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NATIONAL DEFENSE RESEARCH COMMITTEE CWS-19

REPORT NO. A-64 : PROGRESS REPORT

RADIO PROXIMITY FUZES FOR BOMBS AND ROCKETS

As of May 28, 1942

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CRDL, A Cml C, Md.

by

Harry Diamond

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July 1, 1942

Subject: Progress Report A964, May 28, 1942
"Radio Proximity Fuses for Bombs and Rockets"

To: The Commanding General, Edgewood Arsenal, Maryland.
Attn. Research and Development Department.

1. Forwarded herewith is 1 copy of the above subject report - copy No. 30.

2. Your attention is especially invited to paragraph 4(a), pp. 14, 15 of the report.

By order of the Chief, Chemical Warfare Service:

W. C. KABRICH
Colonel, C.W.S.
Chief, Technical Section

1 Incl:
Copy of subject rpt.

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July '42

NATIONAL DEFENSE RESEARCH COMMITTEE

REPORT NO. A-64 : PROGRESS REPORT

RADIO PROXIMITY FUZES FOR BOMBS AND ROCKETS

As of May 28, 1942

by

Harry Diamond

Approved On June 12, 1942 — Harry Diamond
Harry Diamond, Group Leader
Radio Fuze Development

Approved on June 12, 1942 — Lyman J. Briggs
Lyman J. Briggs, Director
National Bureau of Standards

Approved on June 12, 1942
for submission to the Division Chairman — Alexander Ellett
Alexander Ellett, Chairman
Section E, Division A

Approved on June 13, 1942
for submission to the Committee — Richard C. Tolman
Richard C. Tolman, Chairman
Division A

Preface

The work described in this report is pertinent to the projects designated by the War Department Liaison Officer as OD-27, OD-33 and CWS-19, to the projects designated by the Navy Department Liaison Officer as 77B and 77R and to Division A projects 770B and 770R.

This work is being carried out at the National Bureau of Standards with funds transferred to the Bureau by the National Defense Research Committee.

Disposition of copies of this report. -- The report was prepared for duplication on June 15, 1942. The initial distribution of copies was as follows:

Copies No. 1 to 24, inclusive, to the Office of the Secretary of the Committee for distribution in the usual manner;

Copy No. 25 to Capt. G.L. Schuyler, Bureau of Ordnance, Navy Department;

Copy No. 26 to Capt. S.R. Shumaker, Bureau of Ordnance, Navy Department;

Copy No. 27 to A. Ellett, Chairman, Section E, Division A;

Copy No. 28 to E.C. Watson, Member, Division A;

Copy No. 29 to H. Diamond, National Bureau of Standards.

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RADIO PROXIMITY FUZES FOR BOMBS AND ROCKETS

As of May 28, 1942

The development of radio proximity fuzes for bomb and rocket applications has been under way at the National Bureau of Standards since January 1941.[1/] Three bomb fuzes (for chemical warfare, plane-to-plane, and jet-accelerated armor-piercing bombs) and two rocket fuzes (for high-altitude antiaircraft and plane-to-plane rockets) are under study and development.

The actuation of a radio proximity fuze is brought about by radio waves. The type of radio fuze which we have developed consists essentially of a radio transmitter and a loosely coupled radio receiver. When the projectile on which this fuze is mounted reaches the vicinity of a target, the fuze is actuated as the result of the interaction between the radio waves emitted by the fuze and the waves from the same source which are reflected or scattered by the target.[2/]

1. Brief review of the developmental work

The early work was directed to the study of fundamental requirements and to the accumulation of data on basic principles. Consideration

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1/ For more detailed, technical descriptions of certain aspects of this work, see R.D. Huntoon, Radio controlled antiaircraft proximity fuze : the reflection of radio waves from airplanes, NDRC Report A-19 (OSRD No. 21); C. Brunetti, Computed operating heights of radio ground-approach fuzes, NDRC Report A-55 (OSRD No. 602).

2/ There exist a number of other possibilities as to the mechanism by which this actuation may be affected. See R.C. Tolman, NDRC Report A-15(OSRD No.18); also M.A.Tuve, NDRC Report A-42(OSRD No. 522).

of various possible methods led to the adoption of the circuit arrangement which is still in use. This circuit includes a class C oscillator which feeds power to a tuned diode circuit; the antenna is connected across the diode and thus serves both for transmitting and for receiving. The diode load-resistor feeds a two-stage audio amplifier, the output of which is connected to the thyratron and squib. This circuit arrangement affords the advantages of maximum power output for a given oscillator tube, with attendant increased freedom from jamming, and ease of adjustment because of separated oscillating and detecting functions. These advantages are secured at the cost of somewhat increased filament and plate-battery capacity.

Laboratory and field tests showed that the circuit functioned as anticipated; on May 26, 1941, six radio fuzes mounted in Mark 38, 100-lb practice bombs were dropped from 3000 ft and were found to operate satisfactorily upon approach to the ground at heights conforming closely to computed values.

Upon proof of the principle employed, attention was focused on improvements in design needed to fit the radio fuze to service requirements. There followed a long period of laboratory and field experimentation. In the laboratory, work was devoted to the testing and selection of tubes free from microphonics and having other suitable characteristics; to the development of methods of feeding the antenna which gave the desired distribution of sensitivity; to the development of efficient radio-frequency circuits, with special emphasis on ease of adjustment and uniformity of performance; to

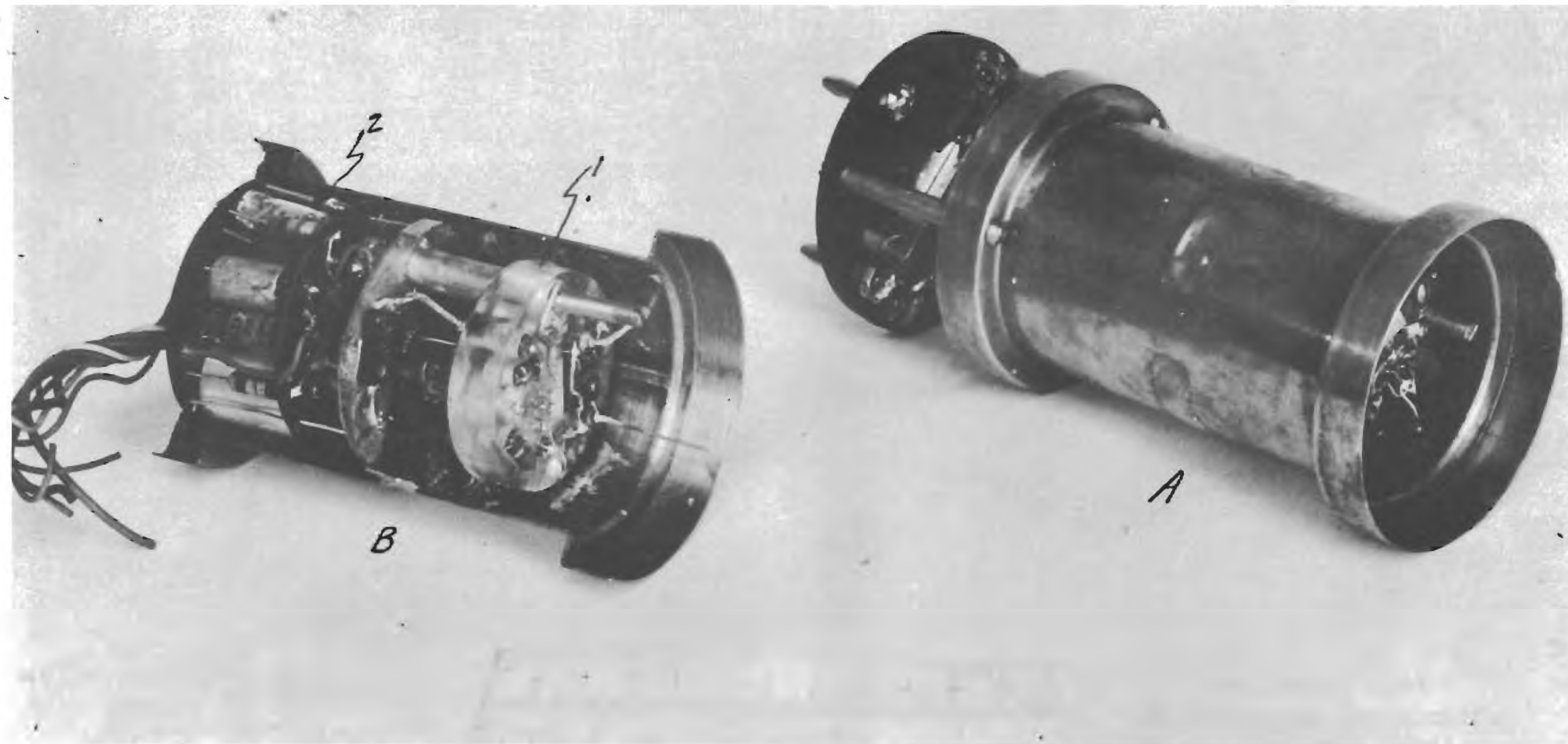

Fig.1. Radio proximity fuze unit used in field tests on bombs and rockets: A, assembled in unit container with switch plate at left; B, cut away to show the radio-frequency oscillator and diode assembly at 1 and the audio amplifier at 2. The entire unit excepting the radio-frequency coils is filled with polymerized tung oil to provide mechanical rigidity and shock mounting.

Fig.2. Radio proximity fuze mounted in the tail of a 100-lb practice bomb. (This is the arrangement used in practically all of the drop tests to date.) The entire assembly forms the radio antenna for transmission and reception; the antenna is excited between the small metal cap 1 and the body of the unit and bomb; 2 is an insulator for mounting the metal cap.

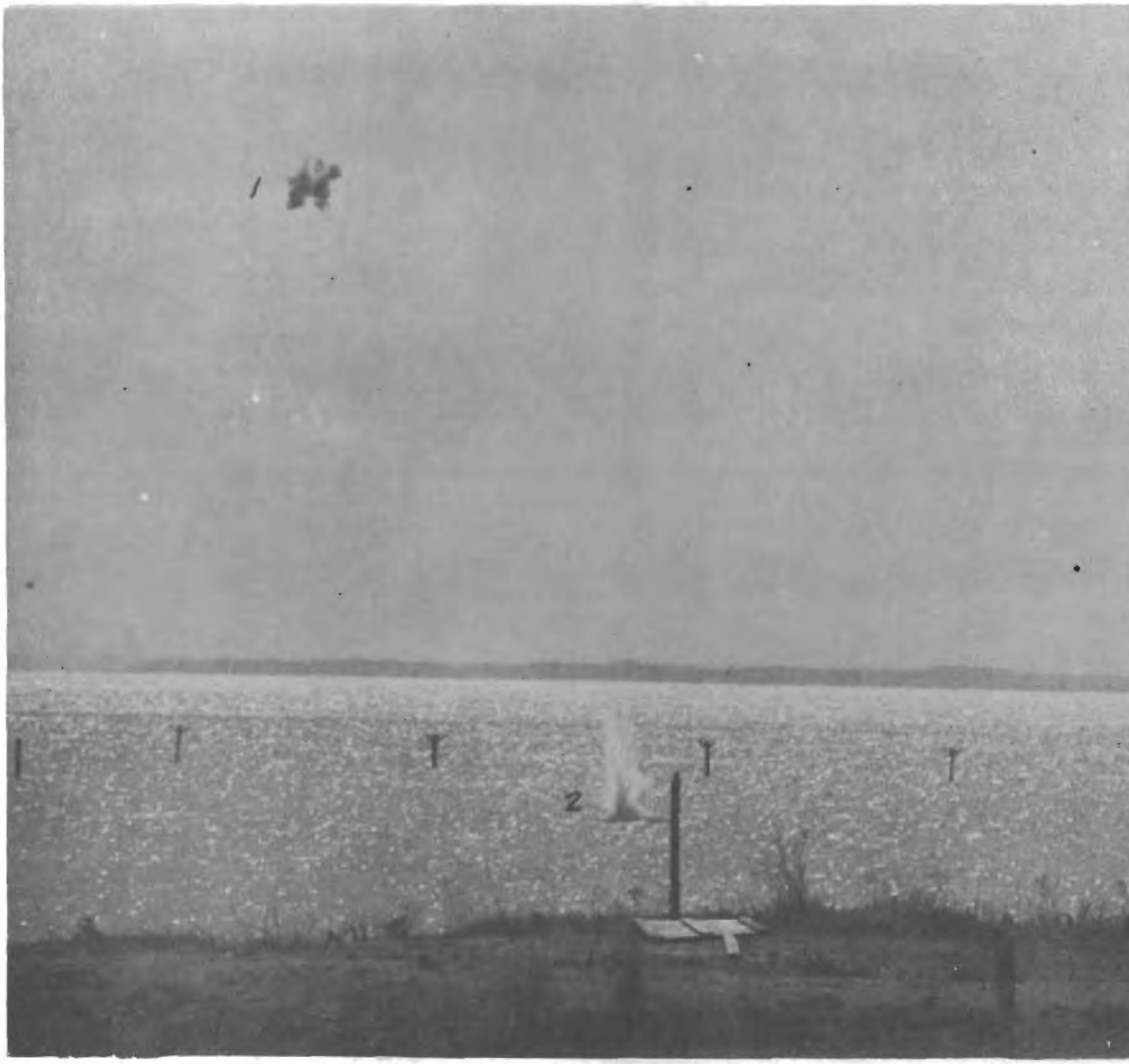

Fig.3. View showing operation of smoke puff, at 1, caused by the functioning of a radio proximity fuze as the bomb carrying it approached the sea. The splash of the bomb is seen at 2, near the target. The bomb was dropped from 10,000 ft and the fuze operated at 300 ft above the water.

Fig.4. Radio proximity fuze mounted in an antiaircraft rocket. (This is the arrangement used in practically all of the firing tests to date.) The fuze unit is mounted at 1, between the rocket motor and the high explosive chamber; 2 is a smoke-puff indicator for demonstrating proximity operation; 3 is an insulator coupling across which radio frequency excitation is supplied so that the entire assembly forms the transmitting and receiving antenna. This combination provides the forward-looking sensitivity pattern discussed in the text.

the shaping of the audio amplifier characteristics to conform with particular antenna sensitivity distributions to give desired end results; and to the development of test methods and equipment for simulating operating conditions in the laboratory so as to allow predetermination of fuze operation. In the field, the work included extensive "fly-over" tests to determine the nature of the voltage delivered to the diode as the projectile passed an airplane target -- including the effects of "aspect" of the projectile and of the target, of the distance between them, and so forth -- and occasional drop tests from an airplane to evaluate mechanical and electrical performance.

At the end of this developmental period, it was felt that the necessary technic and information had been accumulated to permit the designing of a radio fuze to meet any particular set of requirements. Beginning about January 1942, the work was therefore directed to the solution of problems of producing the fuzes in small quantities and to field testing. Groups were formed at the Westinghouse Electric and Manufacturing Company and the Julien P. Friez and Sons Company to cooperate in meeting production problems. The field testing included drop tests in bombs from an airplane at altitudes up to 10,000 ft and firing tests in rockets at several angles of elevation to check operation in proximity to the ground (at the end of the trajectory). Firing tests against targets were delayed because of lack of target and range facilities; the first significant target tests took place on May 27, 1942. The results of the tests are summarized in Sec. 2.

2. Results of proof tests

Some 75 radio fuze units were dropped in bombs from January 29 to April 15, 1942. Of these units, 50 functioned satisfactorily, 10 functioned prematurely and 15 were duds. Classified according to the altitude from which the bombs were dropped, satisfactory results were obtained with 80 percent of the units dropped from 5000 ft, 65 percent of those dropped from 7500 ft and 60 percent of those dropped from 10,000 ft.

Some 50 radio fuze units were fired in rockets from February 3 to May 7, 1942. Of these, over 90 percent successfully withstood a setback acceleration of 500 g -- that is, 500×32.2 ft/sec^2 -- as evidenced by the presence of an oscillator carrier-wave, and over 50 percent functioned satisfactorily in proximity to the ground. Of the failures, the ratio of duds to prematures was 3 to 1. In a more recent test, on May 7, 1942, 10 out of 13 units functioned satisfactorily.

Seventeen radio fuze units were fired in rockets on May 27, 1942 against a balloon-suspended target comprising two arrays of half-wave dipole antennas crossed at their centers and of 80 ft over-all length. The elevation of the target with respect to the firing point varied between 20° and 30°. Nine of the units functioned on the target, one functioned on arming, four were duds with no function either on the target or on the ground, and three functioned well ahead of the target (at 2.2 sec after firing). These were by coincidence the most sensitive units and were fired at the lowest angle (22°); it is believed that they were triggered by a row of trees about 200 yd in front of the projector. The units that fired on the target were up to 60 ft distance from it.

3. Discussion of proof-test results

(a) Radio fuze for bombs. -- In the drop tests, the radio fuze units were mounted in the rear of Mark 38, 100-lb practice bombs. The antenna pattern has axial symmetry with maximum sensitivity at an angle of about 60° from the nose and half-sensitivity at 35° and 85°, respectively. The backward sensitivity (toward the bombing airplane) was negligible. Although this pattern is ideally suited for the armor-piercing bomb application where dive-bombing operation from altitudes of the order of 6000 ft is probably indicated, it is not appropriate for drops from extremely high altitudes; the fuze sensitivity reduces to only about 5 percent of its maximum value when the striking angle, measured from the vertical, is 6° -- corresponding to a drop from an airplane flying 150 mi/hr at 20,000 ft. The sensitivities used in the drop tests were such as to cause operation at an average of about 150 ft above the ground when the bomb was dropped from 10,000 ft. On the basis of supporting laboratory tests and analysis, the following conclusions were reached:

(i) The decreasing percentage of successful operations with increasing bombing altitude can probably be attributed to the flimsy structure of the practice bomb used; vibration of the tail fins at the increased bomb velocities and friction between nonbonded parts are believed to be largely responsible for faulty operation.

(ii) On this basis, it is considered safe to assume that reliable fuze operation can be expected for bombing heights up to

10,000 ft (or for the dive-bomber case), provided the bomb is of reasonably rigid design.

(iii) For the chemical warfare application, where a high-altitude bomb is required, a different distribution of fuze sensitivity is necessary; namely, one in which the maximum sensitivity lies along the bomb axis. With such a distribution, the required sensitivity may be reduced at least five-fold as compared with that of the fuze units already tested; hence, successful operation from very high altitudes should be feasible.

(b) Radio fuze for rockets. -- In the firing tests use was made of rocket motors employing fast-burning powder -- burning time, 0.3 sec -- and attaining initial velocities of the order of 700 ft/sec. The fuze was mounted between the motor and the high-explosive section so as to give a forward sensitivity pattern identical with that described for the bomb mounting in Sec. 3(a). In this way, the influence of the ground during the ascending portion of the rocket flight was eliminated. The fuze sensitivity was adjusted to the value found by computation to be the one required for operation at a distance of the order of 100 ft from the average aspect of a medium-sized airplane. This sensitivity provides a margin within which lies the value probably required. The amplifier characteristic was shaped so as to provide for operation of the fuze ahead of the target for a wide variety of firing angles and ranges. Hence, successful operation of the fuze against a practical target may be predicted in projected tests with this motor. The latter conclusion is based largely on the results of the tests on May 7, 1942, and on the further

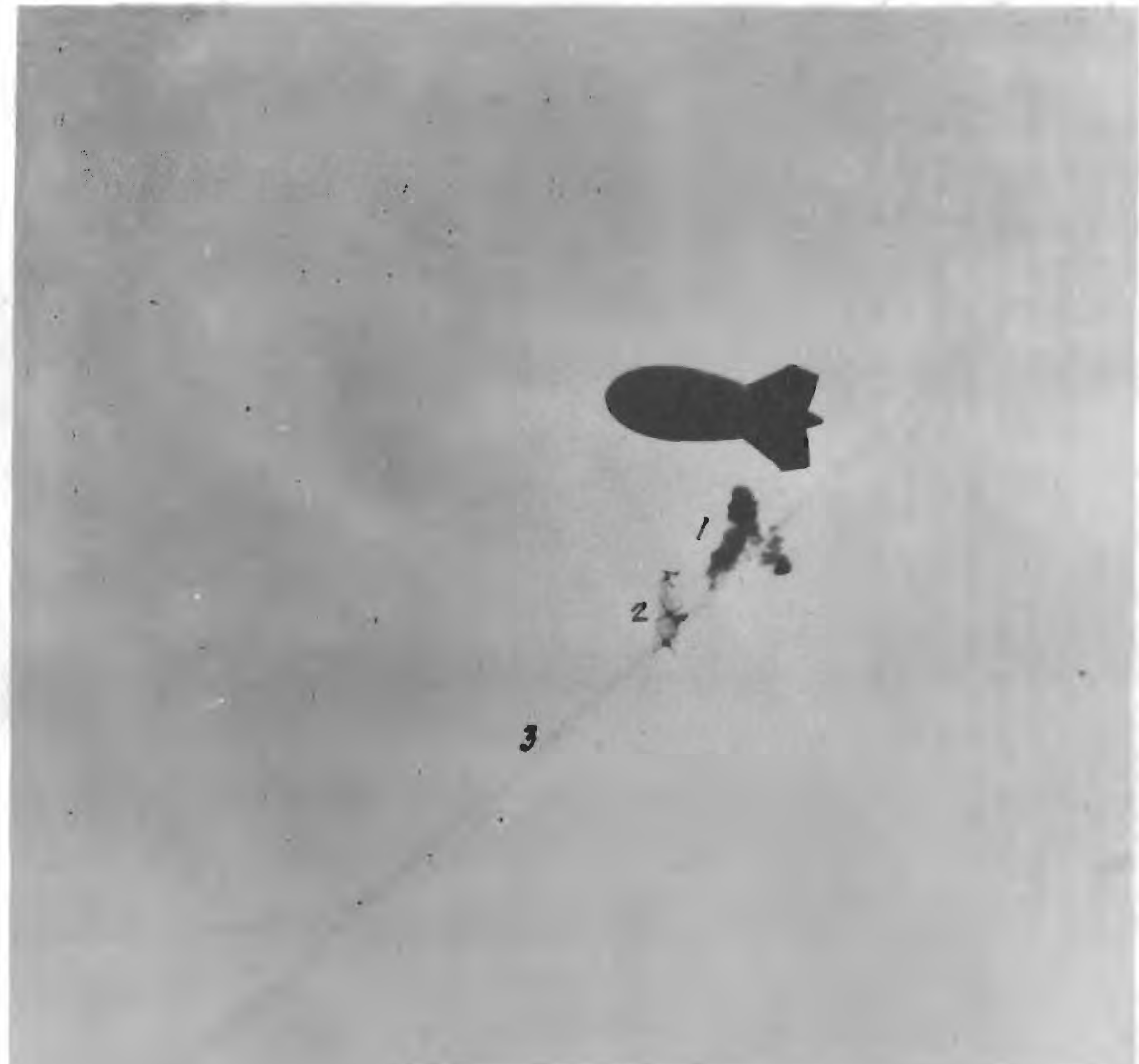

Fig.5. Operation of smoke puff, at 1, caused by the functioning of a radio proximity fuze as the antiaircraft rocket carrying it approached the balloon-suspended target at 2. The trajectory of the rocket is shown by the specially provided smoke trail 3. The smoke puff occurred after the rocket passed the target because of time-delay in the test squib used.

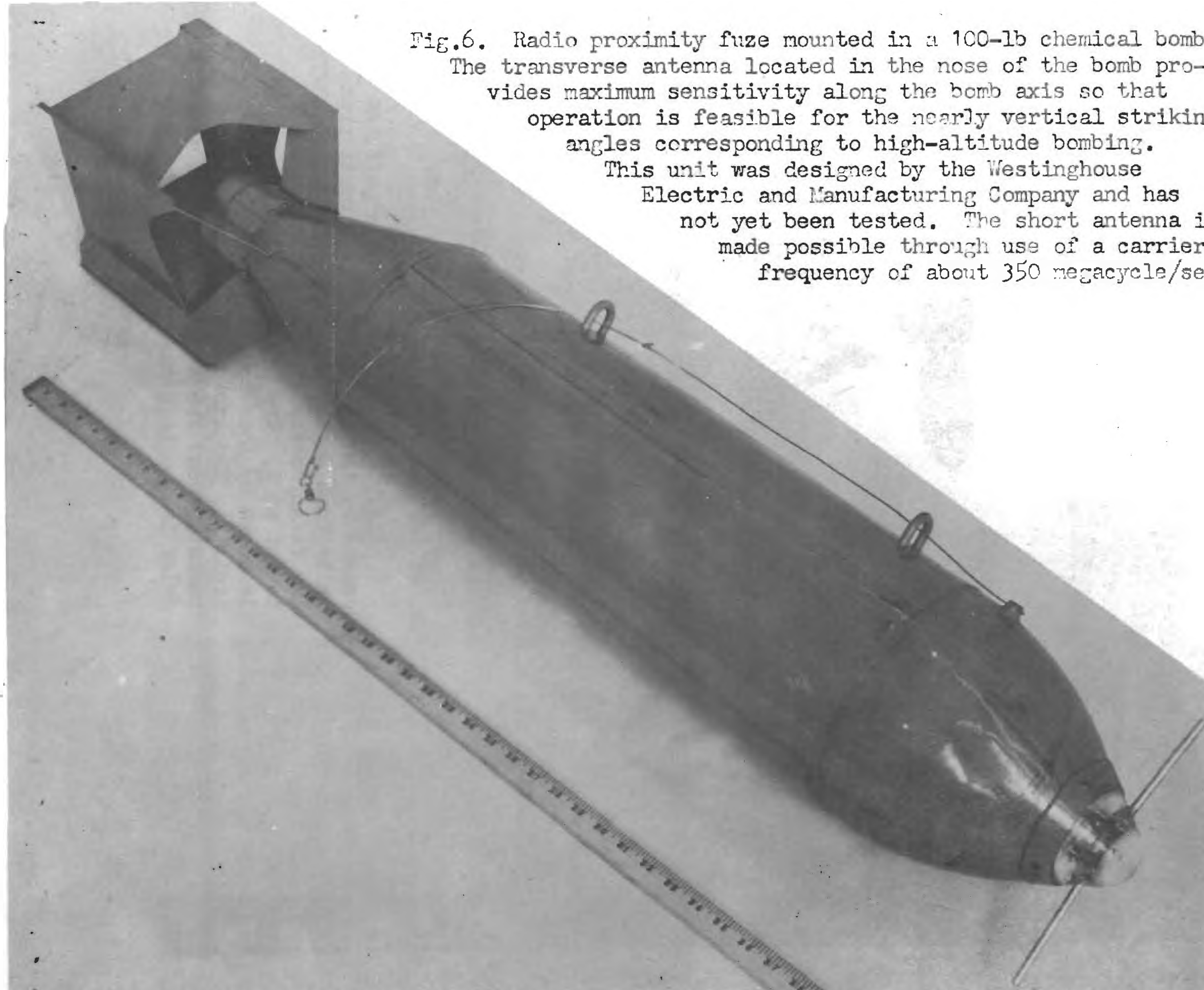

Fig.6. Radio proximity fuze mounted in a 100-lb chemical bomb. The transverse antenna located in the nose of the bomb provides maximum sensitivity along the bomb axis so that operation is feasible for the nearly vertical striking angles corresponding to high-altitude bombing. This unit was designed by the Westinghouse Electric and Manufacturing Company and has not yet been tested. The short antenna is made possible through use of a carrier frequency of about 350 megacycle/sec.

consideration that recent centrifuge tests of the fuzes point to a defect in them that is easily corrected and which has probably been responsible for a large percentage of the failures. The results of the first tests against a simulated target, reported in Sec. 2, tend to confirm this conclusion.

4. Present status of the fuze design

It is well first to point out that each fuze application presents a different problem in mechanical and electrical design; for, unlike the case of the photoelectric fuze,[3/] the vehicle on which the fuze is mounted is an important design consideration. Proper functioning, particularly if control of the angle of burst with respect to an aerial target is considered, requires a careful choice of wave-length, sensitivity distribution and audio amplifier characteristic. This choice is restricted by practical considerations of fuze location -- such as aerodynamic balance, nozzle location, interchangeability with standard fuzes, and so forth -- and by the dimensions of the projectile. Details of arming and safety, which are just beginning to be considered, add further complications. Nevertheless, sufficient flexibility of design remains so that it is believed that a satisfactory design can be evolved for each of the applications under consideration. In the following subsections, each application will be considered separately.

3/ L.R. Hafstad, NDRC Report A-20 (OSRD Nos. 22 and 23); Pilot P.E. Fuze Development Group, NDRC Report A-44 (OSRD No. 458).

(a) Chemical warfare bomb. -- Work is under way on the design of a transverse-type antenna[4] to secure the desired axial sensitivity pattern. Two avenues of approach are under investigation: (i) increasing the operating frequency to about 300 megacycle/sec -- that is, 1 meter wave-length -- so that a rigid antenna of over-all length of the order of 10 in. may be used; or (ii), retaining the present operating frequency of about 135 megacycle/sec, or 2.2 meters wave-length, and using a mechanically folded antenna with an over-all length, after release and arming of the bomb, of about 22 in. Preparation is under way for drop tests intended (1) to demonstrate the principles of operation involved and (2), to establish principles of mechanical design.

From discussions with officials of the Army Ordnance Department and the Chemical Warfare Service, it appears that the fuze for the chemical warfare bomb must be located in the nose of the bomb. From an engineering standpoint, it would be highly desirable to design the bomb structure so as to provide optimum mounting of the fuze but, from the point of view of expediency, there may be some advantage in designing the fuze unit to screw into the bomb in place of the standard contact-type fuze. Recent developments indicate that the fuze unit may be reduced in size sufficiently to render nose mounting quite feasible.

It is desirable in the very near future to place orders with a manufacturer with the object of securing semi-service units of an

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4/ See C. Brunetti, Report A-55 (OSRD No.602), Part III.

experimental character.[5] An order for 100 units for the use of the National Defense Research Committee should be placed promptly. It would also prove helpful if the service agencies interested would arrange for procurement of a small quantity -- about 500 units -- for experimental use.

It is to be emphasized that there is considerable mechanical design work to be done in connection with the inclusion of suitable safety and arming features. Since there are essential differences in the requirements of such devices when applied to the radio fuze, it is important that the manufacturers be afforded the opportunity to consult directly with Army and Navy Ordnance officials in addition to their normal consultations with the personnel of the National Bureau of Standards. This recommendation also applies to the design of safety and arming features for the other fuze applications discussed in this report.

(b) Plane-to-plane bomb. -- In the case of this bomb also, it appears desirable to mount the radio fuze in the nose. Again, the question arises of whether to design a unit to fit the standard bomb or to design the bomb to provide optimum mounting for the fuze. In this connection, it is worth noting that the size of the fuze may be materially reduced, if such reduction proves to be essential. However, in the present design, emphasis was focused on reliability of operation, provision of sufficient sensitivity to allow functioning

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5/ The Westinghouse Electric and Manufacturing Co. has given consideration to the design of this fuze for the chemical warfare bomb and is recommended as a suitable manufacturer.

under average rather than optimum conditions, ease of adjustment -- hence, reduced cost -- battery shelf-life, and similar considerations. Moreover, there are some definite limits, connected particularly with battery capacity, on the extent to which the size and weight may be reduced without affecting performance and reliability. It would be helpful to have information from the interested service organizations on the maximum weights and dimensions allowable for fuzes for the several fuze applications.

The electrical requirements for the plane-to-plane application are quite simple. Fortunately, a sensitivity pattern in which maximum sensitivity occurs at right angles to the bomb axis appears usable. Adequate control of the angle of burst may be obtained by suitable shaping of the amplifier characteristic. Such a pattern may be obtained with the radio fuze mounted in the nose if the wave-length is so chosen that the length of the bomb is somewhat less than a half wave-length. It is anticipated that the plane-to-plane bomb will be used from heights ranging from 1000 to 4000 ft above the enemy airplane and with relative horizontal velocities ranging from zero to the sum of the two airplane speeds. These considerations, together with that of the operating wave-length, determine the audio-amplifier shaping required. Sensitivity requirements appear to lie well within the range already attained.

Since the safety and arming features required for the plane-to-plane bomb are substantially identical with those for the chemical warfare bomb, it might be advisable to postpone the development of this design until after the chemical warfare fuze is completed.

(c) Armor-piercing rocket bomb. -- As indicated in Sec. 3(a), a thoroughly tested electrical design is available for the jet-accelerated armor-piercing bomb. The only electrical change required will be an alteration of the operating wave-length to secure the same sensitivity pattern with this much larger bomb. However, much mechanical design work remains to be done to provide the requisite arming and safety features. A special feature[6/] is that the arming propellor must not begin to operate until after a certain minimum air speed has been reached; this is to prevent operation in the propeller slip stream if the bomb is accidentally dropped from the rack. Other special safety features also appear to be necessary.

It should be pointed out that the type of tail assembly which we have been informed is to be employed for the armor-piercing rocket bomb is entirely satisfactory for use with a radio fuze. Hence, it would be unfortunate if some other less satisfactory type of tail assembly were adopted; for example, one incorporating a collapsible fin structure, which might prove injurious to the operation of the radio fuze, is likely to be adopted.

(d) Antiaircraft rocket. -- The proof tests discussed in Secs. 2 and 3(b) were for a radio fuze designed for use on the antiaircraft rocket. The essential operating differences existing under actual service conditions will be the higher velocities attained, which are of the order of 1500 ft/sec, and the greater length of an actual rocket -- for example, the British $3\frac{1}{4}$-in. rocket. Although this

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6/ Specified by Capt. S.R. Shumaker, Bureau of Ordnance, Navy Department.

higher velocity may give rise to greater vibration problems, it is anticipated that the reserve of sensitivity available will be sufficient to compensate for such effects. A change in amplifier-characteristic shaping will be required because of the higher Doppler frequencies involved, but this is readily accomplished. The effect of after burning may be relatively large and will have to be investigated. The different dimensions present no problem in obtaining the desired forward-looking sensitivity pattern.

Units for this application have been manufactured in small lots by the Julien P. Friez and Sons Company and a lot of 250 is now being produced. A similar lot of our own design is now under construction in the shops of the National Bureau of Standards. The Friez design is quite satisfactory and, on the whole, has given superior performance to our own design. A setback switch and means for self-destruction have not been included, but space for them is provided in the unit case. It would appear to be appropriate to include these features in at least part of the lots now under construction.

With the new provision for range facilities at Fort Fisher[7/] and prospective target facilities, it should be possible to test the operation of this type of fuze within the next few months.

The target presents a much greater problem in the case of the radio fuze than in that of the photoelectric fuze; this is true for the plane-to-plane bomb and rocket applications as well as for the

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7/ For a description of these facilities see a forthcoming memorandum by L.S. Taylor on Proving ground operations and facilities of Section E, Division A.

present application. The personnel of the Radiation Laboratory at the Massachusetts Institute of Technology has suggested the use of three square, mutually-perpendicular plane screens, each two to four wave-lengths on a side. Since, at 135 megacycle/sec, the wave-length is 7 ft, such a target would be suitable only for suspension from a fairly large balloon.8/ A more practicable target is a metalized glider suspended from a barrage balloon; steps are under way to procure a suitable balloon. Perhaps the best of all targets would be a drone, and it should be provided, at least for the final proof tests. In order that the results of target tests may be fully significant, the target must present the same range of aspect as does an actual airplane.

(e) Plane-to-plane rockets.9/ -- The application of the radio fuze to the plane-to-plane rocket presents few new problems. It is necessary to mount the radio fuze in the nose of the rocket but, fortunately, similar considerations apply to the plane-to-plane bomb. An operating wave-length substantially the same as that for the anti-aircraft rocket fuze is appropriate. Although one question of design that must be taken into account is the possible effect of the collapsible fins on the operation of the fuze, it is anticipated that careful

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8/ To expedite target testing using the smaller balloons already available, the target described in Sec. 2 was devised. It is estimated that this target will give the same intensity of reflected signal as the poorest aspect of a medium-sized airplane.

9/ The fuze for this application is described in much greater detail in a forthcoming report by H. Diamond et al. on the Radio proximity fuze for plane-to-plane rocket application.

bonding should provide a solution to this problem. A second design factor is that the warm-up time of the fuze must be limited to a value of the order of 0.3 sec; this appears to be entirely feasible.

Officials of the Army Ordnance Department have indicated the desirability of making the fuze for the plane-to-plane rocket as small as possible in order to increase the pay load. A design which goes a long way in the direction indicated appears practicable [see also Sec. 4(b)]. This application has just been assigned a high order of priority, and intensive activity is under way to produce and proof-test a practicable design. The production of units for test and the design of production models of this type of fuze have just been begun.[10]

5. Tube status

Assistance is being obtained from the Raytheon Manufacturing Company and from the Hygrade-Sylvania Company for securing tubes of improved performance, under current Division A contracts. The General Electric Company is also rendering assistance in providing special thyratrons and triodes on order. Although some improvement, particularly in triodes, is still desired, the status of the tube development is now fairly satisfactory. For example, in the case of one design, all tests were passed by 60 percent of the triodes as received from the manufacturer, 95 percent of the diodes, 95 percent of the pentodes and nearly 100 percent of the thyratrons.

10/ By groups at the Westinghouse Electric and Manufacturing Co., the General Electric Co. and Julian P. Friez and Sons Co.

A matter of some concern is the requirement that rugged tubes be eliminated from all projectiles except shell. This presents real difficulty, particularly in securing satisfactory triodes.

6. Battery status

Until very recently, the entire fuze design has been based on the use of dry batteries of six-month shelf life, with the expectation of changing to the perchlorate-type reserve battery when the latter became available.[11] The space required for such a battery is 3-1/8 in. in diameter and $3\frac{1}{2}$ in. long. It is largely the battery that determines the size of the fuze. If smaller fuzes are desired, smaller batteries now available may be employed; however, the use of these batteries would introduce as yet unanswered questions of shell-life, operation at low temperatures, and so forth.

11/ These batteries are being developed for Section E, Division A, National Defense Research Committee, by the National Carbon Co. For a description of this type of battery see Schrodt, Craig and Vinal, NDRC Reports A-13 and A-49 (OSRD Nos. 17 and 558).