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Effects of Nuclear Detonations on the Ionosphere

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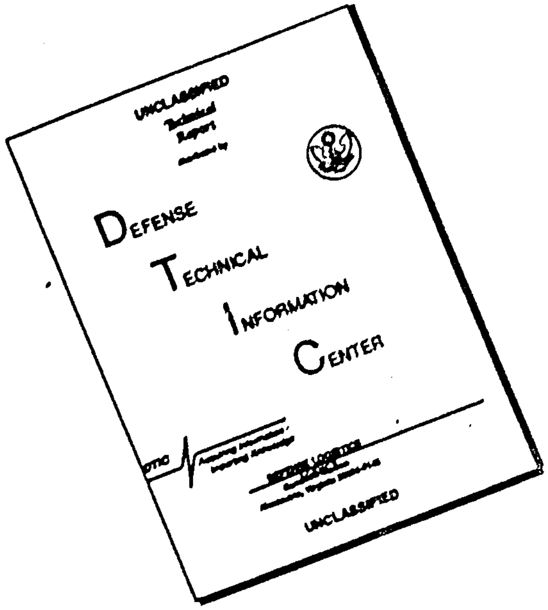

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The original objectives of this experiment were to determine the effects of very high-altitude, large-yield nuclear detonations on the ionosphere and on signals propagated via the ionosphere. However, the location of the Teak and Orange Shots was changed and it was not possible to obtain suitable project sites. Therefore, the original objectives no longer applied and the experiment became an attempt to increase the store of knowledge about ionospheric effects of large-yield ground-level detonations (using the sites that had already been instrumented for Teak and Orange).

It is recommended that any future project of this type that might operate at a site where commercial power is not available, furnish its own run-in diesel generators, including 100 percent backup, all necessary maintenance supplies, and transfer pump with fuel line fittings.

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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 6.9

EFFECTS OF NUCLEAR DETONATIONS ON THE IONOSPHERE

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FOREWORD

This report presents the preliminary 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 original objectives of this experiment were to determine the effects of very-high-altitude, large-yield nuclear detonations on the ionosphere and on signals propagated via the ionosphere. However, the location of the shots (Teak and Orange) was so changed that it was not possible to obtain suitable project sites. Therefore, the original objectives no longer applied, and the experiment became an attempt to increase the store of knowledge about ionospheric effects of large-yield ground-level detonations (using the sites that had already been instrumented for Shots Teak and Orange).

To accomplish the original objectives, two ionosphere recorders had been installed, one at Kusaie and one at Wake (1,600 km apart), so located that the great-circle path between them lay nearly along a meridian and with a midpoint about 100 km northwest of Bikini Atoll. Attempts to operate the two recorders synchronized for oblique-incidence-propagation data proved unsuccessful, due to malfunctioning of the synchronizers. Ionspheric observations were then made at vertical incidence only. However, no useful data was obtained at Wake, due to failure of three generators. Recordings of vertical data were made as the frequency was swept through the range from 1 to 25 Mc each 15 seconds.

At Kusaie, to the south of the detonations, effects were observed for Shots Fir and Koa that were very similar to those obtained during Operation Redwing at the same site. The average velocity from shot time until the arrival of the first disturbance overhead was again found to be 20 km/min. A second disturbance, with an indicated velocity of about 13 km/min, also was observed again.

PREFACE

The assistance and cooperation of the following individuals and organizations are hereby acknowledged:

The members of Mobile Section A, U. S. Army Signal Ionosphere Station, who performed their duties excellently, doing their utmost in attempts to make the project successful.

U. S. Army Signal Radio Propagation Agency, which provided the services of the military personnel and whose personnel aided in the planning and support.

Civil Aeronautics Administration, Military Air Transport Service, and Search and Rescue (Kwajalein Detachment), which gave full cooperation in connection with administration and logistics at the Wake Island site.

Coast Guard personnel, Air Force project personnel at Wake, and CAA auto shop personnel, all of whom were most helpful when operating difficulties beset the Wake Island station.

Jack Youngstrom, of Kusaie Island, who gratuitously provided machine-shop facilities for vital generator repairs.

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Chapter 1
INTRODUCTION

1.1 OBJECTIVES

The original objectives were to determine the effects of very-high-altitude, large-yield nuclear detonations on the ionosphere and on signals propagated via the ionosphere. However, subsequent to installation of the equipment at the selected field sites, the planned location of Shots Teak and Orange was changed from Bikini to Johnston Island, remote from the instrumented sites. No suitable islands could be found for relocation of the project equipment. It had been planned to give particular attention to the phenomena described below, but the shot relocation reduced the objectives to the last three items (Sections 1.1.4 through 1.1.6).

1.1.1 Increased Ionization. The principal phenomena to be investigated were the duration and lateral extent of the probable ionized absorption region in the lower ionospheric layers resulting from the ultraviolet and gamma radiations and, also, the possible increased ionization of the higher layers of the ionosphere.

1.1.2 F-Layer Phenomena. It was desired to determine whether the effects previously observed for low-altitude, high-yield detonations, such as the rising F layer, would result from the very-high-altitude detonation of devices having somewhat smaller yields.

1.1.3 Absorption Effect from Radioactive Cloud. Also to be investigated was the absorption resulting from the radioactive cloud, the duration and extent of this absorption, and its relation to that found during Operations Castle and Redwing.

1.1.4 Traveling Disturbances in Ionosphere. Another phenomenon to be studied was the nature of the origin of distant effects due to traveling disturbances in the ionosphere, believed to be connected with hydromagnetic waves.

1.1.5 North-South Differences. It was also desired to determine whether ionospheric disturbances associated with compressional and hydromagnetic waves exhibit any differences between northerly and southerly observations at approximately equidistant stations.

1.1.6 Other Ionospheric Effects. It was anticipated that evidence of other phenomena might appear from examination of the data; for example, abnormal forward-scatter propagation might result from creation of inhomogeneities in the E region.

1.2 BACKGROUND

Experiments to determine possible effects of nuclear detonations upon the ionosphere have been performed during six previous test operations, starting with Operation Greenhouse. Ionospheric data were also obtained during Operation Buster Jangle, shortly thereafter.

1.2.1 Blast-Wave Effects. In was not until the results of Operation Tumbler-Snapper were analyzed that the relationship between the blast wave and all ionospheric effects observed until then became clear. Local changes in ion density occur when the blast wave arrives in the ionosphere. These distortions of the ion-density distribution account for the effects observed in the ionograms recorded at vertical incidence near ground zero. These inhomogeneities also accound for observed effects upon radio signals traversing the E region above ground zero, such as abnormal forward-scatter propagation and other additional modes of propagation with resultant interference (Reference 1).

Further corroborations of these results and a better understanding of the mechanism of these blast-wave effects have resulted from participation during Operations Ivy and Castle (References 2 and 3). Recently, an expected dependence of these disturbances upon the orientation of the propagation path with respect to the geomagnetic field was found when data were taken to the south of the shot locations during Operation Redwing (Reference 4). Pronounced effects were found 750 km to the south of the blast for all shots of the order of and upward, whereas to the east the effects were much smaller at a third of the distance.

1.2.2 Rising F Layer. During Operation Ivy, a new ionospheric phenomenon was found (Reference 2). Following the shot (Mike), the F2 layer above Bikini (360 km east of the shot) rose to unusual heights and remained above normal for about 4 hours, with a simultaneous depression of the F2-layer critical frequency (indicating lowered ion density). During Operation Castle, the end of the rising F-layer phenomenon was seen in the ionograms recorded at Rongerik following two of the three largest shots at Bikini. (The early portion was obscured by absorption.) An indication that such a phenomenon also occurred as a result of the third large detonation was given by the presence of what is known as a "G condition" in the ionosphere. The rising-F-layer phenomenon has apparently occurred after all shots having a yield greater than a certain value.

Theory developed for the draft final report of Redwing Project 6.3 indicates that, for propagation of the blast wave upward from sufficiently large detonations, the overpressure never becomes much less than 100 percent of atmospheric pressure. Consequently, heat is imparted to the atmosphere for the entire path from the ground to the F region, with the resultant F-layer effect.

1.2.3 Absorption. An unanticipated effect occurred during Operation Castle (Reference 3). Vertical echoes from the ionosphere were completely cut off at Eniwetok, about 360 km west of ground zero, for many hours after the large shots at Bikini. An ionosphere recorder located to the east, however, observed nothing remotely approaching such a blackout. The complete signal disappearance to the west was attributed to absorption resulting from ionization associated with the radioactive cloud, which reached an altitude of about 100,000 feet. Knowledge of the probable cloud movement resulting from high-level winds in that geographical region makes it likely that the radioactive particles would have been carried to the west, arriving near Eniwetok at the time when the absorption was found to occur.

An airborne ionosphere recorder was used during Operation Redwing to locate the absorption area up to several hours after the detonations (Reference 4).

the cloud rise was smaller, the wind velocity at the appropriate level was less, and hence the duration and extent of the absorption were smaller. Nonetheless, sufficient data were obtained to corroborate the Castle results and to serve as the foundation for a new theory, which was expounded in the final Redwing report (see Section 1.3.3 and Reference 4).

1.2.4 Distant Effects. Disturbances in the F layer at locations as far as 4,500 km from ground zero were found following the largest shots of Operations Ivy and Castle (References 2 and 3). The arrival times of these disturbances indicated a velocity of the order of 8 to 16 km/min, which is the same range as that found for traveling disturbances that are apparently naturally caused.

During Operation Redwing, an effect described in Reference 4 as the "second disturbance" (at Kusaie, 750 km to the south of the shots) occurred repeatedly with an indicated velocity of 13 to 14 km/min. Hence, it was attributed to the same type of wave as the distant disturbances, namely, a hydormagnetic wave.

Such a wave might be initiated in the ionosphere by the vertical component of the blast wave, which near the geomagnetic equator, is also perpendicular to the magnetic field of the earth.

1.3 THEORY

1.3.1 Increased Ionization. The Chapman theory of the formation of the earth's ionospheric layers attributes them primarily to selective absorption of ultraviolet radiation from the sun. This theory is generally accepted as being fundamentally correct. Hence, it was expected that both the ultraviolet and gamma radiations from Shots Teak and Orange would increase ionization in the upper atmosphere for a short period. At the lower ionospheric levels (D and possibly E regions), increased ionization was expected to result in strong absorption; whereas at higher levels, it might increase the reflecting power of existing layers. The duration, degree, and nature of the effect would depend upon the altitude of the ionization peak or peaks. That altitude would depend upon existing ionization-density distribution and the spectrum of the emitted radiation.

1.3.2 F-Layer Phenomena. In developing the theory for the final report of Redwing Project 6.3 (Reference 4), the work of Ledsham and Pike was used as a basis for computing the overpressure in the shock wave vertically above the blast. Since their work was based upon a surface blast, it would be invalid for a high-altitude detonation, particularly for a shot above the intermediate temperature maximum. Therefore, a new theoretical treatment would be required to determine the relationship between the minimum yield required to produce the phenomenon and the altitude of the burst.

1.3.3 Principal Absorption Region. Reference 4 contains a theory that located the principal region of absorption well above the cloud, in the neighborhood of 70 km altitude, and which ascribed the absorption to ionization produced by gamma radiation from the radioactive cloud. The gamma radiation expected from the high air bursts of Operation Hardtack might be less than that from the Redwing shots; but significant absorption might result, because the cloud would be located near the altitude principally responsible for absorption.

1.3.4 Traveling Disturbances. A complete theory has not been formulated for the origin of hydormagnetic waves in the vicinity of the shot. It was hoped, however, that some information would be obtained during Operation Ha : to help understand the mechanism of the generation of traveling ionospheric dis . .nces.

1.3.5 Comparison between Northerly and Southerly Observations. Theory indicated that ionospheric disturbances due to compressional and hydromagnetic waves traveling equal distances northward and southward from the shot location would, upon comparison, show differences because the earth's magnetic field is inclined upward with respect to southward propagation and downward with respect to that moving northward. For the compressional wave, the difference was expected to involve only the change of ion-density distribution, because the compressional wave itself would not be affected by the difference in magnetic-field inclination, but the resultant electron motion might have a larger vertical component at the northern site, where the inclination is greater. On the other hand. a hydromagnetic wave, which tends to follow the direction of the magnetic-field lines, would move downward as it progressed northward; consequently, the height at which the disturbance is observed would tend to be lower and the velocity to be less. However, if the disturbance seen to the north were at a height similar to the southerly one, the velocity would be expected to be greater.

1.3.6 Other Ionospheric Effects. A great deal of turbulence exists in the atmosphere above nuclear detonations. Past ionospheric experiments have indicated that this turbulence extends to the E region. If this is so, one should expect inhomogeneities to occur in the ion density there, resulting in forward scatter (which may be interpreted by means of the Booker scattering theory).

The length of the propagation path chosen for Project 6.9 would have fallen within the optimum range for ionospheric forward scatter under normal conditions. Consequently, traces above the critical frequency were expected to be observed in more records and to extend to higher frequencies following detonations than they normally have been found to do during prior operations.

Chapter 2
PROCEDURE

The ionospheric-sounding equipment was located at two sites—Wake, the northern site, and Kusaie, the southern site—both outside of the EPG. The site locations and their relationship to the shot areas are shown in Figure 2.1.

2.1 SHOT PARTICIPATION

This project was to have been primarily concerned with Shots Teak and Orange (see Reference 6 for description). A secondary interest was in the oblique-incidence data to be recorded for Shot Yucca (see Reference 6 for description of shot). Additional data were to have been taken for all low-altitude shots having predicted yields of 100 kt and above. However, due to (1) relocation of Shots Teak and Orange, (2) failure of oblique-incidence equipment to operate properly, (3) failure of three generators at the northern site, and (4) early rollup, the only data obtained were vertical ionograms at the southern site for Shots Yucca, Fir, Butternut, and Koa, and at the northern site for Shot Yucca. The times and locations of these shots are given in Table 2.1.

2.2 INSTRUMENTATION

Two modified Model C-4 ionosphere recorders (Figure 2.2), one at each site, were used for the usual vertical-incidence soundings. It was originally planned to connect the recorder at Kusaie to an auxiliary rhombic antenna for simultaneous transmission toward Wake and to connect the recorder at Wake to a similar rhombic antenna for reception of the signals from Kusaie. If synchronization of the two recorders had been effected, data could have been obtained for radio signals obliquely incident to the ionosphere. However, synchronization was not achieved for the reasons discussed in Section 2.3.1. Hence, the rhombic antennas were disconnected after Shot Yucca in order to improve the efficiency of the vertical-incidence system.

It was originally planned to vary the frequency from 1 to 24.7 Mc in 45 seconds by means of the special cams described in Section 2.2.2. With elimination of oblique soundings, however, operation reverted to the normal vertical procedure of a 15-second logarithmic sweep from 1 to 25 Mc. Pulses of 50-μsec duration were transmitted at the rate of 60 pulses/sec.

2.2.1 Vertical-Incidence Ionosphere Recorder. Model C-4 ionosphere recorder is a device which measures and records the virtual heights and critical frequencies of the various ionospheric layers by (1) transmitting radio-frequency pulses ranging from 1 to 25 Mc, (2) receiving these pulses after reflection from the ionosphere, (3) displaying them as oscilloscope traces, and (4) photographing these traces automatically. On the face of the oscilloscope is presented the virtual height of reflection plotted against the frequency of the signal. Height markers are used for each 100-km interval, and frequency markers are used for each megacycle. The height of the echo is based upon half the travel time at the speed of an electromagnetic wave in free space. Further background information about these records and their use in probing the ionosphere may be found in Reference 5.

2.2.2 Modifications to Vertical-Incidence Recorder. Both of the Model C-4 ionosphere recorders were modified as described below so that oblique ionospheric soundings could be made in addition to the vertical soundings, but these modifications were eliminated upon reversion to normal vertical operation.

Each recorder was modified for connection to a synchronization unit, which supplied a stablized 50-cycle power source to the recorder for operating the frequency-sweep and

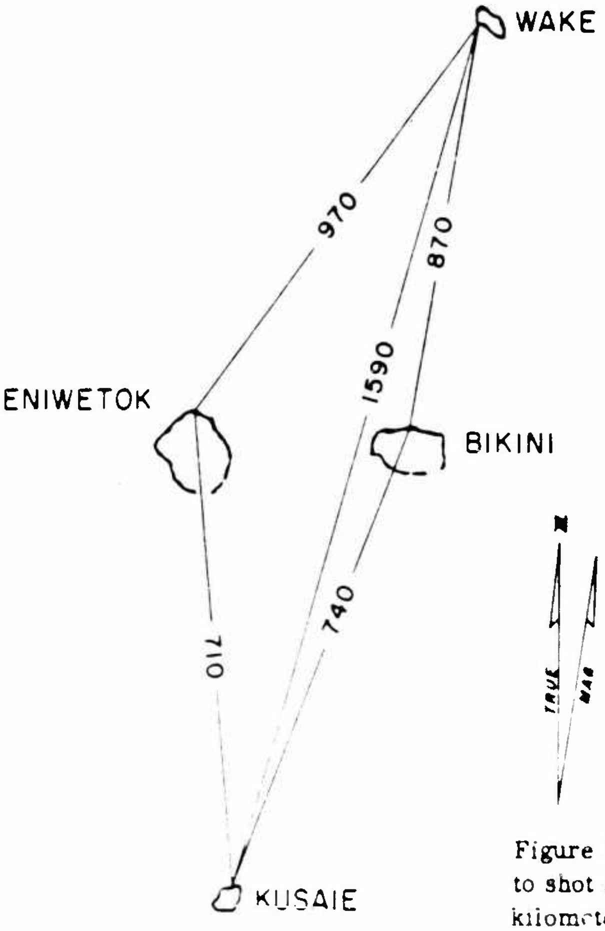

Figure 2.1 Project sites and their relationship to shot areas. All distances shown are in kilometers.

camera motors in order to maintain frequency synchronism. The synchronization unit also supplied stabilized 25-cycle and 3,000-cycle signal sources for controlling the range-sweep circuits in order to maintain pulse synchronization and to provide range markers.

The motor in the frequency-sweep mechanism of each recorder was replaced by a lower-shaft-speed motor, thus permitting the frequency range of 1 to 25 Mc to be covered in either 45, 90, or 360 seconds (in place of 15, 30, or 120 seconds).

The recorder at Kusaie (transmitting end) was provided with a special fixed-step cam so shaped that the frequency sweep varied linearly from 1 to 9.7 Mc, in 0.5-Mc steps from 9.7 to 13.7 Mc, in 1-Mc steps from 13.7 to 18.7 Mc, and 2-Mc steps from 18.7 to 24.7 Mc. The sixteen steps from 9.7 to 24.7 Mc were selected to minimize interference with operating services. The recorder at Wake (receiving end) was provided with a spe-

Figure 2.2 Modified Model C-4 ionospheric recorder.

cial adjustable-step cam with a similar overall shape, except that the frequency steps were adjustable so that each step could be independently adjusted for frequency agreement with the corresponding step on the fixed (transmitter) cam. Both cams were designed and constructed at U. S. Army Signal Research and Development Laboratory (USASRDL). (Photographs will be included in the final report.)

The receiver in the recorder at Wake was modified by provision of a range-gate output covering the portion of the range above about 1,600 km (the 800-km height marker). An additional oscilloscope display unit and camera were provided for expanding and viewing the gated portion of the range, which included the oblique traces.

A separate synchronization unit was used for each recorder.

2.2.3 Antennas and Coupling. At each site, multiple-wire vertical-delta antennas were used for the vertical soundings. The antennas at Wake and Kusaie had apexes 50 and 70 feet, respectively, above the ground; slanting legs terminating 65 feet from the base of the center pole; and 600-ohm terminations. The transmitting and receiving antennas and the plane of the ground were in mutually perpendicular planes. These antennas were designed to radiate and receive principally in the vertical direction over the entire band of frequencies; however, side lobes exist at some frequencies (near the high end), and the vertical-radiation pattern is broad at other frequencies (near the low end). Although the above-described vertical antennas were the only ones used for recording data during the actual experiment, a detailed description of the horizontal rhombic antennas and the coupling devices designed and constructed for operating as originally planned is given below.

TABLE 2.1 SHOT DATES, TIMES, AND LOCATIONS

Descriptions of Shots are given in Reference 6.

Shot	Date	Time	Location
Yucca*	28 April	1440M	140 km ENE of N tip of Eniwetok Atoll
Fir	12 May	0550M	Bikini Atoll
Butternut	12 May	0615M	Eniwetok Atoll
Koa	13 May	0630M	Eniwetok Atoll

* Balloon-borne very-high-altitude shot.

This experiment imposed severe requirements on the oblique-propagation-transmission antennas. The transmitting antennas had to radiate adequately over a large frequency range, as well as over a considerable range of wave angle (elevation angle of radiation). The likely wave angles for both E- and F-layer propagation and the corresponding frequency ranges of interest for the various modes of propagation were therefore examined in detail. These considerations led to the design of a rhombic antenna (identical for transmission and reception) to provide a good compromise between the various desired characteristics.

The horizontal rhombic antennas erected for the oblique propagation had the following dimensions: leg length, 225 feet; height above ground, 42 feet; tilt angle, 70 degrees. The antennas were oriented so that the axes of the main antenna beams pointed toward each other. A 600-ohm termination was used on each antenna, and multiple-wire construction was used to minimize impedance variation with frequency.

Table 2.2 shows the computed frequency ranges over which the radiation intensity in the forward direction of the horizontal transmitting antenna exceeded a tentatively selected threshold value[1]. The three elevation angles (3.8, 15, and 30 degrees) corresponded respectively, to E, 1-hop F, and 2-hop F propagation modes for the experimental path and for normal layer heights.

In order to connect two antennas to the transmitter at Kusaie and two antennas to the receiver at Wake, with a division of power at the transmitter in a 2-to-1 ratio favoring the oblique-propagation circuit while maintaining a proper impedance match throughout the frequency range, a special transformer was designed and constructed at U. S. Army Signal Engineering Laboratories (USASEL). The broadbanding (1 to 25 Mc) was accomplished by the use of a ferrite core[2]. The transformers were given an operating test, before being sent to the field sites, with a C-4 transmitter output being coupled through

TABLE 2.2 COMPUTED USEFUL FREQUENCIES FOR HORIZONTAL ANTENNA

Propagation Mode	Elevation Angle	Frequency Range
	deg	Mc
E layer	3.8	14 to 25 and above
1-hop F layer	15.0	8 to 25 and above
2-hop F layer	30.0	5 to 18

the transformer to a standard vertical-delta antenna and a 600-ohm dummy load. The transformers performed satisfactorily over the entire frequency range, even when the pulse repetition rate was increased above that planned for the field experiment. Of course, when the dummy load was replaced by the rhombic antenna, the power division varied, because of the impedance variation.

2.3 EQUIPMENT DIFFICULTIES

The planned operating procedure was drastically revised in the field because of the difficulties described in the following sections. Separate sections are used, because the problems connected with the synchronizers concerned a type of equipment new in this field, whereas the generator problems were of a logistical nature.

2.3.1 Synchronizing Equipment. This discussion is included in the hope that it will be of assistance to future workers attempting to synchronize ionosphere recorders for oblique-sounding experiments. It had been planned to test the equipment prior to the field operation, using conditions that simulated the experiment as closely as possible. However, due to shortage of time, the testing was limited to a brief, synchronized operation at a 15-mile

[1] 130 mv/meter at a distance of 1 mile from the antenna with an input of 1 kw.

[2] Such transformers were not commercially available at the time and represented a new development.

separation using existing antennas only and no sweep of the frequency range. The time was limited, because the manufacturer required about 6 months to deliver the synchronizers; the contract for the synchronizers could not be placed until the funds were definitely committed; an early shipping date was necessary under the conditions of this experiment.

During four trial runs, a usable signal from Kusaie was received at Wake on each frequency step up to 20.7 Mc. (This reception occurred only during the hours from about 0800 to 1300. These hours corresponded to the time of the optimum signal-to-noise ratio, as predicted for this project by the U. S. Army Signal Radio Propagation Agency.) The transmitter at Wake was off during these trials; when turned on, the signal was lost, probably due to loss of synchronization. When the signal was received, there was vertical-sweep (range) synchronization only. On one occasion, when an attempt was made to sweep horizontally (i.e., allowing the cam to change the frequency), the signal was completely lost after two or three frequency sweeps. (Only a few of the steps appeared during each of these sweeps.)

The frequency-dividing circuit included slave-oscillator circuits, pulse-shaping circuits, and flip-flop multivibrator circuits. The first-two-named circuits were highly unstable, making alignment difficult and critical; spurious oscillations tended to occur. The multivibrators were apparently triggered by the C-4 ionosonde operation, thus destroying synchronization. It is thought that re-design and modification in the laboratory, possibly by more complete shielding, might result in proper operation of the synchronizers. It is to be noted that the range markers produced with these synchronizers seem to be satisfactory at present.

2.3.2 Generators. For the Wake Island site, one 20-kw Continental Red Seal diesel generator was furnished. This generator had a smashed control box when received at Wake; it had apparently been dropped. There were no maintenance manuals, batteries, rheostat, or vital preventive maintenance supplies (such as filters and fan belts). Project personnel managed to borrow batteries and a rheostat and were able to repair the control box, thus placing the generator in operation. After 2 weeks' operation, the coupling between the motor and the generator sheared. A new connecting plate was fabricated by the CAA, which allowed four more days of operation (when similar failure recurred).

Another generator of the same model was flown in from Kwajelein. This one arrived in good condition, but lacked the same maintenance items as the first generator. It operated well for 3 weeks, but because of lack of preventive maintenance (particularly change of the throw-away-type filters), dirt apparently entered the system and the generator failed. This failure occurred after Shot Yucca. As a consequence, the Wake station was off the air for Shots Fir and Koa, which were of major interest to this project. Attempts were made by Army, Air Force, and Coast Guard personnel to put the generators back into operation; but without the maintenance items, they were unsuccessful.

For the Kusaie Island site, one 30-kw diesel generator was furnished for the combined use of Projects 6.4 and 6.9. Difficulty was encountered in siting this unit, because the freight-handling equipment had inadequate capacity. Fortuitously, no damage to the diesel unit occurred. As at Wake, there were no manuals, batteries, fittings, or vital preventive maintenance supplies. The generator functioned improperly, due to pitted commutator rings. Fortunately, a lathe, owned by an island resident, was made available, and repairs were made.

For each site, a 5-kw, gasoline-operated PE-95 unit was shipped as a backup source of power. These units were used extensively during the periods when the diesel units were inoperative. The PE-95 at Wake broke down before Shot Fir. It had to be operated at about half load thereafter and for short per s only. The power unit at Kusaie worked excellently.

An operating difficulty at both sites was the lack of a transfer pump with proper hose and fittings suitable for pumping fuel from 50-gallon drums. Such an item had to be borrowed from an Air Force project each time it was needed.

2.4 OPERATION

Pending successful synchronized oblique-incidence operation, only vertical-incidence soundings were made following the shots. Both stations used a sweep time of 15 seconds, during which the entire range of frequencies from 1 to 25 Mc was covered.

The Wake ionosonde was operated continuously from Yucca plus 5 minutes to plus 70 minutes (with 3 minutes out for film change at about plus 30 minutes), then routinely (five times an hour) for the next 18 hours.

The Kusaie ionosonde was operated continuously during Shots Yucca, Fir, Butternut, and Koa, starting at H minus 1 hour (except for radio-silence periods), until about H plus 6 hours. Then a schedule of sweeps at 5-minute intervals was resumed.

Chapter 3
RESULTS

No oblique-incidence data was obtained; also, no pertinent vertical-incidence data was obtained at the northern site for comparison with the effects to the south.

3.1 SHOT YUCCA

No effects from this shot were observed in the ionosphere above either site.

3.2 SHOT FIR

At about H plus 35 minutes, an additional segment began to appear in the recorded trace. Like the effect termed the "first disturbance" observed at the same site after seven shots of Operation Redwing, this disturbance occurred above the critical frequency of the F layer. It moved downward in height, as shown in Table 3.1. Thus, it fit the former interpretation of an approaching region of increased ion density viewed obliquely.

TABLE 3.1 FIRST DISTURBANCE ABOVE KUSAIE, SHOT FIR

Shot Fir was detonated at 0450 hours, L time; h'F2, f_oF2, and f_xF2 are standard symbols indicating, respectively, the virtual height and the ordinary and extraordinary critical frequencies of the F2 layer.

Time After Shot	First Disturbance		Regular Layer		
	Apparent Height	Frequency Range	h'F2	f_oF2	f_xF2
minutes	km	Mc	km	Mc	Mc
27	—*	—*	230	—	6.7
36	370	6.5 - 7.2	230	5.8	6.2
37¼	350	5.3 - 8.3	240	5.5	5.9
38	340	5.6 - 7.7	240	—†	—†
39¼	315	5.0 - 7.9	240	—	—
40	300	5.0 - 7.0	230	—	—

* Disturbance not yet visible in ionogram.

† The effect has now apparently arrived overhead, the two traces have joined, obliterating the regular-layer critical frequencies. Actually, the segment associated with the disturbance now determines the critical frequencies.

Further confirmation was indicated by the appearance of an additional trace 240 to 250 km above the descending segment, as had occurred during the Redwing shots. This was interpreted as a signal refracted vertically groundward by the disturbed portion of the F region, then reflected upward from the earth's surface, and back to the recorder over the same path.

A "second disturbance" was also observed with an appearance similar to the Redwing records. It could not be determined precisely when it was overhead, but it was seen moving lower in height at shot time plus 54 and 55 minutes (385 km to 370 km). It was probably overhead at about shot time plus 1 hour.

3.3 SHOT BUTTERNUT

Shot Butternut was detonated just 25 minutes after Shot Fir. Consequently, if any effect were to result from this smaller-yield shot, its appearance at Kusaie would have coincided with the arrival of the second disturbance from Shot Fir, i.e., at Shot Fir plus 60 minutes. No effect of Shot Butternut could be differentiated from that disturbance.

3.4 SHOT KOA

The 35-mm records, normally used to scale data, were absent for this shot, because the camera lens failed to open. Fortunately, 16-mm records were made for the purpose of giving a moving-picture presentation of the changing ionospheric layers. Although this film was rather dark, both the first and second disturbances could be discerned. The former was overhead at approximately H plus 35 minutes, the latter at about H plus 50 minutes.

Chapter 4
DISCUSSION

The dependence of the effects observed at Kusaie upon location, distance, geomagnetic orientation, season of the year, and time of day is not completely known, since these parameters have been approximately the same for many of the observations made during this operation and Operation Redwing. During Operation Redwing a major difference between eastward and southward effects was found; a possible seasonal dependence was also noted (see Reference 4). The effects would no doubt be very different for detonations at locations other than near the geomagnetic equator, where the magnetic field is nearly horizontal. Also, a major difference was anticipated for observations to the north of the detonation, but power difficulties prevented obtaining such data. It is probable that important variations would be found when atmospheric and ionospheric conditions are different than they are near dawn. Roll-up at Kusaie prevented the obtaining of data for Shot Yellowwood, detonated in midafternoon on 26 May. Further experimentation might well be designed to study variations in at least some of the parameters.

Chapter 5
CONCLUSIONS and RECOMMENDATIONS

5.1 CONCLUSIONS

In agreement with results of Operation Redwing (see Reference 4), the energy responsible for the first disturbance in the ionosphere above Kusaie was propagated with a mean velocity of 20 km/min. Also corroborating previous results, the second disturbance resulted from energy propagated with a mean velocity of about 13 km/min. The first effect has been postulated as due to a compressional wave and the second to a hydromagnetic wave. The fact that the first effect was seen approaching but not receding might indicate that the ion-density variation associated with the disturbance is asymmetrical.

5.2 RECOMMENDATIONS

It is recommended that any future project of this type that might operate at a site where commercial power is not available furnish its own run-in diesel generators, including 100-percent backup, all necessary maintenance supplies, and transfer pump with fuel-line fittings. A diesel mechanic should be included on the project roster.

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