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MEASUREMENTS IN SUPPORT OF THE OOSIK EXPERIMENT

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13. ABSTRACT

At 0659 GMT March 7, 1972 a shaped barium charge was released high above central Alaska by the Los Alamos Scientific Laboratory and the University of Alaska. In support of this experiment, known as OOSIK, Stanford Research Institute operated two existing radar facilities in Alaska. In addition, a low-frequency receiving site was established and operated near the down-field intercept of the barium release. A preliminary analysis of the data indicates that a magnetic substorm began 17 minutes after the injection and was accompanied by considerable auroral activity. A number of factors suggest that the substorm was not triggered by the barium injection but was of natural origin. If a magnetospheric instability was later triggered by the barium release its effects were masked by the natural event.

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ABSTRACT

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CONTENTS

ILLUSTRATIONS

ACRONYMS, SYMBOLS, AND ABBREVIATIONS

ARPA	Defense Advanced Research Projects Agency
DNA	Defense Nuclear Agency
GMT	Greenwich Mean Time
Hz	Hertz, one cycle per second
kHz	Kilohertz, 1000 hertz
km	Kilometer, 1000 meters
km/s	Kilometer per second, 1000 meters per second
L	Geocentric distance to the top of an earth's field line in multiples of the earth's radius.
K-band	Approximately 800 to 1600 megahertz
LASL	Los Alamos Scientific Laboratory
m/s	Meter per second
min	Minutes
N	North
R	Time of release
s	Second
SRI	Stanford Research Institute
UA	University of Alaska (Geophysical Institute)
ULF	Ultra low frequency, less than 30 hertz
UHF	Ultra high frequency, 300 to about 800 megahertz
VLF	Very low frequency, 3 to 30 kilohertz
VHF	Very high frequency, 30 to 300 megahertz
W	West
$^{\circ}$	Degree
γ	Gamma, unit of magnetic-field density

I SUMMARY

Recent theoretical investigations by Brice[1,2*] and by Cornwall,[3,4] among others, have suggested that aritificial injection of a relatively small amount of cold plasma into the magnetosphere can initiate instabilities. An increase in cold-plasma density leads to a change in the number of particles that can be stably trapped in the earth's radiation belt. The excess is precipitated into the atmosphere as the result of pitch-angle modification. Amplification of ULF and VLF radio waves can accompany the instability.

Particle precipitation and wave amplification may have military importance if they can be controlled. Both of these subjects are being studied by a number of organizations under sponsorship of the Defense Advanced Research Projects Agency (ARPA). Stanford Research Institute (SRI) is one of the participants in this study and a more detailed discussion of magnetospheric instabilities and their application is given in an Interim Technical Report[5] on Contract N00014-72-C-0402.

An opportunity to test magnetospheric instability theories arose in March 1972 when the Los Alamos Scientific Laboratory (LASL) and the University of Alaska (UA) announced plans to fire a shaped barium charge along the earth's magnetic field high above central Alaska. The Defense Advanced Research Projects Agency contracted with Stanford Research Institute to carry out radar and radiowave measurements. Arrangements were made to operate the VHF/UHF/L-band radar at Homer, Alaska and the

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[*] References are listed at the end of the report.

L-band radar at Chatanika, Alaska.* Radiowave and magnetic sensors were installed and operated at Venetie, Alaska, near the down-field location of the barium release. Field sites and instrumentation are discussed in Section III of this report.

The OOSIK shaped barium charge was released at approximately 0659 GMT, March 7, 1972 at an altitude of 538 to 544 km on an L shell of about 6.75. After several minutes a number of adjacent magnetic flux tubes were observed to be populated by barium ions. As many as eight different tubes were populated at times greater than R + 10 min. Optical tracking of the populated flux tubes indicates that they moved to the southeast at about 400 m/s. A more detailed description of the launch and release in given in Section IV.

Seventeen minutes after the barium release a sudden-commencement magnetic perturbation was observed over a wide geographic area. The cryogenic magnetometer at Venetie showed the excursion to have been at least as great as 320 γ in 11 minutes. The initial negative excursion lasted only about 20 minutes, while the subsequent positive bay lasted over an hour. Considerable auroral activity accompanied the magnetic substorm. Weak aurora, visible far to the south of Venetie, became much brighter and more active as it moved north. Between 0722 and 0726 GMT, aurora formed overhead at Venetie. A fairly narrow arc of aurora extending from the eastern to the western horizon remained near the magnetic zenith at Venetie for more than half an hour. Radar aurora observed from Homer was not well correlated with visible aurora before the substorm. Radar returns were received from the test area prior to and following the release, although no aurora was visible from Venetie before

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*The Chatanika observations were carried out as a part of the research program sponsored then by the Defense Nuclear Agency, under Contract DNA001-72-C-0076. Both the Chatanika and Homer radars are DNA facilities.

the substorm. The correlation was much better following the substorm. The Chatanika radar observed large ionospheric drift velocities prior to the barium release. Section V contains a brief description of the experimental data obtained.

The conclusion drawn from a preliminary examination of the OOSIK data is that a natural magnetic substorm and associated aurora occurring 17 minutes after the release masked any magnetospheric instability that may have been triggered by the barium injection. An important qualification to this conclusion is that under favorable magnetospheric and ionospheric conditions it is likely that an instability can be triggered by a rocket-launched shaped barium charge. Shaped charges appear capable of injecting the several ions per cubic centimeter required in the equatorial plane at L = 6.75 to initiate an instability.

II INTRODUCTION

Energetic particles trapped in the earth's magnetic field are estimated to store 10^{15} joules of energy. Very little practical use has been made of this energy since the radiation belts were discovered by Van Allen[6] in 1958. Perhaps this will change as the result of recent work by Brice[1,2] and by Cornwall.[3,4] Their investigations suggest that when certain conditions exist in the magnetosphere, instabilities can be initiated by artificial injection of cold plasma. Triggering of instabilities can lead to useful control of wave amplification in the magnetosphere and precipitation of particles into the atmosphere. Both of these phenomena are known to occur naturally and may have military application if controlled. Natural wave amplification is manifested in certain features of whistler and micropulsation propagation. Natural precipitation has been discovered to be responsible for localized absorption regions in the ionosphere.

An opportunity to test the Brice/Cornwall theories became available in the early months of 1972. Los Alamos Scientific Laboratory (LASL) and the University of Alaska (UA) jointly announced that a shaped barium charge would be released high above Central Alaska in March 1972. The experiment, to be known as OOSIK, would be a continuation of a joint LASL/UA program to utilize the photoionization property of barium to map magnetic fieldlines. The technical and logistical feasibility of mapping field lines had been proven in October 1971 when two shaped charges[7] were released above Kauai on low-latitude field lines. The Kauai tests, known as ALCO and BUBIA, were part of operation BARBIZON and were successful in populating an entire flux tube with barium ions.

Extensive optical measurement of OOSIK was planned by LASL/UA. If OOSIK succeeded in placing sufficient cold plasma in the magnetosphere to trigger instabilities, its occurrence would best be detected by radio and radar measurements. The Defense Advanced Research Projects Agency contracted with the Stanford Research Institute to provide such measurements. The instrumentation fielded by SRI during OOSIK is described in Section III of this report. The OOSIK launch and release are described in Section IV, and the results obtained are presented in Section V. Conclusions follow in Section VI.

III FIELD SITES AND INSTRUMENTATION

The experimental program developed by SRI included the following:

(1) Operation of the L-band radar at Chatanika, Alaska

(2) Operation of the VHF/UHF/L-band radar at Homer, Alaska

(3) Establishment and operation of a low-frequency radio-wave reception site at Venetie, Alaska.

Location of these three sites relative to the barium release is shown in Figure 1.

The Chatanika radar[8] is a Defense Nuclear Agency (Project 6.17) facility operated by SRI under Contract DNA001-72-C-0076. The personnel of this facility were informed of the OOSIK release and urged to operate the radar in a manner that would fulfill three objectives. The first objective was to search for radar returns from the release point, the second objective was to monitor the ionosphere down-field from the barium release, and the third objective was to monitor drift velocities in the lower ionosphere.

The particular utility of the Homer radar, also a DNA facility, is seen in Figure 1. Transmissions from this radar intercept magnetic field lines below the barium release very nearly at right angles. Contour lines in Figure 1 indicate the deviation from perpendicular intersection at an altitude of 120 km. Because of this geometry, the radar is very sensitive to field-aligned irregularities, enabling it to monitor natural or triggered auroral activity. Staff members from SRI-Menlo Park traveled to Homer to operate the facility.

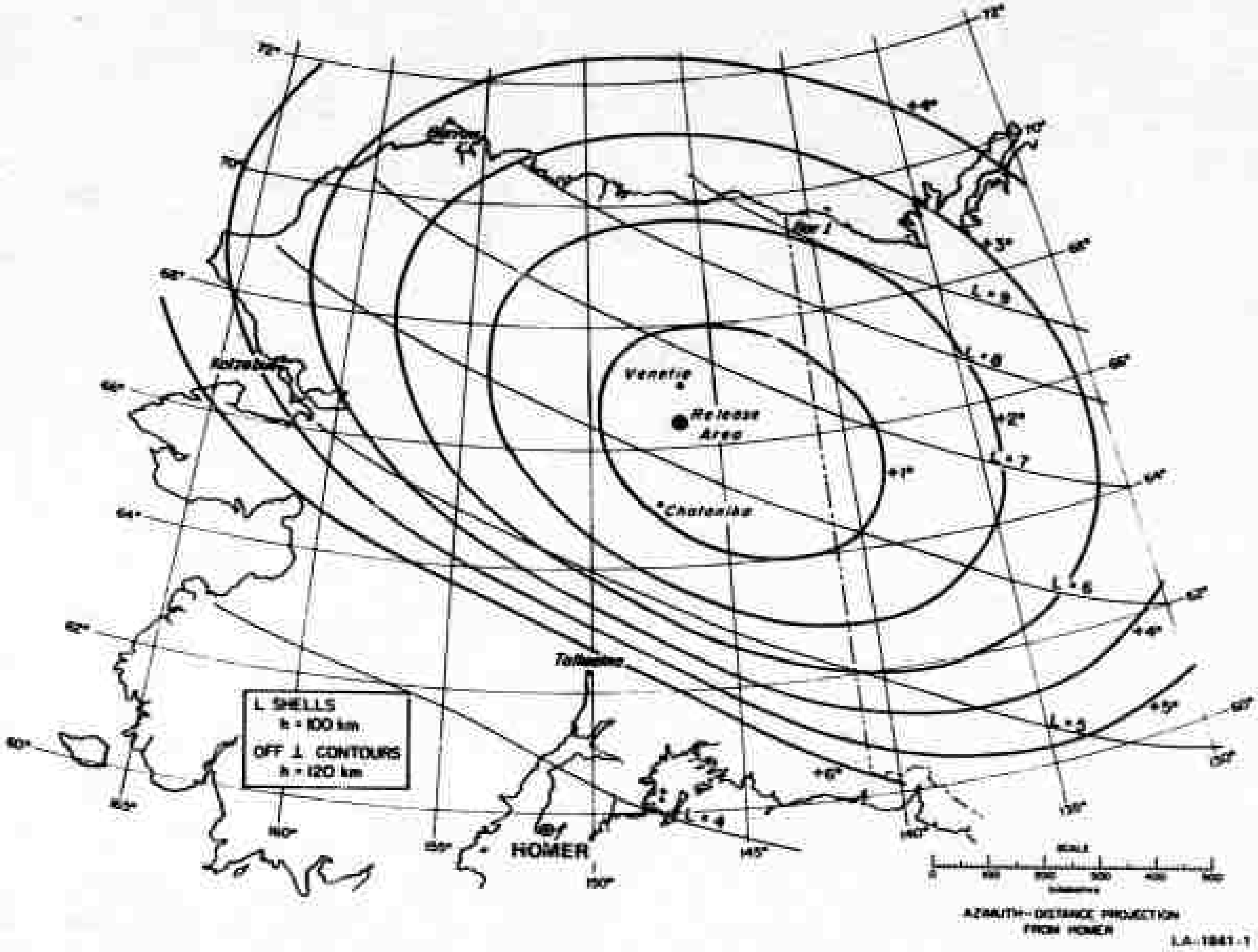

FIGURE 1 BARIUM RELEASE AND FIELD SITE LOCATIONS

Choice of Venetie for the low-frequency radio-wave receiving site is based on a down-field extrapolation of the magnetic field line through the nominal barium-release location. The nominal release point at 66.12°N, 147.61°W, 539 km altitude extrapolates down to a location at 66.96°N, 146.63°W, only 11 km southwest of Venetie. The advantage of placing a receiving site at the down-field location is that low-frequency radio waves amplified near the equatorial plane or generated in the ionosphere by particle precipitation will be most favorably received there. The frequency range from 0 to 80 Hz was monitored by a very sensitive cryogenic magnetometer, while the range from a few hundred hertz to 100 kHz was monitored using conventional loop and whip antennas.

IV LAUNCH AND RELEASE PARAMETERS

The rocket carrying the OOSIK shaped barium charge was launched from Poker Flat at approximately 0653 GMT on March 7, 1972. Nearly 6 minutes later, at 0659 GMT, the vehicle achieved alignment with the earth's magnetic field and the barium was fired upward along the field. Velocities perhaps as great as 15 km/s were achieved. The altitude of the vehicle at time of release was roughly 538 to 544 km. The 538-km altitude is associated with a sub-release point at 66.42°N, 147.58°W determined from radar tracking of the vehicle. The 544-km altitude is associated with a sub-release point at 66.33°N, 147.52°W determined from optical triangulation. A third sub-release point, 66.51°N, 147.54°W, can be derived from photographs taken at Venetie if we assume an altitude of 544 km. This latter estimate is not very sensitive to the assumed release altitude because of the very high elevation angle of observation.

Optical tracking of barium ions released near Venetie has indicated[9] that populated magnetic flux tubes moved to the south and east at approximately 400 m/s. Large electric fields in the ionosphere probably were responsible for the drift. Barium ions did, in fact, populate more than one magnetic flux tube; at least eight were evident in photographic data taken 17 minutes after release. The large electric fields may have been responsible for the multiple population.

V EXPERIMENTAL OBSERVATIONS

Magnetic and auroral activity was high prior to launch of the rocket and again at times more than 17 minutes after release. Prior to launch, auroral arcs were observed from Venetie to form in the north, move down through the test area, and remain visible far to the south. During this period large drift velocities were measured in the lower ionosphere by the radar at Chatanika. At launch time, 0653 GMT, the sky above Venetie had virtually cleared of visible aurora and remained that way for nearly half an hour. Radar observations from Homer following launch indicate the continued presence of radar aurora generally north of Venetie. During the period between launch and release of barium, the radar aurora observed from Homer slowly moved south and diminished in strength. Following release at 0659 GMT, radar aurora grew in strength and was well above the noise four minutes later when the orientation of the Homer antenna was changed. One of the two radar returns during this period came from the general vicinity of the down-field extrapolation of the barium release.

A very large and rapid change in magnetic-field strength began at 0716 GMT. An excursion of 275 γ occurred within 7.5 minutes after onset, with the maximum excursion of 320 γ being apparent by 0727 GMT. The initial negative phase lasted approximately 20 minutes and was followed by a positive bay with a duration of more than one hour. The visual aurora south of Venetie became much more active during the magnetic substorm as it moved north. By 0725 GMT, aurora formed at the magnetic zenith of Venetie. The magnetic zenith remained the focal point of auroral activity for more than half an hour. Radar auroral activity, as seen from Homer, also increased markedly after the magnetic storm onset. Returns were received from nearly all ranges between 500 and 1,000 km for more than an hour.

It is very tempting to attribute the magnetic substorm and auroral activity after 0716 GMT to the barium release 17 minutes earlier. There are several reasons why we must probably choose another explanation. Magnetic and auroral activity observed over a wide geographic area is indicative of natural origin; in addition, there is some indication in Hawaiian magnetometer data that a substorm was underway more than an hour before the barium release. The timing of the substorm relative to the release leaves much to be desired. Even the fastest barium ions would have ascended less than one third of the way to the equatorial plane where plasma instabilities are most easily initiated. A further argument against a triggered magnetospheric instability is the behavior of barium ions following the release. Within minutes of release, barium ions appeared in several magnetic flux tubes and by R + 17 min there were at least eight tubes populated. The density in any one tube probably did not reach a level sufficient to trigger an instability.

VI CONCLUSIONS

The principle conclusion to be drawn from the research conducted to date is that a natural magnetic substorm and associated auroral activity following the OOSIK barium release by about 17 minutes masked any magnetospheric instability that may have been triggered by the barium injection.

From this one experiment alone we should not conclude that rocket-launched shape charges are incapable of triggering a magnetospheric instability. Theoretical studies suggest that when favorable condictions exist in the magnetosphere, the addition of a few ions (electrons) per cubic centimeter may be sufficient to start an instability. If we assume a flux-tube diameter of 5 km at the injection point, an L value of 6.75, and a yield of 1×10^{24} ions (electrons) with velocities sufficient to reach the top of the field, the average density in the tube is about 5 per cubic centimeter. To achieve such densities it is very important to avoid the multiple-tube population that followed OOSIK.

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