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OPERATION HARDTACK—PROJECT 6.6

X-Band Radar Determination of Nuclear-Cloud Parameters

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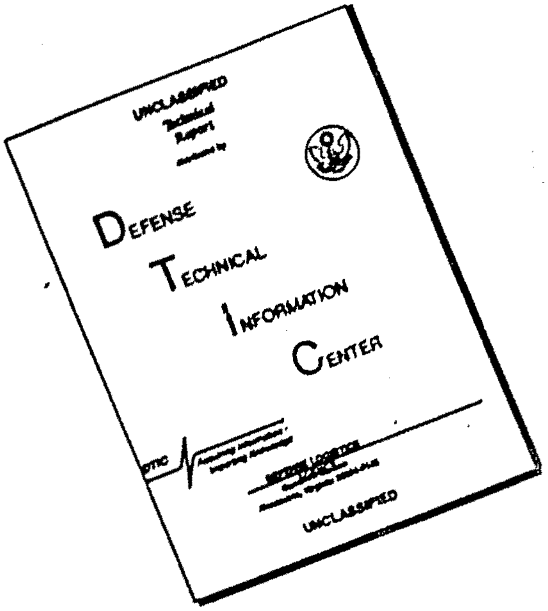

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The general objectives of this project were to make observations with weather Radar Set AN/CPS-9 in order to determine what characteristics and parameters of a nuclear detonation could be detected with X-band radar.

The specific objectives were to obtain data that would lead to the determination of the following information relative to the nuclear cloud: rate of rise, rate of horizontal growth, maximum height, maximum diameter, stabilized height, fallout pattern due to the initial cloud formation, and range and azimuth versus time.

As a result of this project, it was determined that the AN/CPS-9 radar is well suited for observations of surface or near-surface bursts, as would be expected from a comparison of its performance characteristics with those of other available radar sets.

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FOREWORD

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

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

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

OPERATION HARDTACK—PROJECT 6.6

X-BAND RADAR DETERMINATION of NUCLEAR-CLOUD PARAMETERS

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FOREWORD

This report presents the final results of one of the projects participating in the military-effect programs of Operation Hardtack. Overall information about this and the other military-effect projects can be obtained from ITR-1660, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussions of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

ABSTRACT

The general objectives of Project 6.6 were to make observations with weather Radar Set AN/CPS-9 in order to determine what characteristics and parameters of a nuclear detonation could be detected with X-band radar.

Equipment was located at Eniwetok, Rongelap, and Kwajalein during the EPG detonations, and at Johnston Island and Maui Island, T.H., for the high-altitude missile shots. The AN/CPS-9's were modified to give range-height-indicator scales of 150,000 and 300,000 feet in addition to the normal 50,000-foot height, and also to allow surveillance to ranges of about 400 miles. Data was reduced with the aid of a microfilm viewer and enlarged prints of film recordings.

The Shot Fir cloud was observed at a 201-mile range; this was the maximum detection range for Project 6.6. The longest period of observation was 4½ hours (Shot Koa). Data was obtained on the following cloud parameters: rate of rise, rate of growth, maximum height, maximum diameter, range, and azimuth. No significant returns were received from any of the high-altitude detonations.

For surface or near-surface bursts, the range of detection with Radar Set AN/CPS-9 is the line-of-sight distance to the resulting cloud, except under conditions of anomalous propagation. The duration of detection is four to six times as long in humid as in dry areas. The range, azimuth, and rate of vertical and horizontal development of nuclear clouds can be measured within the accuracies of the radar equipment. For high-altitude bursts, there are insufficient particles and electron densities to produce echoes on Radar Set AN/CPS-9.

It is recommended that similar studies be conducted during future operations with radar sets such as the AN/MPS-34, as well as longer-wave-length sets. Further studies should be made to correlate the observed radar image with various phenomena connected with nuclear detonations.

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Chapter 1

INTRODUCTION

1.1 OBJECTIVES

The general objectives of Project 6.6 were to make observations with weather Radar Set AN/CPS-9 in order to determine what characteristics and parameters of a nuclear detonation could be detected with X-band radar (see Table 1.1 for Radar Set AN/CPS-9 specifications).

The specific objectives were to obtain data that would lead to the determination of the following information relative to the nuclear cloud: rate of rise, rate of horizontal growth, maximum height, maximum diameter, stabilized height, fallout pattern due to the initial cloud formation, and range and azimuth versus time.

1.2 BACKGROUND

During Operation Greenhouse, observations were made with Radar Sets AN/APQ-24 installed in two B-50-D aircraft flying at 30,000 to 50,000 feet (Reference 1). Radar echoes from the immediate area of ground zero were recorded for 23 seconds during three of six attempts. The radar returns were in the shape of a horseshoe, and close coincidence to the leading edge of the shock wave was noted.

During Operation Redwing, photographic recordings were made of the radar echoes received from the stem and cloud of several detonations (Reference 2). The observations were made with Radar Set AN/CPS-9 used at the Eniwetok weather central and with the AN/SPS-8A height-finder radar aboard the USS Estes. Although adequate instrumentation was not available, sufficient time, range, and height data were obtained to show that the rate of growth and the maximum and stabilized cloud heights could be detected. For Shot Tewa, location of the resulting cloud and its movement were observed for 3 hours to a maximum range of 200 miles.

Becaus• . the interesting data obtained during Operation Redwing, Project 50.3 of Exercise Desert Rc · . VII and VIII fielded a radar observation experiment during Operation Plumbbob. Radar equipment was used in L, S, and X bands to collect data on low-yield detonations in an area of low humidity (Reference 3). The AN/CPS-9 radar, which produced the best results, detected a cloud from a at a range of 100 miles.

Project 6.6 participation in Operation Hardtack was designed to continue the study of radar detection of nuclear detonations with yields similar to those experienced at NTS; however, the locale at Eniwetok would be more humid than that at NTS.

In addition, the Operation Hardtack high-altitude events were of great interest because of the unknown effects of high-yield devices in the upper atmosphere.

1.3 THEORY

Although radar echoes can be received from a small area of discontinuity such as the shock wave resulting from a nuclear detonation, echoes reflected from a large number of particles scattered by the detonation reveal more information and give greater range to the observations. The echoes of interest to Project 6.6 were reflections from the particles composing the nuclear cloud, such as dust, debris, water droplets, and ice crystals.

TABLE 1.1 TECHNICAL CHARACTERISTICS OF THE AN/CPS-9 RADAR SET

A. GENERAL	
Range:	
Nominal maximum	250 statute miles
Minimum	1/2 mile
Accuracy of maximum range	2 percent
Determination	By interpretation of time difference measured between instant of transmission of the main pulse and arrival of the target echo signal
Resolution	246 feet (short pulse), 2,460 feet (long pulse)
Azimuth:	
Operational	Choice of 360° continuous rotation, 0°-60° sector scan, or manual control
Accuracy	1°
Determination	By synchronizing PPI sweeps with antenna rotation
Resolving power	Beam width approximately 1° between half-power points
Elevation:	
Operational	Choice of 0°-50° sector scan or manual control
Accuracy	1°
Determination	By synchronizing RHI sweep with antenna elevation
Resolving power	Beam width approximately 1° between half-power points
Installation requirements:	
Antenna tower	18-foot square platform at top to support [illegible] pounds plus wind loading
Tower base shelter	Weatherproof and heated; 8 feet square
Main operating position	Weatherproof and heated; 20 feet by 18 feet
Remote observation position	Weatherproof and heated; 8 feet square
Assembly time	80 hours by a crew of 4 trained men
B. TRANSMITTING SYSTEM	
Frequency	9,317 ± 87 Mc
Wave length	3.2 cm
Peak power	250 kilowatts minimum (short pulse), or 84.0 dbm
Average power	115 watts (short pulse), or 230 watts (long pulse)
Pulse repetition rates	931 pps on short pulse, or 186 pps on long pulse
Pulse widths	0.5 µsec (short pulse), or 5.0 µsec (long pulse)
Source of RF power	Magnetron (tube Type 6002)
C. RF SYSTEM	
Antenna reflector	Paraboloid, 7 3/4 feet in diameter
Reflector feed	Horn type
Transmission line	3-cm pressurized wave guide
Antenna beam width (horizontal and vertical)	Approximately 1° between half-power points
Attenuation of back and side lobes	20 db
Duplexing	TR tube (Type 5e63) and two ATR tubes (Type 6004)
D. RECEIVING SYSTEM	
Operating frequency	9,317 ± 87 Mc as established by transmitter magnetron
Nominal IF gain	93 db (wide band), 103 db (narrow band)
UHF oscillator	Klystron (tube Type 2K25) with AFC
UHF oscillator frequency	9,347 ± 8? Mc (operating frequency plus 30 Mc)
Mixers (signal and AFC)	Balanced crystal (1N23B)
Intermediate frequencies (signal and AFC)	30 Mc
Band widths	Approximately 8.0 Mc (short pulse), and 0.8 Mc (long pulse)
Sensitivity time control	Provides 20 db reduction in gain at 10 miles, with linear increase in gain from 10 to 100 miles
E. SYNCHRONIZING AND INDICATING SYSTEM	
1. Pulse Generator O-61/CPS-9	
Range standards	Crystal-controlled blocking oscillators (1, 5, 25, 100, and 500 statute miles)
System triggers	100 statute mile range standard (short pulse), and 500 statute mile range standard (long pulse)
Number of tubes	34

TABLE 1.1 CONTINUED

2. Indicator Control C-513/CPS-9	
Presentation	Direct reading range-in-miles counter (statute miles)
Range measuring device	Variable range ring applied to PPI, RHI, and A/R scopes
Number of tubes	13
3. Range and Height Indicator IP-28/CPS-9	
Presentation	Standard RHI, 7-inch CRT
Sweep ranges	10, 25, 50, 75 statute miles short or long pulse; 100 statute miles long pulse only
Height scale	0 to 50,000 feet
Elevation scale	−5° to +90° around circumference of CRT, cursor indicates antenna position
Number of tubes	23
4. Range Indicator IP-26/CPS-9	
Presentation	A/R scope, 5-inch CRT
Sweep ranges	5, 20 statute miles R-type sweep; 75, 400 statute miles A-type sweep
Range determination	Fixed and variable range markers on sweep
Number of tubes	15
5. Range-Azimuth Indicator IP-24/CPS-9	
Presentation	Standard PPI, 7-inch CRT
Sweep ranges	25, 75 statute miles short pulse; 25, 75, 200, 400 statute miles long pulse; variable ranges also available, with continuous control from 25 to 400 statute miles
Range determination	Fixed and variable range rings on CRT
Azimuth scale	0°-360° around circumference of CRT; cursor for reading target azimuth
Elevation scale	−5° to +65° around circumference of CRT; flasher shows antenna elevation setting
Number of tubes	14
6. Plan Indicator IP-222/CPS-9	
Presentation	Standard or off-center PPI, 7-inch CRT
Off-centering	Up to two radii in either direction along cursor
Sweep ranges	25, 75 statute miles short pulse; 25, 75, 200, 400 statute miles long pulse; variable ranges also available with continuous control from 25 to 400 statute miles
Range determination	Fixed and variable range rings on CRT
Azimuth scale	0°-360° around circumference of CRT; cursor for reading target azimuth
Elevation scale	−5° to +65° around circumference of CRT; flasher shows antenna elevation setting
Number of tubes	18
7. Azimuth and Range Indicator IP-25/CPS-9	
Presentation	Standard PPI, 12-inch CRT
Sweep ranges	25, 75 statute miles short or long pulse; 200, 400 statute miles long pulse only
Range determination	Fixed and variable range rings on CRT
Azimuth determination	0°-360° azimuth scale around circumference of CRT with cursor for reading target azimuth
Elevation determination	−5° to +90° elevation scale around circumference of CRT with flasher for reading antenna elevation setting
Number of tubes	27
F. ANTENNA POSITIONING SYSTEM	
Azimuth:	
Drive system	Servo-controlled hydraulic motor
Types of operation	Continuous rotation, sector scan, or manual control
Continuous rotation speed	5 rpm ± $^1/_4$ rpm
Position indication	PPI sweeps indicate antenna position on azimuth dials
Elevation:	
Drive system	Servo-controlled hydraulic motor
Types of operation	Sector scan (when stopped in azimuth), or manual control
Position indication	Pointer on RHI scope elevation dial, optional flasher on PPI scope elevation dials

The strength of the signal returned to the radar by a single particle is determined by the radar scattering cross section, which is a measure of the amount of power scattered in a backward direction as compared with the amount of power falling on the particle. This scattering cross section depends on the size of the particle and the dielectric characteristics of the material. Of these two factors, the size of the particle is of greater importance.

The scattering cross section of a spherical particle is proportional to the sixth power of the drop diameter; thus, the scattering cross section of a drop of water 2.0 mm in diameter is equivalent to that of 4,096 drops of water that are 0.5 mm in diameter. Therefore, nuclear clouds that contain a number of large particles give a much stronger return than clouds with relatively small particles.

The strength of the signal returned from a cloud, which is composed of many particles, is a function of the radar reflectivity and the volume of the atmosphere being sampled. The radar reflectivity per unit volume of nuclear cloud is the sum of the scattering cross sections of all the particles in that volume. At any instant, the radar set samples a volume of the atmosphere that is determined by the cross section of the radar beam and one-half the pulse length. Since the radar cross section of small spherical targets is usually directly proportional to the fourth power of the frequency, higher-frequency radars (X and K bands), should give the best results for particle detection. In addition, if there is sufficient moisture available to form water droplets or ice crystals, the physical characteristics of the resulting cloud will be more sharply defined by radar observations.

Of all the radar equipments available at the present time, Radar Set AN/CPS-9 is the one best suited for obtaining reflections from nuclear clouds.

Chapter 2
PROCEDURE

2.1 SHOT PARTICIPATION

The nature of the numerous characteristics and parameters included as objectives required data from shots of various yields and detonation environments. Both surface and high-altitude shots, with yields varying from about were studied (Table 2.1). Several shots of similar yields were observed for repetition of data.

The radar equipment at Kwajalein operated satisfactorily up to and including Shot Yucca. This station did not participate in any other shot because of a defective hydraulic antenna-positioning system that had to be returned to the manufacturer for necessary repairs and overhaul. The Rongelap station operated satisfactorily until 17 May 1958, when it was dismantled for transfer to Johnston Island for the high-altitude shots. The Eniwetok station recorded data on all events up to 27 May 1958, with the exception of Shot Wahoo.

2.2 INSTRUMENTATION

2.2.1 Installation. Radar Set AN/CPS-9, a high-powered weather radar set, was used at Eniwetok, Rongelap, and Kwajalein. For the high-altitude shots, Teak and Orange, the equipments were relocated at Johnston Island and at Maui, T.H. (Figures 2.1 and 2.2).

Equipment at Kwajalein and Rongelap was identical in all respects. The operating console was mounted in a V-51 (28-foot) van with a small photographic darkroom. A second V-51 van was used as the communications, repair-shop and logistics van. The radar antenna, with its pedestal that included the receivers, transmitter, and associated test equipment, was mounted on a 2½-ton, 6 by 6 cargo truck. The Rongelap equipment was grouped together as shown in Figures 2.3 and 2.4, and located on the western shore of the island. Likewise, the Kwajalein equipment was grouped together and located near the northwestern shore of the island, at a height of approximately 20 feet. On Fred Island, Eniwetok, the existing fixed-station radar equipment of the Air Weather Service was used by Project 6.6 for radar observations of the shots. An inter-atoll voice-communications network was operated to synchronize data recording and to discuss any technical difficulties that developed.

2.2.2 Modification. All AN/CPS-9 radar sets were modified to give range-height-indicator (RHI) scales of 150,000 and 300,000 feet in addition to the normal 50,000-foot height. The sets were also modified to allow surveillance to ranges of approximately 400 miles on the RHI scope, depending on the relation of the radar to the expected path of the cloud. Watches with sweep-second hands were used on all scope recordings. An azimuth indicator was added to the RHI data-recording equipment, and a group of lights was added to the A-scope recording setup to indicate the elevation angle of the antenna.

Each radar set had a special remote plan-position-indicator (PPI) unit that was used to collect radar weather data. This proved to be a valuable aid in evaluating weather conditions in the EPG area. Each set was equipped with recording cameras on the RHI scope, A scope, and off-center-PPI and remote-PPI scopes.

2.2.3 Operation. The mode of operation of each AN/CPS-9 varied depending on the yield, location, and type of shot (surface or high altitude).

When it was anticipated that vertical cross-section information (such as for high yields at distances up to 250 miles or low yields at ranges up to 80 miles) could be gained by observing the RHI scope, this scope was recorded with simultaneous A-scope recordings. This method gave rate of cloud development cloud homogeneity.

When the cloud stabilized, PPI sweeps were made at various elevation angles. This data made available the volume and a three-dimensional picture of the cloud as seen by the radar. Alternating RHI and PPI recording programs were continued at a sufficient rate to record significant changes until 15 minutes after the returns were no longer visible on any scopes (RHI, PPI, or A).

When the range was great, as for Rongelap station observations of shots at Eniwetok or when low-yield shots at Bikini were to be viewed by the Eniwetok station, the radar set recorded sector-scan PPI data at the lowest elevation angle possible without clutter in the burst area. Upon detection of the cloud, the elevation angle was raised in successive sweeps to determine

TABLE 2.1 SHOT PARTICIPATION AND YIELD

Date	Code Name	Yield (Approx. Max.)	Remarks	Eniwetok	Rongelap	Kwajalein
28 April 1958	Yucca		Free balloon, altitude 90,000 ft Boxer launched	X	X	X
6 May 1958	Cactus	17 kt	Surface, 120 degree concrete shield	X	X	
12 May 1958	Fir		Barge, crater, no shield	X	X	
12 May 1958	Butternut		Surface, 120 degree concrete shield	X	X	
13 May 1958	Koa	1.4 Mt	Surface, water tank shield 10 ft water	X	X	
16 May 1958	Wahoo		500 ft below surface in 3,200 ft of water		X	
21 May 1958	Holly		Pinex barge, 180 degree concrete shield	X		
26 May 1958	Yellowwood		Barge, 180 degree concrete shield	X		
27 May 1958	Magnolia		Pinex barge, 180 degree concrete shield	X		
31 July 1958	Teak		Burst altitude, 250,000 ft via Redstone	Johnston Island and Maui Island		
11 August 1958	Orange		Burst altitude, 125,000 ft via Redstone	Johnston Island and Maui Island		

X Denotes participation

whether sufficient height had been obtained to give valuable RHI recordings. When such data was available, the program of alternating RHI and PPI recordings was instituted.

The azimuth bearing for RHI scanning was visually sighted by a theodolite operator when the cloud itself could be sighted. When such sighting was not possible, the azimuth angle was obtained by periodical PPI sector scanning.

For Shot Yucca, the Eniwetok station used an X-band corner reflector attached to the balloon to locate the device before detonation. The Rongelap station operated its radar in azimuth sector scan at zero-degree elevation at detonation time, because this station was located at too great a range to track the Shot Yucca corner reflector.

For the high-altitude rocket events, the antennas at Johnston Island and at Maui, T.H., were oriented on the target area at detonation time; photographic records were made of the A scope to detect any signal that might be returned from the target area.

Figure 2.1 Johnston Island installation as viewed from the aircraft control tower. The southwest and southeast entrances to Bunker 405 are on the left and right, respectively, of the V-51 van that supports the antenna.

Figure 2.2 Johnston Island installation as viewed from the southeast entrance of Bunker 405, with the antenna oriented at the target location for Shot Orange.

2.2.4 Photography. All radar scopes, except the A scope, were photographed at the rate of one exposure per sweep of the antenna, either vertical or horizontal. The A scope was photographed at 16 frames/sec during the RHI sweep, and the remote-PPI scope was photographed with 1-minute exposures.

Figure 2.3 Rongelap installation, showing grouping of equipment.

All photographic processing was done at Eniwetok and Johnston Island, with the exception of the developing of test strips of film to check out the equipment at Rongelap and Kwajalein.

2.2.5 Calibration. The radar antenna required leveling and orientation at the time of installation. Leveling was accomplished by observing the built-in liquid levels on the pedestal as the

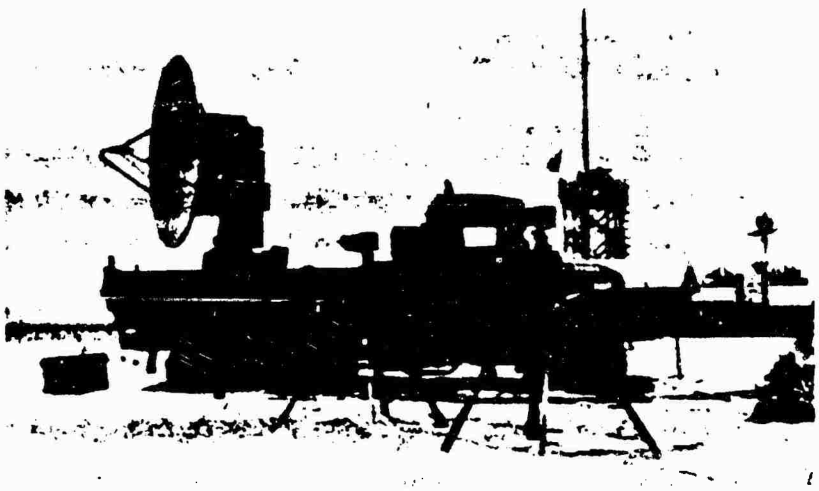

Figure 2.4 Rongelap installation, showing close-up of antenna and camera equipment.

adjustment screws were manipulated. The leveling was checked before and after each shot. The azimuth scale was set with the aid of a magnetic compass corrected to determine true north. This adjustment was accomplished by comparing the bearing of an object sighted with a compass with that indicated on the PPI scope by the same object.

Before and after each observation, the power output, sensitivity, and frequency of the AN/CPS-9 were measured. The remainder of the radar-set calibration was accomplished in accordance with the operating manual.

WWVH radio time signals were used to synchronize the watches on all scopes when the official countdown was not available.

<u>2.2.6 Data Recording and Reduction.</u> All radar-scope presentations were photographed with time indications that were readable to ± $\frac{1}{2}$ second. A data card containing the location, event, and date was attached to the face of each of the radar scopes. Azimuth and elevation angles were accurate to the nearest degree, with the exception of the set at Eniwetok. This set was in error by 4 degrees because of a corroded wave-guide positioning assembly. This same condition sometimes caused multiple echoes to appear on the radar scopes. Insufficient time was available before the scheduled shots to obtain the replacement parts to correct this condition. The radar sets were accurate in range to ± $\frac{1}{2}$ mile.

The data was reduced with a microfilm viewer and enlarged prints of the film recordings. Specific data required to plot or calculate various parameters was scaled from the photographs.

Chapter 3
RESULTS

Positive data was obtained to allow the determination of the following parameters of the nuclear cloud for some of the surface shots: rate of rise versus time, rate of horizontal growth versus time, maximum height, maximum diameter, stabilized height, area covered by the nuclear clouds during radar detectability, and range and azimuth versus time.

3.1 MAXIMUM RANGE OF CLOUD DETECTION

Maximum range of detection occurred when the Eniwetok station observed Shot Fir (detonated at Bikini) at a range of 201 statute miles. The radar echo was first observed visually at H + 2 minutes. However, the cloud was kept under surveillance for only 20 minutes, since the Eniwetok station had also planned to make observations of Shot Butternut, which was detonated at Eniwetok 25 minutes after Shot Fir. Figure 3.1 illustrates the Shot Fir cloud, showing its location, growth, and movement.

3.2 DURATION OF DETECTION

The longest period of observation was $4\frac{1}{2}$ hours (Shot Koa). Echoes from the vicinity of ground zero were detected for $1\frac{1}{2}$ hours. A portion of the cloud separated from the main stem and was detected approximately 90 miles from the radar station and 90 degrees from the ground-zero bearing. Shot Fir, was tracked for a period of 40 minutes by the Rongelap station, located 115 miles from ground zero.

The events, Shots Butternut, Cactus, and Magnolia, were observed and tracked by the Eniwetok station for periods of $1\frac{1}{4}$ to $1\frac{1}{2}$ hours.

3.3 CLOUD PARAMETERS

During the first 6 minutes of Shot Butternut, the radar antenna was sector-scanned in azimuth at various elevation angles in order to measure the rate of growth through a horizontal section of its cloud stem. In Figure 3.2, the horizontal cross section at various times indicates the increase in area during the early stages of cloud development.

Following the horizontal-cross-section observation of this event, the vertical cross section was recorded. From Figure 3.3, which was made at 2-minute intervals, considerable difference was observed in the parameters of the mushroom, thus indicating extreme turbulence in this section of the cloud. Such rapid changes in cloud structures are seldom detected in weather clouds.

The rate of vertical growth of Shot Koa was recorded with the RHI camera (Figure 3.4). The cloud reached a maximum height of 72,000 feet in 5 minutes. The rate of rise versus time for Shot Koa is shown in Figure 3.5. This data was calculated from photographic records. The maximum rate of rise was 66,000 ft/min during the first 10 seconds of cloud development.

Figure 3.6 shows a comparison of the stabilized cloud heights of two shots of different yields, Shots Tewa and Koa. Shot Tewa (5 Mt) was detonated during Operation Redwing (Reference 2). The two clouds stabilized in the same period of time after detonation but at different heights; the Shot Tewa cloud stabilized 12,000 feet higher than that of Shot Koa. Also, the Shot Koa cloud reached its maximum height about 1 minute earlier than that of Shot Tewa. A maximum height of 99,000 feet was reached by the Shot Tewa cloud as compared to a 72,000-foot maximum for the Shot Koa cloud.

The cloud diameter versus time at constant heights for Shot Koa is shown in Figure 3.7. A

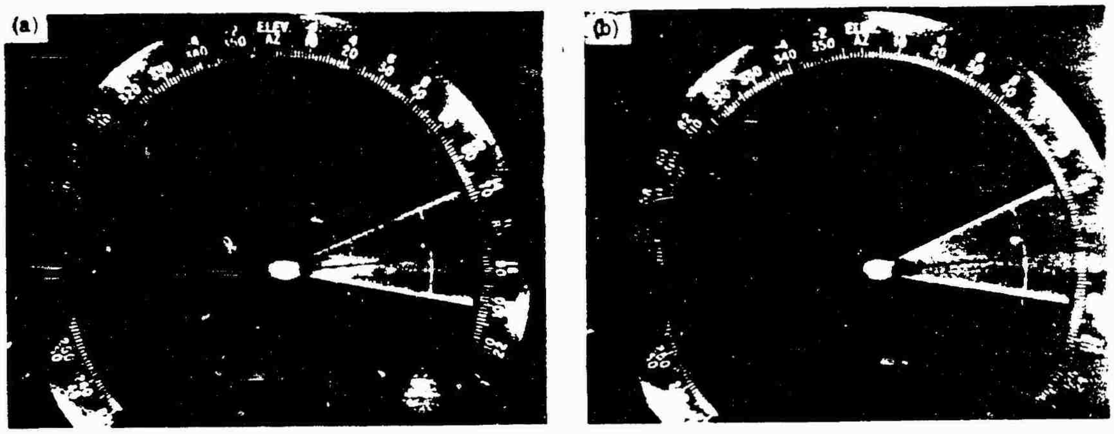

Figure 3.1 PPI presentations, Eniwetok, Shot Fir (detonated at Bikini). Range marker, 210 miles; target, 201 miles and 81-degree azimuth. Photo (a) was taken at H + 6 minutes, 25 seconds; photo (b) was taken at H + 11 minutes, 55 seconds.

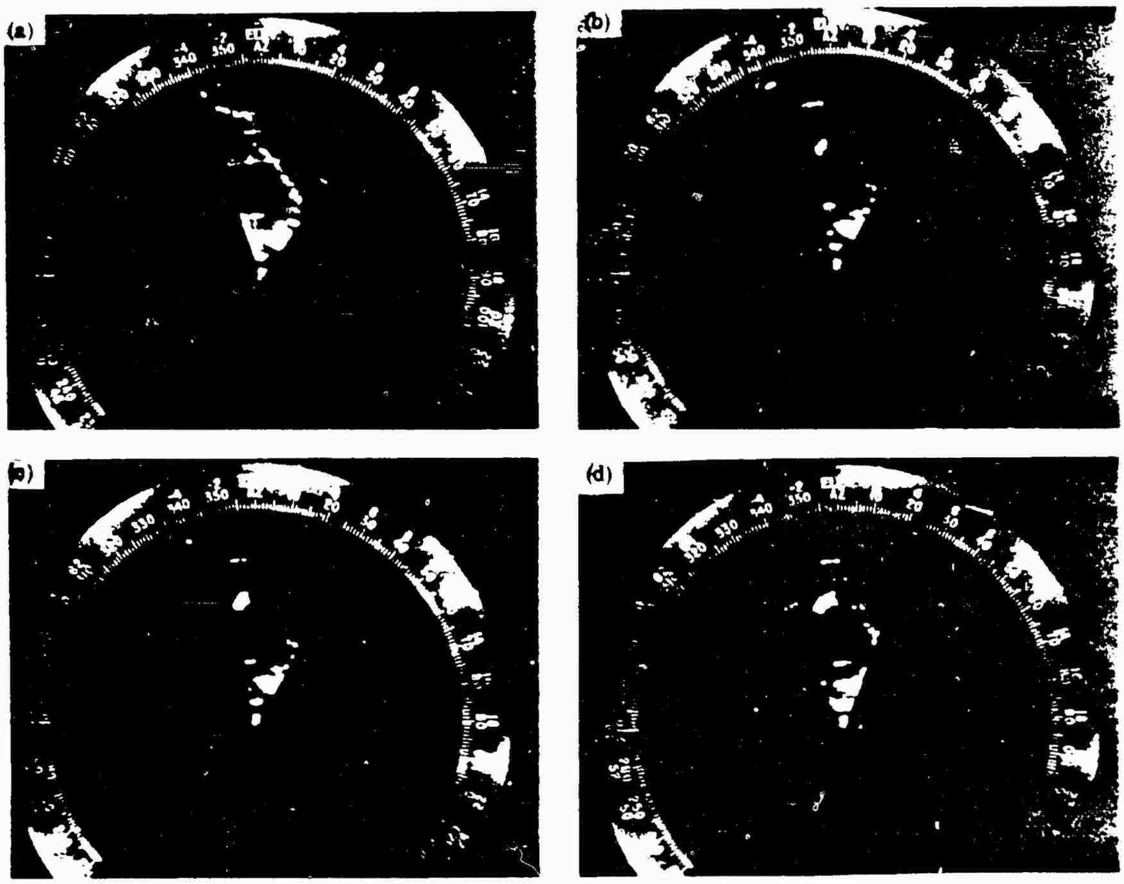

Figure 3.2 PPI presentations, Eniwetok, Shot Butternut. Range markers, 5-mile intervals; target, 15 miles and 354-degree azimuth. Photos (a) through (d) were taken at H + 5, 6, 7, and 9 minutes, respectively.

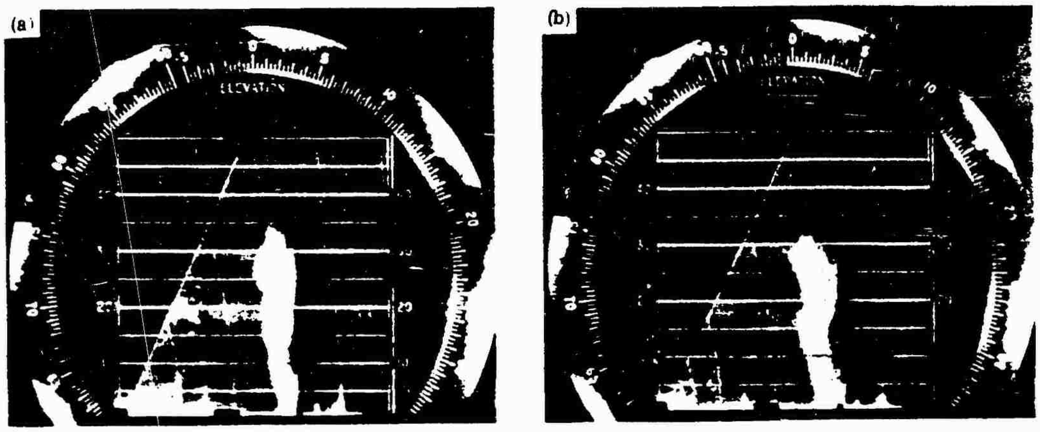

Figure 3.3 RHI presentations, Eniwetok, Shot Butternut. Range markers, 5-mile intervals; height values, thousand-foot levels; target, 15 miles. Photo (a) was taken at H + 7 minutes; photo (b) was taken at H + 9 minutes.

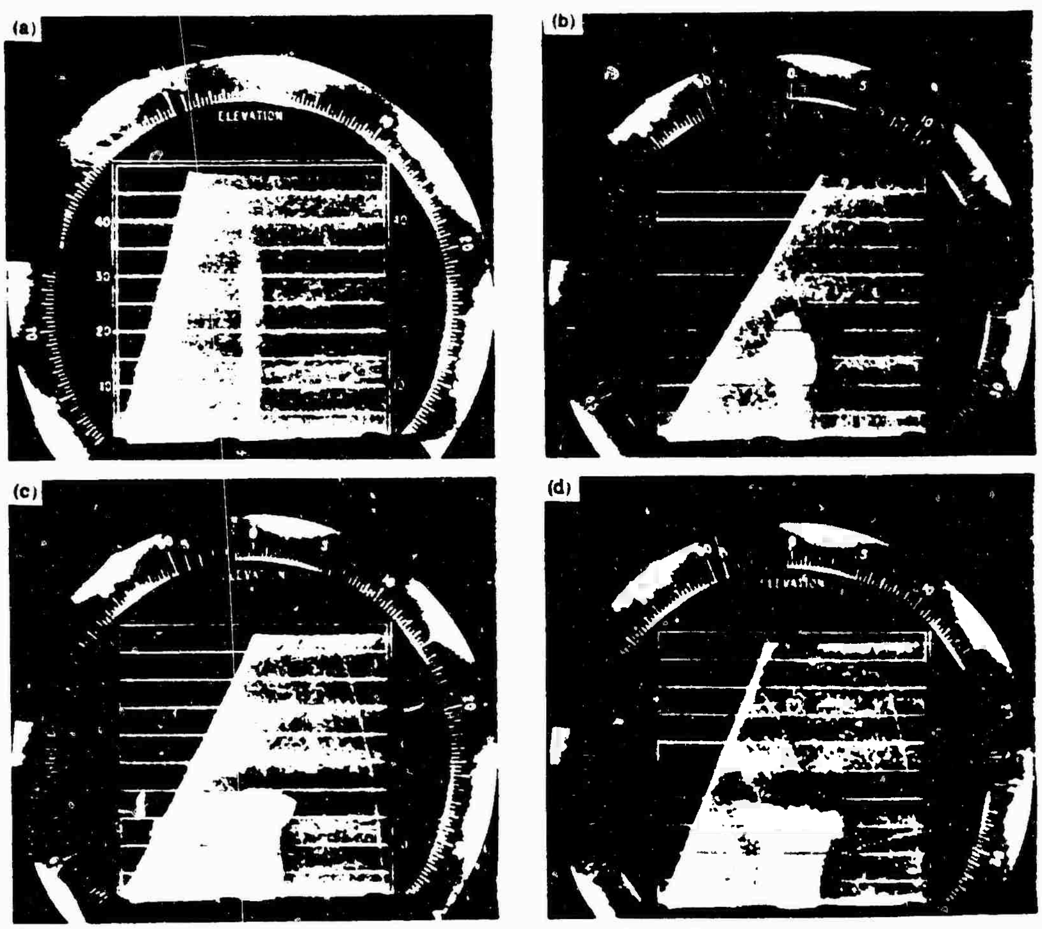

Figure 3.4 RHI presentations, Eniwetok, Shot Koa. Range markers, 5-mile intervals; height scale on photos (b), (c), and (d) is three times the indicated 10,000-foot levels. Photos (a) through (d) were taken at H + 1 minute and 45 seconds, 5 minutes, 8 minutes, and 17 minutes, respectively.

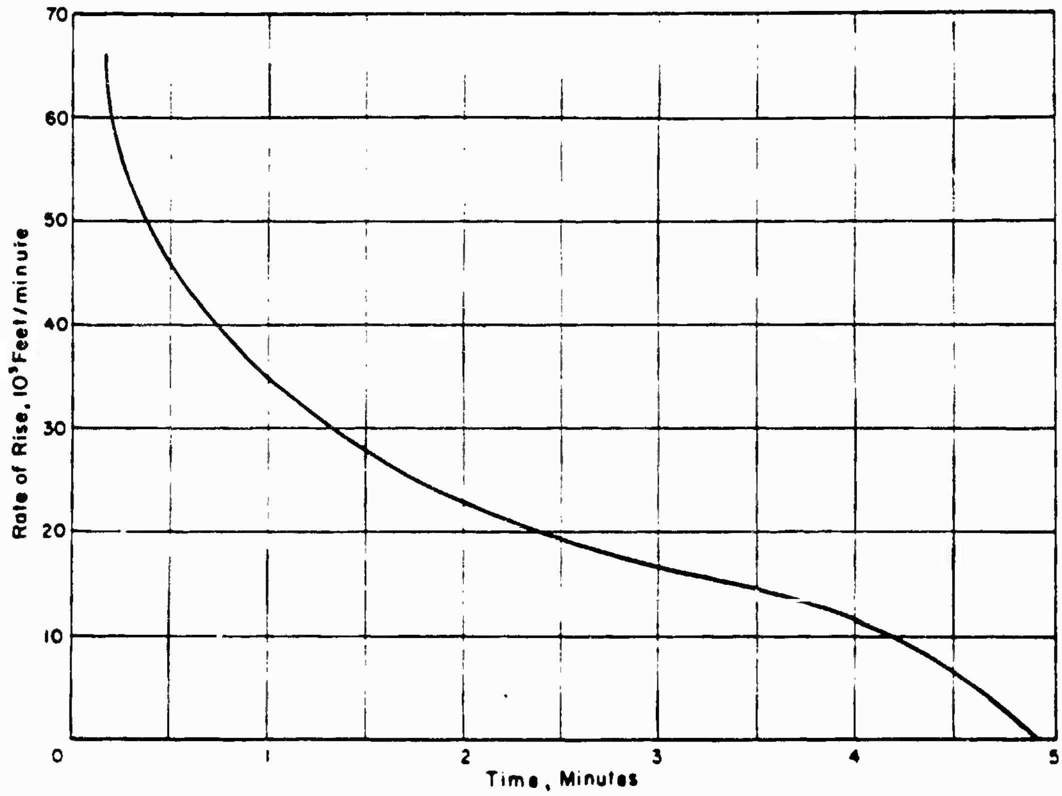

Figure 3.5 Rate of rise versus time, Shot Koa.

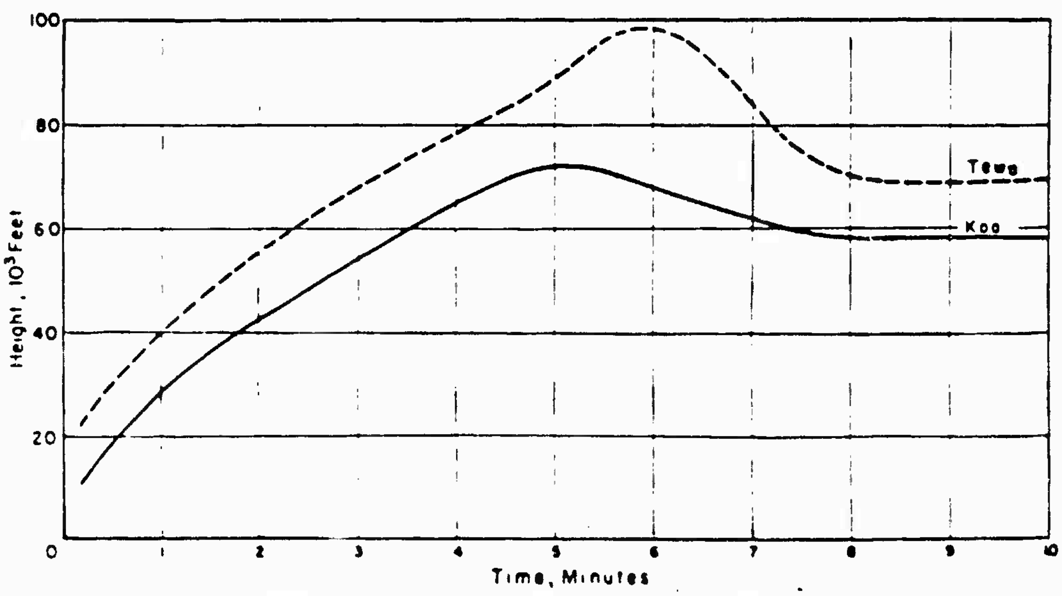

Figure 3.6 Comparison of stabilized height versus time, Shots Koa and Tewa.

maximum cloud diameter of 19 miles was reached at the 50,000-foot level. The PPI recordings shown in Figure 3.8, which were made at various elevation angles, give the cross-sectional area at various heights through the cloud. As indicated in Figure 3.8f, the periphery of the cloud top was irregular. Figure 3.8a further shows that the early stages of the stem cloud are not always circular, as it is sometimes assumed, but can be distorted by wind shear. The echo received from Shot Butternut (Figure 3.3) also shows considerable elongation of the stem cloud to the northeast.

Figures 3.9 through Figure 3.13 show the area covered by the nuclear clouds of Shots Koa, Butternut, Yellowwood, Magnolia, and Cactus. These patterns cover the period of time during which the different clouds were under radar observation. The data for these figures was reduced from the PPI recordings.

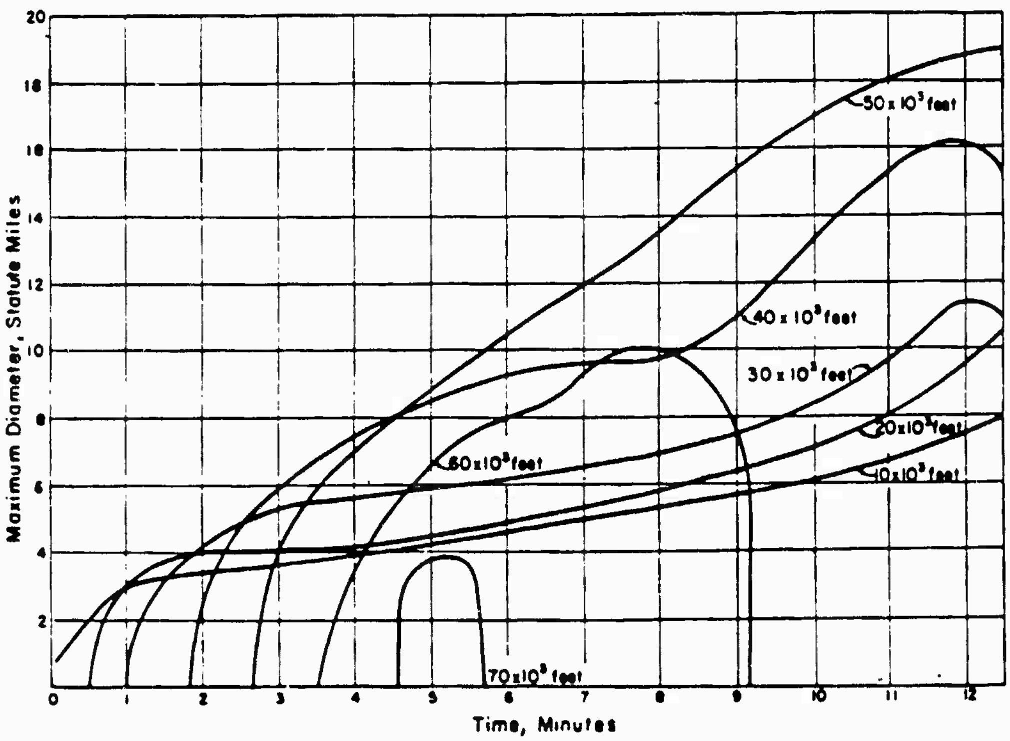

Figure 3.7 Maximum diameter at constant heights versus time, Shot Koa.

3.4 HIGH-ALTITUDE EVENTS

3.4.1 Shot Yucca. This shot, which was balloon-borne and detonated at 90,000 feet, gave no radar return at either the Rongelap or the Eniwetok stations. The Eniwetok station was positively on the target at time zero at a range of 100 miles, as indicated by the tracking of the Shot Yucca X-band corner reflector, which was under radar surveillance for 3½ hours prior to time zero. The reflector target presented intermittent echoes because of the slow rotation of the reflector about a vertical axis, which caused the echoes to fade in and out; however, the slow horizontal movement of the target enabled reliable tracking. At H − 30 seconds, the echo from the corner reflector faded out; at shot time, no signal was received by the radar equipment.

3.4.2 Shot Teak. This shot, which was detonated at 250,000 feet, was not detected by the Johnston Island station. Because of a 5¼-degree deviation of the actual rocket path from the predicted path, the center of the detonation was approximately 5 miles outside the antenna beam

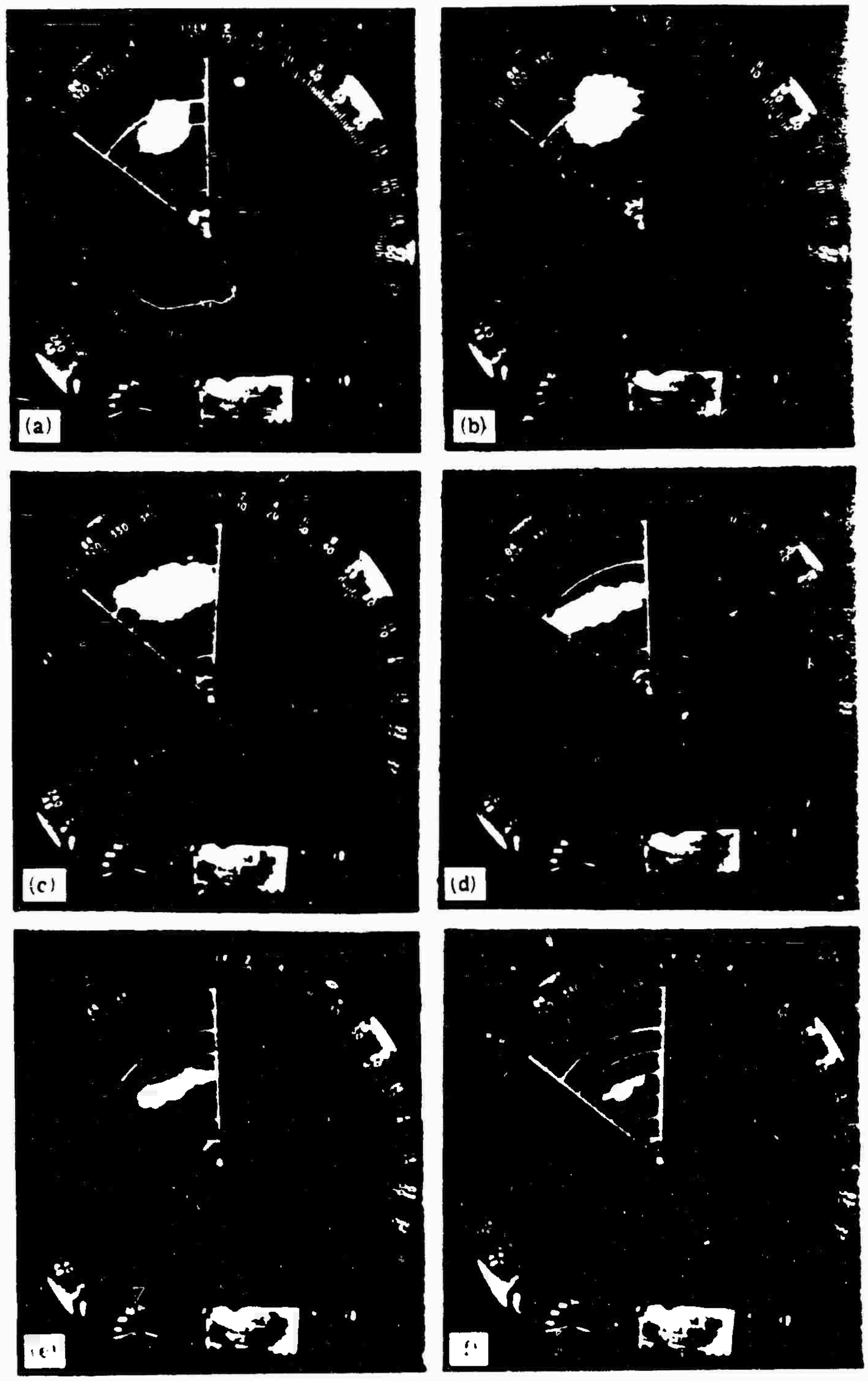

Figure 3.8 PPI presentations, Eniwetok, Shot Koa. Range markers are at 5-mile intervals. Photos (a) through (c) were recorded at angles of 10 to 20 degrees in 5-degree steps, and (d) through (f) at 25 to 35 degrees in 5-degree steps.

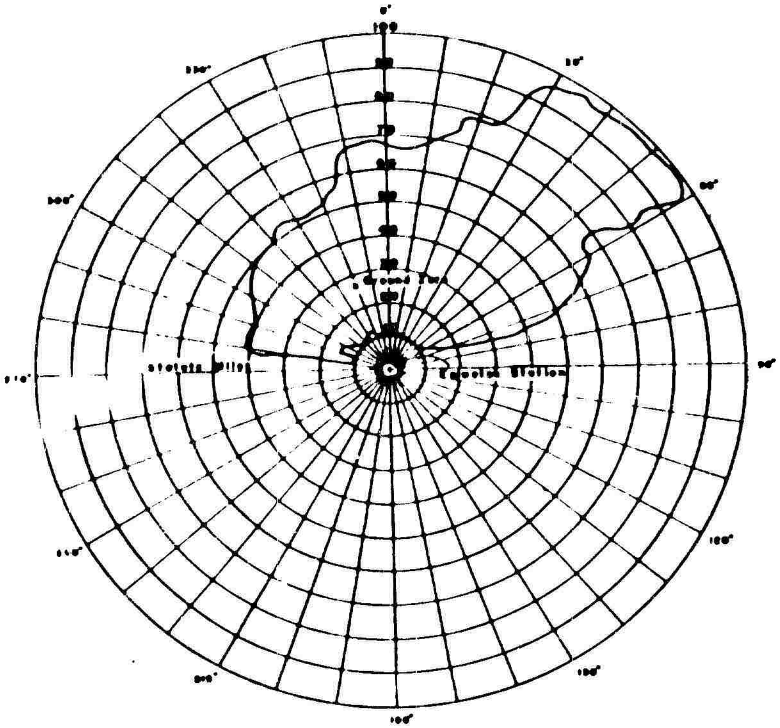

Figure 3.9 Area covered by Shot Koa cloud during time of radar detectability.

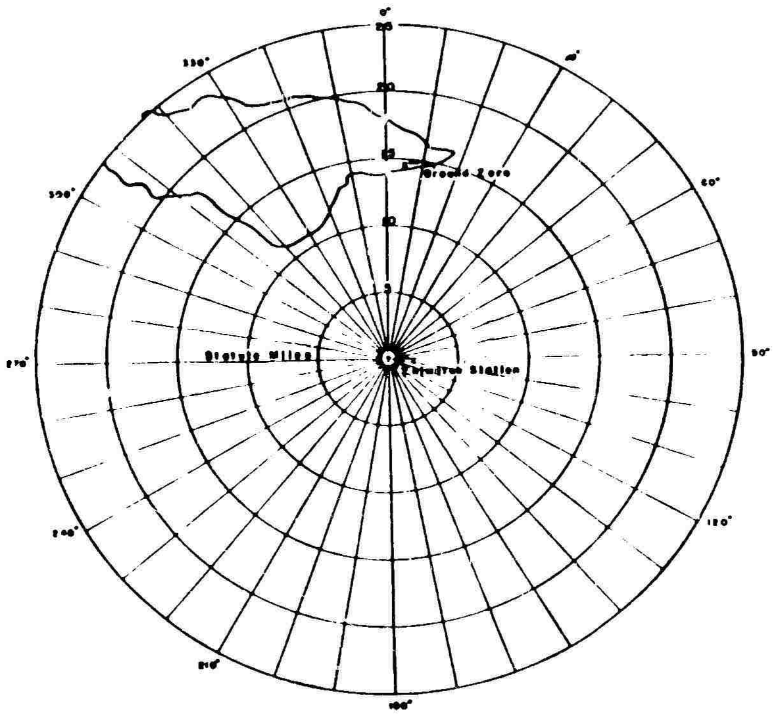

Figure 3.10 Area covered by Shot Butternut cloud during time of radar detectability.

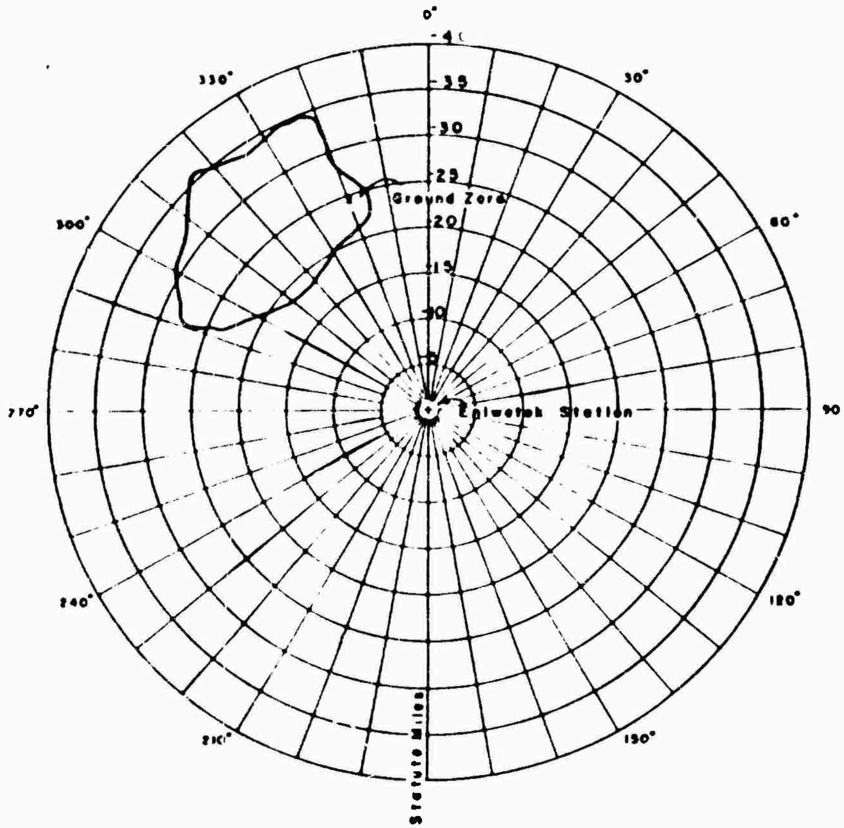

Figure 3.11 Area covered by Shot Yellowwood cloud during time of radar detectability.

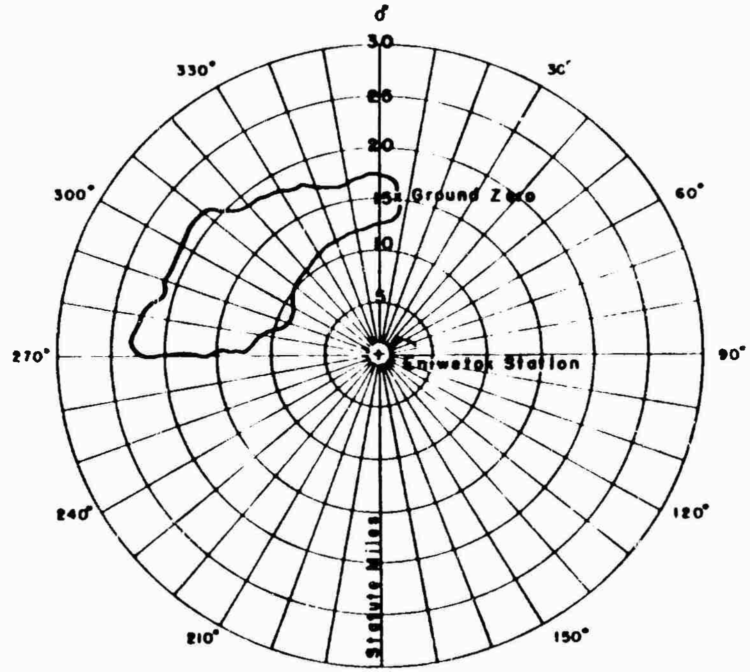

Figure 3.12 Area covered by Shot Magnolia cloud during time of radar detectability.

which had a span of only 1 mile at the 50-mile target range. In addition to not being on target, the radar set ceased operating at H + 1 second. Since the time synchronism was correct to the nearest second, it is not certain whether the radar set was actually in operation at shot time.

This shot was monitored both visually and by radar from the Maui station; however, no radar returns were received.

3.4.3 Shot Orange. This shot, which was detonated at 125,000 feet, gave an echo at shot time that was observed by two operators viewing the A scope. The echo, which did not saturate the radar receiver, persisted for less than a second at a 35-mile range, which was nearly the actual slant range to the target area. The appearance of this echo was attributed to the Redstone missile

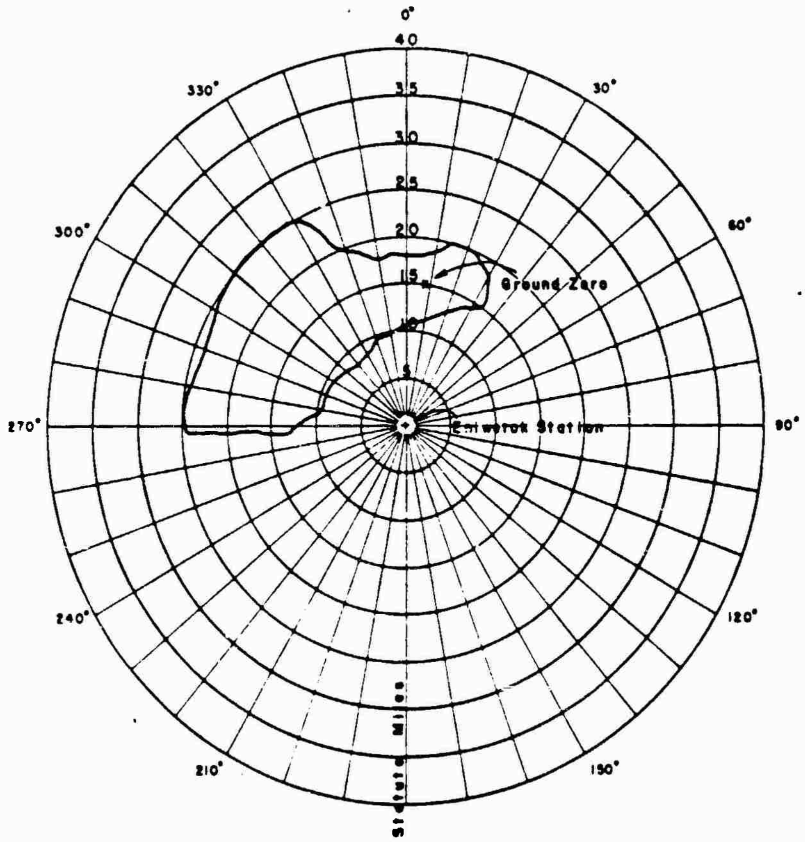

Figure 3.13 Area covered by Shot Cactus cloud during time of radar detectability.

as it approached the target area. No further radar echoes were received from the burst area.

A target first appeared as a point target at 23:45:08 hours, at a short range of 5 miles, an azimuth of 172 degrees, and a height of approximately 4.9 miles. This target began to fade, and at 23:47:33 it started to reintensify at the same slant range but at a slightly higher altitude. At 23:47:59, two targets were observed, the one described above, and an oval target centered about an azimuth of 145 degrees and a range of $7\frac{1}{2}$ miles. Thirty-four seconds later the second target had disappeared and the first echo had increased in size, slant range, and intensity. This target was centered about an azimuth of 170 degrees. At this time the slant range was 7 miles. Eleven seconds later, the echo began to decrease in intensity, increase in size, and move at a more or less constant slant range of 7 miles to an azimuth of 145 degrees. The elevation of the antenna for the above observations began at 80 degrees and was progressively increased to 86 degrees.

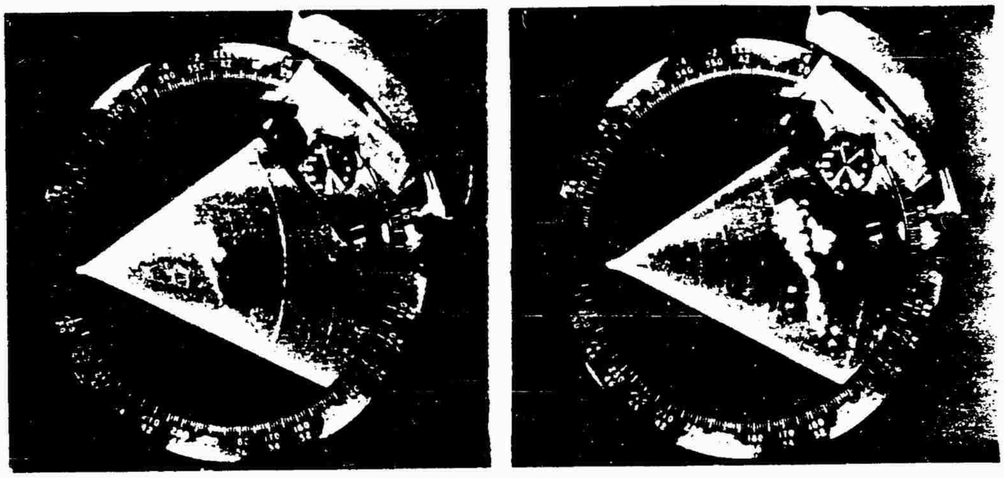

Figure 3.14 Cloud cover to the east of Johnston Island prior to zero time, Shot Orange

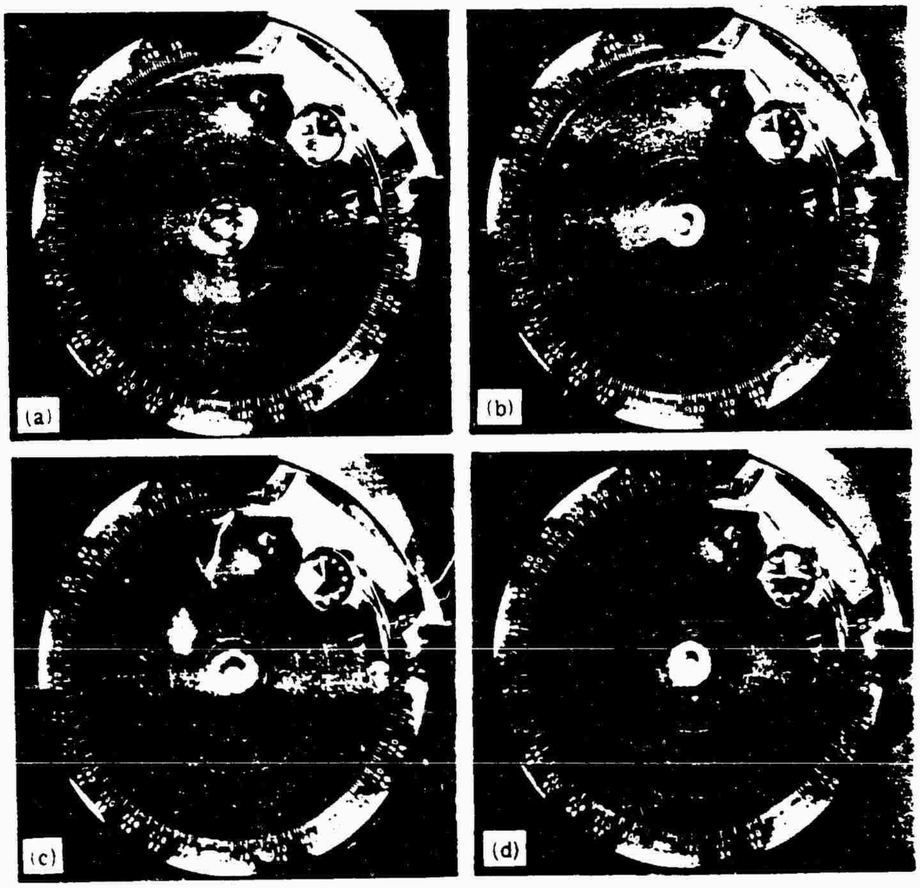

Figure 3.15 PPI presentations of Shot Orange target area, Johnston Island.

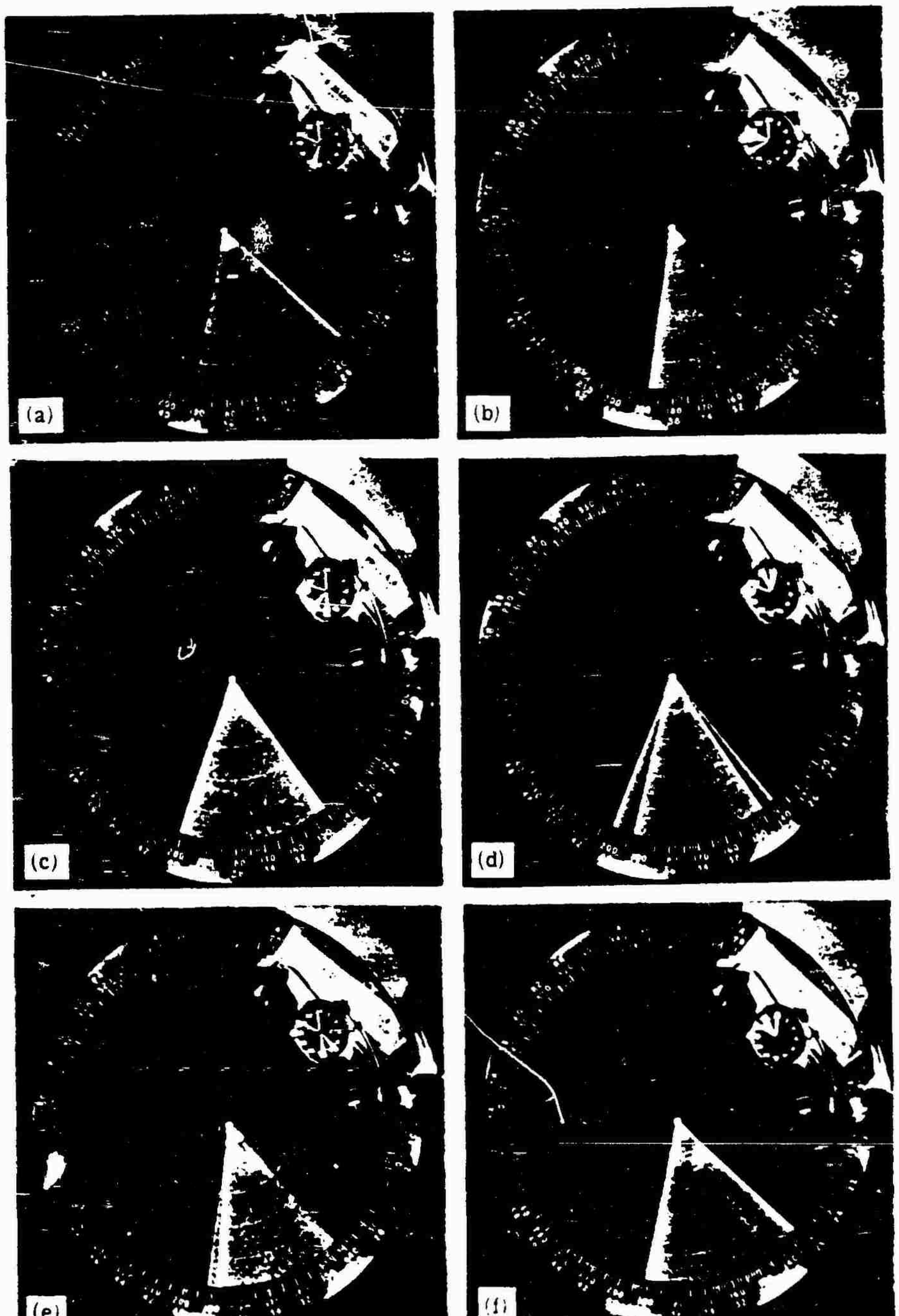

Figure 3.16 PPI presentations of unidentified radar echoes received during Shot Orange.

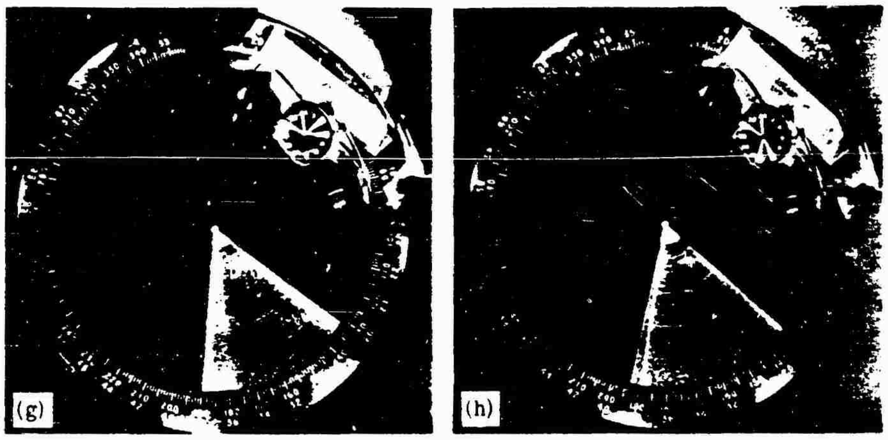

Figure 3.16 (Continued.)

At 23:51:06, the target began to regain its oval shape and increased in intensity. From subsequent observations, the target increased in elongation and continued to move in a counterclockwise direction at a constant slant range of $6\frac{1}{2}$ miles to an azimuth of 85 degrees at 00:00:16. At 00:01:56, the target began to fade, and was last observed at 00:05:38.

The height of the target ranged from 4.8 to 7.9 miles. The slant range varied from 5 to 8 miles. The target appeared to reach its greatest size at 23:49:58. At that time the target covered an arc 1,300 feet long and 900 feet wide.

Figure 3.14 shows the cloud cover to the east of the station (the direction of the prevailing winds) at H – 33 and H –21 minutes, respectively. The major range rings are at 5-mile intervals. This cloud was moving at about 7 miles per hour. Figures 3.15 and 3.16 show the surveillance of the area from H + 13 minutes to H + $20\frac{1}{2}$ minutes. Figure 3.15d shows the target described above as it first appeared.

Chapter 4
DISCUSSION

4.1 RANGE OF CLOUD DETECTION

The cloud from Shot Fir, as it reached its maximum height, was successfully observed at a 200-mile distance by the AN/CPS-9 at Eniwetok. This performance was within the capabilities of the radar equipment and the line-of-sight propagation law, using a $\frac{4}{3}$ earth radius. The optimum time of detection for greatest range occurs just when the cloud has reached its maximum height. At this time, the greatest amount of large particles are suspended at the highest level of the cloud.

The nondetection of Shot Koa by the Rongelap station, even though the cloud top exceeded the minimum height of detection by 27,000 feet for the 300-mile range, was believed to have been caused by anomalous propagation that existed to the west of Rongelap at that time. Anomalous propagation is due to a particular set of meteorological conditions that cause the radar beam to bend either so that it intercepts targets which are normally below the horizon, or so that it does not intercept targets which are normally at line of sight. This condition may be caused by a sharp temperature inversion at low levels or by a surface layer of high-water-vapor content. A marked increase of temperature with height, or decrease of humidity with height, or both, is necessary. Conditions for this phenomenon are most favorable when warm dry air is overrunning a shallow layer of cool moist air, as is often the case over bodies of cool water. This inversion was revealed when two towers on Bikini were detected. At this range, the towers would need to be 4,000 feet high to be detected under normal conditions. An inversion may have been sufficiently pronounced during Shot Koa observation time to deflect the radar beam, thereby causing a dead area in the direction of the target.

4.2 DURATION OF DETECTION

The duration of detection of the cloud resulting from a surface or near-surface nuclear detonation is dependent upon yield, height of burst, ground-zero surface composition, winds, and range from the observing station. The yield of a device is the prime factor, because it determines the height of the cloud and the amount of particles projected into the atmosphere.

Winds can shorten the time of tracking when a considerable amount of wind shear is present to disperse the cloud, thus leaving a lower concentration of suspended particles for radar detection. This condition is shown in Figure 3.4. As the particles composing the nuclear cloud rise or fall to levels with different wind speeds and directions, the particles are deflected laterally. The amount of this deflection is a function of the wind speed at different levels, the size of the particles composing the cloud, and the rising or falling rates of these particles. In such cases, the actual distribution of winds aloft can be estimated from the RHI patterns.

In the absence of wind shear, tracking time can also be reduced by high winds moving the cloud in a direction away from the observing station.

4.3 RATE OF RISE

In the first few seconds following a nuclear detonation, the fireball grows rapidly until the pressure inside the fireball is roughly that of the ambient air. The cloud will gradually cool during its rise, partly because of the entrainment of the outside air, partly because of loss of heat by radiation, and partly because of adiabatic expansion. After the cloud has reached thermal equilibrium with the surrounding air, there will be no further buoyancy and the cloud as a whole will become stabilized. This condition occurs at about 6 to 10 minutes after burst, regardless of the yield.

The speed with which the top of the radioactive cloud ascends depends on the energy yield of the device. The eventual height reached by the radioactive cloud depends upon the heat energy of the detonation, the temperature gradient, humidity, and density of the surrounding atmosphere, radiant heat loss, and other factors. The greater the amount of heat liberated, the greater the upward thrust will be due to the buoyancy, and thus the greater will be the distance the cloud ascends. However, the maximum height attainable by a nuclear cloud is probably affected by the height of the top of the troposphere (for nuclear clouds which reach this level).

A study of the data obtained from Operation Hardtack indicates that the yield of a nuclear detonation can be approximated from the rate of rise of the cloud and its maximum height.

4.4 CLOUD STABILIZATION AND HORIZONTAL GROWTH

Section 4.3 states that the nuclear cloud ceased rising after it had reached thermal equilibrium with the surrounding air. However, at this point the kinetic energy of the toroidal circulation may still be considerable. For devices with yields of a few kilotons, this circulation breaks up at about the same time that the cloud reaches its point of stabilization; but for devices in the megaton range, this toroidal circulation continues to pump air in at the bottom of the cloud for 10 to 20 minutes later.

The net result of this pumping action is a significant increase in the horizontal size of the atomic cloud. Also, after the cloud has reached its maximum height, the larger particles of debris begin to fall and increase the horizontal size of the cloud stem. In falling, these particles are subjected to prevailing winds at different levels, which spread and distort the cloud horizontally.

Because of the lack of radar observation of a sufficient number of Operation Hardtack shots, and the inadequacy of the data obtained from some of the observed shots, a number of desired cloud parameters could not be independently presented by Project 8.8. However, sufficient data has been obtained and published from previous operations to permit adequate comparisons with Operation Hardtack data.

4.5 HIGH-ALTITUDE EVENTS

Three high-altitude events were observed: Shots Yucca, Teak, and Orange, at 90,000, 250,000 and 125,000 feet, respectively. Although the radar equipment operated quite satisfactorily during Shots Yucca and Orange, no results were obtained from these events. Reliable information regarding nuclear detonations of this type is not available at this time. However, certain observations can be made based on the known characteristics of the shot environment. Shot Koa was observed to a maximum height of 72,000 feet, and Shot Tewa, which was detonated during Operation Redwing, was observed to a maximum height of 99,000 feet. Each of the aforementioned shots were surface shots. However, sufficient debris, dust, and water vapor were present to cause the nuclear cloud to remain detectable to the heights indicated above. In the case of Shot Yucca, a balloon-borne shot, and Shot Orange, a rocket-borne shot, the radar equipment was definitely in satisfactory operation and properly oriented on the target area. This observation was substantiated by the tracking of the corner reflector which was carried aloft by the balloon and by the appearance of rockets in the beam of the radar.

The above considerations imply that, had a nuclear cloud of sufficient particle size been formed, the cloud would have been detected by the radar equipment. The absence of a detectable nuclear cloud is believed to be due primarily to the absence of sufficient water vapor and debris and to insufficient electron densities at the observed altitudes.

4.6 COMPARISON OF DATA WITH OPERATION PLUMBBOB RESULTS

The duration of detectability for detonations of similar yields was four to six times as long at the EPG as at the NTS. This difference is attributed to the following: (1) the EPG shots were surface bursts, which cause more particles to be projected into the atmosphere; and (2) a greater amount of water was present at the EPG.

At the NTS, the detonation was always at a height sufficient to ensure that there would be no intersection of the fireball with the ground. Greater amounts of moisture were present in the EPG area because of the normally humid conditions there and the additional water vapor liberated by the blast from the soil and nearby water surfaces. With considerable amounts of water vapor added to already moisture-laden air, the cooling of the rising cloud leads to condensation and to the formation of water droplets. This condition enables detection of a nuclear cloud for a longer period because of the greatly extended time before droplet evaporation. The suspended dust particles in the arid atmosphere of the NTS do not combine to produce the larger particles required for extended radar detection.

Because of the high concentration of dust particles during the stabilization period of a nuclear cloud at the NTS, strong echoes were received at long ranges. The length of time available for long-range detection was shorter in this area than at the EPG because of the lack of enough moisture to form larger particles of lesser concentration as the cloud disseminated.

Chapter 5
CONCLUSIONS and RECOMMENDATIONS

5.1 CONCLUSIONS

For surface or near-surface bursts, the range of detection with Radar Set AN/CPS-9 is the line-of-sight distance to the resulting cloud. However, under conditions of anomalous propagation, the range of detection will deviate from the line-of-sight distance because of meteorological conditions that cause the radar beam to bend so that it intercepts targets which are normally below the horizon.

The duration of detection is four to six times as long in humid areas as in arid ones. In humid areas, the duration of detection can be shortened and the process of tracking the nuclear cloud can be made more difficult by the presence of rain showers and large clouds during and immediately following a detonation. Wind shear can also shorten the duration of detection by dispersing the cloud particles.

The range, azimuth, and rate of vertical and horizontal development of nuclear clouds can be measured within the accuracies of the radar equipment. If the area immediately under the nuclear cloud can be assumed to receive some amount of fallout, local fallout patterns can be constructed. However, since the mechanics of fallout are quite complex, additional studies and correlations with more positive means of measuring fallout will be needed to evaluate the above assumption.

For bursts at 90,000 feet or higher, insufficient moisture or particles are present to produce an X-band radar return, and the electron density resulting from a yield as high as insufficient to produce an echo on Radar Set AN/CPS-9.

The total number of events and the range of yields under various climatic conditions (warm humid, warm dry and arctic), which have been simultaneously observed visually and by radar, is far from being adequate to permit preparation of accurate curves for yield estimation.

The AN/CPS-9 radar is well suited for observations of survace or near-surface bursts, as would be expected from a comparison of its performance characteristics with those of other available radar sets.

5.2 RECOMMENDATIONS

In view of the success of this project on the present operation, it is recommended that:

(1) This study be continued on future operations to explore further the X-band radar determination of nuclear-cloud parameters using Radar Set AN/MPS-34.

(2) Provision be made to observe every nuclear burst, visually and by radar, in order to build up an adequate basis for radar estimation of yield. Concurrent mesometeorological data should be taken. Shot data from arctic areas is quite vital.

(3) Further radar observations be made to measure rate of rise versus time, rate of horizontal growth versus time, maximum overshoot height, and height and diameter of stabilized nuclear clouds.

(4) An AN/CPS-9 radar set be installed on a stabilized mount on a ship to make it possible to select various ranges for observations.

(5) Two radar stations be operated simultaneously and in conjunction with each other at the proving ground to permit simultaneous horizontal and vertical observations.

(6) Longer-wave length radars, as well as the AN/MPS-34 radar set, be used for observing high-altitude events.

(7) A more extensive study be made to determine the relations between radar-detectable nuclear-cloud movement and fallout.

(8) For application to fallout prediction, the value of radar observations of changes in cloud profile as a function of time be investigated.

(9) A study be conducted to ascertain whether there is a correlation between the intensity of the signal received by the radar, and the yield and burst height of the detonated device.

(10) More reliable and extensive photographic coverage be obtained for this study on any future operation.

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