMS EXPOSED, SHOT 6

Film EG&G	Number LML	Location	Nav. Data	Comments
24467	125C3	RB36	OK	Clouds, NG
24468	132B3	5561	OK	Clouds, NG
24469	135B	5615	OK	Clouds, read 3 minutes
24470	135A	5482	OK	Clouds, NG
24471	ALD42A	RB36	OK	Clouds, NG
24472	ALD43	5615	OK	Clouds, read 5 minutes
24473	ALD42B	5482	OK	Clouds, read 8 minutes
24450		PARRY		Clouds, NG
24451		PARRY		Clouds, NG
24457		PARRY		Clouds, NG
24463		PARRY		Clouds, NG
24464		PARRY		Clouds, NG

5.7 DISCUSSION

Although the results presented here cover a shorter time interval than had been expected and although unforeseen operational difficulties were encountered, it is believed that these measurements are good over the most-important time period, prior to cloud stabilization. Over this period the data are by far the best we have ever had to work with.

TABLE 5.6 SUMMARY OF CLOUD PARAMETERS

Shot	Height to Top (thousands of feet) Max.	1 min.	Fireball Yield (MT)	Diameter (thousands of feet) 1 min.	10 min.
Castle					
1	114	47	14.8 ± 0.2	38	370
2	110	44	11.0 ± 0.4	33	316
4	94	35	6.88 ± 0.11	26	125
5	110	44	13.5 ± 0.2	34	270
6	72	25	1.69 ± 0.03	19	147
Ivy					
Mike	98	39	11 ± 1	30	200
King	76	28	0.550 ± 0.029	11	90

The results of the cloud-rise measurements are generally in good agreement with the less-accurate results from Operation Ivy. For purposes of comparison, Table 5.6 lists for the Ivy and Castle shots the following pertinent information: the maximum observed value for height-to-top, the height-to-top at 1 minute, and the cloud diameters at 1 minute and at 10 minutes. The height at 1 minute is a fair measure of the upward velocity of the rising cloud. This appears to increase with yield although the data for Shot

6 are rather out of line compared with Ivy King. It may well be significant that Shot King was an air burst, whereas the others were all at ground level. The ground bursts always seem to hover for a while before beginning to rise.

The operation has been a good education to all of the groups concerned, and has demonstrated the steps and precautions that must be followed to assure results of even better quality in the future.

Chapter 6

SUPPLEMENTARY MEASUREMENTS

On detonations of the magnitude of the Castle shots, several phenomena occur which, on smaller shots, either do not appear or are extremely short-lived. Hence, it is desirable to report here other measurements in addition to the height and diameter of the main cloud. "Skirts," "bells," condensation rings, thunderheads, ice caps, and the stem have been measured wherever they appear. Their diameters and heights have been calculated in the same manner as the dimensions of the main cloud. Figure 6.1 is an idealized sketch of a nuclear cloud in the megaton range, showing the nomenclature employed in this chapter.

Films from K–17C and Eclair cameras located in aircraft have been utilized for the purpose of obtaining the supplementary measurements, since most of these secondary phenomena occur at later times than are covered by the high-speed, ground-based cameras.

6.1 SHOT 1

The cloud, at various stages in its development, showed four condensation rings, three ice caps, two skirts, and three bells. Figure 6.2, taken at 45 seconds, shows the condensation rings and two of the ice caps. Figure 6.3 is a plot of the diameters of all the measurable phenomena and Figure 6.4 gives their heights with respect to sea level. No reliable data can be obtained on heights of the bells.

The four films measured for stem diameter showed good agreement through ten minutes. Unfortunately, it was not possible to measure the diameters of the four condensation rings, as all the aircraft were located too close to ground zero. Data from two Eclair films did, however, permit determination of these heights through 25 minutes. Diameters of skirts and bells were measured from one film each. In both cases, the diameter measured is that of the widest portion; e.g., for a skirt the diameter measured is that of the base of the skirt. Three films gave good data on diameters of two ice caps. The height curves are based on only one film, however, since the other two films yielded poor data. Only one film showed the third ice cap; hence, the resulting calculations yield only estimated figures. Between 1.0 and 1.5 minutes the diameter of the third ice cap increased from 45 to 65 thousand feet; in the same time range, the height to bottom was between 20 and 25 thousand feet.

6.2 SHOT 2

Figure 6.5 shows the diameter and height of the five skirts visible during this shot. Because of the particular arrangement of the skirts, it appeared that the two upper skirts had a common base, as did the two lower skirts, although it was possible to measure distinctly separate diameters for all five. Figure 6.6 shows the upper two skirts, the two bells, and a portion of one other skirt. Two condensation rings were visible, the maximum diameter of one at 68,000 feet, and of the other at 110,000 feet. The growth of the diameters of the two rings is plotted in Figure 6.7.

The diameters of the two bells observed are plotted in Figure 6.8. The heights of the bells were measurable on only one film, which shows the base of the lower bell at approximately 30,000 feet and the upper at 40,000 to 45,000 feet throughout the measurable range, from 2 to 15 minutes.

The stem could be measured from only one film, between 10 and 14 minutes. During that interval, its diameter increased from 9,000 feet to 14,000 feet.

6.3 SHOT 4

Six condensation rings were visible on three films from this shot. Figure 6.9 shows all six rings distinctly. Their diameters are plotted in Figure 6.10, together with the

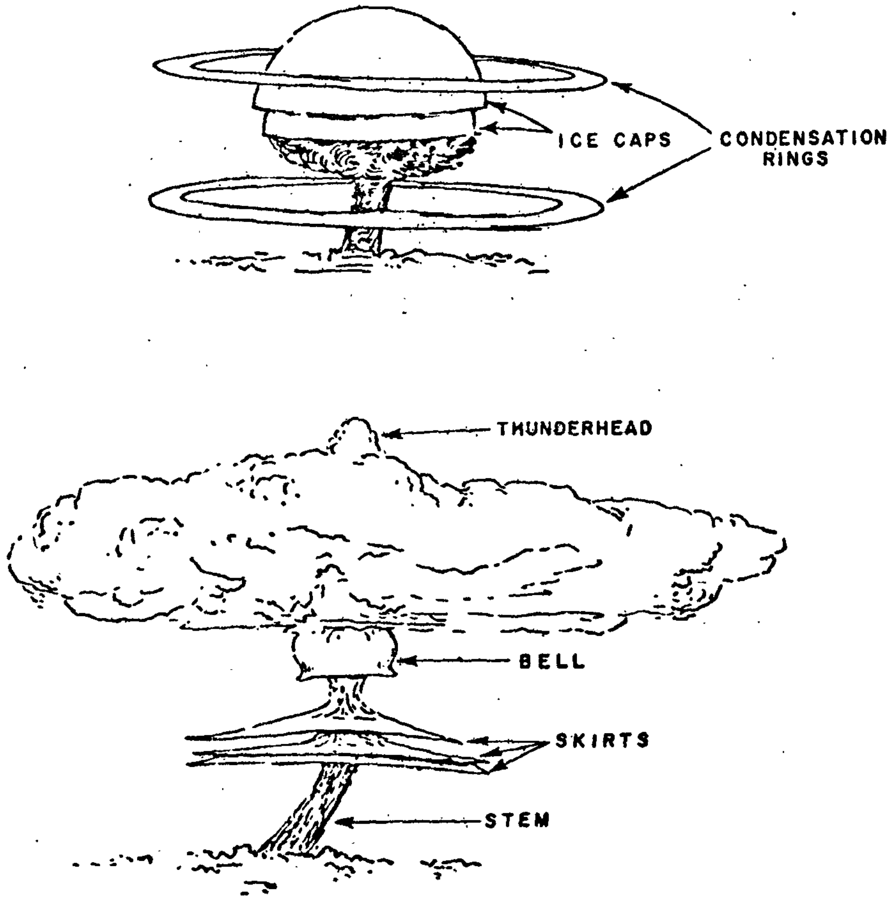


Figure 6.1 Idealized sketch of cloud phenomena from multimegation bomb with top view showing early cloud stage and bottom view at later time.

diameters of the shock wave and the Wilson cloud chamber, which were visible in one of the films. All the rings except No. 3 remained at approximately the same height throughout the period measured. The rings were all measurable from about 0.3 minute to 0.6

minute. They were located at 5,000, 12,000, 14,000, 22,000, 23,000, and 25,000 feet. Ring No. 3 was the only one to show a definite change in altitude (from 22,000 to 18,000 feet) though the sparse data from one film for rings No. 2, No. 4, and No. 5 indicated that they also lost about 4,000 feet of altitude during the 0.2 minute period after the last measurement on the remainder of the films. Figure 6.11 shows the growth of the diameter and main skirt with time.

6.4 SHOT 5

Diameters of the stem and the one bell visible on this shot are shown in Figure 6.12 as functions of time. Height of the bell could not be determined reliably. Figure 6.13

TABLE 6.1 CASTLE CLOUD DIMENSIONS AT 35,000 FEET TO 50,000 FEET ALTITUDE

Shot	Time Minutes	Altitude Feet	Stem Width Feet
Shot 1	20 (ALD-11)	35,000 50,000	63,000 (in main cloud)
	20 (ALD-10)	35,000 50,000	39,000 44,000
	25 (ALD-10)	35,000 50,000	56,000 52,000
Shot 2	25 (ALD-18)	35,000 45,000	31,000 38,000
	29 (ALD-19)	35,000 45,000	24,000 39,000
Shot 4	28 (ALD-31)	35,000 50,000	48,000 54,000
	30 (ALD-33)	35,000 50,000	46,000 55,000
	45 (ALD-33)	35,000 50,000	3,800 (stem dissipating) 140,000 (main cloud)
Shot 5	25 (ALD-35)	45,000	110,000
	34 (ALD-35)	45,000	92,000
Shot 6	21 (ALD-43)	35,000	63,000

gives the diameters of the eight condensation rings measured. Rings No. 1 and No. 2 were close together near the base of the cloud. No. 3 the next highest, No. 4 and No. 5 in the next higher group, and No. 6, No. 7 and No. 8 forming the top group. Good measurements were not obtainable on rings No. 7 and No. 8, because of their relatively short lives. All the rings remained at approximately the same height througout the period measured. The lowest ring was measurable from 0.3 to 0.7 minutes, during which time it remained at an altitude of 35,000 feet. Rings No. 2, No. 3 and No. 4 were visible between 0.5 and 0.9 minutes, at altitudes of 39,000, 49,000 and 55,000 feet, respectively. Rings No. 5 and No. 6 were measured at 57,000 and 60,000 feet from 0.6 minute to 0.8 minute. No data were obtainable on Rings No. 7 and No. 8.

The height to the top of the thunderhead was measured on three films. The resulting data are in poor agreement but indicate that the thunderhead reached a maximum height of 135 ± 10 thousand feet at approximately 9 minutes. Measurements on four films of height to the base of the lowest skirt were equally unsatisfactory. It is estimated that the base of the skirt remained at a constant altitude of 31 ± 10 thousand feet between the initial appearance

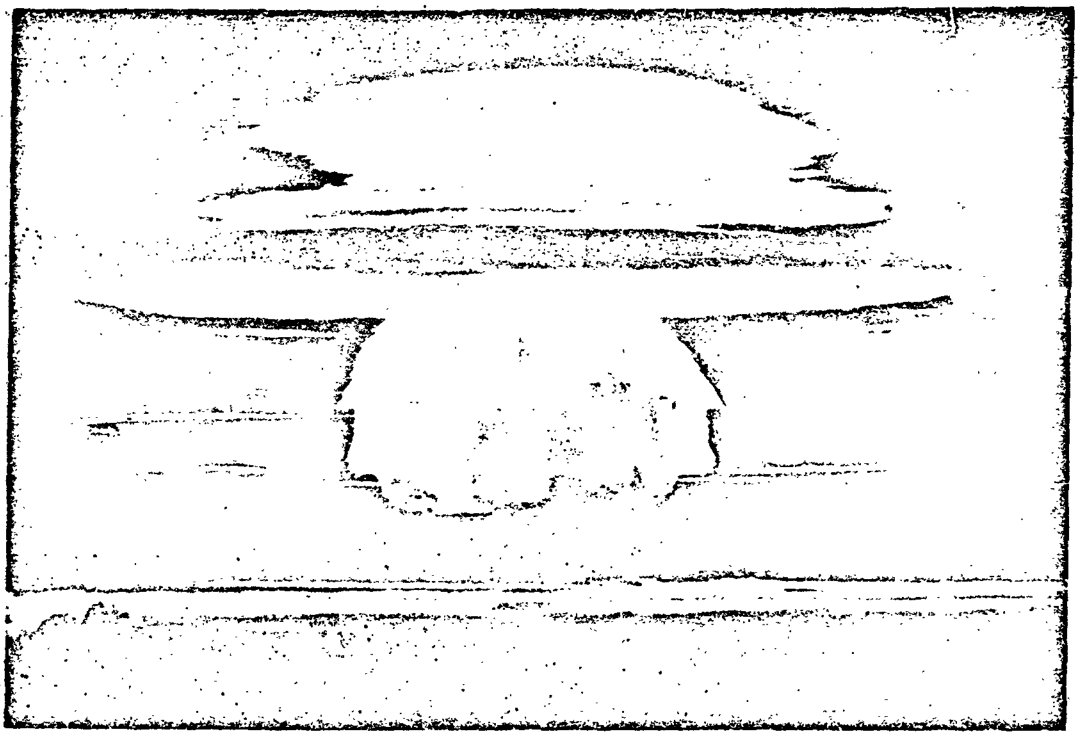


Figure 6.2 Cloud at 45 seconds, Shot 1.

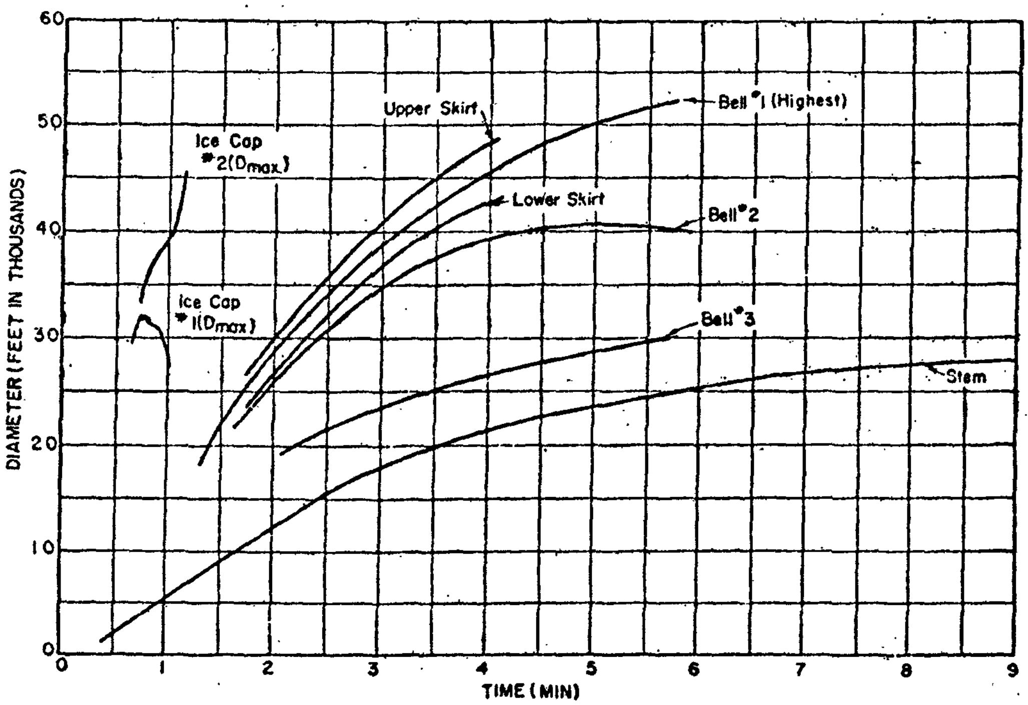


Figure 6.3 Diameters of auxiliary phenomena, Shot 1.

SECRET

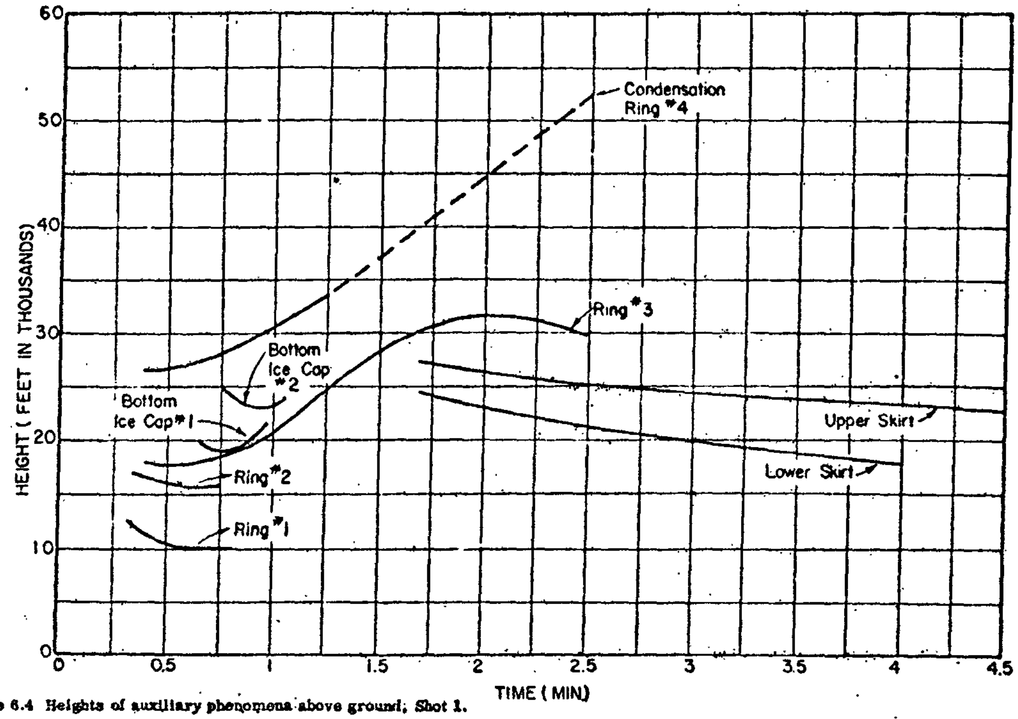


Figure 6.4 Heights of auxiliary phenomena above ground, Shot 1.

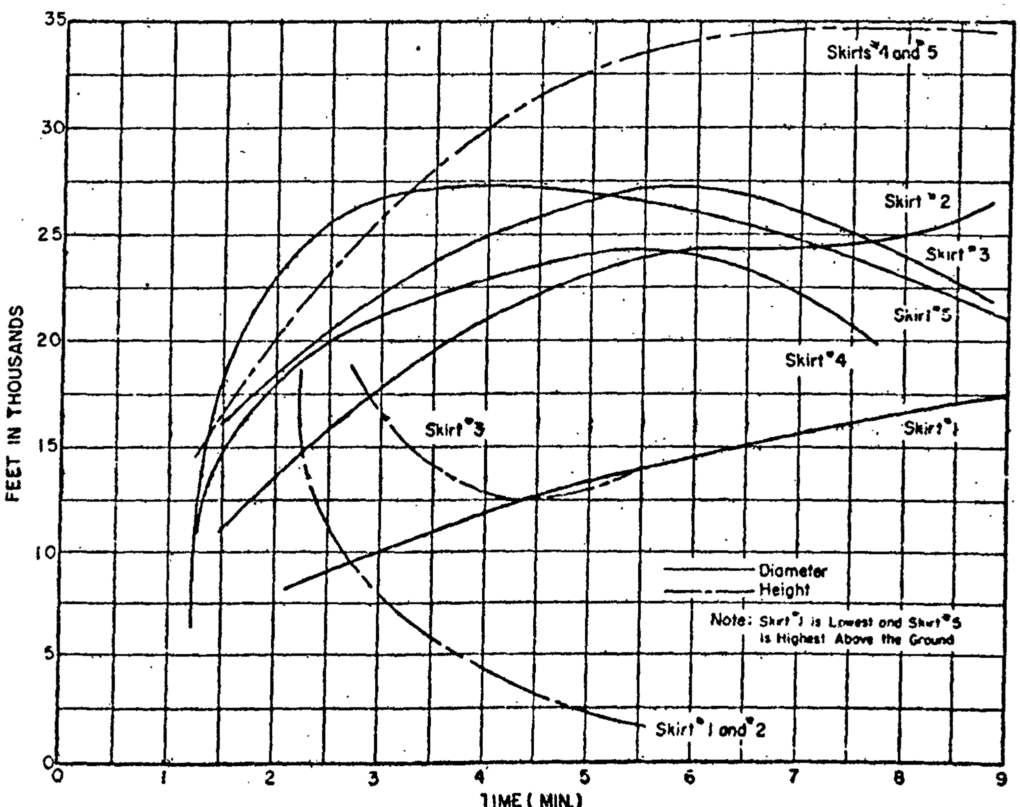


Figure 6.5 Diameter and height of skirts, Shot 2.

Figure 6.6 Cloud at 14 minutes, Shot 2.

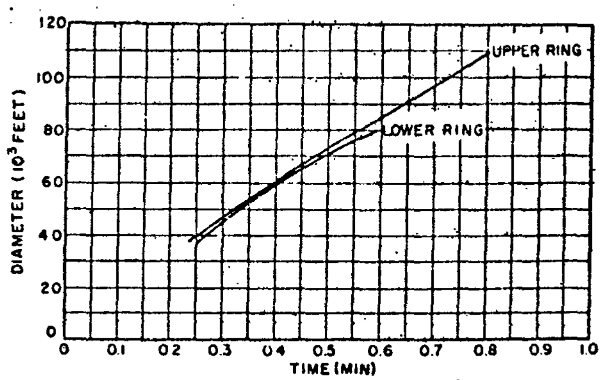


Figure 6.7 Diameter of condensation rings; Shot 2.

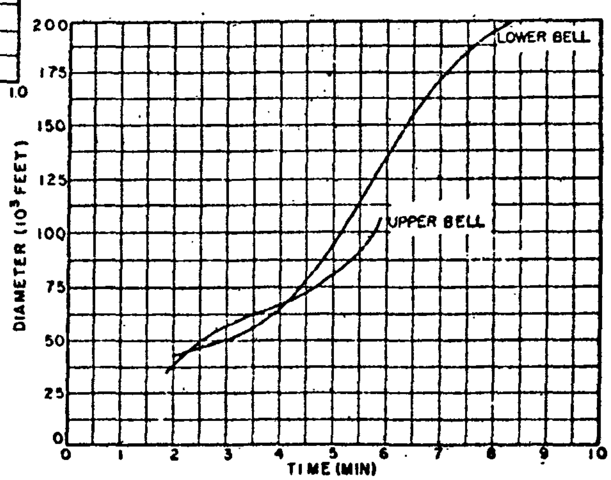


Figure 6.8 Diameter of bells; Shot 2.

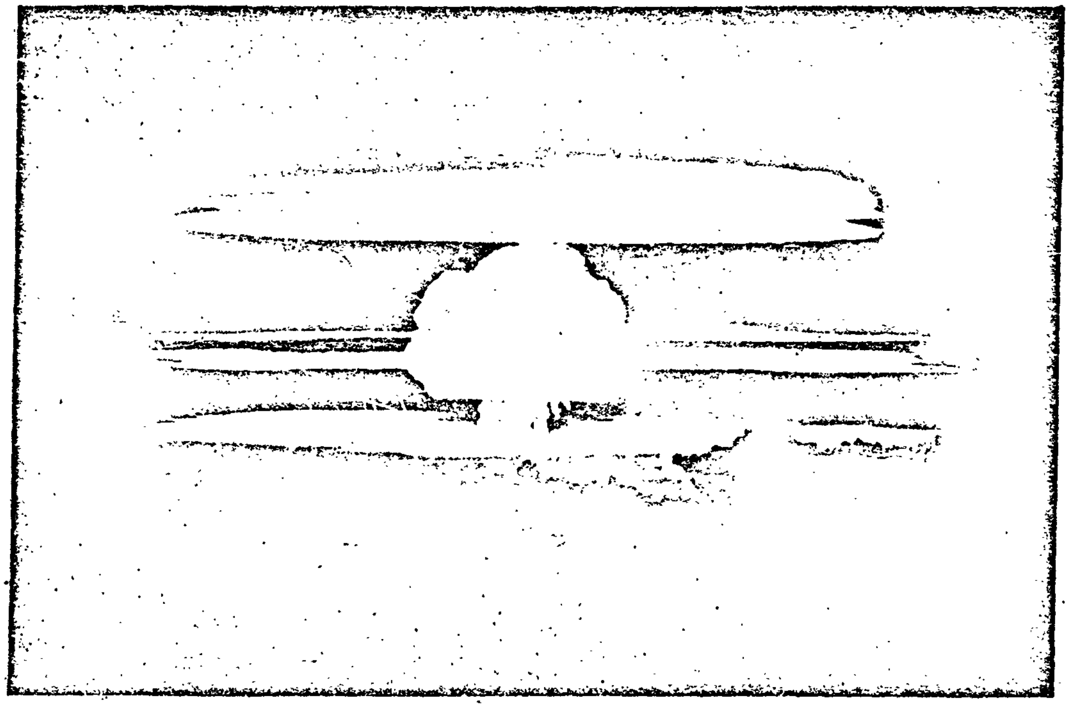


Figure 6.9 Cloud at 28 seconds, Shot 4.

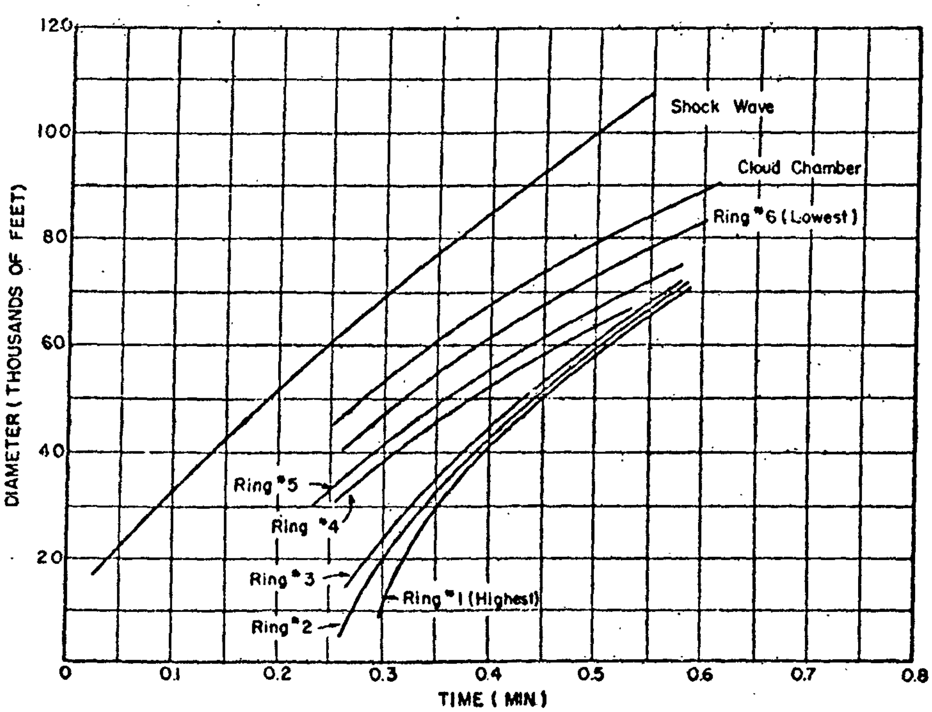


Figure 6.10 Diameter of rings, shock, and Wilson cloud; Shot 4.

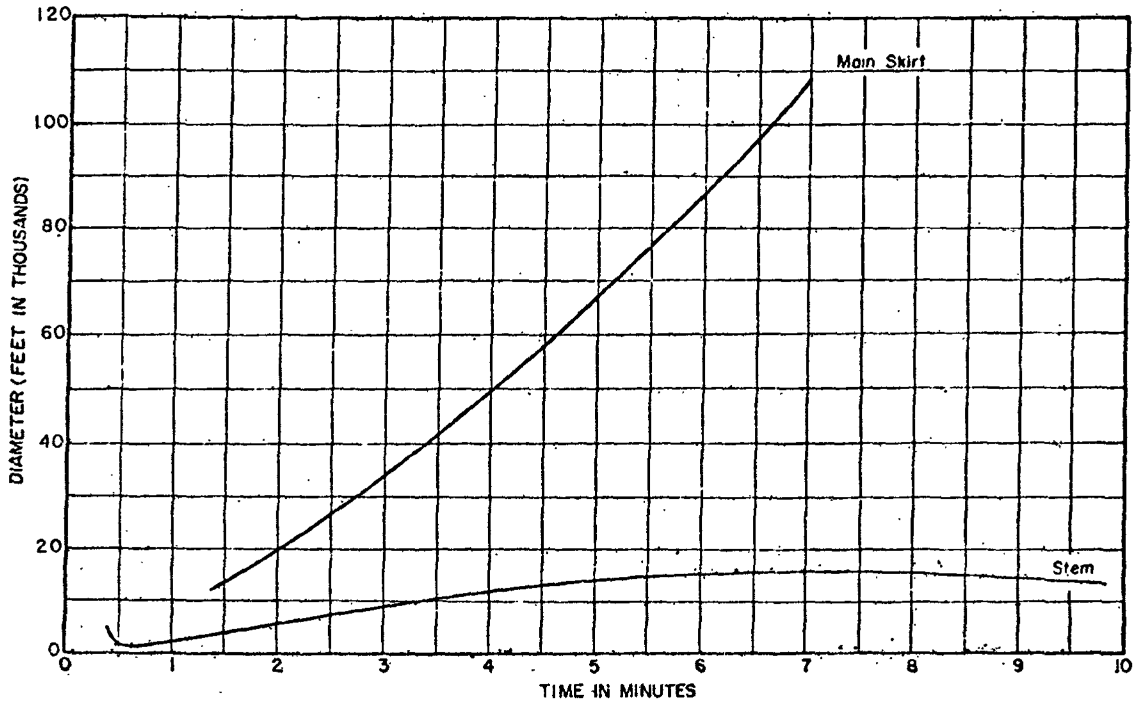


Figure 6.11 Diameter of stem and main cloud: Shot 4.

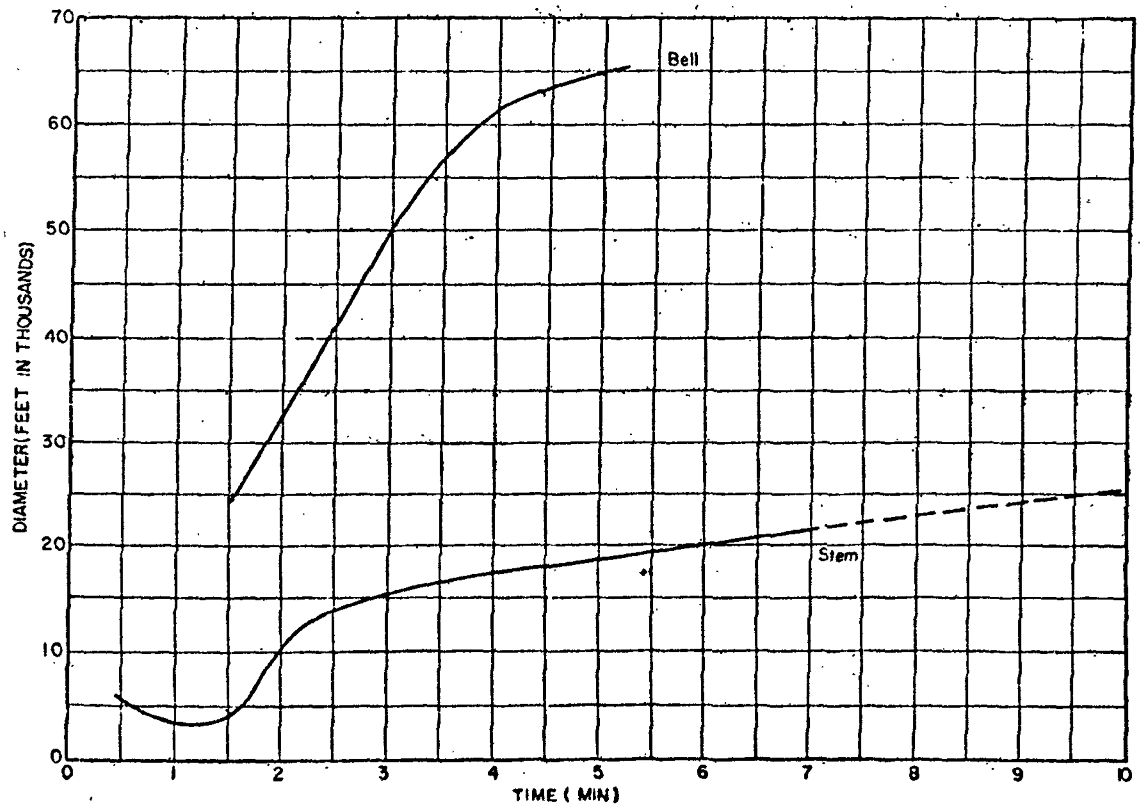


Figure 6.12 Diameter of stem and bell: Shot 5.

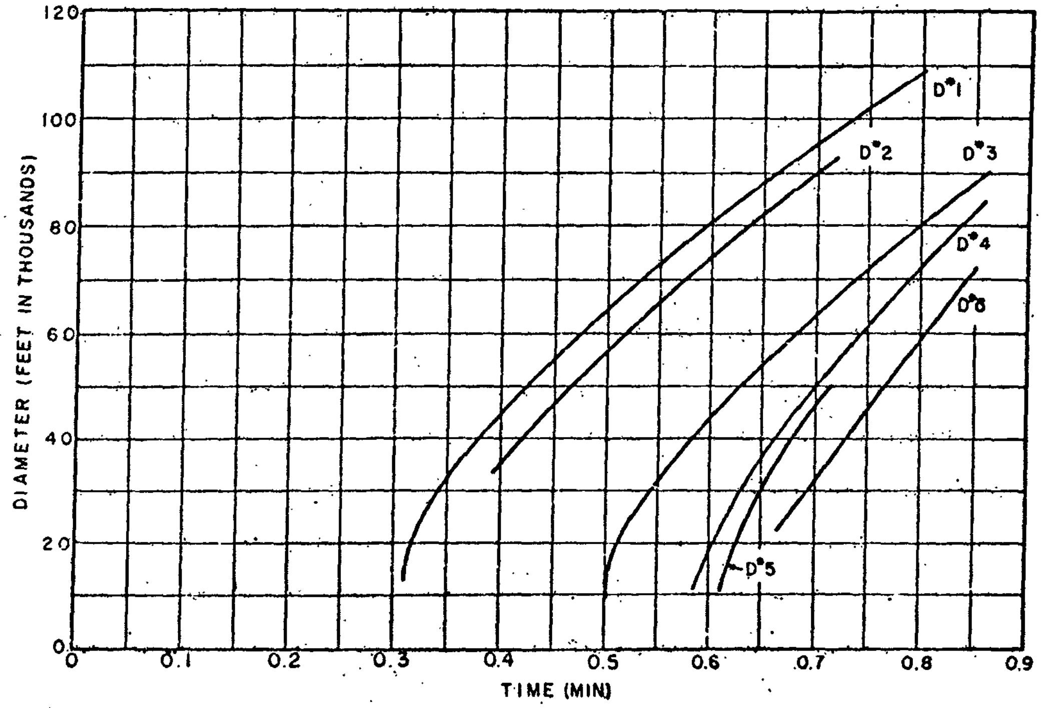


Figure 6.13 Diameter of condensation rings; Shot 5.

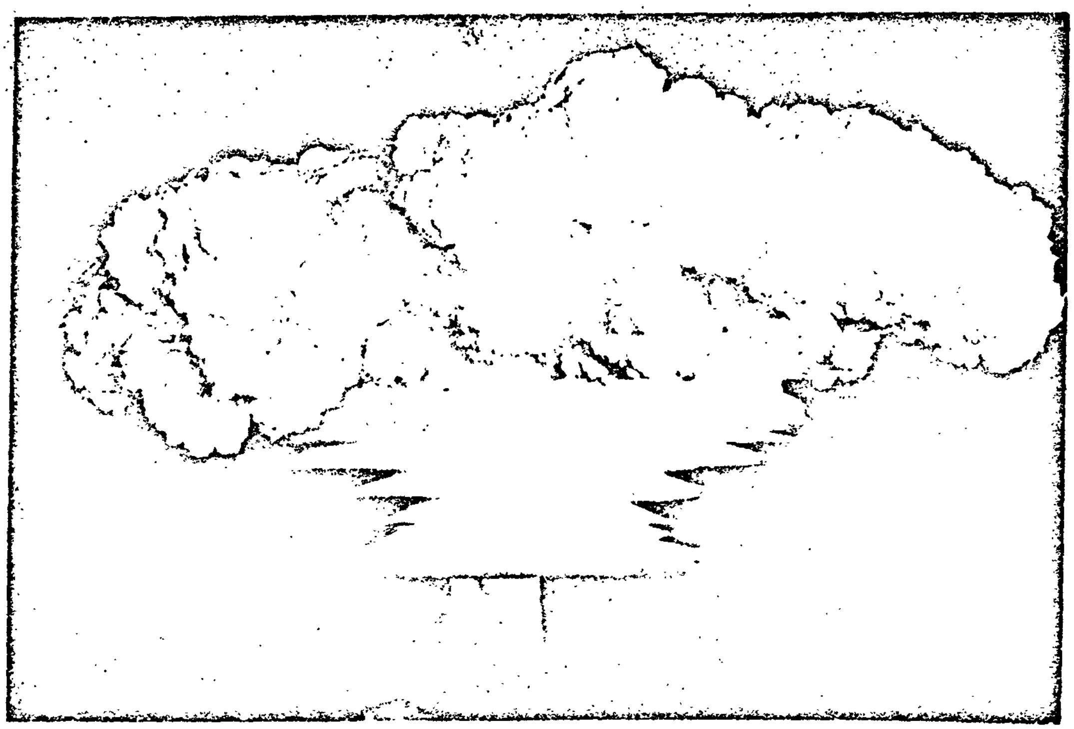


Figure 6.14 Cloud at 14 minutes, Shot 5.

of the skirt at 1.5 minutes and the latest measurement at 10 minutes. Figure 6.14 is an excellent example of the appearance and multiplicity of skirts visible on this and other shots.

6.5 SHOT 6

Because of natural cloud cover, no measurements of the subsidiary features of the cloud from this shot were possible.

6.6 CLOUD DIMENSIONS AT HIGH ALTITUDES

It was possible to make some rough approximations of the cloud and stem dimensions of the Castle shots at altitudes of 35,000 and 50,000 feet at times up to 45 minutes. The figures presented in Table 6.1 are only approximate, because of uncertainties in aircraft positions at such late times. It is felt, however, that this information may be of assistance in estimating hazards to which personnel of a sampling aircraft might be subjected in penetrating the cloud or stem after a detonation.

Chapter 7

CONCLUSIONS

The data obtained for Project 9.1 are by far the best yet, although they extend only over the first 10 minutes; little information was obtained for later times.

Good measurements were made for five of the six Castle shots. Shot 3 was fired under weather conditions such that none of the cameras saw the cloud. On the other shots, natural cloud interference turned out to be less serious than had been expected. The utility of high-flying aircraft for these purposes is confirmed, as is also the desirability of using distant ground-level cameras.

The A-28 stabilized mounts have performed brilliantly and have saved many pictures that would otherwise have been useless for measurement purposes. The calibrated cameras have similarly performed well. Many photographs, whose only reference level is the camera fiducial-mark system, were measured successfully. This gives increased confidence in the results and in the methods by which they were obtained.

Chapter 8

RECOMMENDATIONS

It is believed that the basic plan used during Castle is the correct one to use and that improvements can be achieved through careful attention to details rather than by drastically altering the method of operation.

8.1 ALTITUDE

The best data were obtained by the RB-36 installation, flying at 40,000 feet altitude. The superiority of these results is attributable almost entirely to the high altitude, and it is recommended that every effort be made to use high-flying platforms wherever possible. This recommendation applies to operations in Nevada as well as in the Pacific—there is much to be gained in operating above the atomic clouds.

8.2 SUPPLEMENTARY DATA

The collection of subsidiary data—without which the photographs are merely pictures, not scientific data—should be made automatically. Personnel efficiency declines rapidly as altitude increases, and the probability of error or complete loss of information becomes prohibitively large. The crew members have to fly the plane and, naturally, carry their routine jobs out even at the expense of the scientific mission. This is not a criticism, but rather a fact that needs recognition. The program should provide automatic means of recording every bit of information it needs without relying on the crew. Among the data to be so recorded are: aircraft position, altitude, course, attitude, airspeed, and groundspeed; also, the camera parameters such as aiming, timing, aperture, and shutter settings. Much of this information could be recorded by voice on a tape recorder. It should be emphasized, however, that it is better to photograph instruments than to have a man read them and relay the data to the tape, while working on other jobs at the same time. It follows that such data as plane's position might be obtainable more reliably from the ground than from the plane itself; but if it is done from the plane, the instruments and the terrain directly below, if necessary, should be photographed, rather than relying on a person who has other duties.

8.3 PHOTOGRAPHIC CONTROL

Judgment is sometimes impaired while working at high altitudes, and the picture-interval program should not be placed at the discretion of the operator. The professional photographer is often inclined to take more photographs than have been specified. The cameras are usually loaded with more film than is needed, and the operator shoots it all. In two cases during the Castle operation, this caused the loss of otherwise good data; but in a third case, it must be admitted, information was obtained which would not have resulted from the specified program. (However, the information is of value to Project 1.1 rather than 9.1.)

It is clear that the photographer must be freed of as many manual duties as possible. He should not have too many cameras to operate, the controls should be simple, and clearly labeled, and should be as automatic as possible. His duties should be planned, not to throw certain switches at given times according to a check-list (a timer can do the job better), but rather to adjust apertures in accordance with prevailing light levels and to chase and correct trouble when it occurs. The installation should try to do him out of his job.

8.4 DIVIDED ASSIGNMENTS OF AIRCRAFT

Requirements of several programs for the use of a given aircraft inevitably conflict. The position of the plane is the perpetual quarrel — some want it close in, and some want it far away; some high, and some low, and so on. There should be enough planes in the program to satisfy everyone without forcing compromises between the "near-inners" and the "far-outers" in the use of a single plane. This is a particularly heartfelt recommendation; much valuable data were lost during the operation because the planes were closer to ground zero than desired. This always resulted in cloud images extending beyond the edges of the picture.

8.5 CAMERAS

It is recommended that a study be made to find a more-satisfactory camera for these purposes. The modified K-17C cameras are heavy and bulky and are subject to shutter malfunction. The resulting images are sometimes superb, but are more frequently worthless, owing to hangover of the shutter. However, picture quality usually is limited by natural cloud interference, the diffuse and nebulous edges of the atomic cloud, and low light levels. Large images with high resolution are nice to work with but simply are not necessary; it is better to accept smaller images from a more-reliable camera. On the other hand, it is felt that the 35-mm motion-picture camera is the minimum frame size; a 70-mm frame should be about right.

The 70-mm frame should be arranged horizontally to give a picture about $2\frac{1}{4}$ inches high and $3\frac{1}{4}$ inches wide. Lenses should be available in 3-inch, 4-inch, and 6-inch focal lengths and of as wide an aperture as possible. The camera should hold at least 20 feet of film, for a total of 60 pictures.

Each installation is visualized as using two 70-mm cameras: The first uses slow film and takes one picture every second during the time fireball light is shining; the other uses fast film to photograph with the prevailing sky light. The second camera works on a program of increasing time intervals, such as six pictures per minute for 5 minutes, one per minute from plus 5 to plus 20 minutes, and one every 5 minutes thereafter. The cameras should be placed on stabilized mounts of the type employed so successfully during Operation Castle.

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2. "Greenhouse, Program 4, Cloud Tracking Photography"; (Draft, 15 July 1951); EG&G OUT 728, WT–115.

3. "Technical Photography on Buster–Jangle"; WT–417.

4. "Buster–Jangle Cloud Data"; 29 February 1952; EG&G OUT 832.

5. "Technical Photography on Operation Tumbler–Snapper, Program 12.1"; WT–569.

6. "Tumbler–Snapper 5–8, Pictorial, Late Stage, 0–10 Seconds"; 6 October 1952; EG&G OUT 1009.

7. "Technical Photography on Operation Ivy"; WT–639.

8. "Ivy, Cloud and Stem Phenomena"; Report No. 1136, 23 April 1954; EG&G OUT 1555.

9. "Ivy, Cloud Pictorial"; Report No. 1080, 10 February 1953; EG&G OUT 1074.

10. "Technical Photograpahy on Operation Upshot–Knothole"; WT–824.

11. Letter from L. Fussell, Jr., "Cloud Phenomena on Operation Castle," to Captain N. E. Kingsley, 29 May 1953; EG&G OUT 1117.

12. "Photographic Requirements, Project 9.1, Operation Castle"; Report No. 1086, 5 August 1953; EG&G OUT 1156.

13. "American Practical Navigator"; Bowditch.

14. "Advanced Surveying"; Breed and Hosmer.

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119 Commander, Air Research and Development Command, PO Box 1395, Baltimore, Md. ATTN: RDDN

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