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14 October 1959

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OFFICIAL:

IRAZIM J. HAYNES
Major, SigC
Adjutant

H. McD. BROWN
Colonel, Signal Corps
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5 RADAR DETECTION AND OBSERVATION OF NUCLEAR CLOUDS (U) ~~(S)~~
(Part II Project 50.3, Desert Rock VII and VIII, Operation Plumbbob)(U) 8

43 C. W. Bastian and R. L. Robbani,

DA TASK NR. 3-99-04-111

U. S. ARMY SIGNAL RESEARCH AND DEVELOPMENT LABORATORY

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ABSTRACT

(C) Satisfactory detection of nuclear detonations and observation of the resulting clouds by Radar Set AN/CPS-9 during Operation Redwing at the Eniwetok Proving Ground indicated that radar equipment could be used in future nuclear tests for nuclear cloud study, fallout prediction techniques, cloud monitoring, locating ground zero during poor visibility, and measuring detonation yield. The ability of the AN/CPS-9 or other type radars to detect detonations (in the kiloton range) under the adverse atmospheric conditions of an arid climate was unknown.

(S) An experiment was designed by the USASRD and approved by the USCONARC to include radar equipment of two different frequencies (1,300 and 9,300 mc) in Part II of Project 50.3 (Desert Rock VII and VIII, Operation Plumbbob) at the Nevada Test Site. Radar test results, presented in this report, indicate that Radar Set AN/CPS-9 was superior to the other radars used in detecting and tracking nuclear clouds. The AN/CPS-9 detected fourteen of the eighteen shots in which it participated, including two of the three shots from the 40-mile range, three of the five shots from the 100-mile range, and all line-of-sight shots. Radar Set AN/TPS-1D indicated clouds from two shots at close range; Radar Set AN/MPG-1 indicated no nuclear clouds, but detected detonations by target attenuation; and Radar Set AN/FPS-6 indicated the cloud of one shot. Cloud height, approximate detonation time, ground-zero location, rate of rise, and cloud movement were all indicated by radar. Within the range of yields and the operating conditions of the Nevada tests, the cloud height measured by Radar Set AN/CPS-9 indicated the yield within a factor of approximately two on all detonations in which the entire cloud was observed.

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RADAR DETECTION AND OBSERVATION OF NUCLEAR CLOUDS (U)

(Part II Project 50.3, Desert Rock VII and VIII, Operation Plumbbob) (U)

INTRODUCTION

(C) This report presents radar test results of Part II Project 50.3, Operation Plumbbob. The prime objective of this operation was to determine the ability of radar equipment to detect and observe low-yield nuclear clouds in the low humidity conditions of the Nevada Test Site. Secondary objectives were to determine the following: ground-zero locations; absolute detonation time; dependence of cloud detection on radar equipment having 1,300-, 2,800-, and 9,300-Mc radio frequency; cloud dimensions; rate of cloud rise; whether correlation exists between yield and the radar detectable characteristics of the cloud; and the possibility of studying fireball growth by radar.

BACKGROUND

(C) When radar equipment was used in nuclear tests prior to Operation Redwing at the Eniwetok Proving Ground, nuclear detonations were detected for only a few minutes after firing time. Most of the tests were made with airborne equipment in flight that recorded a ring around ground zero. No radar detected the cloud resulting from the detonation.

(C) During Operation Redwing at the Eniwetok Proving Ground, a USASRDL technical observer used Radar Set AN/CPS-9 to detect several nuclear clouds at ranges up to approximately 200 miles. The radar scopes, photographed on three occasions, showed growth and dissipation, shape, rate of rise, and direction and speed of movement of nuclear clouds.

(C) The satisfactory performance of this radar equipment during Operation Redwing implied: 1) That radar equipment could be used by the Army to obtain input data for fallout prediction, and 2) That this equipment should be tested to determine its capabilities for investigating the characteristics of tactical-size nuclear explosions in the dry atmospheric conditions of the Nevada Test Site. This laboratory considered the task sufficiently important to arrange with the USCONARC to include it in the Desert Rock VII and VIII tests, Operation Plumbbob. Test results, however, were not expected to equal those of Operation Redwing, even after equipment modification, because of the low humidity of the area. Radar detectability is dependent on the moisture content of the air above the burst and on the amount and character of debris (soil particles, etc.) that the burst throws into the air.

EQUIPMENT

(C) Five radar sets were used in this operation to collect the required data. The AN/CPS-9 radar recorded the vertical cross-section

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of the clouds (showing the characteristic mushroom-shaped clouds). The AN/APQ-13 radar determined the best azimuth setting for optimum radar returns of the AN/CPS-9. The AN/TPS-1D radar permitted determination of the frequency dependence of cloud detection by comparison of 1,300- and 9,000-Mc radar equipments. The AN/MPG-1 radar was used to study the fireball growth. The AN/FPS-6 radar permitted determination of the frequency dependence of cloud detection by comparison of the 2,500- and 9,000- Mc radar equipments. The detecting ability of each radar set is given in Appendix I. The method used to compute the detecting ability of each radar set is given in Appendix I. Table 1 tabulates the various radar equipment characteristics and Table 2 indicates the relative ability of each radar equipment to detect nuclear clouds as compared with Radar Set AN/CPS-9. Appendix II discusses the communication equipment used in Operation Plumbbob.

Radar Set AN/CPS-9 (9,300 Mc)

(U) The AN/CPS-9 is a high-powered (250-kw peak) storm-detection radar. Its prime meteorological function is to detect water and/or ice particles in storm areas, and locate and track storms occurring within 400 miles of the radar location. There are four indicators on the console to be used by the operator: 1) Range-Height Indicator¹ (RHI) (to a 100-mile range); 2) A-Scope Indicator² (to a 5-, 20-, 75-, and 400-mile range) with a gating system that permits any 5- or 20-mile sector to be observed on an expanded sweep; 3) Plan Position Indicator³ (PPI) (to a 25-, 50-, 100-, 200-, and 400-mile range); and 4) Offset PPI that locates the center of the PPI sweeps in any position on the scope face, thereby expanding the presentation and permitting increased detailed observation.

(C) The AN/CPS-9, designed for fixed-station operation, has large component parts (console 10-by-4-by-3 feet; modulator 6-by-4-by-3 feet). All indoor equipment was housed in a V-51 van, and the antenna assembly was mounted on a 1 $\frac{1}{2}$ -ton stake-body truck for easy transportation in the test area. All interconnecting cables were fitted with connector units for rapid setup and breakdown of equipment with a minimum of error. This radar set required approximately 30 minutes to become fully operational on arrival at a new location. The RHI was modified to allow the height range to be increased from the standard 50,000 feet to 100,000 feet by the operation of a switch. The AN/CPS-9 was the only radar set that offered automatic sector scanning in either PPI or RHI operation.

Radar Set AN/TPS-1D (1,320 Mc)

(U) The AN/TPS-1D is a mobile search radar having both PPI and A-scope indication. It was modified to include a step control

¹RHI indicates range and height of target areas by sweeping the antenna in a vertical plane through the target area.

²A-Scope indicates range and intensity of echo return from target.

³PPI indicates range and horizontal cross-sectional area of target.

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TABLE 1 DESIGN CHARACTERISTICS OF RADAR EQUIPMENTS (U)
(PART II, PROJECT 50.3)

| | AN/CPS-9 | AN/TPS-1D | AN/AFQ-13 (Modified) | AN/FPS-6 | B Score | AN/MFG-1 FPI |
|------------------------|----------|-----------|-------------------------|----------|-----------------|-----------------|
| Peak Power (kw) | 250 | 650 | 40 | 5,000 | 35 | 35 |
| Wavelength (cm) | 3.2 | 22 | 3.2 | 10.7 | 3.2 | 3.2 |
| Pulse Width (usec) | 5 | 2 | 2 | 2.5 | .25 | 1 |
| Antenna Gain (db) | 47 | 27 | 35 | 39 | 22 (calculated) | 22 |
| Noise Figure (db) | 13 | 11.5 | 14 | 8.5 | 14 | 14 |
| Bandwidth (Mc) | .5 | 1 | 4 | .8 | 10 | 10 |
| Pulse Rep. Freq. (cps) | 186 | 400 | 315 | 360 | 4,097 | 1,024 |

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TABLE 2 RADAR DETECTABILITY OF NUCLEAR CLOUDS (U)

| | S/N S/N (AN/CPS-9) |
|-----------------------|-----------------------|
| Radar Set AN/CPS-9 | 1 |
| Radar Set AN/TPS-1D | 2.42 (10^{-4}) |
| Radar Set AN/APQ-13 | 9.55 (10^{-4}) |
| Radar Set AN/FPS-6 | .3 |
| AN/MPG-1 (B Scope) | .332 (10^{-4}) |
| (PPI) | .784 (10^{-5}) |

for 0°, 6°, 18°, 32°, and 54° antenna-elevation angles. The radar is self-contained in a GSS-1 shelter that is mounted on a 2½-ton 6 x 6 cargo truck. Its antenna protrudes from the shelter roof. The only requirement to make this equipment operational is to connect the power cable from the power-unit trailer. Owing to the wide vertical antenna pattern of the radar set and the terrain of the Nevada Test Site, ground clutter was extremely difficult to eliminate from the detonation areas.

Radar Set AN/APQ-13 (9,100 Mc)

(U) The AN/APQ-13 is an airborne bombing radar equipment with PPI and A-scope indication. It was modified for use as a lightweight ground weather radar. The console equipment is housed in an S-56/G shelter; the modulator, receiver, and transmitter are housed in weatherized enclosures on a 20-foot sectional antenna tower. The set required approximately 2 hours to become fully operational. Because of maintenance problems, this radar was used in only three shots.

Radar Set AN/MPG-1 (9,000 Mc) (Modified)

(U) The AN/MPG-1 is a van-mounted fire-control coast artillery equipment with PPI and B-scope indication. The antenna assembly was mounted on a 2½-ton cargo truck. The B-scope continually displayed the target area ($\pm 1,000$ yards by 2°) by sweeping the radar beam horizontally through the target area within the prescribed azimuth sector (10°) 16 times/second. A numerical dial on the console indicated the range to the center of the target area. A continuous elevation control was incorporated that required a complete change in the pedestal's mechanical and electrical design and the addition of complete servo and amplidyne circuitry.

Radar Set AN/FPS-6 (2,800 Mc)

(U) The AN/FPS-6, a height-finding radar equipment with an RHI display, was made available to Project 50.3 in August 1957 for photographic recording. It was located at Angels Peak Nr. 1, approximately 30 miles from Yucca Lake.

Photographic Equipment

(U) Each sweep of the RHI of Radar Sets AN/CPS-9 and AN/FPS-6 and each sweep of the PPI of Radar Sets AN/MPG-1 and AN/TPS-1D were recorded with single-frame 35-mm cameras equipped with motor-driven film advance. The auxiliary A-scopes of the AN/MPG-1 and the AN/TPS-1D were photographed with 16-mm motion-picture cameras. The PPI displays of the AN/CPS-9 and the AN/APQ-13 were recorded with 4-by-5-inch film-pack cameras. The B-scope of the AN/MPG-1 was filmed with a 35-mm motion-picture camera at 16 frames/second (the antenna-azimuth sweep rate). The atomic clouds were photographed with a 4-by-5-inch film-pack camera at the radar location on

the test site. One event was recorded in color with a 16-mm movie camera. A watch with a sweep second hand was placed on each indicator to record the time of each frame. This recording system permitted data analysis to the nearest second.

PROCEDURE

Pretest Period

(U) On 28 March 1957, personnel arrived at Camp Desert Rock to make the necessary technical and administrative arrangements. Part II of Project 50.3 was scheduled to begin testing operations approximately one month before the series started to avoid possible interference with other radar equipment at the Nevada Test Site. Camp Desert Rock, however, did not become operational until the first week of May, causing the interference tests to be delayed until the Project 50.3 equipment received an approved site in the forward area. The AN/CPS-9 and AN/APQ-13 radars, requiring only minor alignments and repairs after being transported across the continent, were set up in the Camp Desert Rock signal yard and tested while awaiting permission to enter the forward area. To test the antenna assembly in the signal yard, the antenna was placed on the rear of a $1\frac{1}{2}$ -ton stake body truck. The antenna's performance was sufficiently stable to make this the permanent installation for the remainder of the test. The complete mobility of the AN/CPS-9 reduced the setup time from approximately 4 hours to 30 minutes.

(U) On 11 May 1957, two days before the first dry run, all radar sets except the AN/MPG-1 were set up on a previously chosen site on the west side of Yucca Lake at an ideal location for operation. A dry run of all equipment was required before each shot to make sure that there was no interference. Any equipment not undergoing this test could not participate in the shot. The same day that the equipment was checked for operation, Project 50.3 personnel were notified that the site would be used for another project. Another site was located on the southeast side of Yucca Lake and the equipment was again placed in operating condition for the dry run. Since the AN/MPG-1 radar did not participate in the dry run, it was not used as transmitting equipment in the first shot.

Test Period

(U) There were substantially two phases of operation during the Plumbbob test series. During the initial period all radars were grouped within a small area where they remained for ten detonations (Fig. 1). This location permitted comparison and evaluation of equipment operating with the same terrain, distance, and elevation to ground zero. For the second phase the equipments were divided into two groups. The equipments capable of detection at greater distances were moved to several longer range sites to determine the maximum operating distance. The nondetecting

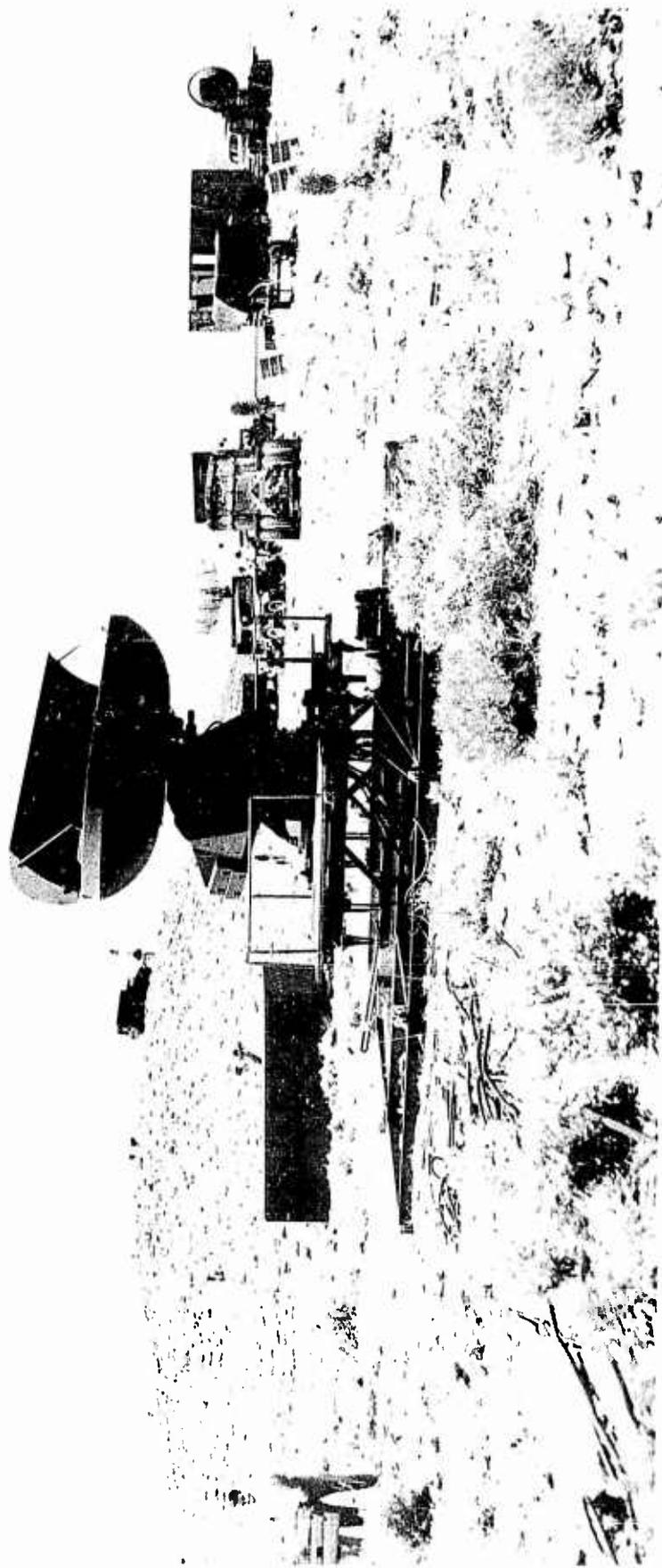


Fig. 1 View of Operating Site Southwest of Yucca Lake (U) (Showing antenna of Radar Set AN/MPG-1 in center foreground, Radar Set AN/TPS-1D in center background, Radar Set AN/CPS-9 at extreme right, and Radar Set AN/APQ-13 on top of knoll)

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equipments were moved closer to ground zero or to the most advantageous location permissible. This phase was extremely difficult owing to the necessity of simultaneously manning three and four widely separated sites.

(C) On the first shot (Boltzmann), three radars were operated as transmitting equipments and one set, the AN/MPG-1, was operated as a passive set (not transmitting). None of the radars caused any interference to other projects during the first three events. Then Project 50.3 personnel were notified that the AN/CPS-9 was causing interference to a Department of Defense (DOD) project, which was responsible for aircraft location in the test area, and was requested to keep the AN/CPS-9 off the air until 20 seconds after shot time. Consequently, for the remainder of the shots, the initial rate of cloud rise and other phenomena occurring from detonation time to detonation time plus 20 seconds were unobserved by this equipment.

(C) During the initial period the A-scope of the AN/CPS-9 was photographed by a single-frame camera at various antenna elevations to measure the intensity of the echo return from different portions of the cloud. At the first site (ground-zero range varied from 8.5 to 20 miles), the AN/CPS-9 detected all but one of the shots in which it participated, while the observers of the other radar sets saw no indication of any shot.

(C) An attempt was made to measure the intensity of the signal return from the cloud to obtain a quantitative value for a numerical comparison between 1,300- and 9,300-Mc radar equipments. The AN/TPS-1D and the AN/MPG-1 were used for this comparison because their figures of merit to detect scattered distributors were most comparable (Table 2). Two calibrated oscilloscopes were connected to the equipments as auxiliary A-scopes and the sweeps were photographed by motion-picture cameras. These sets, however, did not give sufficient indication for this comparison to be made.

(C) On Shot Priscilla, fired from Frenchman's Flat, all the equipments except the AN/APQ-13 were placed in operation $4\frac{1}{2}$ miles from ground zero. The shock wave at this location was sufficient to force open the locked doors of the AN/CPS-9 van, stopping the photorecording of the RHI for a few minutes. Operators of the AN/TPS-1D did not observe an indication of the cloud but photographs of the PPI clearly showed it (Fig. 2). This was the first time that the AN/TPS-1D indicated any ability to detect atomic clouds.

(C) Since the AN/MPG-1 did not detect any of the previous shots even at the 4-mile range, the set was moved to the minimum safe distance from ground zero for Shot Stokes in order to obtain some indication of the set's detectability. The B-scope, PPI, and auxiliary A-scope were

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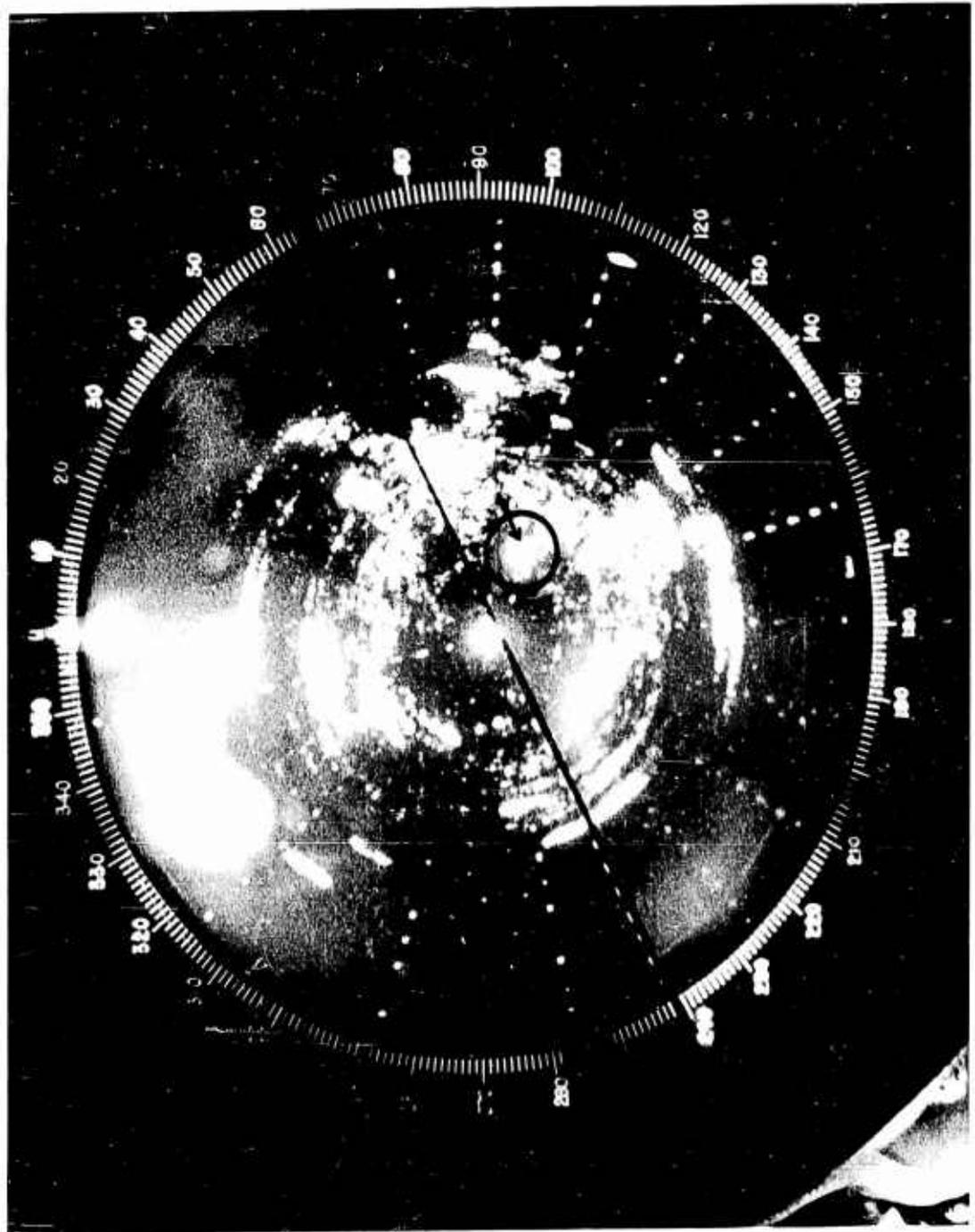


Fig. 2 PPI Display of Shot Priscilla on Radar Set AN/TPS-1D at 4.5-Mile Range (C)
(Time approximately T + 2 min)

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photographed on the remainder of the shots. After the Stokes event, the AN/TPS-1D was also moved to the minimum safe distance from ground zero since it had failed to indicate any cloud other than that from Shot Priscilla. These radar operators did not detect any clouds by visual observation from the minimum ranges.

(C) The AN/CPS-9 was moved off the Nevada Test Site to an area 40 miles northeast of Yucca Lake to determine its ability to detect atomic clouds at a greater range (Fig. 3). The set remained at this location near the Hiko Village for three shots. Since maps of the area were unavailable for an accurate azimuth bearing of ground zero, the AN/CPS-9 was operated in sector scan, and the offset PPI was photographed for each sweep of the antenna. As soon as the cloud was detected, the antenna was placed on the correct azimuth and the RHI was photographed. From the Hiko location the AN/CPS-9 was moved to a location 100 miles south of Yucca Lake near Boulder City, Nevada (Fig. 3). Here the AN/CPS-9 made observations until the end of the test series.

(U) For the last three shots the AN/TPS-1D was moved to the ridge between Yucca Lake and Frenchman's Flat (Navy Hill) where the location was high enough to help eliminate the ground clutter that had made detection difficult (Fig. 4). The AN/MPG-1 continued to be placed at the minimum range whenever possible.

(U) The AN/FPS-6 radar (2,800 Mc), located on Angels Peak Nr. 1 about 30 miles from Yucca Lake, was operated by the 865th Aircraft Control and Warning Squadron. Since this was a restricted area, clearance was arranged through the 27th Air Division, Norton Air Force Base, California. By 15 August 1957, permission was granted Project 50.3 personnel to photograph the RHI of the AN/FPS-6. This set was photographed during the remaining shots of the series, except during Shot Wheeler.

RADAR TEST RESULTS

Reliability of Radar Equipment

(U) In the entire test series the AN/CPS-9 was inoperable on two shots because of malfunctioning. It was not operated on a third shot because fallout on the approved operating site was predicted. On two other shots the antenna had to be operated manually when dust in the hydraulic fluid clogged filters in the antenna-drive system shortly before shot time. Prior to each of the first four shots, the sensitivity, power output, and frequency of the AN/CPS-9 were checked. After the fourth shot, the signal generator was no longer reliable for measuring sensitivity and power output. For the remainder of the shots, the only means of checking equipment performance was by using a built-in echo box and measuring the ring time on the A-scope.

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a. Radar Site at Henderson Pass near Hiko Village at 40-Mile Range (C) (Desert Valley is the low land seen through the mountain pass; Yucca Lake lies two mountain ranges beyond.)

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b. Radar Site near Boulder City at 95-Mile Range from Yucca Lake (C)

FIG. 3 Site of Radar Set AN/CPS-9 at 40- and 95-Mile Ranges (C)

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Fig. 4 Radar Set AN/TPS-1D Located on Navy Hill (U)
(The radar set is looking north across the
Yucca Flats. The northern end of Yucca Lake is
seen at the right.)

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(U) The AN/TPS-1D was operable on all shots. On one shot, however, the equipment operated at a lower output because of the arcing in a high-voltage pulse cable. The AN/MPG-1 was inoperable on one shot owing to malfunctioning. The antenna positioning system was inoperative in PPI operation for a period of time after the set had been hurriedly moved to a new location for a dry run. Only the AN/APQ-13 radar had excessive maintenance problems during the tests.

Reliability of Shot Data

(U) Data collected during the test series are summarized in Table 3 and include: shot number, shot name, detonation time, equipment, time duration of observation, maximum height of detected clouds, measured height, range, rate of rise indicated (where possible) by cloud height at T + 2 minutes, and remarks.

(S) Of the ten detonations detected on the AN/CPS-9 RHI, seven indicated the maximum cloud height within 5 percent of that measured by the Civil Aeronautics Authority (CAA). The measured cloud height was obtained from the CAA at Mercury, Nevada, and the measured yield was received from the Mercury Fallout Prediction Unit. On Shots Boltzmann and Stokes, the AN/CPS-9 did not verify the CAA maximum heights within this percentage. On Shot Boltzmann (Shot Nr. 1) the detonation occurred near a macadamized ground cover that might have restricted the amount of large detectable particles thrown into the upper cloud. (Figure 5 is a photograph of the Boltzmann cloud.) On Shot Stokes the radar indicated the maximum cloud height to be 22,000 feet, while the CAA height was approximately 35,000 feet. The cloud, however, separated into two distinct parts approximately 5 minutes after shot time. (Figure 6 is a photograph of the Stokes cloud.) The lower cloud (stem) had a measured maximum height of 22,000 feet. The upper cloud was not detected for two possible reasons: 1) The radar detected the larger particles of the stem but not the smaller particles contained in the upper cloud; or 2) The upper cloud moved out of the antenna beam and the radar continued to track the lower cloud.

(U) The RHI photographs were taken as time exposures of the cathode-ray tube indicator. The antenna was moved in elevation rapidly from zero degrees to an angle sufficiently high (with one exception) to include the cloud top, as visually seen on the indicator (Figs. 6-9). The return sweep to zero degrees was also photographed on the "down-scan." Each sweep required approximately 3 seconds. Rapid sweeping was used in an attempt to obtain detailed information on cloud growth (rate of rise). A single sweep of the indicator, however, will not show weak signals that are detected by photographic integration. Thus the rapid sweeping procedure used during this test was not conducive to detecting the smaller particles comprising the outer edges and areas of weaker cloud returns.

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TABLE 3 SUMMARY OF TEST DATA (PART II PROJECT 50.3) (U)

| Shot No. | Shot Name | Date (1957) | Time | Equipment | Scope | Duration of Observation (minutes) | Maximum Height of Cloud | Range (Miles) | Cloud Height At T + 2 Min. | Support |
|----------|-----------|-------------|------|--|---------------------------------------|-----------------------------------|--------------------------------|------------------------------|----------------------------|-------------|
| 1 | Boltzmann | 28 May | 0455 | AN/CPS-9 AN/TPS-1D AN/APQ-13 | RHI PPI PPI | 8 0 0 | 17,000 ft. --- --- | 11.8 11.8 11.8 | 12,000 ft. --- --- | Tower |
| 2 | Franklin | 2 June | 0455 | AN/CPS-9 AN/TPS-1D AN/APQ-13 AN/MFG-1 | RHI PPI PPI B | 4 0 0 0 | 9,000 ft. --- --- --- | 8.5 8.5 8.5 8.5 | --- --- --- --- | Tower |
| 3 | Lesser | 5 June | 0455 | AN/CPS-9 AN/TPS-1D AN/APQ-13 AN/MFG-1 | RHI PPI PPI B | 1 0 0 0 | 2,000 ft. --- --- --- | 14.6 14.6 14.6 14.6 | --- --- --- --- | Air balloon |
| 4 | Wilson | 18 June | 0500 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | Not operative PPI Not operative | -- 0 -- | --- --- --- | 15.0 15.0 15.0 | --- --- --- | Air balloon |
| 5 | Priscilla | 24 June | 0630 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | RHI PPI B | 26 8 0 | 41,000 ft. --- --- | 4.5 4.5 4.5 | 27,000 ft. --- --- | Air balloon |
| 6 | Hood | 5 July | 0440 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | RHI PPI B | 20 (Est.) -- -- | 40,000 ft. --- --- | 15.0 15.0 15.0 | --- --- --- | Air balloon |
| 7 | Diablo | 15 July | 0455 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | Not operative PPI B | -- -- -- | --- --- --- | 19.5 19.5 19.5 | --- --- --- | Tower |
| 8 | John | 18 July | 0700 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | RHI PPI B | 0 0 0 | --- --- --- | 16.5 16.5 16.5 | --- --- --- | Air balloon |
| *9 | Kepler | 24 July | 0450 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | A-RHI A A | Greater than 10 minutes 0 0 | 22,500 ft. --- --- | 13.2 13.2 13.2 | 15,000 ft. --- --- | Tower |

*Camera ran out of film. Strong return was indicated on last frame of film.

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TABLE 3 SUMMARY OF TEST DATA (PART II PROJECT 50.3) (Contd)

| Shot No. | Shot Name | Date (1957) | Time | Equipment | Scope | Duration of Observation (Minutes) | Maximum Height of Cloud | Range (Miles) | Cloud Height At T + 2 Min. | Support |
|----------|----------------|-------------|------|---|--|-----------------------------------|---|------------------------|----------------------------|-------------|
| 10 | Owens | 25 July | 0630 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | A-RHI A A | 11.5 0 0 | 32,000 ft. --- --- | 14.6 14.6 14.6 | 20,000 ft. --- --- | Air balloon |
| 11 | Stokes | 7 Aug. | 0525 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | RHI A-PPI B | 30 0 0 | 23,000 ft. --- --- | 11 11 3.5 | 15,000 ft. --- --- | Air balloon |
| 12 | Shasta | 17 Aug. | 0500 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | Not operative PPI B | -- 0 0 | --- --- --- | -- --- --- | --- --- --- | Air balloon |
| 13 | Doppler | 23 Aug. | 0530 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | PPI A-PPI A | 15 0 1 sec. | --- --- --- | 14 3.5 3.5 | --- --- --- | Air balloon |
| 14 | Franklin Prime | 30 Aug. | 0539 | AN/CPS-9 AN/TPS-1D AN/MFG-1 AN/FPS-6 | PPI,RHI A A RHI | 15 (Est.) Momentary " 0 | 26,000 ft. --- --- --- | 39 3 3 30 | --- --- --- --- | Air balloon |
| 15 | Smokey | 31 Aug. | 0529 | AN/CPS-9 AN/TPS-1D AN/MFG-1 AN/FPS-6 | PPI,RHI Not operative Not operative RHI | 20 -- -- 0 | Greater than 30,000 ft. --- --- --- | 41 --- --- 30 | --- --- --- --- | Tower |
| 16 | Gallelio | 2 Sept. | 0540 | AN/CPS-9 AN/TPS-1D AN/MFG-1 AN/FPS-6 | PPI,RHI Not operative Not operative RHI | 0 -- -- 0 | --- --- --- --- | 50 --- --- 30 | --- --- --- --- | Tower |
| 17 | Wheeler | 6 Sept. | 0545 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | PPI PPI PPI | 0 0 0 | --- --- --- | 100 8 8 | --- --- --- | Air balloon |

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TABLE 3 SUMMARY OF TEST DATA (PART II PROJECT 50.3) (Contd)

| Shot No. | Shot Name | Date (1957) | Time | Equipment | Scope | Duration of Observation (Minutes) | Maximum Height of Cloud | Range (Miles) | Cloud Height At T + 2 Min. | Support |
|----------|-----------|-------------|------|---|----------------------------|---------------------------------------|-------------------------|----------------------|----------------------------|-------------|
| 18 | La Place | 8 Sept. | 0600 | AN/CPS-9 AN/TPS-1D AN/MFG-1 AN/FPS-6 | PPI A-PPI PPI RHI | 0 0 0 0 | --- | 100 8 8 30 | --- | Air balloon |
| 19 | Fiiseau | 14 Sept. | 0945 | AN/CPS-9 AN/TPS-1D AN/MFG-1 AN/FPS-6 | PPI PPI A RHI | 10 21 Shock wave momentary 5 | --- | 97 7.5 8 30 | --- | Air balloon |
| 20 | Whitney | 23 Sept. | 0530 | AN/CPS-9 AN/TPS-1D AN/MFG-1 | PPI PPI A | 7 Momentary attenuation " | --- | 90 19 15 | --- | Tower |
| 21 | Newton | 16 Sept. | 0550 | AN/CPS-9 AN/TPS-1D AN/MFG-1 AN/FPS-6 | PPI A-PPI PPI RHI | 8 10 sec. 0 5 | --- | 99 15 -- 30 | --- | Air balloon |

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b. Shot Hood

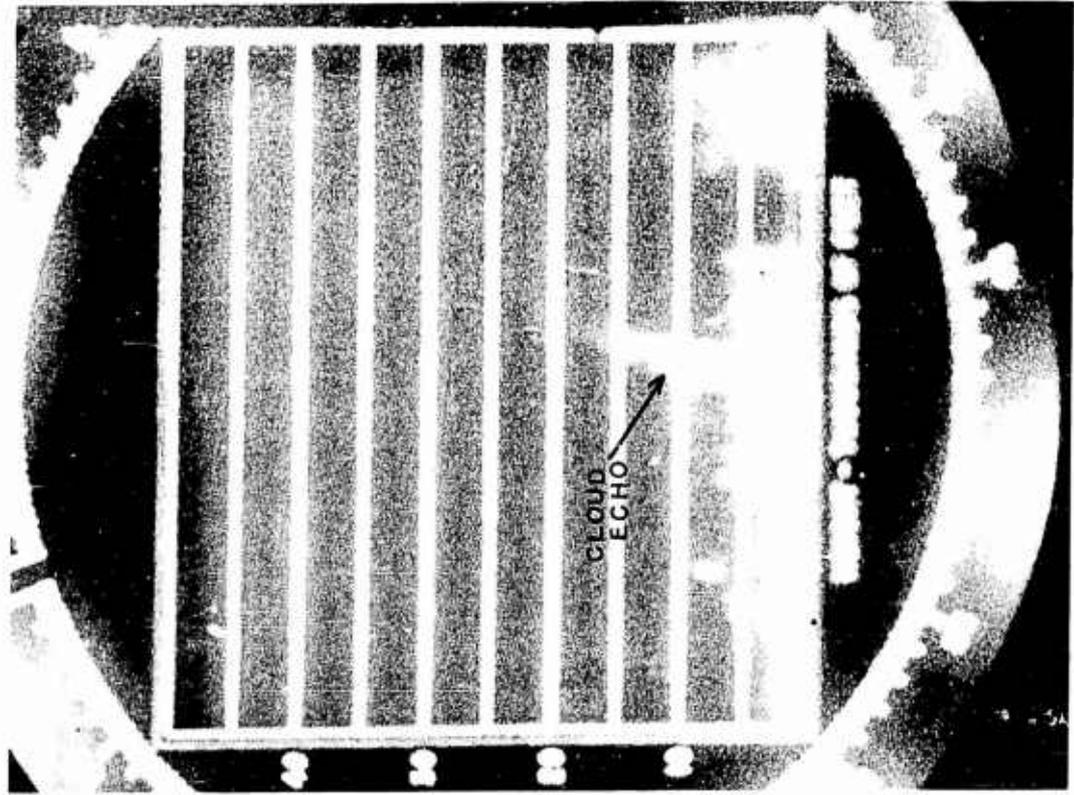


a. Shot Boltzmann

Fig. 5 Views of Shots Boltzmann and Hood Showing Wind Shears (U)
(Wind shears disperse particles, decreasing radar detection)

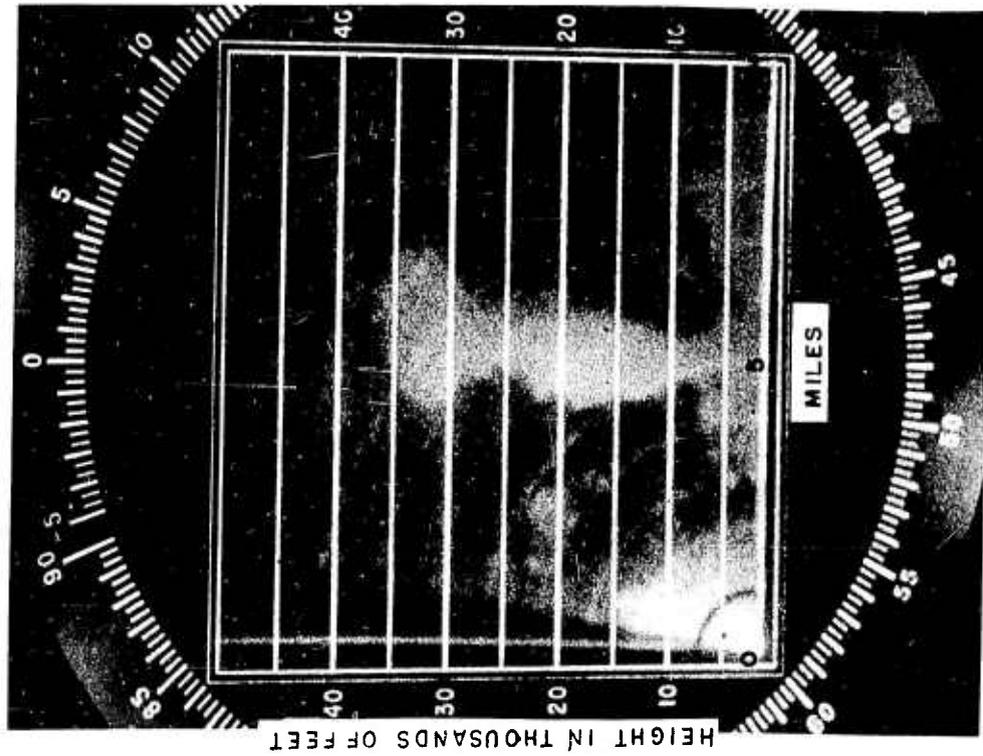
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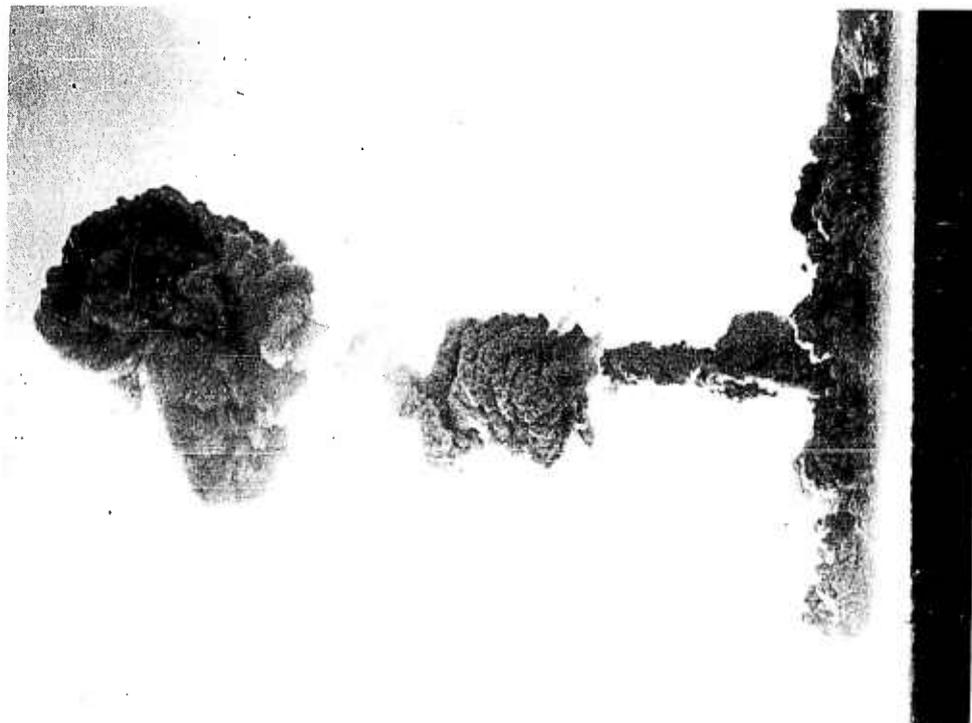
a. Shot Stokes from Test Site at 3.5-Mile Range (C)
b. RHI Display of Shot Stokes on Radar Set AN/CPS-9 at 11-Mile Range (T + 5 min) (C)

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b.

b. RHI Display of Shot Priscilla on Radar Set AN/CF6-9 at 4.5-Mile Range (T + 5 min) (C)



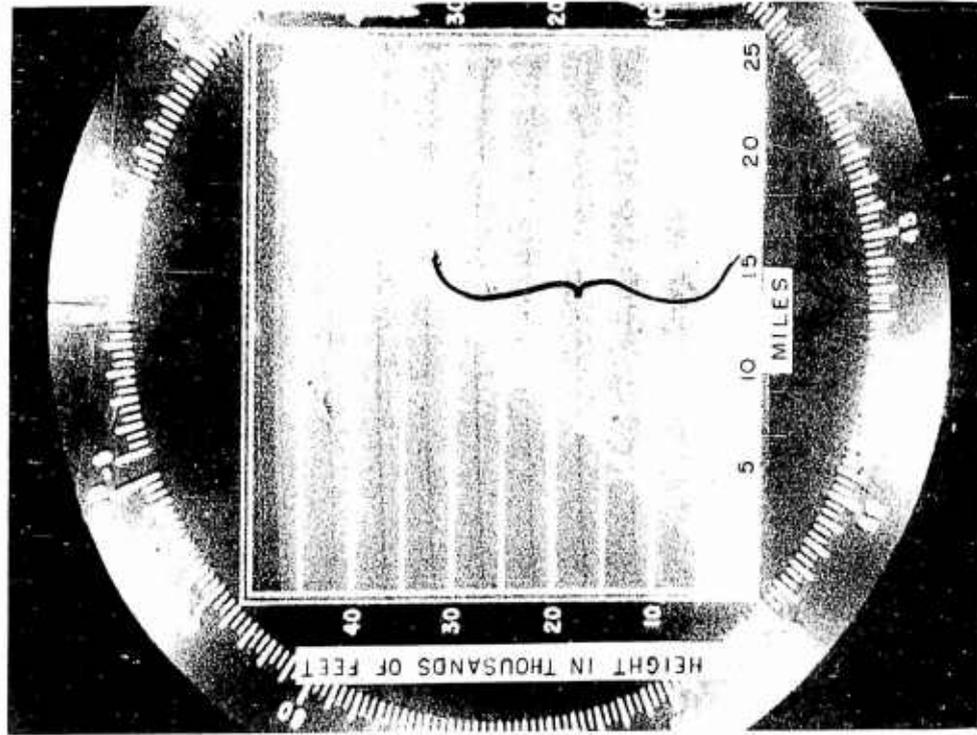
a.

a. Shot Priscilla from Test Site at 4.5-Mile Range (C)

Fig. 7

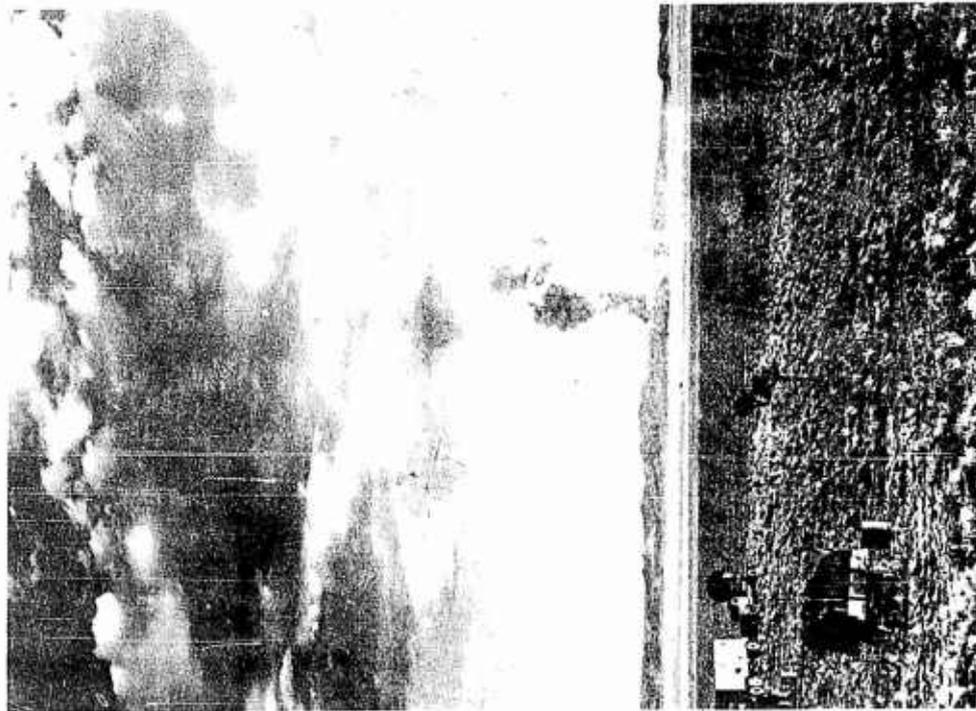
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b.

Fig. 8 b. RHI Display of Shot Oven on Radar Set AN/CPS-9 at 14.6-Mile Range (T + 6 min) (C)

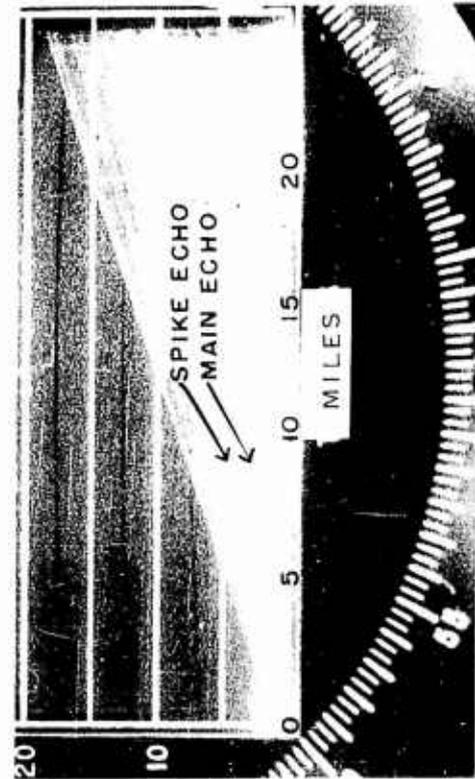


a.

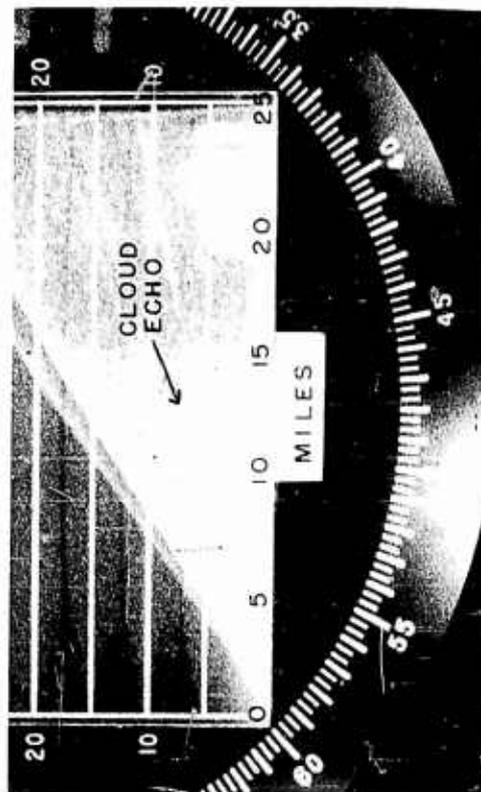
a. Shot Oven from Test Site at 14.6-Mile Range (Radar Equipments in Foreground) (C)

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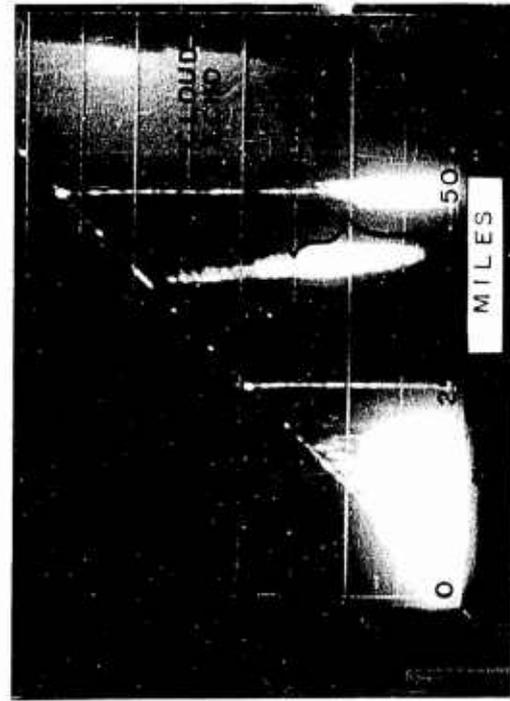
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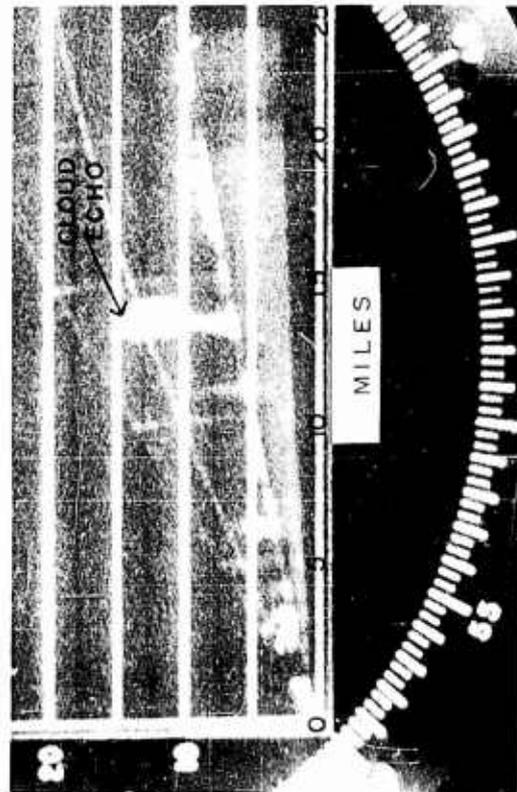
HEIGHT IN THOUSANDS OF FEET



HEIGHT IN THOUSANDS OF FEET



HEIGHT IN THOUSANDS OF FEET



HEIGHT IN THOUSANDS OF FEET

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Fig. 9 RHI Display of Shots Boltzmann, Franklin, Kepler, and Smokey on Radar Set AN/CPS-9 (U)
 a. Shot Boltzmann at 12-Mile Range (T + 1½ min) (C) b. Shot Franklin at 8-Mile Range (T + 5 sec) (C)
 c. Shot Kepler at 13-Mile Range (T + 2 min) (C) d. Shot Smokey at 40-Mile Range (T + 8 min) (C)

Ground-Zero Location

(U) Ground zero was located on the shots detected by the AN/CPS-9 and AN/TPS-1D radars. The range and azimuth of ground zero with relation to the radar location could be read directly from the radar scopes (Figs. 2 and 10). From long-range sites, the clouds were detected by the AN/CPS-9 only after the detectable particles rose above the elevation of the intervening terrain. While the radar was at long-range sites, a number of shots were fired when large wind shears (speed and direction) were present. These shears were used to dissipate and scatter the clouds as soon as possible to minimize fallout hazards. On some shots this shear prevented the detectable particles from reaching the altitudes necessary to intersect the radar beam (Fig. 5).

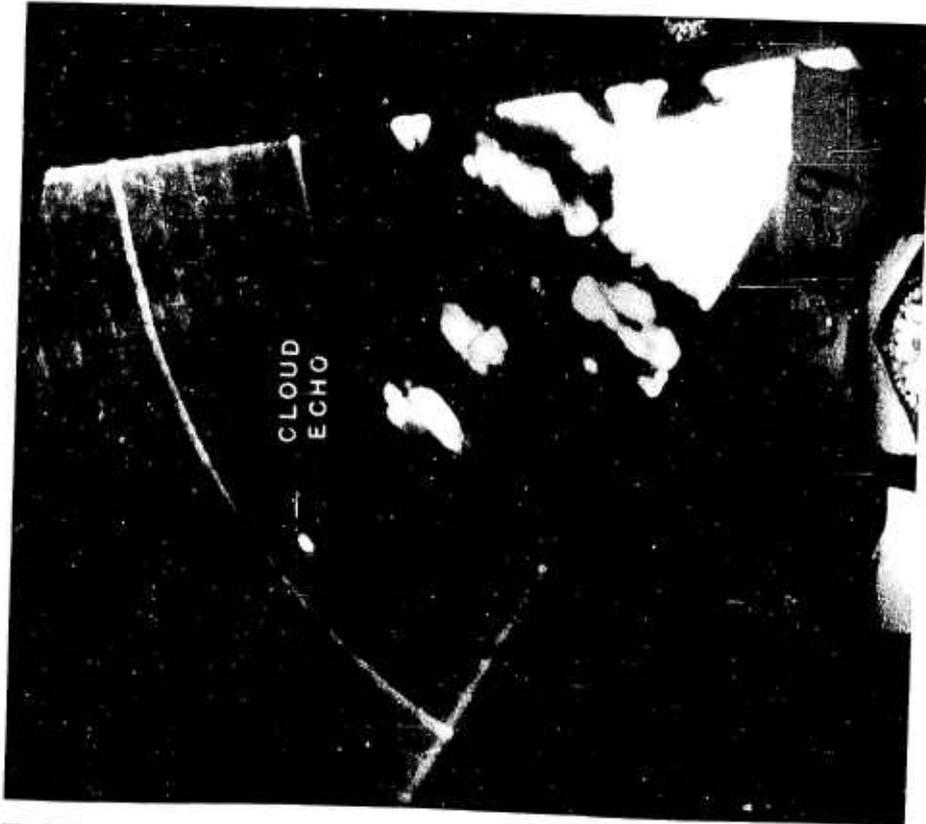
(U) The accuracy of locating ground zero depends on the height at which the cloud is detected, the elapsed time after detonation, the rate of rise of the detectable cloud, and the radar characteristics (pulse width and beam width).

(U) Beam Width (Azimuth and Elevation Location). Figure 11 shows curves depicting the width of the radar beams (between half-power points) at various ranges up to 50 miles for the various radar sets. The smaller the beam width, the more accurate the target azimuth or elevation location. A target that is small with respect to beam width will indicate essentially the same location on a display regardless of its position in the beam. Since the beam direction is considered to be along the axis of the beam, the maximum error in locating a target smaller than the beam width is plus or minus one-half the beam width at the range of the target. Appendix III shows the method for calculating the beam width at various ranges.

(U) Pulse Width (Range Location). The range accuracy of a radar set depends among other factors on its pulse width. The shorter the pulse width, the more accurate the range location. With clouds as targets (distributed scatterers), the portion of the pulse that reflects a detectable signal is not known. The cloud edge is difficult to detect on account of the tapering off of the scatterer density. If the pulse center is assumed to be the target range, the maximum error in range location will be plus or minus one-half the pulse width. The formula to convert pulse width (T) into radar distance (d) is: $d = CT/2$ where C is speed of propagation. Table 4 shows the pulse width of the various radar sets.

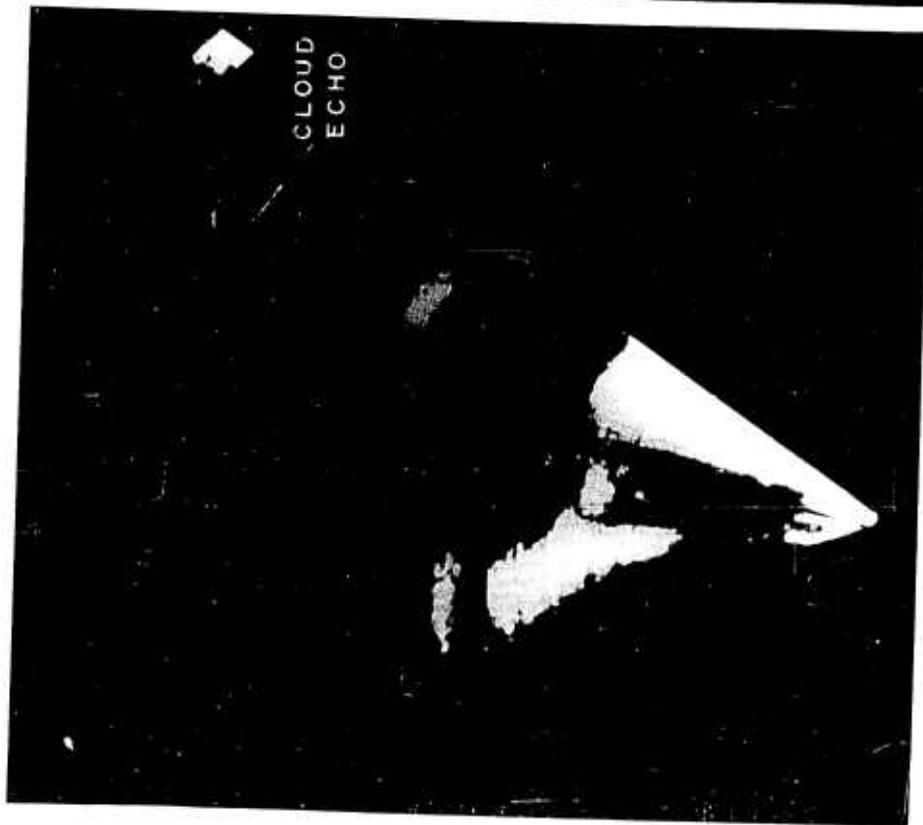
(U) The detection height affects the accuracy of the ground-zero location. If only the upper cloud is detected, its large diameter makes ground zero more difficult to estimate than if the narrow stem were detected. The higher the cloud, the more time the wind has to move the cloud away from ground zero (Fig. 5a). The elapsed time to detection affects location accuracy---the longer the period before detection, the more time the wind has to move the detected cloud away from ground zero.

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b.

b. PPI Display of Shot Fizeau at 95-Mile Range (T + 18 min) (C)



a.

a. PPI Display of Shot Franklin Prime on Radar Set AN/CFS-9 at 40-Mile Range (T + 1 min) (C)
(Off-center PPI scope used to expand area under surveillance)

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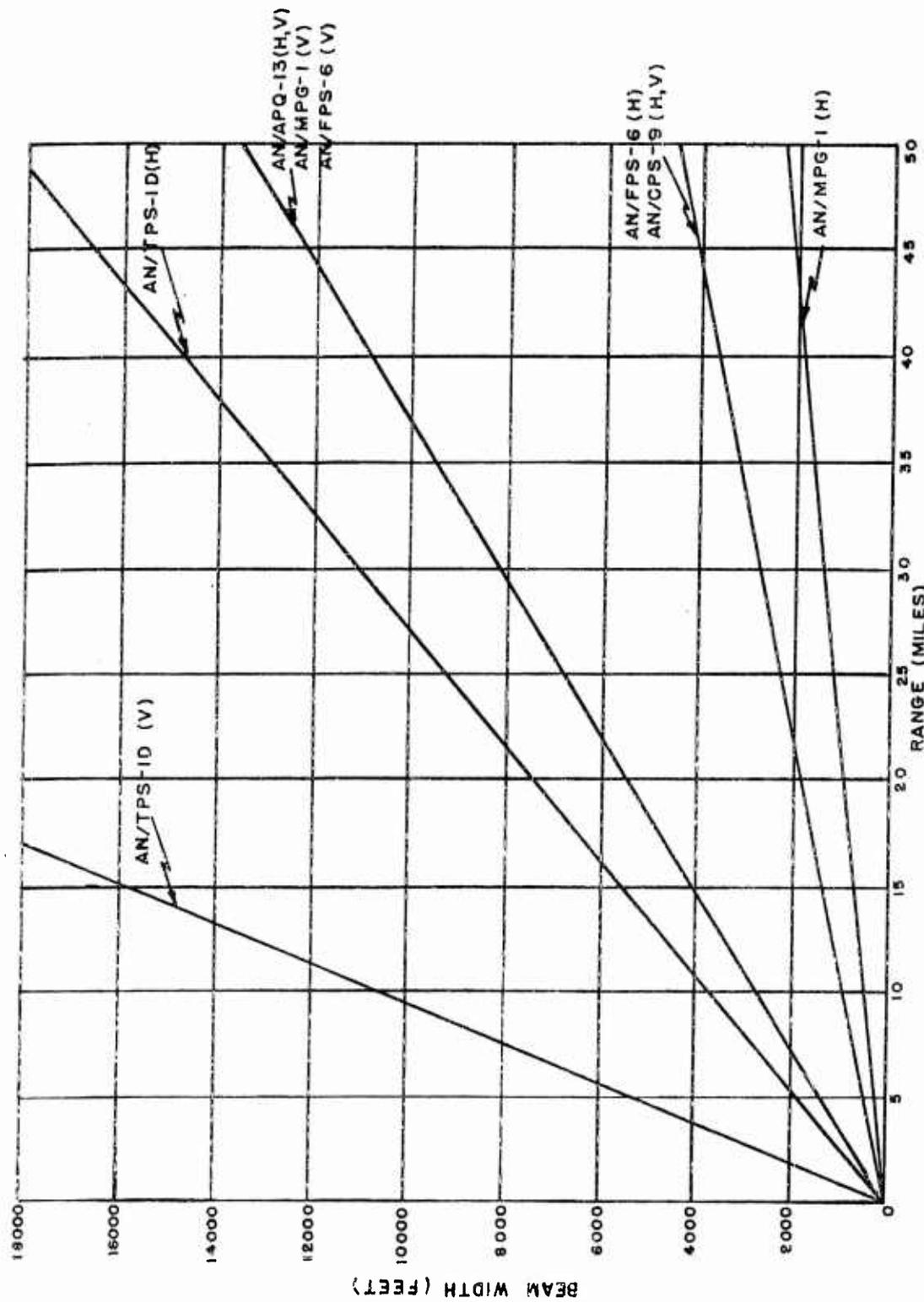


Fig. 11 Range Versus Beam Width (U)

TABLE 4 RANGE ACCURACY OF RADAR EQUIPMENTS (U)
(Part II, Project 50.3)

| | | |
|-----------|---------------|----------------|
| AN/CPS-9 | 5 μ sec | \pm 1,225 ft |
| AN/CPS-9 | .5 μ sec | \pm 123 ft |
| AN/TPS-1D | 2 μ sec | \pm 490 ft |
| AN/APQ-13 | 2 μ sec | \pm 490 ft |
| AN/MPG-1 | .25 μ sec | \pm 61 ft |
| AN/FPS-6 | 2 μ sec | \pm 490 ft |
| AN/FPS-6 | 3 μ sec | \pm 735 ft |

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The rate of cloud rise affects location accuracy owing to its relation to the elapsed time to detection.

(C) Detection by Attenuation. The AN/MPG-1 did not indicate clouds on any shot even though it observed the detonations at the minimum safe distance from ground zero. However, the fireball was detected on an auxiliary A-scope by the attenuation of targets beyond ground zero. Signals from these targets would disappear within a second after T-0 and be absent for 6 to 7 seconds. They would completely recover in less than one second. The fireball activity might have absorbed enough radar energy to weaken the return from the echoes beyond the detonation. The A-scope may have indicated the shock-wave movement but since the indication was very small, no definite conclusions can be made.

Yield Correlation

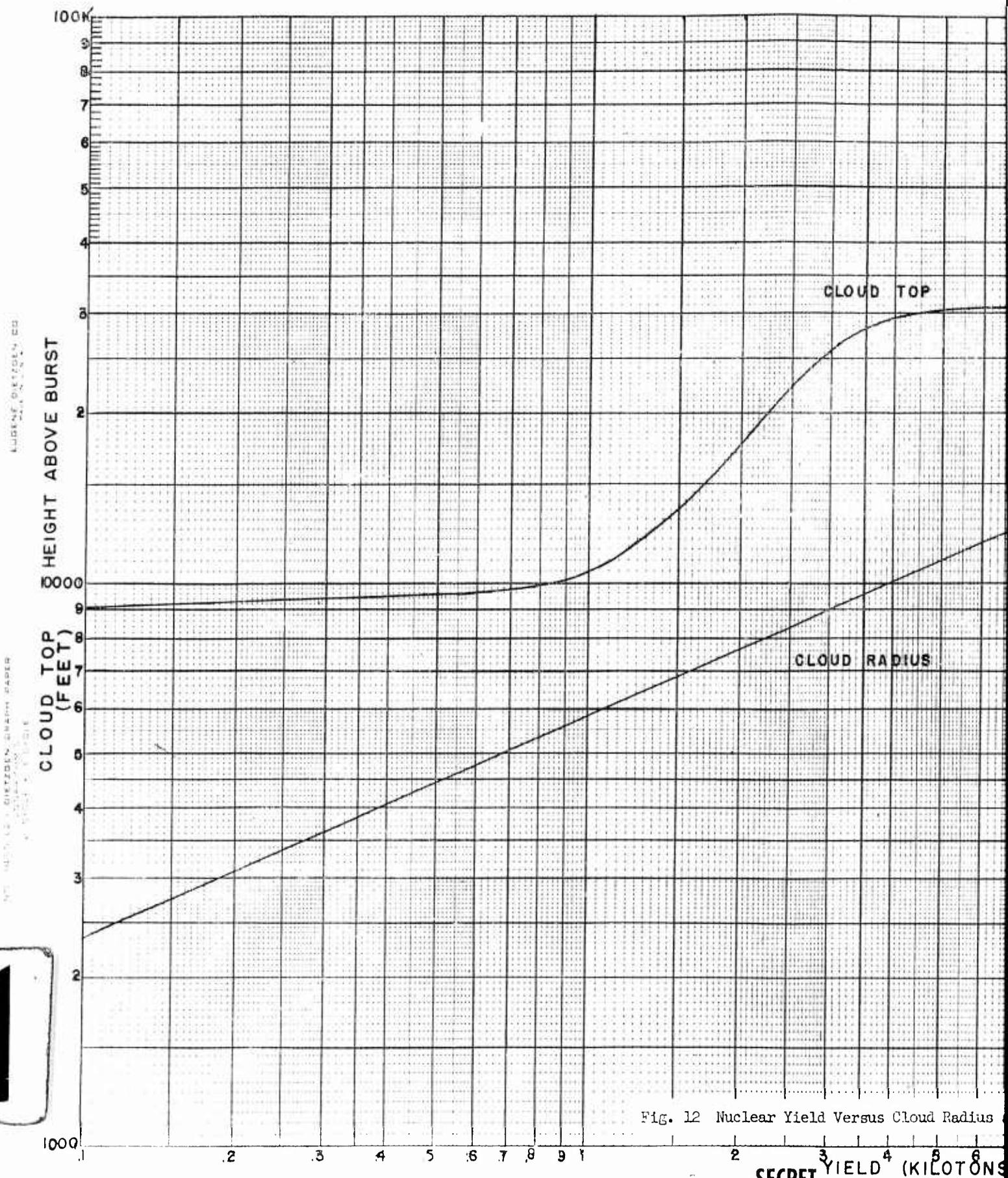
(S) Cloud Height. Since seven of the ten shots observed on the AN/CPS-9 RHI indicated the maximum cloud heights within 5 percent of the cloud height measured by the CAA at Mercury, Nevada, a correlation was attempted between yield and maximum cloud height observed by radar. On one occasion the radar cloud height exceeded the CAA-measured height by 2,200 feet. The radar echo in this case was more accurate in determining the maximum cloud height than the CAA measurement since radar energy must be reflected from a target to be indicated. The beam width could have caused an error of approximately 1,500 feet at the 15-mile cloud range; however, this error is too small to explain the height difference.

(C) To determine the correlation of the radar's maximum cloud height and yield, a curve was drawn using all the data available from previous tests. Figure 12 shows the curve from which it was drawn. Variation in cloud heights for equal yield detonations made it difficult to fit a representative curve to the data. The absence of low-yield detonations from 1 to 10 kt is clearly indicated. Figure 12 shows that the yield can be determined within a factor of two by measurement of the cloud height without consideration of meteorological conditions.

(C) The stabilization height of the top of a nuclear cloud is primarily a function of the yield of the burst. Although meteorological conditions present in the cloud's environment somewhat alter the theoretical stabilization height (up to ± 15 percent), an unknown yield can be estimated with knowledge of cloud-stabilization height.

(C) A nuclear cloud may continue to rise (or sink) after stabilization, subject to the environmental conditions present. These changes in height after stabilization, however, are due to meteorological effects. They cannot be considered in estimating the yield of the burst. For bursts of all yields, stabilization (which usually occurs 4 to 6 minutes after detonation) can be considered to be complete by 10 minutes after detonation.

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Fig. 12 Nuclear Yield Versus Cloud Radius

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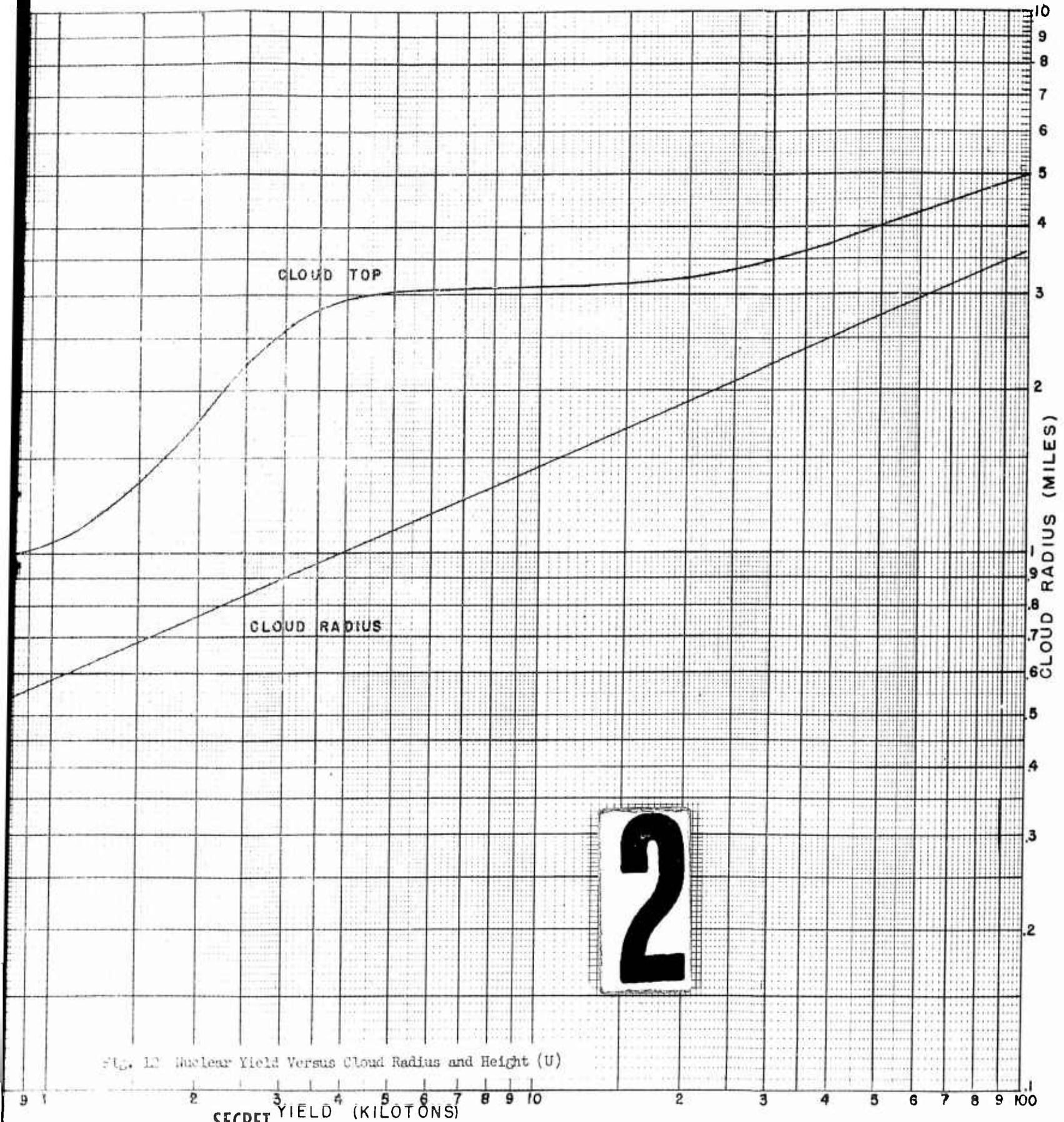


FIG. 12 Nuclear Yield Versus Cloud Radius and Height (U)

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(S) Table 5 shows: 1) A comparison between the measured yield of the detonation and the estimated yield from radar data, using the radar-detected cloud height and the cloud height from the curve of Figure 12; 2) The ratio of the measured yield to that estimated by radar cloud detection; 3) A direct comparison between the cloud heights measured by the CAA and by radar; and 4) The ratio of the cloud height indicated by radar to that measured by the CAA. From Table 5 it appears that radar equipment operated under the conditions of the Nevada Test Site may be able to determine the yield of a detonation (when the entire cloud height is measured) to a factor of approximately two. Further participation in nuclear tests is required so that sufficient data may be collected from various yield detonations at different ranges and altitudes. With improved and advanced instrumentation, the resulting data will permit a more accurate determination of yield.

(C) Radar equipment may offer a more accurate means of measuring cloud heights than other equipment. Optical ground-based equipment does not have the ability to see through intervening clouds. It is extremely difficult, if not impossible, for this equipment to observe the extreme top of the cloud at short ranges because of the cloud shape. The CAA observations rely on the aircraft altimeter and on the judgment of flight personnel.

(C) From the analyzed data, Project 50.3 personnel believe that the cloud heights could be measured more accurately by slowing the antenna sweep motion. Greater integration of the signals, gained by the slower antenna sweep, would allow the weaker echoes to be indicated on the radar's RHI.

(C) Cloud Diameter. Cloud-diameter measurement is another possible method of correlating the detonation yield and the radar cloud indication. A curve of stabilized cloud radius versus yield was developed by the Fallout Team of Project 50.3 (Fig. 12). The radar equipment did not give a very accurate cloud-diameter measurement because of the indicator ranges required for cloud indication. In addition, no quality data are available on the actual cloud diameters. Therefore, no correlation of yield versus cloud diameter has been made. On future operations a recording theodolite will be used to record cloud dimensions including time, azimuth, and elevation angle information. Greater accuracy in determining radar cloud-diameter measurements could be obtained by using the 5- or 20-mile gated sweeps of the AN/CPS-9 A-scope.

(C) Rate of Rise. The initial rate of cloud rise may offer a means of correlating yield and radar indication. Unfortunately the interference that kept the AN/CPS-9 from transmitting for 20 seconds after detonation time prevented a complete rate of rise study. Data were available for only the first two shots.

(C) On Shot Franklin the cloud echo appeared to decrease in height after $T + 12$ seconds and resumed its climb again after $T + 36$ seconds.

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TABLE 5 COMPARISON OF NUCLEAR YIELD WITH CLOUD HEIGHT (U)
(Part II, Project 50.3)

Cloud tops are measured above ground zero.

| Shot | Measured Yield (kt) | Estimated Radar Yield (kt) | Measured Yield | | CAA Measured Cloud Top (ft) | Radar Measured Cloud Top (ft) | H _{CAA} |
|----------------|---------------------|----------------------------|----------------|-------|-----------------------------|-------------------------------|------------------|
| | | | Radar Yield | Yield | | | |
| Boltzmann | 11.5 | 1.95 | 5.9 | | 28,000 | 17,000 | .61 |
| Franklin | .14 | .1 | 1.4 | | 12,200 | 9,000 | .75 |
| Lassen | - - - | - - - | - - - | | 1,200 | 2,000 | 1.67 |
| Priscilla | 36.6 | 53.0 | .69 | | 40,200 | 41,000 | 1.02 |
| Kepler | 10.3 | 2.6 | 4.0 | | 21,200 | 22,500 | 1.06 |
| Owen | 9.2 | 19.0 | .48 | | 30,300 | 32,000 | 1.06 |
| Stokes | 19.0 | 2.6 | 7.3 | | 32,200 | 23,000 | .715 |
| Smokey | 43.0 | 19.0 | 2.36 | | 33,300 | 30,000(f)* | Approx. 1 |
| Hood | 77.0 | 50.0 | 1.54 | | 42,300 | 40,000 | .95 |
| Franklin Prime | 4.7 | 3.0 | 1.56 | | 27,000 | 26,000 | .96 |

*The antenna was not elevated enough to measure the cloud top. The highest height recorded was 30,000 feet, but the signal strength indicated that greater heights would have been recorded if the antenna had been elevated higher.

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The decrease, which occurred during the time that the fireball's influence may still be prevalent, might be directly related to the effects of the fireball. One solution is that the fireball or resulting heat may create a radar signal reflector that initially rises to a height above the debris thrown into the air. As the fireball dissipates, the echo may decrease in height until the debris rising from ground zero is detected as a rising cloud. A detailed account of Shot Franklin detected on the AN/CPS-9 RHI is given in Appendix IV.

(C) Another unexpected phenomenon occurred on Shot Franklin. Very narrow columns or spikes appeared directly over ground zero at T + 5 seconds, extending to the maximum height of the antenna sweep (6,500 feet), and persisted for 12 seconds. They might have been streams of electrons forced upward from ground zero.

(C) Figure 13 shows the rate of rise of the shots recorded from the AN/CPS-9 RHI. From these curves it appears that a correlation might exist between rate of rise and yield. At a particular time after detonation, before cloud stabilization, the lowest yield shot shows the lowest cloud height reached at that time, and the cloud heights increase as the yield increases. This indicates a faster rate of rise for higher yields. Three shots of similar yields, two at 10 kt and one at 11 kt, show cloud heights within 3,000 feet of each other at equal time after detonation. There should be further tests to determine the complete rate of rise of various yield shots. The present data are inadequate for definite conclusions. Since the AN/CPS-9 was calibrated to indicate 50,000 feet in 4.5 inches, it was difficult to observe and measure clouds in the first few thousand feet.

(U) The AN/CPS-9 antenna-elevation-positioning system also makes it difficult to accurately measure rate of rise. The antenna was manually controlled to increase the number of vertical sweeps per minute. This caused the antenna to reverse direction much faster than with automatic control and also to move faster to follow the manual control. The increased antenna movement accentuated the servo lag, causing the successive up and down sweeps to measure a one-degree difference in elevation angle or approximately 1,500 feet at a 15-mile range. This type of error can be reduced by photographing successive sweeps instead of isolated up or down sweeps or by slowing the antenna motion.

DETECTION THEORY

(C) In nuclear tests prior to Operation Redwing, shots were observed by radar equipment and the resulting echoes were recorded. A ring around ground-zero location that gradually increased in size and moved away from the detonation area was recorded by aircraft radars. This ring coincided with the measured movement of the shock wave. Several shots showed a horseshoe-shaped echo around ground zero rather than a continuous ring. The open part of the horseshoe might be attributed to the attenuation of

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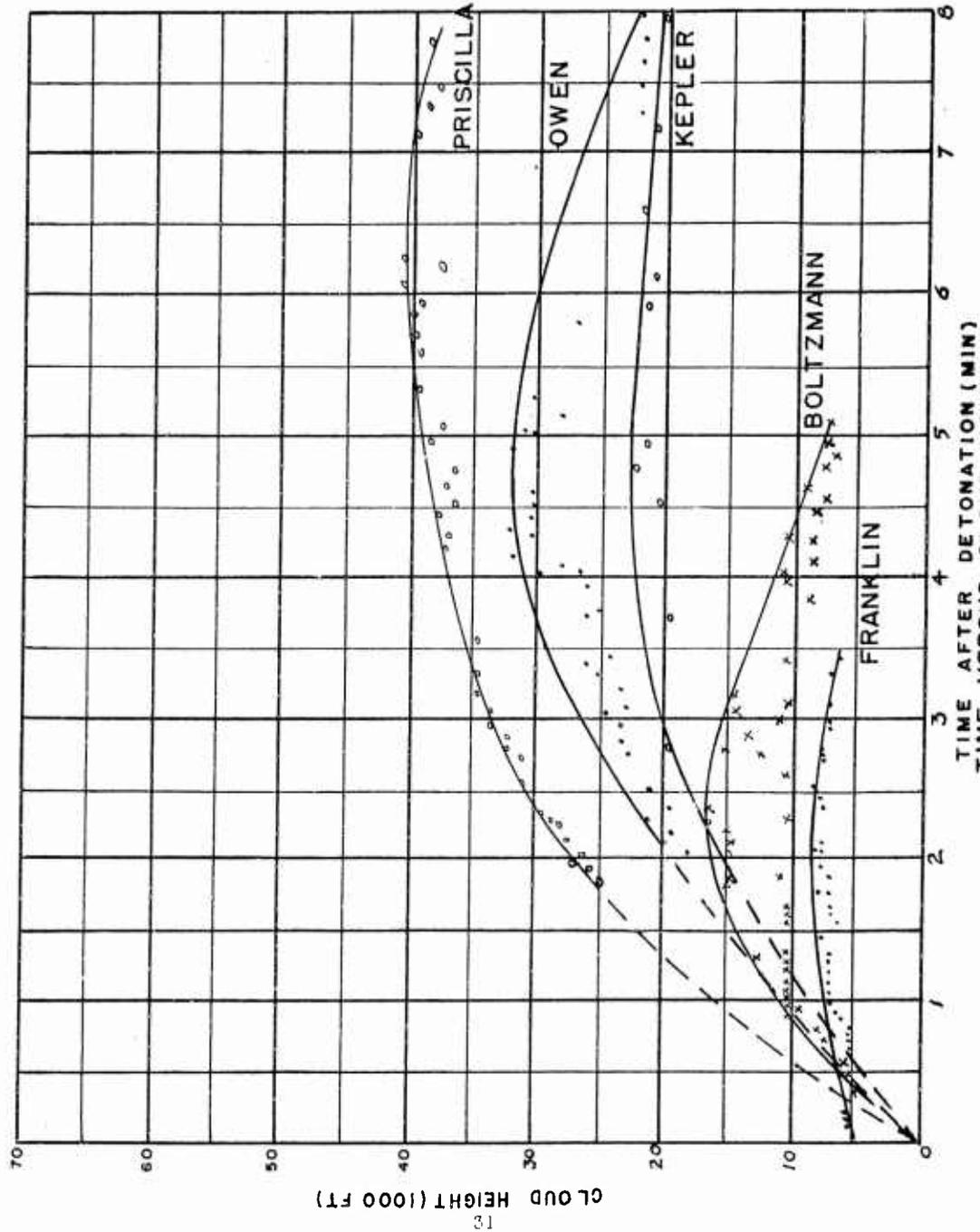


Fig. 13 Rate of Rise of Cloud Height(U)

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CLOUD HEIGHT (1000 FT)

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radar signals as they passed through the nuclear cloud or fireball. There are two possible reasons for this detection: 1) The shock wave might have caused a surface disturbance that reflected the radar energy, or 2) The sharp discontinuity at the shock-wave front might have reflected the radar energy. A combination of both actions might have caused the signal return. A detailed study of this reflection has not been made.

(C) The success of the AN/CPS-9 in detecting and tracking atomic clouds at the Ehiwetok Proving Ground may be attributed to a number of factors: 1) This was the most powerful X-band set used during Operation Redwing; 2) The equipment was developed to detect water particles associated with storm areas and these areas possess many atomic-cloud characteristics such as a large volume of scatterers, slow azimuth movement, vertical structure, etc; and 3) The high humidity of the atmosphere and the moisture from the surface water at ground zero made the Pacific Test Area almost ideal for detonation detection and cloud tracking. The entire cloud (stem and upper cloud) was detected at a 200-mile range.

(C) The detectability of the radar equipment in the low humidity conditions of the Nevada area was not expected to compare with the results obtained in the Pacific area. The radar energy was scattered by water particles and by debris and dust particles thrown into the air by the burst. Since the upper cloud remained visible long after the radar indication was lost, the undetected cloud might have consisted of dust and water particles too small to reflect enough energy for radar detection. The small moisture content at the Nevada Test Site would partly contribute to the scatter of the radar energy---the moisture at the lower levels is forced to the higher, colder levels and condensed into larger particles. These droplets might have been large enough to reflect the radar energy from the cloud and as they grew, became heavy enough to counteract the lift of the burst and fell back toward the ground. The heat at the lower levels might have evaporated these particles.

CONCLUSIONS

(C) From radar data collected at the Nevada Test Site during Operation Plumbbob, it was concluded that:

(C) 1. The AN/CPS-9 radar set (9,300 Mc) was superior to both the AN/TPS-1D (1,320 Mc) and AN/FPS-6 (2,800 Mc) radar sets in detecting and tracking atomic explosions.

(C) 2. The radar echoes were reflections from dust and debris particles thrown into the air and from water droplets condensed by the explosion effects. (The large particles were of sufficient size to reflect detectable energy back toward the radar equipment. The small particles that remained suspended for long periods of time did not reflect sufficient energy for detection by the present receiving systems.)

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(C) 3. The AN/CPS-9 detected 14 of the 18 shots in which it was operational. On three of the eight shots, with equipment located at distances of 40 and 100 miles, sufficiently large particles did not rise above the elevation of an intervening mountain (6,000-7,000 feet). One shot (John) was an atomic warhead rocket, fired from an aircraft in flight, for which insufficient particles were available for reflection of radar signals. (At detonation time the radar antenna was not on target because of operating difficulties and it swept through the area at T + 2 minutes.)

(S) 4. The AN/CPS-9 detected a 1,500-pound detonation at a 15-mile range (the lowest yield detonation in this operation), a 5-kt detonation at a 40-mile range, and a 10-kt detonation at a 100-mile range. (Three observations were made at the 40-mile range---5, 10, and 40 kt---and five observations were made at the 100-mile range---.25, 2, 10, 15, and 40 kt.) For detection at longer ranges, the atomic cloud had to rise above the terrain elevation between the radar location and ground zero.

(C) 5. The AN/TPS-1D radar detected and tracked atomic clouds from two of the 21 shots, one at a range of 4.5 miles and the other at 7 miles. On a number of shots the detonation could be observed by the attenuation of the echo signals of targets beyond ground zero, but the cloud could not be located.

(C) 6. The AN/FPS-6 radar detected two of the four shots in which it participated at a site 30 miles from the Nevada Test Site where there were no intervening high mountains.

(C) 7. The AN/MFG-1 radar did not detect any clouds because of its low-power output, low-gain antenna, and low-sensitivity characteristics. This set might have observed the shock wave of two detonations on the auxiliary A-scope. The detonation was indicated by the attenuation of signals from targets beyond the range of ground zero.

(C) 8. Ground-zero location of an atomic explosion can be determined within the accuracies of the radar equipment provided sufficiently large particles are projected high enough to intersect the radar beam directly above ground zero.

(S) 9. The maximum cloud height as indicated by the RHI of the AN/CPS-9 was within 5 percent of the CAA measured value on 7 of 10 detonations. These detonations were at ranges from 4 to 40 miles and varied from 5- to 40-kt yields. Because four of the radar-measured heights indicated values higher than the CAA-measured heights, the use of radar equipment might be a means of accurately measuring cloud heights and cloud dimensions from ground-based equipments.

(S) 10. Detonation time as compared to radar-detection time will depend on the rate of cloud rise and terrain elevation between the radar

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location and ground zero. On direct line-of-site locations at the Nevada Test Site, approximately 3 seconds was required before detonations became clearly visible on the AN/CPS-9 RHI.

(S) 11. Within the range of yields and operating under the conditions of the Nevada tests, the cloud height measured by Radar Set AN/CPS-9 indicated the yield within a factor of approximately two on all detonations in which the entire cloud was observed.

(C) 12. The antenna-elevation sweep was too fast to allow the weaker cloud echoes to be indicated. The integration gained by slower sweeps and multiple-sweep photographs would improve the detectability of weak cloud echoes and allow measurements of cloud dimensions.

(C) 13. A correlation exists between rate of cloud rise as detected by radar and yield. The present data are inadequate to determine the yield correlation.

RECOMMENDATIONS

(C) 1. It is recommended that further radar detection and tracking of nuclear clouds be made at both the Pacific and the Nevada Test Areas to determine the following:

a. The maximum range at which the AN/CPS-9 can detect nuclear explosions of tactical-size detonations (all yields up to 100 kt) and large yield detonations (100 kt upward) under the humid conditions of the Pacific area and the dry conditions of the Nevada area.

b. The degree of accuracy at which the radar can measure the entire cloud dimensions under the atmospheric conditions of both test sites. (Adequate measurement of the entire dimensions of clouds should be made with a recording theodolite for a good comparison check with the radar equipment.)

c. The initial rate of cloud rise. (The elevation scale on the RHI must be expanded to allow the initial rate of rise to be indicated on the scope for accurate measurement in determining correlation of yield and radar echo.)

d. Whether the existence of fallout can be indicated by the intensity of the echo return and whether this intensity of the return from various portions of the cloud can be related with the measured fallout.

(C) 2. A study should be made of the effects of atmospheric conditions at detonation time on atomic-cloud characteristics.

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(C) 3. A method should be devised to enable the operator to determine by use of RHI the occurrence of an atomic explosion. The radar-scope display should indicate the shot location when a sudden echo appears on the scope.

ACKNOWLEDGMENTS

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APPENDIX I

EQUATION FOR COMPARISON OF RADAR EQUIPMENTS CHARACTERISTICS (U)

(U) The two areas for comparing radar equipments are:
1) The received signal power from a particular target, and 2) The sensitivity of the individual equipments. The received signal power indicates the amount of reflected signal received from the target, and the sensitivity of the equipment indicates the equipment's ability to distinguish the received signal in spite of inherent noise levels.

(U) The equation for the ratio of received signal power to receiver noise power is:

$$\frac{S}{N} = K \frac{PG\tau}{\lambda^2} \cdot \frac{\sqrt[3]{f}}{nB} \left(\frac{\tau}{1/\tau B} \right)^2$$

where: S = received signal power (watts)

N = receiver noise power (watts)

P = peak power output (Kw)

τ = radar pulse length (microseconds)

G = antenna gain

λ = wavelength (centimeters)

B = receiver IF bandwidth (Mc)

n = receiver noise figure

K = constant incorporating all other factors not dependent upon radar characteristics

f = pulse repetition frequencies (sec^{-1}).

(U) There are two assumptions: 1) That the target cloud consists of a uniform distribution of small particles and that this target cloud fills the beam and extends over a depth of at least one-half the pulse packet; and 2) That all radar equipments used are at the same range from the target.

(U) The above equation is not the same expression as that applicable to the detection of a point target.

APPENDIX I (CONTD.)

(U) The received signal-to-noise power ratio of the radar equipments used in Project 50.3 and comparison of each with Radar Set AN/CPS-9 are tabulated in Table 2 of this report. The higher the value of the received signal-to-noise power ratio, the greater the ability of the equipment to detect nuclear clouds.

APPENDIX II

COMMUNICATIONS FOR PART II, PROJECT 50.3, OPERATION PLUMBBOB (U)

(U) During the preparative stages of Part II, Project 50.3, considerable thought was given to the use of frequencies and equipment that would give reliable voice communication and teletype reception over a 24-hour period. Voice communication was necessary for coordination of the various radar equipments that would be located from one to two-hundred miles apart and for the teletype-facsimile reception of weather information. Owing to the range variation and the mountainous terrain, frequencies in the high-frequency (HF) range were desirable for long distances and those in the very-high-frequency (VHF) range were desirable for shorter distances. Therefore, requests for four HF fixed stations, one VHF fixed station, and six VHF mobile stations were forwarded to the Frequency Coordinator of Operation Plumbbob.

(U) After these frequencies were authorized, equipments were selected for the communication link and for establishing teletype information by landline and radio channels. Consideration was given to the possibility of: 1) Obtaining data on count down and on weather; 2) Combining with other project networks; and 3) Monitoring all frequencies from high frequency through very-high frequency that might be of value to Project 50.3.

(U) The communication control center, the nucleus of this operation, was located at the same site with Radar Set AN/CPS-9. This communication control center occupied one-half of the V-51 van that transported the AN/CPS-9 pedestal and antenna. In the van were: two workbenches, all necessary communication equipment, receivers for HF to VHF reception, the AN/TRC-22 base station for VHF, the VRC-6 for the VHF mobile station, the BC-610 and T-368 for HF transmission, the CV-115 frequency shift conversion, Model-28 teletype for weather copy, the TT-4 teletype for straight copy, the AN/TXC-1 facsimile, and complete test equipment for maintenance and repair of all communication equipment.

(U) During the first half of the test series, all radar sets were located close to one another, simplifying communication to and from the various equipment sites. There was considerable difficulty, however, in maintaining VHF communication between the base camp at Camp Desert Rock, Nevada, and the AN/GMD-1 site at Almo, Nevada, owing to the mountainous conditions of the forty-air-mile separation. Because of lack of space in the AN/GMD-1 van for installation of the HF transmitter and receiver, high frequency was not used. After continued efforts to use very-high frequency to the extent of installing special high-gain antennas, the 50.4-Mc frequency was abandoned and communication was accomplished by landline.

(U) Field phones EE-8 were used for communication among grouped radar sets; VHF radio link and landline were used for communication

APPENDIX II (CONT'D.)

between radar site and base camp. A walkie-talkie, furnished by the Department of Defense (DOD), was used throughout the series to enable Project 50.3 personnel to communicate directly with the DOD control center and to receive instructions during dry runs, and for use as an emergency link during the actual tests. This communication was supported by landlines supplied by the DOD and the Desert Rock operations. Count down was monitored on very-high frequency and on landline.

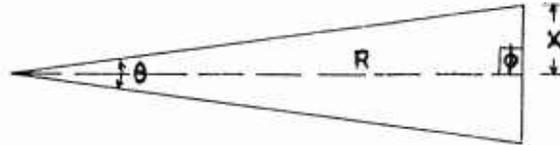
(U) While Project 50.3 was still in the preparative stage, plans were made for the fallout team to occupy the rear half of the V-51 van as this space would be vacant when the AN/CPS-9 was set up for operation. In this location the fallout team could receive weather data over teletype and facsimile equipment. However, on arrival at the Nevada Test Site, the team was located adjacent to the weather station where its facilities could be used, making it unnecessary for Project 50.3 to set up its own weather-data receiving station.

(U) During the second half of this operation when the radar equipment had to be moved to various locations, communication became more complex. The radars located within the test area were supported with VHF radio links mounted in weapons carriers. The AN/CPS-9 radar located off site used HF radio link to the base camp at Desert Rock.

(U) From experience gained in this operation, reliable communication links are important safety measures in addition to being necessary tactical equipment. In an operation of this size, preparedness for handling communication problems was invaluable in fulfilling the technical aspects such as synchronization of observations and exchange of technical information among the various operating sites.

APPENDIX III

DERIVATION OF BEAM WIDTH VERSUS RANGE EQUATION (U)



θ = beam width angle

R = range

X = $\frac{1}{2}$ beam width at R range

Since $R \gg X$, ϕ is assumed to be a right angle

$$\tan \frac{1}{2} \theta = \frac{X}{R}$$

$$X = R \tan \frac{1}{2} \theta$$

$$\text{Beam width at R range} = 2 R \tan \frac{1}{2} \theta.$$

| <u>Beam Width</u> | <u>Horizontal</u> | <u>Vertical</u> | <u>Pulse Width</u> |
|-------------------|-------------------|-----------------|--------------------|
| AN/CPS-9 | 1° | 1° | .5 & 5 μ sec |
| AN/TPS-10 | 4° | 12° | 2 |
| AN/MPG-1 | .55 | 3° | .25 |
| AN/APG-13 | 3° | 3° | 2 |
| AN/FPS-6 | 1° | 3° | 2 & 3 |

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APPENDIX IV

RANGE-HEIGHT-INDICATOR DATA OF SHOT FRANKLIN (U)

(C) Several photographs of the range-height indicator prior to time zero on Shot Franklin indicated double returns or echoes from the shot tower, as well as from all other areas having small cross sections. The double returns were about 0.5 miles apart, the stronger echo having the greater range. This appears to be due to frequency modulation in the magnetron output. The tower height as indicated by the radar equipment was about 2,500 feet. At the T / 2 seconds sweep, the tower target rose 1,000 feet and the cross section of the double image increased to the extent of almost merging into one large return. The image at T / 5 seconds had further merged and risen another 1,000 feet. Appearing directly above the area of each of the double tower images were spike returns extending 1,000 feet or more higher than the rest of the return. The height might have been greater, for the antenna sweep was stopped at this height over the target. At $7\frac{1}{2}$ seconds the main body of the image had thinned out, but the spikes remained up to at least 5,500 feet, the maximum antenna-scan height. At 10 seconds the main body of the return was again heavy and the spikes were up to at least 6,500 feet, which was the top of the increased antenna-elevation sweep.

(C) The results are shown in the table attached to this appendix entitled "Tabulation of Heights with Time for Shot Franklin."

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TABULATION OF HEIGHTS WITH TIME FOR SHOT FRANKLIN (U)
TABLE 1 (Appendix IV)

| Time T + Seconds | *Top of Spikes | Top of Main Echo | Remarks |
|---------------------|-------------------|---------------------|--|
| -Pre shot | ---- | 2500 ft. | Tower - two individual echoes, $\frac{1}{2}$ mile apart. |
| 2 | ---- | 3500 ft. | Main echo intense, almost merged. |
| 5 | 5500 ft. | 4500 ft. | Main echo further merged. |
| 7 $\frac{1}{2}$ | 5500 ft. | 4500 ft. | Main body less intense. |
| 10 | 6500 ft. | 4500 ft. | Main body again very intense. |
| 12 | 6500 ft. | 4500 ft. | Main body merged; spikes strong. |
| 15 | 6500 ft. | 4000 ft. | Separated images; spikes weak. |
| 17 | 6500 ft. | 4000 ft. | Separated images; spikes weak. |
| 19-25 | 7000 ft. | 4000 ft. | Separated images; spikes weak. |
| 27-36 | ---- | 4000 ft. + | Separated images; spikes no longer visible. |
| 38 | ---- | 4800 ft. | Separated images; spikes no longer visible. |
| 41-54 | ---- | 5000 ft. | Separated images; spikes no longer visible. |
| 56-59 | ---- | 5500 ft. | Stem and cloud separating. |
| 62-70 | ---- | 6000 ft. | Stem barely detectable immediately above ground clutter. |
| 73-90 | ---- | 7000 ft. | Top 2000 feet of cloud less dense. |
| 93 | ---- | 9000 ft. | 5000-9000 ft level spreading out. |
| 97-205 | ---- | 6000 ft. | 5000-6000 foot level of the return was all that was visible except for what was left of the tower. The return gradually faded out as it settled. Last frame was T + 3 minutes and 25 seconds, and the image on this frame was detectable only because of film integration. |

*Echo may have extended higher, because the antenna was not elevated to view greater heights. The spikes although undetected visually by the operator were revealed on film.

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