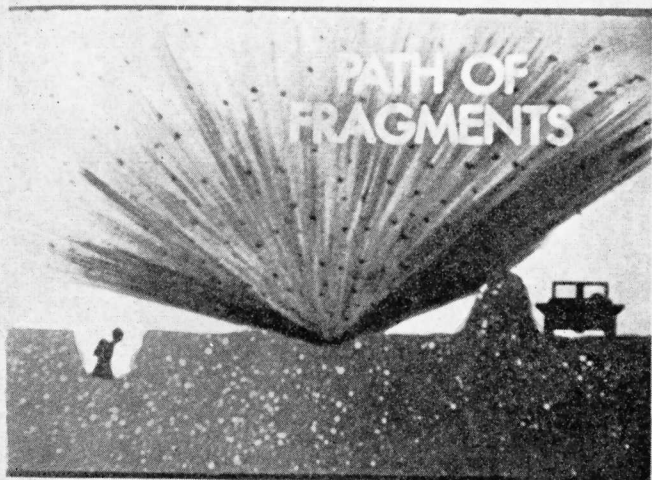


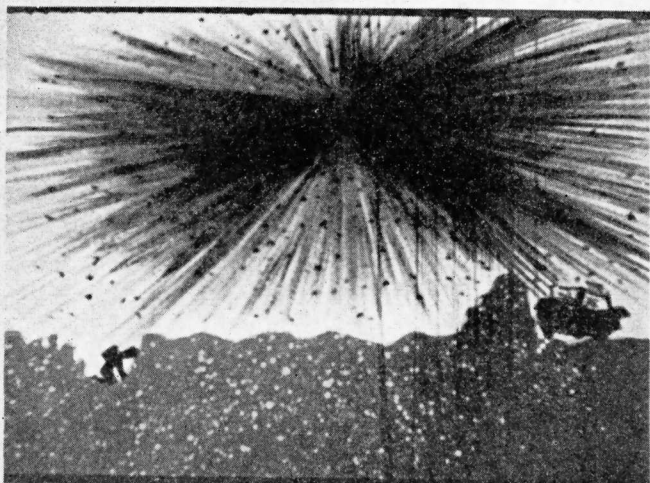
THE RADIO PROXIMITY FUZES
for
BOMBS, ROCKETS AND MORTARS

A brief story of the development, production, and use of these radio proximity fuzes, with some of the historical circumstances, is presented. The project was sponsored, administered and supported by the National Defense Research Committee jointly with the Army, with the National Bureau of Standards serving as the central laboratory.

THE SENIOR STAFF OF
THE ORDNANCE DEVELOPMENT DIVISION
NATIONAL BUREAU OF STANDARDS
OCTOBER 1945



INSTANTANEOUS BURST PATTERN



AIR - BURST PATTERN

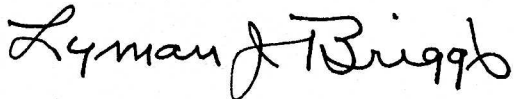
Washington, D. C.

October 23, 1945

To the Members of the Ordnance
Development Division:

Throughout the war, I have watched the work of your Division with great interest. You were made responsible for the successful completion of a great undertaking and you have justified the trust that was placed in you. The enthusiasm with which you approached each task and the teamwork and diligence with which you carried it through deserve the highest commendation.

You may well take pride in your record of accomplishment.

A handwritten signature in cursive script that reads "Lyman J. Briggs". The signature is written in dark ink and is positioned above the typed name.

Lyman J. Briggs, Director,
National Bureau of Standards

I. THE PURPOSE OF THE FUZE

With the conclusion of World War II, stories of new and highly secret weapons are being published. One of the most spectacular of these weapons, and one whose existence the Allied Command guarded most closely, was the radio proximity fuze—the fuze which automatically explodes a projectile, be it shell, bomb, rocket, or mortar, approximately at the point at which the most damage will be inflicted. Navy press releases have furnished information on the VT shell fuze development, and Army releases have told of VT fuzes for bombs, rockets, and mortars. There follows a brief story on the development, production and use of these latter three fuzes.

The idea of a fuze which will explode when it is *close* to a target is an old one in ordnance circles. The advantages are obvious. If a fuze can be made to explode anywhere in the vicinity of an airplane target, the effective size of the target is greatly increased and fewer shots are wasted. Many projectiles which miss the airplane would explode close enough to destroy it.

When projectiles are used against ground targets, such as infantry, the advantage of air burst is equally great. With a contact fuze, if the projectile misses the target, it is relatively ineffective, most of the projectile fragments and blast being directed upward and away from the target. Relatively shallow foxholes or slight depressions in the ground provide good protection from all save direct hits. It is again obvious that if the projectile could be made to explode say twenty or thirty feet in the air, even deep foxholes would afford scant protection to enemy troops. Furthermore, destruction of buildings by the blast effect is considerably enhanced with the air burst.

The VT fuze, therefore, is a weapon of almost overwhelming possibilities. Projectile effectiveness (casualties per round) is increased from five to twenty times that of the same projectile fitted with a contact fuze. To realize completely the importance of this, we must consider, in addition to the increase in enemy casualties, the all-important problems of logistics—the movement of men and supplies. One squadron more than does the work of five; less than one-fifth of the usual amount of supplies (food, ammunition and all the sundries) are required for a particular operational use. These advantages are so great that they warrant almost any degree of expenditure and effort to perfect the VT fuze and to supply it in quantity to our service forces.

Even in the First World War, the air burst was much sought after. Many expedients have been adopted to obtain it. One of these was the time fuze. It was a useful but rather poor method of obtaining an air burst at the desired point, since methods for obtaining the precise timing required for projectiles traveling several hundred feet in a tenth of a second were never achieved. Another expedient was a delay fuze fired so that the shell would ricochet and burst in the air. Still another was the "walking stick"—a rod two or three feet long projecting from the nose of a bomb to detonate it at the length of the rod above ground. Greater heights are required for real effectiveness.

Bombs were not a very important weapon in the First World War because of the limited use of airplanes. In the Second World War, they were of first importance. Here the need for VT fuzes was urgent. One startling use of VT-fuzed bombs was to neutralize anti-aircraft gun positions by putting the gun crews out of action or by forcing them to seek cover, so that other bombers could attack without opposition. Applications other than on fragmentation bombs are apparent, such as use on large blast bombs, fire bombs and gas bombs.

Rockets are one of the most important new ordnance items used in the recent war. Their widespread use resulted in urgent demands for proximity fuzes for these projectiles.

There is no weapon to which the VT fuze is more suited than the trench mortar—the foxhole cannon—none in which the gain in effectiveness is higher. The VT principle was not applied to mortars early in the war because development had not progressed to the point where sufficiently small fuzes could be made. Development was complete at the war's end and large-scale production was well on the way. The final model was less than half the size of the smallest previous fuze and gave evidence of having the best performance of any fuze produced.

The radio proximity fuze is a tiny radio sending and receiving station and is so small that some models may be covered by a man's hand. It operates by continuously sending out radio waves which act as feelers, reaching out to detect any nearby object. When an object of reasonable size is approached, the radio waves reaching that object are reflected back to the projectile. The fuze receiver picks up these reflected waves, and when they reach a sufficient intensity (that is, when the projectile is close enough to the object), they operate an electronic switch which detonates the fuze and the projectile.

The construction and operation of the fuze is, of course, more

complex than this simple description implies. Fuze design is shaped to the intended use; the fuze must fit and must operate according to the particular requirements of the projectile in which it is to be used. Many factors control fuze design—among them, size and velocity of the projectile, the type of target, and the height or position of the desired explosion.

Another factor of primary importance is safety. The ideal fuze is so safe that a child may handle and abuse it without danger. The Ordnance Department of the U. S. Army is insistent that all possible safety precautions be included in all fuzes. The interrupted explosive train is a primary safety means. VT fuzes are designed so that if, by some mischance, one functions prior to its release against the enemy, a thick metal plate is between the detonator (similar to a blasting cap) and the high explosive of the projectile, thereby preventing its detonation.

The method of removing this metal plate so that the explosive train is completed varies with the type of fuze. In bomb fuzes, a propeller drives a gear train to complete the powder train; in rockets and mortars, the force of acceleration, which is from 10 to 10,000 times the force of gravity, operates a mechanical device and, in conjunction with an air-driven propeller and gear train, completes the explosive train.

VT fuzes so far developed are all generally similar in that they have corresponding elements. There are many major differences, but they involve such factors as size, shape, detailed circuitry, safety means, and the type of electric power supply.

II. EARLY DEVELOPMENT

On June 27, 1940, the National Defense Research Committee was organized as an agency to encourage, promote, and coordinate national military research. In the original NDRC organization, Division A, Armor and Ordnance, had the responsibility for development of new and improved ammunition.

In November 1940, the chairman and vice-chairman of Division A discussed with the Director of the National Bureau of Standards, the problem of fullest utilization of the facilities of that Bureau. As a result of these discussions, an NDRC liaison officer to the National Bureau of Standards was appointed, and was shortly thereafter made Chief of the newly organized Section E, of the Armor and Ordnance Division of NDRC. This section was made responsible for development of radio proximity fuzes for non-rotating projectiles. The work on a radio proximity fuze for rotating pro-

jectiles remained at the Department of Terrestrial Magnetism, as Section T of Division A, NDRC.

The services of National Bureau of Standards scientists and engineers were enlisted on December 28, 1940, and work was begun on the development of the radio proximity fuze.

Development work started much earlier in other countries. Great Britain was working on the idea in 1937 and sent a commission to this country in mid 1940 which gave American scientists the benefit of their experiences. Germany started work on similar devices in the early thirties. Difficulties lay not in formulating the basic ideas, which had been proposed by a number of people before the war, but in the determination of basic design data to prove that the job could be done. This involved answers to such questions as how strongly do airplanes and other targets reflect radio waves, what is the detailed form of the signal, what degree of responsiveness can be obtained from radio circuits, and how can that responsiveness be shaped to obtain best fuze operation. Determination of mechanical design detail and the development of tiny yet very sturdy electrical and mechanical components capable of performing under the severe conditions of war were of equal importance.

From the beginning of work on radio proximity fuzes, the prime requirement was speed, and as each development was completed, an increasing number of projects was added. These projects required the successful completion of a tremendous amount of investigation in different scientific fields in a minimum of time and necessitated continuous expansion of the scientific staff engaged in this work at the Bureau. The nucleus of this staff was formed in early 1941 from members of the National Bureau of Standards Staff and, subsequently, many other Bureau scientists were loaned by various Divisions to the fuze project. Scientists and technicians were brought in from university and commercial laboratories all over the country. Notable contributions to personnel were made by the State University of Iowa, Lafayette College, Lehigh University, and the City College of New York. Beginning with a staff of eight in early 1941, the fuze development group at the Bureau of Standards grew into an organization of 400 in 1945.

Consultative service was furnished by all of the regular Bureau Divisions throughout the program.

Both the Army and the Navy assigned personnel to work at the Bureau during the last years of the war. The work of these men contributed greatly to the successful production of the fuzes.

The first object of a bomb fuze development was to build a fuze

to set off a rocket attached to a bomb after that bomb had fallen to within several hundred feet of a battleship. By this means, impact velocities high enough to penetrate and sink a battleship were expected. This requirement served as the first short-time objective, but it quickly gave way to a more general proximity fuze development program.

With this requirement in mind, a general survey was undertaken. Members of Carnegie Institution had been working on proximity fuzes at the Department of Terrestrial Magnetism Laboratories. They supplied the general introduction to the project, proposing a beating oscillator arrangement. From Great Britain came a plan using a reaction oscillator with plate detection, and work was also under way at Carnegie Institution on a similar arrangement. Various other principles, including the principle of the radio altimeter, were considered.

It was soon apparent that a fuze utilizing the Doppler effect of reflected radio waves was the most promising. Members of the Radio Section, Electrical Division, National Bureau of Standards, devised a diode detector arrangement whereby any reflected radio wave caused variation of the radio frequency currents in an antenna to produce the desired signals, and a series of laboratory experiments was undertaken. The first model consisted of a simple square box with radio tubes and batteries properly arranged with rods projecting from each end as antennas, and its operation was tested by raising and lowering the model over ground by ropes and pulleys. Signals reflected from the ground were measured and found to be strong enough to promise successful operation.

The model was taken to the National Bureau of Standards field station at Camp Springs, Maryland, about January 15, 1941, and a private pilot, who was not informed of the nature of the experiment, flew over the model, which was fixed at the top of an 84-foot radio tower. When the plane passed within some fifty feet of the model, indication of its passage was observed. As a result of this test, numerous other tests of this nature were conducted at the Naval Proving Grounds at Dahlgren, Virginia. Models from the National Bureau of Standards, as well as models from the Department of Terrestrial Magnetism, were used. These tests gave the first positive operational information on certain design details which were later used in VT fuzes for anti-aircraft operations.

Later the Bureau Staff supervised an extensive series of tests at the Naval Air Station at Lakehurst with the cooperation of Naval personnel at that station. Fuze models were suspended beneath a blimp and fighter planes dived past the models. Photo-

graphs taken of the form of fuze signal provided information which was of major importance in the design of fuzes for anti-aircraft use.

During January of 1941 there was an experiment at the Bureau's station at Camp Springs, Maryland, in which a VT fuze model was carried aloft by large meteorological balloons (tethered) and the balloons shot down with a .22 calibre rifle. After several failures, the model was released at an altitude of about 300 feet and functioned by detonating a test charge at about 40 feet above the ground. Three models were then built for preliminary operational trials. These were mounted in M38 practice bombs and on February 12, 1941, were dropped from a plane flying at 3,000 feet at the Naval Proving Ground at Dahlgren, Virginia. Two of these models operated after about eight seconds of fall (the time to arming), but the third functioned properly about ten feet above the water target.

A second set of three models was then constructed and tested in the same manner on March 27, 1941. Similar results were obtained, one functioning at about ten feet.

The mechanical design was then changed and new models were made. Six of these were tested at the Naval Proving Ground at Dahlgren, Virginia, on April 26, 1941. With the bomber flying at 3,000 feet, the six bombs were released separately. All six functioned at heights of from 150 to 300 feet over the water, and heights corresponded to the measured responsiveness of the fuzes as determined in the laboratory.

These tests were a strong factor in determining the course of proximity fuze development because they proved that a radio proximity fuze was practical. Up to the date of these tests, a large amount of effort was being expended in various agencies on the development of other proximity fuze principles, notably the photoelectric (a successful development treated later) and the acoustic fuze. These were relegated to second place as the success of the radio fuze became assured.

Having demonstrated the practicability of the principle, it remained to add the detailed engineering and development work needed to turn a "first model effort" into a producible item fitting all of the service requirements. It should be well noted that these first models proved the principle. They did not provide all of the components and practices required to produce a satisfactory service fuze. At this stage the real work was just begun.

However, model construction was based on principles which were adopted for all VT fuzes. All components were mounted rigidly. Circuit elements were either completely immersed in wax or

were tied to a rugged frame structure and given a heavy protective wax coating. Shock mounting was not used, and the principle of making all components so stiff and rugged that there could be no relative motion, even with severe mechanical vibration, is still in general use. Amplifiers were designed to accept the signal frequency band only, and to discriminate against noise and undesirable signals of other frequencies.

The first models were cumbersome. The bomb body was utilized as part of the antenna and a separate section projected out of the tail of the bomb to complete the antenna. This added length was prohibitive from an operational standpoint since it reduced the bomb load which could be carried by a bomber. Substitution of a mock antenna section in the form of a wire coil and topping the coil with a piece of metal, generally in the form of a one-inch cone or a ring, reduced the added antenna section to a length of about two inches.

Experimenting with fuze models mounted on bombs, a peculiar directional effect was found—radiation of radio waves was strongest near the end opposite the radio fuze. This effect was supported in radio literature on antennas in general. In commercial developments before the war, it was of some interest but of no major importance. For this reason, little data on the effect existed. One of the major characteristics investigated in the course of VT fuze work was this phenomenon, which exerted considerable influence on the detailed fuze design.

In about June of 1941, work was extended to include the development of rocket fuzes. Rockets available at that time were of British design built for the defense of London. The complete round was about seven feet long and 3.25 inches in diameter. The initial design for this round placed the fuze between the rocket motor and the high explosive. Except for the size of the fuze occasioned by the large commercial batteries and by the size of the tubes and components, the fuze was reasonably good. From January to May 1942, some quantities were tested at Aberdeen Proving Ground against ground and air targets with considerable success, but the rockets were not very satisfactory and the development was not processed through the production of more than model lots. Julien P. Friez and Sons, of Baltimore, were consultants on the project and built a number of models.

Engineers of the Westinghouse Electric and Manufacturing Co., in Baltimore made many contributions. They suggested the use of tung oil, polymerized to the consistency of art gum, for pot-

ting some of the electronic parts. The suggestion was widely adopted and used generally in fuze production.

During these early months of development, primary attention was directed toward the electronic circuits and principles. When these were reasonably well established, intensive work was started on the mechanical switches and safety mechanisms which played such an important role in the production of the complete fuze. Scientists and engineers drew heavily on the broad knowledge of explosives and safety mechanisms of Army Ordnance experts, and then devised the specific designs.

Development and testing of bomb fuzes was continued during the same period. A number of small lots of fuzes were produced, the main effort being directed toward securing operation from altitudes of 10,000 feet and higher. The higher bomb velocities encountered at these altitudes resulted in vibrations which the radio tubes (of the commercial varieties) could not withstand, and operation of these model lots was poor. It soon became evident that better components would have to be procured if practicable performance was to be realized.

The electronic tubes were of particular importance, the commercial types then available being both large and structurally weak. Small hearing aid tubes offered the best solution to the problem. The Raytheon Manufacturing Company, Hygrade Sylvania, the General Electric Company, and the Hytron Manufacturing Company, who were already working on tubes for the shell fuze under Section T contracts, were consulted, and a development program was begun which finally resulted in the production of very large quantities of high quality, small, and extremely rugged tubes for VT fuzes. Some idea of the difficulties these manufacturers met and solved may be had by a one-sentence description of the mounting of the tube filament—"Working so fast that observation is difficult, young women put invisible wires into invisible holes and weld them in place."

In February of 1942, a new method of arming VT fuzes was proposed and tested by the Bureau staff—RC, or condenser, arming. An electric charge was fed into a condenser through a resistor to provide delay in the charging time. The time delay was controlled by the size of the resistor and condenser. Circuits were laid out so that when a predetermined time had elapsed, the condenser had sufficient electric charge to furnish the current for exploding the detonator when the fuze approached the target. The system was immediately used for tests of sample lots and was later adopted and used in many fuzes, including the VT shell fuze.

During May 1942, a few bomb fuzes were built using an arrangement which later became one of the most successful types. The bomb body was not used as the antenna, but two strong metal bars were built into the fuze and mounted at right angles to the fuze and bomb axis, thus providing an antenna separate from the bomb body. Ten of these were tested on May 18, 1942, at Dahlgren, Virginia, by dropping them from altitudes of 10,000 to 15,000 feet. Four operated properly at heights of from 150 to 300 feet over the water target.

In this same period, work was started on a simplified oscillator employing grid detection and pursued later with the collaboration of a staff member of the Royal Aircraft Establishment of Great Britain, who had also done earlier work on the circuit. The work culminated in the general adoption of the circuit for bomb, rocket, and mortar fuzes.

Fuze development was continually handicapped by testing difficulties. The electronic parts must produce radio signals which are constant to about one part in 10,000, despite the rough treatment the fuze receives when the projectile is used. A bomb approaches maximum velocity after it has fallen some 20,000 feet. This means that air turbulence and drag prevent the bomb velocity from increasing, and a large amount of energy is dissipated in sound and in vibration. The flight time of a bomb or rocket is never over one minute, which is a short time for experimental work on a remote, fast moving object.

Tests under conditions simulating flight conditions were very valuable in development and production, but were never finally conclusive. Field testing is a "one try" proposition, since each test destroys the fuze. Evidence was obtained on a statistical basis, literally thousands of test rounds being required to establish fuze quality or to examine and determine the cause of some defects. Extensive statistical studies were required, and a group of statisticians was established as part of the Proof Operations Section, and later as a separate section.

III. THE FUZE FOR THE M-8 ROCKET

On May 12, 1942, the Army requested Section E, Division A, NDRC, and through them the National Bureau of Standards, to develop a VT fuze for a new Army, 4.5-inch airborne rocket, the M-8. The project was given very high priority, there being an urgent need for the weapon to combat the then all powerful German Luftwaffe. By agreement between Army ordnance engineers, Section E and Bureau scientists, fuze and fuze well dimensions

were established; designs were completed within two days, and construction of test fuze lots began.

Various expedients were adopted to rush completion of samples for testing. Complicated mechanical and plastic parts were fabricated by hand to avoid the delay incidental to procuring tools and molds for high speed production. Temporary switch and safety mechanisms were used. Batteries too large for final use were available and these were used until battery development was complete.

The 4.5-inch rocket was not available in any quantity until the fall of 1942, so it was necessary to adopt a substitute round, the 3 $\frac{1}{4}$ -inch Cenco motor, used widely as a target in gunnery training. Its operational characteristics were materially different from the 4.5-inch M-8, but it proved satisfactory as a development tool.

The final design consisted of three primary parts: the fuze head, containing the electric circuits; a new and quite small dry battery developed by the National Carbon Company for the shell fuze; and a switch, interrupter, and booster mechanism.

Both the battery and the switch deserve special mention. Without the cooperation of the battery manufacturers, notably the National Carbon Company and the Burgess Battery Company, development would have been seriously hampered. The original design of the switch and safety mechanism was developed by the Bureau Staff and remained virtually unchanged throughout the model and production stages. The safety record throughout the proof-testing period was remarkable, there being no instance of failure of the safety mechanism. Credit is due Globe-Union, Inc., of Milwaukee, manufacturer of the switch, for their excellent design detail work and for the perfection of their production methods.

Production of small proof lots was begun. The increased responsibilities inherent in the new development required new proving-ground facilities, and the South Atlantic Coast was surveyed for proving ground areas. A suitable area was found just south of Fort Fisher on the coast near Wilmington, North Carolina, where a range of some 2.5 miles along the beach to the mouth of the Cape Fear River was available. The range over the ocean was unlimited. Test operations were started there in June 1942. The proof operations section set up the field station and the necessary laboratories, targets, and range accessories. These facilities included extensive photographic equipment for determining projectile and fuze performance. Examination of projectile performance was needed because of the inter-dependence of the fuze and the rocket. This was not firmly established until some months

later when the early precautions of taking complete operational records aided in determining and correcting a series of faults in the 4.5-inch rocket and fuze combination.

Two markedly different fuzes were developed simultaneously for the 4.5-inch rocket, the radio fuze and the photoelectric fuze. The latter fuze was one of the first successful types developed. Mention of its use has been omitted up to this point because properties inherent in this fuze prejudiced its operational use.

The fuze is just what its name implies—a fuze which is sensitive to changes in light intensity. It is a photoelectric cell equipped with a lens. When an object passes between a portion of the lens and the sky, the light intensity changes and the fuze detonates the projectile. Functionally, the fuze was excellent. Under conditions favorable to its use, nearly all of the fuzes tested functioned properly. The position of burst for airborne targets was exact since the field of the lens was a narrow circular band about 30 degrees ahead of the geometric plane perpendicular to the axis of the projectile. Two faults inherent in this type of fuze prejudiced its service use and ultimately resulted in suspending further development work: (1) the fuze depended on light for operation and could not be used at night, and (2) when the sun moved into and out of the lens, the fuze functioned prior to reaching the target. Methods for resolving both difficulties had been devised, and tested, but the radio fuzes were working so well that the project was eventually suspended in order to concentrate all available effort on that fuze.

The Bell Telephone Laboratories collaborated in the development of the photoelectric fuze and made many contributions.

It should be noted that the same satisfactory operation had previously (1941) been obtained by other workers with the photoelectric fuzes for bombs, and the project was shelved for the same reason that the photoelectric rocket fuze was shelved.

Meanwhile, development and testing of the radio proximity fuze was proceeding. The initial model lots for preliminary testing were produced in small-scale production lines at the National Bureau of Standards and at the Westinghouse Electric and Manufacturing Company. Some 55 of these fuzes were first tested at Fort Fisher during the period June 6 to June 18, 1942. Operation was rather poor for a number of reasons. Target facilities consisted of a crossed dipole array, some 100 feet long supported by a small barrage balloon. The arrangement was difficult to handle and high winds frequently prevented its use. Variable winds and a swaying target made aiming difficult. Finally, the fuze circuits

were not entirely satisfactory. As a result, tests were spotty and tedious.

The difficulties were relieved by two simultaneous developments: (1) highly selective fuze circuits using feedback principles, now used in all bomb, rocket and mortar fuzes, were devised, and (2) a method of using a fixed ground target was found. At this point it is relevant to point out that VT fuzes are not activated by objects whose distance from the fuze does not change, as, for instance, an object moving parallel to the fuze projectile and at the same velocity. From this it is obvious that if the VT-fuzed projectile is made to travel parallel to a level plane, it will not operate on that level surface; it must *approach* that surface to function.

Following this principle, a rocket projector (gun mount) was set up at Fort Fisher on a tower about 30 feet above a level sandy area. Some 700 feet ahead of the projector, a wire screen 12 feet wide and 60 feet long was set up 20 feet above the level sand plane. When the projectile was fired over this range, the fuze functioned only on approach to the wire screen, since this was the only object on the range whose distance with respect to the projectile was changing.

Nearly all of the development testing of the fuze for the 4.5-inch rocket was done on a range of this type. Various improvements were made. The height of the tower mounting the rocket projector was increased; photographic facilities were provided on the projector tower and the target was changed from a flat screen 20 feet above the ground to a wire target of the shape of a medium bomber 60 feet above the ground. This arrangement proved to have the constant characteristics needed for the fuze development. It was useful in all kinds of weather. While with the old aerial targets, 12 test rounds per day was a good average, a round a minute was possible with the ground target.

More than 1000 fuzes were built in the Bureau's model shops during June and July. Field tests were quite satisfactory; almost all of the rounds passing within 60 feet of the target exploded alongside. The effect of ejected gases on fuze function was an important problem which was investigated extensively and successfully. On August 4, 1942, the first detailed specifications were completed.

Seven manufacturing companies were asked to accept OSRD contracts to develop production designs and produce the fuzes. These companies were: the Westinghouse Electric and Manufacturing Company of Baltimore, Emerson Radio and Phonograph Company, Julien P. Friez and Sons, Philco Radio and Television

Corporation, and the General Electric Company for the radio fuze, and The Rudolph Wurlitzer Company, Westinghouse Electric and Manufacturing Company in Mansfield, Ohio, and the Bell Telephone Laboratories for the photoelectric fuze. Complete production designs were drawn up and full production was started without waiting for initial model trials. It will be recognized that any such procedure is a gamble, since first engineering designs are seldom perfect. However, the urgency of the project did not permit the slow-but-sure policy of testing new models completely prior to production.

Under the agreement with the Army Ordnance Department, the Signal Corps handled the procurement of all of the rocket fuzes and a substantial portion of the bomb fuzes which followed, and they maintained resident engineers and inspectors in the factories throughout the contract life. An extensive quality control laboratory, with equipment to provide a critical analysis of the fuzes, was set up at Belmar, New Jersey, in November, 1942, and continued through August, 1943, at which time the activity was transferred to the National Bureau of Standards.

It is noteworthy that while three different production designs for the radio fuze were used by the various companies, the performance of all three was so nearly alike that no one design could be said to be superior operationally to any of the others.

The photoelectric fuze was built to one design. As previously noted, when test conditions were right, its performance approached the ultimate of 100 per cent, and production fuzes met this high standard.

Production was started in the latter part of 1942 and continued through most of 1943. About 400,000 each of the radio and photoelectric proximity fuzes were manufactured.

While this radio proximity fuze was developed primarily for use against aircraft, the design quite fortunately proved correct either for use from airplanes against troops and gun emplacements, or for use from the ground against such targets. One spectacular application was its use as a barrage weapon from large tanks. A multi-barreled projector holding 60 VT-fuzed 4½-inch rockets was mounted on a General Sherman tank. The rounds were fired at one-tenth second intervals. Operation was excellent, and the ground target area was completely covered by a dense pattern of fragments from the exploding projectiles. Such concentration of fire makes any position without cover untenable.

In December 1942, as a result of a reorganization of the NDRC, the original Section E, Division A of NDRC became Division 4,

NDRC. At the same time, the Ordnance Development Division of the Bureau of Standards was organized and began functioning as a separate Division of the Bureau, devoting its entire time and energy to the development of these fuzes.

IV. BOMB FUZE DEVELOPMENT

Upon the successful completion of the rocket fuze developments and transfer of procurement of rocket fuzes to the Signal Corps, the Ordnance Department requested Division 4, NDRC, in January 1943, to undertake the development of a similar fuze for possible use in air-to-air attacks on enemy bomber formations. This fuze was to fit the same fuze well as standard nose fuzes and to protrude no more than five inches from the bomb. Initially, the tactical situation was considered in which the attacking plane flies above the enemy formation and releases the bomb while flying at the same speed and in the same direction as the formation. As the war progressed, however, it became evident that targets for such weapons were becoming scarce, and that such a weapon might be used more effectively by the enemy than by Allied Air Forces. Accordingly, in May 1943, the request for bomb fuzes for air-to-air use was changed to one for fuzes for air-to-ground use to provide an air burst over personnel and light materiel targets. The major share of attention for the ensuing year was devoted to this problem in its varied aspects.

Certain design considerations were evident in the initial survey of the bomb fuze problem. Because the vehicle on which the fuze is mounted is different and the application is different, the electronic circuit must be different from that of the rocket fuze. The space into which the fuze must fit was also different, and a physical redesign was necessary. Since a bomb is not subject to setback at release, as is a rocket fuze, a different arming mechanism was necessary.

Experience in the development of the first rocket fuze demonstrated that the usual type of dry battery was not very satisfactory as a power source. It deteriorated rapidly in storage, its life being about a year under ideal storage conditions and not more than one or two months under conditions of high temperature and humidity. Dry batteries will not work at the sub-zero temperatures encountered by high-flying bombers. To be fully useful in the military sense, a weapon must be rugged enough to withstand any possible kind of handling or storage. It became a matter of first importance to devise a means for supplying power to the fuze which met all requirements of military usage.

Storage and reserve types of wet batteries were investigated in some detail. The Bureau's Battery Section devoted much time to the project. The National Carbon Company built a number of samples of wet batteries which were energized by rocket acceleration, some of which performed reasonably well, but they had numerous faults which made them unsuitable for service use.

Considerations of the logistics of aerial bombardment required maintenance, or, if possible, improvement, of the high quality level attained with the rocket fuze. The expenditure involved in delivering bombs to the target is such as to justify great care in manufacture, if by so doing the number of defective fuzes is reduced.

For the air-to-air case, the fuze which utilized the bomb body as the antenna was necessary, since such a system is most responsive off the sides of the bomb. This characteristic is necessary for functioning on passing a target. However, for the air-to-ground case, an antenna whose maximum responsiveness is forward is more desirable. This is realized when an antenna is mounted in the fuze itself at right angles to the axis of the bomb.

In the initial development of VT bomb fuzes, the first-named type of antenna system, known as "longitudinal excitation" was utilized, since both the air-to-ground and air-to-air aspects had to be kept in mind, and because electrical circuits for this type of fuze were better known. Soon after, as will be seen, work on the "transverse excitation" type of antenna was also initiated.

The type of arming system selected was one in use in almost all standard bomb fuzes and one which is regarded by the Air Forces as quite reliable; i.e., air travel arming. A small vane at the front of the fuze actuates the arming mechanism so that arming occurs only after this vane has turned through a certain number of turns, representing a definite amount of travel through the air after release of the bomb.

Use of a wind-driven propeller for arming leads naturally to a solution to the power supply problem. Since there is already a rotating system present, this may be utilized to drive a generator which supplies the necessary electrical power for the fuze. Preliminary investigations indicated that sufficient electric power could be obtained from a generator of the necessary dimensions; that control of voltages with speed variation could be attained; and that small rectifiers of suitable characteristics could be made. This type of power supply has, of course, an indefinitely long shelf life, performs well over an extreme temperature range, and has the additional advantage of increased safety, since there is no possible way

the fuze can detonate unless the vane is turning at a high rate of speed.

The requirement for a generator of small size, high power output, rugged design, stable operation, and simple construction led to the development of a permanent magnet alternator. The rotor consisted of a very strong but small disc magnet made of Alnico. Coils were mounted on a magnetic stator surrounding the rotor. The original models of the generator were about $2\frac{5}{8}$ inches in diameter and one inch long. An electrical regulation circuit was developed for this generator which maintained constant generator power output even though the rotational speed of the generator varied over a range of three to one.

The Westinghouse Electric and Manufacturing Company of Baltimore, and the Rudolph Wurlitzer Corporation of Tonawanda, New York, made major contributions in generator design.

In April 1943, the Zenith Radio Corporation was requested by Division 4, NDRC, to make a production design of the fuze generator, and samples were received a few weeks later. These samples were somewhat smaller ($\frac{3}{4}$ " long by $2\frac{5}{8}$ " in diameter) than the original design and proved highly satisfactory. This design was subsequently used in large quantity in fuze manufacture.

Having devised a suitable generator, rectifiers were needed to change the alternating voltage developed by the generator to the direct voltage required by the fuze. Investigating commercial products, selenium rectifiers promised the best solution. In response to requests for these items, the General Electric Company of Lynn, Massachusetts, the Federal Telephone and Radio Company of Newark, New Jersey, and the P. R. Mallory Company of Philadelphia, Pennsylvania and Indianapolis, Indiana, responded by developing mass-production methods whereby millions of selenium rectifier discs were produced. The fuze rectifier assembly is about half the size of a cigarette.

The development of the generator was a milestone in proximity fuze design, but it was not an unmixed blessing. Normal commercial machinery runs at speeds not greater than 3,600 revolutions per minute. High speed tools run at about 12,000 rpm. In these small VT-fuze generators, design considerations required speed up to 50,000 rpm. At such speeds, mechanical stresses and the resulting vibration are great. Much effort was devoted to bearing design, to balancing the rotating mechanism, and to improving the rotor structure so that it would not fly apart at such high speeds. All of these problems were solved satisfactorily, and the wind-driven generator was accepted as the standard power supply for VT bomb fuzes.

The first new models of the radio bomb fuze employed the basic circuits of the early radio bomb fuze and the later radio rocket fuze, utilized the bomb as part of the antenna, were generator-powered, and were armed by air travel. On April 16, 1943, six fuzes mounted on 500-pound bombs were released from 5,000 feet, and five functioned properly. Laboratory testing in this period and subsequent field testing indicated that the vibration associated with the rotating system was frequently sufficient to cause the fuze to function "early" (i.e., without receiving a firing signal from a reflector) even in a carefully assembled fuze. Steps were taken to reduce the vibration and the response of the circuit to the vibration.

Small-scale production of models was begun at the National Bureau of Standards and a field test program was set up at Aberdeen Proving Grounds, Maryland, by the Ordnance Department. Design difficulties were corrected during the ensuing months, and in May 1943, Division 4, NDRC contracted with the Zell Corporation of Baltimore to set up a pilot line. In August 1943, excellent field scores were consistently achieved with pilot line models when mounted on 500-pound bombs and dropped from 10,000 feet. Specifications were written during this period and completed in November and the Philco Corporation was asked to set up quantity production of the fuze.

The Army Ordnance Department then requested that the fuze be designed to operate on all standard bombs from 100-pound to 1,000-pound sizes.

An extensive investigation showed that the various bombs exhibited marked variations in their radiation properties. Field tests confirmed that with some bombs, sensitivity was reduced so that burst heights were too low, while with others, the sensitivity was so increased as to enhance susceptibility to vibration, resulting in increased malfunctions. It was found, however, that by making two fuzes, one for the smaller bombs and another for the larger bombs, the range of bomb sizes could be satisfactorily covered, and good performance achieved on each bomb. The fuze initially developed served, with a slight modification, for one group of bombs, and a second fuze was designed for the other group of bombs. In late 1943 Bowen and Company, of Bethesda, Maryland, was asked by Division 4, NDRC, to set up another pilot line for the second fuze, and soon afterwards the Emerson Radio and Phonograph Corporation was asked to undertake large-scale manufacture of this model.

In the early stages of manufacture, as in the early stages of preliminary production, extreme difficulty was encountered in making the generator type fuze, due primarily to the vibration asso-

ciated with the rotating system and to a lesser extent to the vibration of the bomb itself. The vibration problem remained the most difficult single problem throughout the development and early manufacture of the bomb fuzes. It was found necessary to manufacture certain critical mechanical components to extremely close tolerances and to develop miniature radio tubes which were insensitive to vibration to a degree previously unknown.

Production samples were received from Emerson and Philco in April 1944, and mass production at these plants began in May 1944 and at the General Electric plant in Schenectady in February 1945 and continued until the end of the war. Additional design improvements were made from time to time, until, in June 1945, the quality level was very high and approached the 100 per cent ideal.

Throughout this period an extensive field test program was carried out at Aberdeen. Bureau personnel collaborated with Army personnel in conducting and evaluating the tests.

Preliminary service tests of the bomb fuzes led to minor modifications in the course of production. Chief among these was a device to provide delay in arming (in addition to that built into the fuze) which could be adjusted in the field to permit the fuzes to be dropped safely through deep formations of bombers. It consisted of a small auxiliary vane and gear train externally clipped to the fuse, which released the fuze vane after a pre-selected amount of air travel. The device was designed by the Bureau staff and was engineered for production by Globe-Union, Inc. All bomb fuzes were subsequently equipped with this device.

As noted earlier, the "transverse excitation" type of fuze offered certain advantages in air-to-ground bombing. Specifically, these advantages were: (1) good performance from high altitude, (2) less dependence on bomb dimensions, (3) greater sensitivity; i.e., greater burst heights. The necessary circuit research was initiated in April 1943 and in August models were made and field tested, and the feasibility of the design was established. Experience gained with the previous fuze was exploited. A circuit less sensitive to vibration was utilized and good field performance was obtained on several small lots of models. The vibration problem, however, remained an ever-present concern here also.

In August 1943, the Zenith Radio Corporation was asked by Division 4, NDRC, to undertake the production design of this type of fuze. Production designs were completed in June 1944, and models of the Zenith design were received and tested in July 1944. These first samples gave good performance.

Small-scale production began at Zenith in August 1944 and

gradually increased through the remainder of the year 1944. Extensive field tests were carried out during this period, in the course of which it was found that the fuze functioned properly on all bombs from 100-pound to 4,000-pound sizes, at heights somewhat greater than were attainable with the previous type, and that burst heights were relatively independent of release altitude. Quality was consistently high.

Large-scale manufacture began in January 1945 with the transferral of the production contract to the Signal Corps and continued until the end of the war. A uniform and very high quality level was maintained throughout the entire production period.

A third type of bomb fuze was developed by the Westinghouse Electric and Manufacturing Company (Baltimore and Mansfield plants). This type also utilized the "transverse excitation" antenna scheme, but employed a different type of generator and driving mechanism and different fuze circuits.

Early in the bomb fuze program, when it became apparent that major difficulties would be experienced with the propeller type of driving mechanism, means of altering the mechanical system in such a way as to minimize the vibration resulting from the rotation of the propeller and the generator rotor were considered. By using a turbine, mounted inside the fuze immediately adjacent to the generator rotor, and driven through an air intake duct in the center of the fuze, it is possible to make the rotating system more compact. By locating the generator within the fuze well of the bomb, the entire rotating system is mounted close to the point of support. Such an arrangement reduces the amplitude of vibration and accomplishes a substantial reduction in over-all length.

Under a Division 4, NDRC, contract, Westinghouse had been carrying on experimental work on fuze circuits since February 1942 and had carried out a promising field test of a transverse excitation battery-powered model in June 1942. Preliminary work on a suitable generator had been done in the later months of 1942 and in 1943. In August 1943, the design of a transverse antenna bomb fuze with a turbine-driven generator of the nature outlined above was begun.

A new type of generator having a diameter of $1\frac{3}{8}$ inches and length of $1\frac{1}{8}$ inches, capable of delivering the necessary power and voltage, was developed; tentative circuits and mechanical designs were made; and the first models were built early in 1944. The initial field tests were carried out in the period February through April 1944.

Improvements in the safety features and in the arming sys-

tem, electrical modifications to attain superior performance, and design changes to simplify production were made during the remainder of 1944 and early 1945. A production contract was made with the Ordnance Department in May 1945, and production began in June 1945.

V. THE GENERATOR-POWERED ROCKET FUZE

After the bomb fuze development had passed into the manufacturing stage, the Navy proposed that the OSRD adapt this type for use on the new Navy 5" aircraft rockets. These rockets carry a modified five-inch shell as the warhead and are about six feet long. One type, the AR (aircraft rocket) weighs about 85 pounds and attains a velocity of about 700 feet per second, and the other type, the HVAR (high velocity aircraft rocket) weighs about 140 pounds and attains a velocity of 1300 feet per second. These rockets can be fired from airplanes with remarkable accuracy using launching equipment so small that it adds very little drag to the airplane. Eight of these rockets were mounted under the wings of airplanes, thereby providing them with the equivalent of heavy caliber guns. They were used with great effectiveness by both the Army and the Navy.

Preliminary field tests at Blossom Point, Maryland, using bomb fuzes on these rockets, established the feasibility of using this type of fuze on the AR; however, some difficulties were experienced with the HVAR. Accordingly, in September, 1944, Division 4, NDRC, was requested to design a fuze suitable for use on the AR, which could be produced in a minimum of time.

Additional laboratory work and field testing established that the bomb fuze being manufactured by the Philco Corporation could be readily adapted to use on this rocket for either the air-to-air application or air-to-ground use. The major modification required was in the arming system. Whereas in the bomb fuzes, arming is accomplished by travel through the air, in rockets it is desirable to utilize the acceleration the rocket experiences in launching to provide additional safety. Accordingly, a switch was designed which was physically interchangeable with the gear train used in the bomb fuzes, of such a nature that an acceleration of the order of 10 times the acceleration of gravity for a duration of 0.5 seconds accompanied by an air travel of about 300 feet was required for the fuze to arm.

Upon completion of the design of the electrical and mechanical modifications, pilot production was begun at Bowen and Company in October, 1944, and the design was proved in during the following

weeks. In November Philco was asked to initiate production of the air-to-ground version of this fuze; and in December, 1944, General Electric, also manufacturing bomb fuzes, was asked to start production of the air-to-air version.

The air-to-ground fuze gave less trouble in production than did the bomb fuzes since it was necessarily less sensitive (to provide optimum burst heights over ground), and experience gained in manufacture of the bomb fuzes was fully utilized in manufacture of the rocket fuze. Production at the Philco Philadelphia Plant began in April, 1945, under a Signal Corps contract, and continued until the end of the war. A high field test quality level was maintained throughout production. Production of the air-to-air fuze by the General Electric Company at Schenectady began in July, 1945. Excellent cooperation and testing was furnished by the Naval Ordnance Test Station at Inyokern, California.

Development of a new rocket fuze meeting all service requirements was virtually complete in June, 1945. It featured an enclosed turbine drive for the generator and gear train, self-destruction and variable arming time as field options, and a change-over switch for air-to-air or air-to-ground operation. The mechanical design was similar to that for the mortar fuzes, there being considerable reduction in size over previous rocket fuzes.

VI. THE MORTAR FUZES

VT fuzes having been successfully developed and produced for all common projectiles except trench mortars, and designs having progressed to the point where a VT fuze small enough for the eight-pound mortar projectile appeared possible, Division 4, NDRC, and the National Bureau of Standards were asked to undertake this development. Preliminary design work started in the late spring of 1944, and the project was given top priority by the Army early in 1945. The Bureau of Standards contract with Division 4, NDRC, was taken over by the Ordnance Department on May 1, 1945, and the mortar fuze development project was carried out henceforth under the joint direction of the Ordnance Department and Division 4, NDRC.

The design of a fuze for the eight-pound mortar required the solution of two major problems; ruggedness and size. Whereas the early rocket fuzes were designed to withstand a shock 1000 times the force of gravity and the bomb fuzes had to stand up under normal rough handling in use, a mortar fuze must withstand a firing shock of 10,000 times the force of gravity. In addition, mortar projectiles are so small that fuzes of the size of those used on

bombs would spoil the flight of the projectile and make the round useless. Wind tunnel experiments indicated that if the VT fuze could be held to a diameter of $2\frac{1}{8}$ inches and a length of some 3 inches, satisfactory operation could be obtained. This required a reduction of 3 to 1 in volume as compared to bomb and rocket fuzes and yet the fuze was required to perform all the functions of these other fuzes.

Early design work followed two general patterns. Globe-Union, Inc., cooperated with the National Bureau of Standards under Division 4, NDRC, contracts in a design of a fuze whose general features followed the earlier rocket and bomb fuzes, but whose detailed design represented a marked advance over earlier models. A novel and highly significant feature of this design, carried out by Globe-Union at the request of Division 4, NDRC, was the manufacture of circuit components, such as resistors and condensers and the connections between them, by a new process involving the use of ceramics, thereby obtaining a material saving in space. This is a radical departure in assembly technique and may relegate other methods to the museum.

The second design was prosecuted in its development stages by the University of Florida, and used a small loop antenna instead of the projectile body antenna. The circuit design and power supply followed closely the designs of previous fuzes. A small number of models were constructed by the University of Florida and successfully tested. This design was taken over and engineered for production by the Zenith Radio Corporation.

A variation of the first design, developed by the Rudolph Wurlitzer Company in collaboration with National Bureau of Standards engineers, was externally similar to that built by Globe-Union, but differed from it in internal design.

The operating characteristics of the two types of fuzes differed in the same manner as the characteristics of the two types of bomb fuzes previously described. Since it was known that both would give good operation, and since no experimental evidence was at hand to demonstrate the superiority of one over the other, it was decided to build both types. Zenith Radio Corporation, Globe-Union, Inc., and the Rudolph Wurlitzer Company were asked to produce the fuzes on a large scale.

Again the urgency of the need for the fuzes dictated production prior to completion of development. Development and preparations for production proceeded simultaneously and in June, 1945, the Globe-Union Company, the first in the field, started their production schedule.

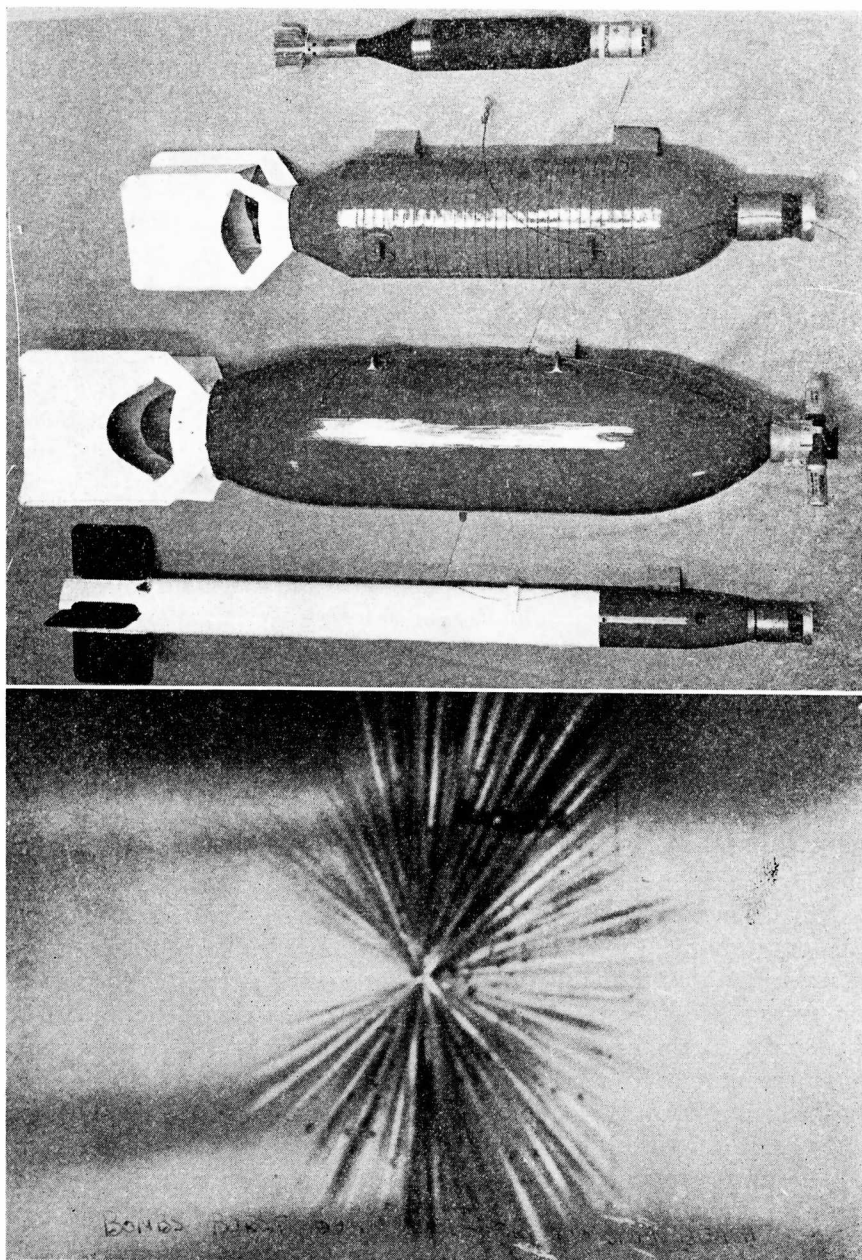
Extensive field testing was carried on from March through July, 1945, the test results furnishing the main guide to improvement in fuze quality. Throughout the development and early production period, field testing was done at the National Bureau of Standards field station at Blossom Point, Maryland and at the University of Iowa field station at Clinton, Iowa.

At the close of the war the Army production program for 100,000 mortar fuzes per month was beginning at the Globe-Union Company of Milwaukee and their subsidiary, Rewelec Mfg. Company of Lowell, Mass. Designs were complete at Zenith and Wurlitzer, and procurement was well under way for an additional 300,000 fuzes per month from these plants. The close of the war brought abrupt cancellation of all of these contracts which had been initiated against the contingency that war in the Pacific would last until mid 1946 or early 1947.

VII. PRODUCTION

From the production viewpoint the radio fuze presented an enormous challenge to production engineers. It is generally called an electronic device, and yet it is more complex mechanically than electrically. Once the electrical arrangements had been established, the primary task was one of mechanical assembly of considerable intricacy. Designs required a nice balance between the perfection and the producibility of each part. The radio fuze is comparable to a highly sensitive radio instrument electrically, and to a fine time fuze mechanically. Few manufacturers were completely qualified in both fields. Manufacturers of electronic equipment had to learn new skills in the precision mechanical field. Firms skilled mechanically had to learn electronic techniques and procedures. Add to this the fact that in each instance, production was required before the development work was complete, and it is apparent that the production task was as large and difficult as the development of the fuze. To handle its phase of this task, the Division, in March, 1943, set up a Production Engineering Section.

As each fuze design progressed to the point where minimum satisfactory performance was achieved, production was started immediately. Final designs were drawn up and frozen. Orders were placed with component manufacturers, and in many instances new component production facilities were set up. To further expedite procurement, Division 4, NDRC, Signal Corps, and the Ordnance Department frequently placed orders with component manufacturers and even purchased production molds and tools to assure an adequate supply of certain critical or new parts.



(Upper) Mortar Shell, Fragmentation Bomb, General Purpose Bomb, Rocket each with Radio Proximity Fuze.

(Lower) Rocket Bursting in Air Against Airplane

Meanwhile, development was proceeding with the primary objective of improving the fuze performance. With each new improvement came the problem of changing procurement and, sometimes, production tools. When it is remembered that mass production methods are generally predicated on a complete stock of component parts *three months* in advance of their use, some appreciation of the problems encountered may be had.

Development of a fuze leads nowhere unless manufacturing and testing techniques are available or are developed. Laboratory methods had to be changed to fit mass production practices. Through the cooperative efforts of the manufacturing companies, Division 4, NDRC, Ordnance and Signal Corps officers and engineers, and personnel of the National Bureau of Standards, satisfactory production was achieved.

The practice of setting up preliminary or "pilot" lines in the various factories was generally followed. By this means a trial of the production procedures and a test run of the production designs was had during the period when procurement for the large production runs was under way.

In addition to the factory pilot lines, Division 4 maintained its own pilot lines, which were operated not only through the development period but through the production period as well. Members of the Bureau Staff collaborated in the administration and direction. The purpose was threefold: (1) Preliminary models were provided in sufficient quantity to determine the practicability of the design before manufacturers' samples could be produced; (2) new improvements were introduced for "proving in" purposes without interfering with regular production; and (3) the fuzes provided a gage of quality for fuzes produced on the large production lines, and contributed to the improvement of manufacturing techniques. Pilot lines were set up at the Zell Corporation, Baltimore, in 1943, and at Bowen and Company, Bethesda, Maryland, in 1944. The latter company was maintained as a facility until the end of the war. The usual production rates were from 50 to 125 fuzes per day.

After mass production had started the problem of keeping quality high became a major effort. The fuze as manufactured was potted and cemented together in such a way that repair was difficult and often impractical, so that a single failure of any component meant the loss of the complete unit. This was a loss in time, labor, and materials which could not be tolerated. To reduce this, NBS personnel spent much time at the plants of the manufacturers assisting with specific problems and helping them avoid

difficulties which had arisen in other plants. Some engineers spent full time at a particular plant while others went from one to another. The manufacturers themselves were very cooperative in sending their engineers to NBS and even to the plants of their peace-time competitors for information and advice. As a result of a concentrated effort by all concerned, the rejection rate, which had been as high as 50% during some preliminary manufacturing runs, fell to less than 10% on most of the assembly lines.

To facilitate this cooperation, early in 1944 NBS established what later became known as a "Paul Revere Squad." This consisted of a group of field engineers of the Production Engineering Section who actually lived out of a suitcase for the next year. They traveled to the various plants, as needed, to help establish production procedures, introduce new techniques, and offer suggestions in an effort to reduce reject percentages and increase production. Trips involved one-day stands or two- or three-week stays, depending on the circumstances. These men were the advance guard for a group of more or less permanent resident engineers who were established at the plants late in the fall of 1944.

Another check on the manufacture of these fuzes was the establishment of the Control Testing Laboratory at NBS. This laboratory received a sample of every lot of fuzes manufactured at each of the various plants. Engineers performed numerous tests on the completed fuzes, including temperature, humidity, and salt spray tests. In this way a continuous check on all production was obtained and in addition all fuzes were manufactured to a central set of standards, resulting in a uniform product.

The final check on quality of production was always the field performance. Samples from each lot were sent to the field and expended on the proper vehicle in order to see whether or not the fuze functioned and to determine the height of function. Statistical studies on these results gave a very good criterion of performance of the overall design and the score of any particular sample showed whether or not the lot was up to standard. In this way the fuze was taken from the laboratory through production to final test in the field and was finally developed into a device suited to mass production and to effective use as a military weapon.

The production started with pilot contracts under NDRC sponsorship which were shifted to Signal Corps contracts when mass production began. The manufacture of the earlier battery powered fuzes (radio and photo-electric) was started in the latter part of 1942 by Westinghouse Electric and Manufacturing Company, Philco Radio and Television Corporation, General Electric

Company, Emerson Radio and Phonograph Corporation, Julien P. Friez and Sons, Western Electric Company, and The Rudolph Wurlitzer Company. A total of 780,000 fuzes of this type was produced.

The later type of generator powered bomb fuzes was manufactured by Zenith Radio Corporation, Emerson Radio and Phonograph Corporation, Philco Radio and Television Corporation, General Electric Company, and Westinghouse Electric and Manufacturing Company. Approximately a million such fuzes were produced by these companies. Philco and the General Electric Company manufactured the generator powered rocket fuze. Some 125,000 of these were manufactured principally at the Philco plant.

The mortar fuze was the last proximity fuze of the war, and its urgency was even greater than that of the other fuzes. In June, 1945, offices were established in Chicago to direct and expedite the start of production in that area, and at North Tonawanda, New York, for a similar purpose in that area. The offices worked with the respective Ordnance district offices, and were responsible to a committee of Ordnance, NDRC, and Bureau of Standards representatives formed to expedite the mortar fuze program.

VIII. TESTS OF EFFECTIVENESS

While the superiority of the radio proximity fuze may be surmised from a casual survey of its operation, a scientific evaluation of the potentialities of the fuze is established only by employing the fuzes in real or simulated combat under systematically controlled conditions and by carefully observing the results. Conditions of actual combat are usually not such as to permit careful controls and observations to be maintained. Thus the appraisal of effectiveness of this fuze, as of any weapon, is based on simulated combat tests carried out at military proving grounds. Computations carried out by mathematicians of the Office of the Chief of Ordnance, had indicated the magnitude of the gain in effectiveness to be expected by bursting projectiles in the air over shielded targets and had predicted optimum heights of burst for various projectiles.

The first test of the effectiveness of air burst rockets or, so far as is known, of any burst weapon, against ground targets was started in February, 1943, and completed with full-scale effect field tests in the latter part of 1943 at Fort Bragg, North Carolina. M-8 rockets were equipped with radio fuzes and with superquick contact fuzes and were fired into an effect field and the results with the two fuzings compared. The effect field consisted of 1 x 6 ft.

boards, 1" thick, spaced 15 feet apart in a checkerboard array, laid 1 inch below the surface. After each round was fired, the number of boards which were hit at least once by fragments which penetrated a distance of $\frac{1}{4}$ " into the wood, were counted. Twenty rounds with radio proximity fuzes and twenty rounds with super-quick contact fuzes were fired over the effect field and scored. Results showed the rockets with radio fuzes produced on the average 5.2 times as many casualties as did the contact fuzed rounds. Burst heights averaged 60 feet.

An exhaustive study of the effectiveness of air burst bombs in inflicting casualties against entrenched personnel was carried out by the AAF Proving Ground, Eglin Field, Florida, in the latter part of 1944. A large effect field, containing some 2200 targets in a square 700 feet on a side, was constructed. The targets consisted of panels of $\frac{3}{4}$ inch plywood, 2 feet wide and 6 feet long, placed at the bottom of slit trenches 12 inches deep, thus roughly representing men in shallow trenches. The targets were spaced over the field in a square array 15 feet apart.

Bombs of 260 lbs., 500 lbs., and clusters of six 20 lb. fragmentation bombs were dropped on the field. After each bomb was dropped, the number of boards perforated by at least one fragment from the bomb was counted. The 260 lb. and 500 lb. bombs were fuzed both with contact fuzes and with radio fuzes and various types of radio fuzes were used to give various burst heights. The clusters of 20 lb. fragmentation bombs were used only with contact fuzes, there being no radio fuzes available at the time for bombs of that size. The use of this cluster provides a valuable comparison, however, since it is widely used as an anti-personnel weapon.

Results of these tests are tabulated below as the ratio of casualties per bomb (or per cluster) relative to casualties per bomb inflicted by the 260 lb. bomb bursting on contact. Each value is an average of five to seven tests:

<i>260 lb. Bomb</i>		<i>500 lb. Bomb</i>		<i>20 lb. Cluster</i>	
<i>Height</i>	<i>Relative Number of Casualties</i>	<i>Height</i>	<i>Relative Number of Casualties</i>	<i>Height</i>	<i>Relative Number of Casualties</i>
Contact	1	Contact	1.7	Contact	.9
16 feet	16	19 feet	21		
50 feet	21	50 feet	37		
70 feet	20	50 feet	37		

Thus a superiority of air burst over contact burst of twenty to one is achieved under these conditions. In the same test it was found that if the target is flush with the surface, a factor of superiority of five to one is observed, a result in good agreement with the Fort Bragg tests. Results of both the Eglin Field tests and the Fort Bragg tests were in good agreement with the Ordnance Department's predictions.

A similar series of tests of effectiveness of airburst bombs against shielded targets was carried out at Ashley Walk, England, also during 1944. Division personnel collaborated with British scientists in conducting the tests and evaluating the results. These tests differed from the Eglin Field test in that the targets were designed to represent men in deep foxholes as well as in shallow foxholes, they were spaced thirty feet apart, were smaller, and the effect of blast for the surface burst was included in the evaluation. The British Ordnance Board reported the following ratios of casualties for the air burst bombs to casualties for surface burst bombs:

<i>Height</i>	<i>Men in Deep Trenches</i>	<i>Men in Shallow Trenches</i>
10 feet	4.0	3.7
35 feet	3.7	5.3

Another series of tests at Eglin Field led to a new application of VT bomb fuzes—use on the new “gel-gas” fire bombs. These bombs, containing up to 165 gallons of emulsified gasoline, are designed to spread burning gasoline over large areas upon exploding. However, when they are dropped from high or medium altitudes and fuzed to explode on impact, these bombs penetrate the earth for some distance before exploding, and a considerable amount of the incendiary material remains in the crater, reducing the effectiveness of the bomb. This wastage is overcome by fuzing the bombs to explode before impact, so that no crater is formed. Extensive tests of this application were carried out at Eglin Field and at Edgewood Arsenal, and it was found that for high and medium altitude bombing, the burned area was doubled when VT fuzes were used.

While gas was never used, the threat of gas warfare required maintenance of facilities for counter-operational use. Tests of the effectiveness of air bursting gas bombs in distributing persistent gas were conducted at the Chemical Defense Experimental Station, Porton, England, in late 1944 and early 1945. Results indicate that if a gas bomb is exploded at a height of 100 to 200 feet above the surface, the area contaminated by the gas is seven times as

great as the area contaminated by a surface burst of the same type of bomb.

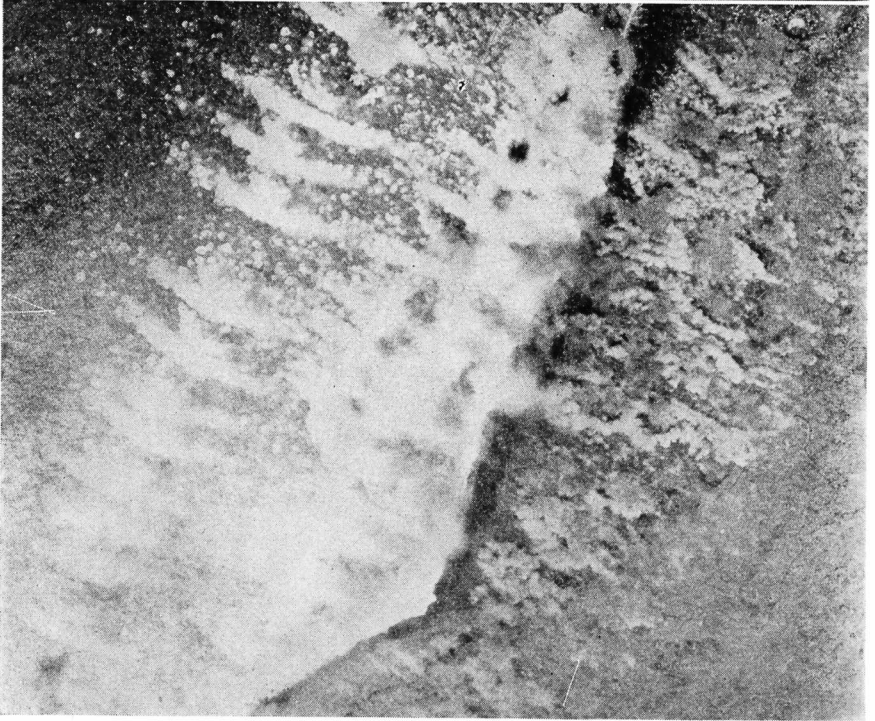
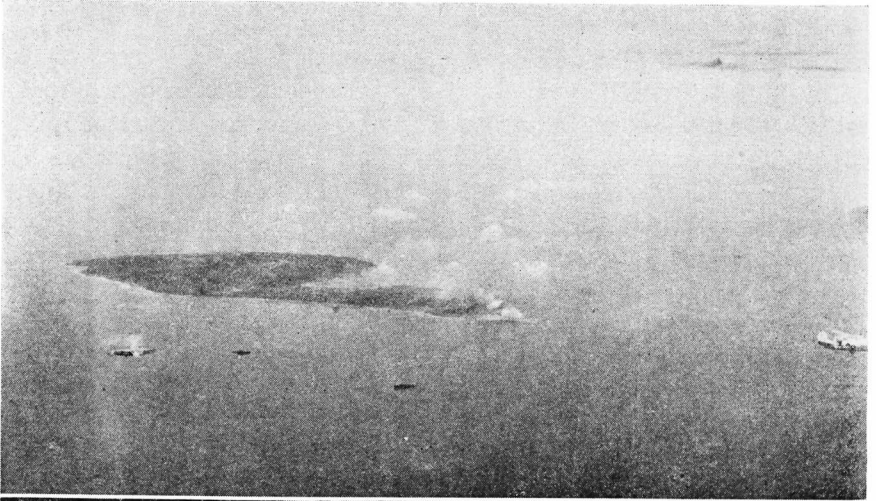
While much of the foregoing discussion has been devoted to effectiveness of the fragments from a bursting bomb, it must be recognized that there is also a blast associated with bomb bursts and that the importance of the blast increases with increasing bomb size. Damage inflicted by very large bombs is almost entirely due to blast. Investigations by Division 2, NDRC, and by British scientists as well, established that the area of damage to buildings by blast is increased 50% to 100% by bursting the bomb in the air.

An evaluation of the effectiveness of the air-to-air rocket fuze was carried out at the Naval Ordnance Test Station, Inyokern, California, in early 1945. Planes operated entirely by remote control, known as "drones" were used as targets for fighter planes attacking with AR rockets carrying radio proximity fuzes.

In the initial phases of the test, high explosive war heads were used on the rockets, and three drones were destroyed with six rounds. Subsequently, in order to avoid further destruction of drones, and since the primary interest was in the position of the bursts, inert war heads were used, function being indicated by the flash of a small charge of powder. Eighty-one rounds were fired at the drone at ranges of 400 to 800 yards, and of these, fifty-eight functioned near the drone, the other rounds passing outside the radius of action of the fuze (about 70 feet). Approximately half of the functioning rounds in this phase of the test were at such distances as to result in almost certain destruction of the drone, if high explosive war heads had been used. It is interesting to note that only one of the eighty-seven rounds actually struck the drone and presumably there would have been one "kill" if contact fuzes had been used. Such a comparison is not particularly significant, however, since the use of contact fuzes on rockets for air-to-air work is out of the question because of the small possibility of a direct hit. Further, it is, of course, not possible to use time fuzes for this purpose. The proximity fuze is the only type of fuze suitable for air-to-air use of rockets.

IX. OPERATIONAL RECORD

The VT rocket fuze was developed primarily as a defense against enemy bombers, which were so effective in the early days of the war. As the number of enemy bombing missions decreased, however, and heavy Allied bombardment increased, the urgency



Bombs Burst in Air Over Iwo Jima Beach

of keeping all information on the VT fuze development out of enemy hands became even greater, since such a fuze might well have been used against us with great effectiveness, or indeed, might have rendered our attacks impossible.

All possible precautions were taken in using VT fuzes to insure that none reached enemy hands. Thus, fuzes for use against aircraft are designed for self-destruction sometime before striking the ground in case of a miss, while in air-to-ground bombardment, the projectile carries an auxiliary contact fuze which functions on impact in case of a failure of the VT fuze. However, in using large numbers of fuzes, it is impossible to insure that no rounds will reach the enemy in such condition that he may utilize them. Further, simply using the fuzes where enemy observation is such that the nature of the fuze might be identified would spur the enemy's own development of similar types.

Accordingly, the Combined Chiefs of Staff decided to limit the use of VT fuzes to operation from warships remote from land until the latter stages of the war when the enemy would no longer have sufficient time to capitalize on possible capture of a sample fuze. The stockpile of rocket fuzes manufactured in 1942 and 1943 constituted a powerful reserve weapon for release in case of a serious enemy threat to Allied air supremacy.

VT fuzes were officially released for general use in December 1944, for the great assaults that were to end the war. Requests for bomb fuzes were received from various theatres of operation and combat use began shortly thereafter.

The first major combat use of VT bomb fuzes was by 7th Air Force bombers operating from Saipan and Guam in the pre-invasion saturation bombardment of Iwo Jima in the period February 10 to 17, 1945. In three missions of this period, 500-lb. and 260-lb. bombs were dropped on anti-aircraft installations and beach defenses on Iwo Jima. Anti-aircraft fire from the island, previously very intense, was reported practically eliminated as a result of these missions and remained ineffective until the assault began.

Subsequently, the fuzes were employed by the 7th Air Force against Marcus Island, the Palau Islands, the Ryukyu Islands, and the mainland of Japan.

In the Mediterranean Theatre of Operations, the 15th Air Force used the VT bomb fuzes on fragmentation bombs against enemy flak positions that defended the avenues of approach into Austria and Germany. The initial use in Italy was on April 1, 1945, when 15th Air Force bombers flying at 25,000 feet dropped

fragmentation bombs against German flak batteries. Each of six batteries attacked ceased firing as the bombs exploded.

Excerpts from the 15th Air Force reports on this mission and a later mission are of considerable interest.

“(1 April attack)—The first attack was against four 4-gun batteries; the second was against two 4-gun batteries. In addition to minimizing the flak opposition, the attacks killed 31 enemy gunners, wounded 9, destroyed 1 20-mm. gun and damaged by direct hits other equipment.

“(19 April attack)—Eighteen aircraft attacked two 4-gun batteries. All opposition ceased after the bombs exploded. Ground reports indicate that: 9 gunners killed, 3 were missing, one 88-mm. and one 20-mm. guns were hit, with unknown results. Succeeding bombers negotiated the area for 2½ hours without encountering nor observing flak.

“. . . Ground reports indicate that fragmentation bombs with VT fuzes reduce morale and accuracy of flak personnel and cause damage to AA equipment. Bomber crews are very enthusiastic about anti-flak missions since they are afforded a chance to fight back.”

VT bomb fuzes were used by the 12th Air Force in Italy in support of the April 1945 offensive of the U. S. Fifth and British Eighth Armies. VT-fuzed general purpose, fragmentation, and “gel gas” bombs were reported to be deadly against personnel and materiel shielded from ordinary contact bursts by walls, revetments or foxholes.

During this period, the VT bomb fuzes were employed tactically by the Ninth Air Force, some of the early missions being carried out in mid-March against Pirmasens, and Neunkirchen, Germany. As a result of preliminary experience with the fuzes in this theatre, a practice of loading the first three planes in a mission with VT-fuzed fragmentation bombs for use against anti-aircraft positions at the target was instituted. The other planes of the mission loaded with standard contact-fuzed bombs for demolition work followed at some distance and approached the target with almost no risk.

Experience of the 14th Air Force in China with VT bomb fuzes is summarized in the following excerpt from Letter ASO 471.6 to AOO, Hq. AAF, subject “Operational Usage of VT Bomb Fuzes,” dated September 1945.

“The limited use of VT fuzes in this Theatre has been very successful, and this fuze has greatly improved the effectiveness of bombs on certain targets. Anti-aircraft positions have been attacked with excellent results, although there are no data available on the length of time gun positions remained

inoperative. Several attacks have been made on entrenched personnel with fighters directed by ground radio liaison teams. The blast effect from VT-fuzed bombs will destroy many buildings of Chinese type construction and successful missions have been conducted against bivouac areas and warehouses."

Navy carrier-based aircraft began using VT bomb fuzes in the spring of 1945 and employed them in increasing numbers throughout the summer. In the final strikes by the Third Fleet against the Japanese mainland in the period July 10 to August 15, about one-third of all bombs dropped by the carrier planes were VT fuzed. Reports from ships participating in this operation show the following use of VT fuzes during this period (expressed as percentages of total bombs dropped): U.S.S. SHANGRI-LA, 37%; U.S.S. RANDOLPH, 35%; U.S.S. BENNINGTON, 30%; U.S.S. SAN JACINTO, 30%; U.S.S. INDEPENDENCE, 37%. Repeatedly, pilots reported diminution or cessation of anti-aircraft fire as a result of air burst bombs. Typical of Navy reports are the following.

Excerpt from U.S.S. COWPENS Report Serial 0180 of 23 June 1945 (attack on Wake Island)

"... on strike number five, heavy AA positions at WA-3-16 were attacked and at least two very close air bursts were obtained. Heavy AA guns were observed firing from this position immediately prior to attack. Five VF aircraft of VF-50 made a second dive on this position five minutes later, and all pilots stated definitely that the guns were not firing on the second attack.

"In the opinion of the Commander CVLG-50, the 260-lb. fragmentation bomb with VT fuze is an excellent weapon for attacks on revetted positions and is far superior to W. P. bombs and to rockets."

Excerpt from U.S.S. TICONDEROGA Report (attack on Kita Shima)

"... several pilots stated that the anti-aircraft fire from the island in general ceased after the attack."

Excerpt from Brief of Action Report, U.S.S. YORKTOWN, for period May 24 to June 13, 1945. (Support of Okinawa operations R/S 018257)

"... pilots were generally enthusiastic about the possibilities of this type of attack."

Excerpt from Flak News Letter No. 24

Subject: Task Force 38 on Successful Kyushu Strike

Target: Kanoya Airfield, 8 June 1945

"This operation is given separate treatment because it was specifically planned to avoid the difficulties of the previous Kyushu sweeps ...

“ . . . Finally, a weapon was selected (260-lb. fragmentation bombs, VT-fuzed) which apparently effectively attacked re- vetted aircraft and anti-aircraft positions. This operation was entirely successful; considerable damage is estimated to have been done the enemy with the loss to ourselves of no pi- lots and only four airplanes.”

Excerpt from U.S.S. BENNINGTON Letter to Cominch, dated August 31, 1945.

“ . . . It is believed that VT fuzes have performed extremely well and that they have solved the long present air burst fuze problem.”

Excerpt from Commander Air Force, Pacific Fleet OWD/jes, Brief of CAG-six, Memorandum No. 3CM-45 on Japan Operations, 10 to 18 July 1945.

“VT-fuzed bombs used extensively against parked aircraft in the Tokyo district and are believed to be ideal loading for this type of target.”

Excerpt from Action Report, 2 July 1945 to 15 August 1945, U.S.S. SHANGRI-LA (CV-38) (Attack on Koriyama, Honshu)

“The field was well covered with VT-fuzed bombs and numer- ous fires were started. Eight planes are known to be destroyed and assessment of others was impossible due to dust and smoke.”

Excerpts from Brief of Action Reports, U.S.S. ESSEX (CV-9) 2 July to 15 August 1945. (CAG-83 Comments)

“ . . . This training must include all types of squadrons, be- cause it is considered the most effective weapon against AA positions, and all types of planes have been used to blanket AA positions during coordinated attacks, as well as against grounded aircraft.”

This same report comments on the fact that in a series of missions against Okinawa, when no VT fuzes were at hand, 15 planes from the ESSEX were damaged by anti-aircraft fire and 7 of them were lost, whereas in a comparable series of missions against Japan in July, four planes were damaged by enemy AA fire and one of these was lost. The report continues:

“It is believed that the principal factors involved in the lower losses to AA are the use of VT fuzes and consequent high pull- out and the high altitude approach used.”

In the European Theatre, VT-fuzed 4½-inch rockets were used by fighter aircraft against ground targets in somewhat the same manner as were the VT-fuzed bombs, and were reported to be ef- fective in damaging parked aircraft, hangars, vehicles, and light fortifications. Superiority of the bomb as an air-to-ground wea-

pon, however, limited this usage of rockets. In the Mediterranean Theatre, VT-fuzed 4½-inch rockets were used in a ground-to-ground role.

It is noteworthy that in practically every instance reported in which air burst bombs were used against enemy anti-aircraft installations, sensational diminution of fire has resulted. The effectiveness of air burst bombs against such targets is readily understood when it is realized that a contact burst to be effective must actually fall within the revetment surrounding the gun. A contact burst, outside the revetment, even very close to the walls, is ineffective, whereas an air burst fifty or more feet outside the revetment showers numerous high-velocity fragments inside the revetment and makes the position untenable. Thus, the number of effective hits against an enemy position with a given bomb load is tremendously increased using air burst. This pays off in fewer casualties among the attacking planes and greater precision in bombing since the chief disturbing factor in precision bombing is eliminated.

An essential phase of the introduction of any new ordnance item into combat use is the instruction of the people who are to use the material in its potentialities, its operation, and its usage. This is particularly true of devices as novel as VT fuzes. To carry out the necessary instruction, a training course in the operation and use of VT bomb and rocket fuzes was set up at the Bureau of Standards and Aberdeen Proving Ground in January 1945, and teams of officers and enlisted men from each of the numbered air forces attended this school. Officers from the Navy also attended. The course consisted of a week of intensive study of the theory and practice of VT fuze design at NBS followed by two weeks of demonstrations and training in the use of the fuzes at Aberdeen Proving Ground, after which the officers and men returned to their respective stations.

To provide advance information about the fuzes and instruction in their use, several members of the Bureau Staff were sent to England and to the European Continent in the fall and winter of 1944 and early 1945. Units of the 8th and 9th Air Forces and of the Royal Air Force were contacted; possibilities, limitations and operation of the fuzes were explained and service needs were ascertained. Ordnance Department Officers introduced the bomb and rocket fuzes into the Mediterranean Theatre. Additional personnel accompanied the initial shipment of fuzes to Saipan in January 1945, and provided advance instruction in the use of the fuzes to the 7th Air Force, leading to initial use of the fuzes on Iwo Jima.

X. MILITARY DIRECTION AND COLLABORATION

In the development of a device of the intricacy of VT fuzes, a high degree of cooperation between the civilian and military agencies involved is vital. The role played by the Army Ordnance Department, the Signal Corps, and the Bureau of Ordnance of the Navy has been a highly significant one in development as well as in production. As has been mentioned, production contracts for the various fuzes were handled by the Signal Corps and by the Ordnance Department. Requests for specific developments originated in the Army Ordnance Department and the Navy Bureau of Ordnance. Throughout the course of the development, these agencies maintained a keen interest in the program and contributed greatly to its success.

An extensive and highly expeditious program of field testing of bomb and rocket fuzes was carried out at Aberdeen Proving Ground under the direction of the Director of Research. Acceptance testing of production lots of bomb and rocket fuzes was carried out in 1945 at Jefferson Proving Ground, Indiana, under the direction of the Commanding Officer of the Proving Ground. Service tests of the fuzes were carried out at the Army Air Force Proving Ground, Eglin Field, Florida, and at the Naval Ordnance Test Station, Inyokern, California.

Production contracts were administered first by the Signal Corps and later by both Signal Corps and the Ordnance Dept. Extensive testing facilities were maintained by both offices.

Participation by military personnel in the development program itself began in the fall of 1944, when officers and men were detailed to the Bureau of Standards to relieve the manpower shortage there. This participation increased until in July of 1945, some fifty Army officers and men, under the supervision of the Ordnance Department, as well as several Navy officers, were engaged in full-time experimental work at the Bureau of Standards.

There follows a list of Army and Navy personnel who participated in the development and production of VT fuzes for bombs, rockets and mortars:

Army Ordnance

Lt. General L. H. Campbell, Chief of Ordnance

Major General G. M. Barnes, Chief of Research and Development Service

Brig. General R. E. Hardy, Chief of Ammunition Division, Industrial Service

Col. G. C. Eddy
Col. W. B. Hardigg
Col. I. A. Luke
Col. H. S. Morton
Col. C. H. M. Roberts
Col. J. G. Shinkle
Col. L. A. Skinner
Lt. Col. Paul Christensen
Lt. Col. Frank Short
Maj. G. A. Bate
Maj. W. M. Teeter
Major J. D. Van Geem
Maj. S. P. Willan
Capt. D. C. Apps

Capt. J. E. Dumaresq
Capt. D. M. Hall
Capt. B. I. Mitchell
Capt. H. W. Sisco
Capt. M. G. Suffern
Lt. A. P. Diehl
Lt. C. H. Gammeter
Lt. E. C. Miller
Lt. L. L. Parker
Lt. Paul Siebeneichen
Lt. E. V. B. Stearns
Lt. D. K. Wright
Mr. B. S. McCutcheon

Army Signal Corps

Maj. Gen. Harry Ingles, Chief Signal Officer
Maj. Gen. W. H. Harrison, Chief, Procurement and Distribution Service

Col. R. L. Hart
Col. Vanness Philip
Lt. Col. John DeWitt
Lt. Col. C. S. Kleinau
Maj. J. Lambert
Maj. R. D. Lowlor
Maj. Wm. Webber

Capt. G. K. Green, Jr.
Capt. Morton P. Rome
Capt. L. J. Wright, Jr.
Lt. James A. Nash
Lt. Alfred Roberts
Mr. E. J. Fister
Mr. Clinton Mims

Navy Department

Capt. F. I. Entwhistle
Capt. S. R. Shoemaker
Capt. J. H. Sides
Capt. C. L. Tyler
Comdr. V. Hicks

Comdr. J. A. E. Hindman
Comdr. R. W. Thompson
Lt. Comdr. J. W. Utecht
Lt. C. R. Buening
Lt. C. H. Ramien

XI. INDUSTRIAL COLLABORATION

No praise is too high for the work of the American manufacturers in the production of the radio proximity fuze. Contributing freely of their engineering talent, and working production miracles in manufacturing the myriad new and special items needed for the

fuzes, they have a large share in the success of the developments.

It is hoped that the following list of some of the principal companies will serve to acknowledge, in some part, the credit due them.

Emerson Radio & Phonograph Co.

Globe-Union, Inc.	Friez Div. of Bendix Corp.
Rewelec Corp.	Bowen and Co.
Zenith Radio Corp.	Zell Corp.
Rudolph Wurlitzer Co.	Raytheon Mfg. Co.
General Instrument Corp.	Sylvania Elec. Prod., Inc.
General Electric Co.	Federal Radio & Tel. Corp.
Westinghouse Elec. & Mfg. Co.	University of Florida
Philco Corp.	University of Iowa
Gilfillan Bros., Inc.	Western Electric Co.

XII. ADMINISTRATIVE AND TECHNICAL STAFF

The history of the Division is a history of teamwork, of unselfish cooperation, and of long hours of extra and unpaid overtime. The following men and women were the members of the Division and Bureau Staffs who were primarily responsible for the success of the program.

Abrams, Simon	Beneteau, Roger J.	Cahn, Leonard
Adams, Dorothy R.	Bennett, Blair M.	Caldwell, Hubert
Adams, Elizabeth G.	Bennett, Evert G.	Callomon, Ilse
Allan, Helen	Bernstein, Bernard	Caponi, Vilma
Ancier, Morton S.	Bister, Joseph, Jr.	Carolin, W.
Andrews, Laurence M.	Blackwell, G. H.	Carroll, Mattie
Apolenis, Charles J.	Blumenfeld, L. M.	Cason, James H.
Apolenis, Ruth N.	Bloom, Abraham	Cayton, Ethyl
Appel, J. F.	Bocciolatt, Anne M.	Caywood, Jane
Armstrong, Willis E.	Body, Joseph J.	Celauro, Francis L.
Arsem, A. D.	Bowling, John W.	Chartock, Abraham
Arsham, Isabelle	Boyd, Dorothy	Clark, E. S.
Artis, C. J.	Bradley, McKay R.	Clark, Ethelwyn
Astin, Allen V.	Bradski, Morton	Clark, G. L.
Atchison, Fred S.	Brame, Victor	Clarke, J. R.
Baer, F. M.	Brehme, Phyllis P.	Chaves, J. W.
Bagg, Thomas C.	Brenner, Morris	Clayman, Shirley B.
Bagwell, Alfred A.	Bretemps, R. F.	Clouden, Kenneth R.
Baker, F. J.	Brill, Patricia	Coble, John H.
Ballard, Kenneth C.	Brooker, Hazel E.	Cohen, H. J.
Bare, Darius D.	Brown, Catherine	Cohen, Leslie
Barfield, Morris L.	Brunetti, Cleo	Cohen, Victor W.
Barnard, James H.	Bryant, Arthur	Coiner, Julia E.
Bartunek, Paul F.	Bryant, Carroll W.	Cole, Milton D.
Bates, Rufus F.	Burke, J. P.	Coleman, Barbara A.
Bayley, Paul L.	Burns, R. C.	Collins, D. D.
Becker, Robert A.	Burton, Miriam	Cones, H. N.
Belfield, Martin D.	Butt, Nelle	Connole, Thomas B.
Bell, Ernestine V.	Button, H. H.	Cook, Herbert D.
Bell, Frankie	Cagle, Evelyn M.	Cook, Richard K.

Cooke, F. L.
 Cooley, F. B.
 Cooley, F. W.
 Cooper, Phrania Z.
 Cooter, Irving
 Corbett, I. M.
 Corey, Kathleen
 Corey, Magaleen
 Cornell, Betty J.
 Cornfield, J. H.
 Cornwell, Beverly J.
 Coury, J. D.
 Cowan, Robert D.
 Cox, Rolfe K.
 Craft, Hooper
 Cragoe, Carl S.
 Craig, D. Norman
 Crane, Clarence B.
 Creed, C. W.
 Cronin, Wallace J.
 Cruzan, Orval R.
 Cunningham, R. O.
 Curtis, Roger W.
 Cutts, Mary F.
 Dalzell, H. P.
 Daniel, Lucenda N.
 Dasher, Edward T.
 Davidson, Clara
 Davis, Joseph C.
 Day, F. H.
 DeAgro, Richard P.
 Decker, Betty L.
 DeCross, S. L.
 Deines, Erwin W., Jr.
 Defandorf, F. M.
 Dellinger, J. Howard
 Diamond, Harry
 Dillard, V. E.
 Dillon, Betty W.
 Diou, Lawrence J.
 Dodd, Jessie E.
 Dodge, Frances
 Domsitz, Altie S.
 Domsitz, Myron G.
 Doob, Henrietta C.
 Downing, John J.
 Doying, Rose S.
 Duke, Charles R.
 Dungan, Edward G.
 Ecker, Naomi
 Eiseman, Sadie C.
 Eisner, E.
 Eliason, Dorothy M.
 Ellis, F.
 Evans, Robert L.
 Eve, C. F.
 Feldman, D.
 Ferrell, J. A., Jr.
 Fisher, David
 Fisher, Ed
 Fishman, Henry
 Flanagan, Louise
 Fletcher, Franklin M.
 Ford, Lawrence
 Forman, Ralph
 Foster, Allen T.
 Foster, Betty K.
 Franklin, Philip J.
 Freuder, Irene
 Friedman, David C.
 Friedman, Edward
 Fuller, E. B.
 Gilharg, David
 Godfrey, Theodore B.
 Godwin, A. J.
 Golden, S.
 Goldman, Nelson E.
 Gordon, Charles C.
 Gore, Edna M.
 Gore, Edward W.
 Gracely, F. R.
 Grant, Wm. K. F.
 Green, Donald G.
 Green, Mabel W.
 Green, R. F.
 Greene, Phyllis E.
 Greer, John W.
 Gregory, Chris
 Grein, Rosemary A.
 Grove, Paul E.
 Guenther, Lewis H., Jr.
 Guillot, Thomas E.
 Gurtowski, John J.
 Gutterman, Sylvia K.
 Hallman, Betty W.
 Harris, Forrest K.
 Hauser, Catherine
 Hawes, Paul T.
 Heilprin, Laurence B.
 Hellmers, Theodore C.
 Henderson, J. E.
 Henderson, M. H.
 Hendricks, Nannie M.
 Henry, Betty J.
 Hertstein, Wilbur S.
 Hess, Ida I.
 Hibbs, J. H.
 Hickok, Charles H.
 Hinman, W. S., Jr.
 Hise, R. D.
 Hoffman, J. G.
 Hofstadter, R.
 Holland, James E.
 Hollis, Forrest
 Hornstein, Irwin
 Hornstein, Naomi
 Horton, Earl F., Jr.
 Howard, June
 Hudgins, Olive V.
 Hughes, Leo L.
 Hunt, E. W.
 Huntoon, Robert D.
 Huy, Robert H.
 Inman, F. E.
 Isaacs, Jane Garland
 Jackson, Barbara M.
 Janifer, John H.
 Jett, Margaret
 Jirauch, Francis W.
 Joel, Robert
 Johnson, Betty V.
 Johnson, C. F.
 Johnson, G. E.
 Johnson, John R.
 Johnson, Lyle T.
 Johnson, Paul V.
 Johnson, Ruth M.
 Jones, L. G.
 Kaiser, Herman J.
 Karr, Philip R.
 Katz, M. J.
 Kaufman, Bruce
 Kaufman, Joseph
 Kear, M.
 Kenrick, Jane L.
 Kerley, Anna M.
 Kern, Paul P.
 Kesteven, Arthur M.
 Kilker, Rosemarie W.
 Kinard, E.
 Kincheloe, Adeline N.
 King, Anna May
 King, J. B.
 Kingsbury, Aileene J.
 Klein, David
 Kolodny, Samuel
 Koontz, Harry L.
 Kotter, F. Ralph
 Kraushaar, William L.
 Krock, Mary
 Kroger, Elizabeth S.
 Krug, Fay R.
 Krupen, Philip
 Lachenbruch, Simon H.
 Landis, Paul E.
 Langdon, Mary
 Lauritsen, T.
 Lavins, Genevieve
 Lawhorn, Mary M.
 Lawson, Mary J.
 Lawson, Roy E.
 Lee, Mabel
 Lees, Wayne
 Leiner, A. L.
 Lemberos, George
 Lent, F. A.
 Leonhard, Rosebud B.
 Lester, Mary
 Letcher, R. L.
 Levin, I.
 Lifschitz, H.
 Limparris, Nick
 Lindberg, Andrew R.
 London, A.
 Loughridge, Donald
 Lowe, George A.
 Lusby, J. M.
 Luttrell, J. A., Jr.
 McCorkle, M. C.
 McCoy, James
 McElveen, Sarah E.
 McGolrick, Joseph E.

McLean, W. B.
 McLellan, Quinton A., Jr.
 Mallory, James A.
 Manov, F. S.
 Marion, Mary K.
 Marion, S. L.
 Marion, Sarah C.
 Marion, T. M.
 Martin, Flora M.
 Martin, Paul J.
 Martinson, Glen
 Mason, C.
 Massey, M. M.
 Massie, Minnie R.
 Menapace, Hubert V.
 Messer, E. V.
 Milbauer, Iwan Z.
 Miller, Bertrand J.
 Miller, L. C.
 Mills, John L.
 Mills, Richard F.
 Minkel, Merlin S.
 Mitchell, Verline
 Moffitt, Josephine K.
 Mohler, F. L.
 Moon, Charles
 Moon, Clara Grace
 Moore, Agatha
 Morgan, Raymond
 Morris, E. C.
 Morrissey, Marguerite H.
 Mosley, Vernon M.
 Moyers, Fay R.
 Mulvey, James H.
 Murphy, Wm. B.
 Murray, Exa
 Musicant, Harry
 Musil, Jack
 Myers, J. Kennedy
 Neddermeyer, S. H.
 Neil, Richard
 Nemir, Fred
 Neverson, Lucille
 Newman, Nathan
 Nordquist, George
 Nutt, Donald A.
 Nutter, R. L.
 O'Brien, Eileen E.
 O'Connell, N. B.
 Orden, Alexander
 Osterhoudt, Helen G.
 Ostrow, Stanley
 Padgett, Joseph V.
 Padgett, Lemuel J.
 Page, Carrie W.
 Page, Chester H.
 Palmer, James W.
 Parbuoni, T. John
 Park, J. H.
 Park, Julius
 Parks, George B.
 Parks, Ray F.
 Parks, Ruth C.
 Parish, George T.
 Parnell, Hunter H.
 Payne, Ruth E.
 Pearl H. F.
 Pearson, H. A.
 Pearson, J. H.
 Peck, Mahlon F.
 Pelikan, Marie H.
 Peters, K. O.
 Peterson, A. E.
 Phelps, Ellsworth
 Philbrick, W. D.
 Phillips, W. G.
 Pidgeon, B. J.
 Pike, J. L.
 Pochop, Leonard C.
 Porter, Claude T.
 Portmess, D.
 Pratt, Harvey A.
 Procter, John W.
 Propper, Betty
 Protz, Thomas F.
 Rabinow, Gladys
 Rabinow, Jacob
 Rafferty, Dorothy Melling
 Ragazzo, Julia
 Ragsdale, J. Arthur
 Ransom, Francis A.
 Rapier, Betty L.
 Rasp, Alice M.
 Rasp, Eleanor H.
 Ravitsky, Charles
 Reber, Wm. M., Jr.
 Redcay, P. Wilson
 Reddan, Martin J.
 Reed, Mary I.
 Reid, Joseph G., Jr.
 Reutemann, Kathryn F.
 Riley, Earl P.
 Riley, Lester A.
 Roach, John J.
 Roberson, Laura W.
 Roberts, Estelle M.
 Roberts, Morrel
 Robinson, Francis
 Roiter, Aaron
 Rosenberg, Harry J.
 Rosenhaft, Mortimer
 Ross, Helen M.
 Rotor, Emma U.
 Rude, Doris M.
 Rump, June E.
 Russell, William R.
 Rutstein, Leila Spanier
 Sanford, Raymond L.
 Saunders, A. R.
 Saunderson, H. D.
 Schellhase, Robert L.
 Schrodtt, John P.
 Schulkin, Morris
 Schuman, Louis
 Schwartz, Rosalind B.
 Schwartzman, Murray
 Scillian, Glenn L.
 Scofield, Marjorie A.
 Scott, Dorothy G.
 Scott, George, Sr.
 Scott, L. D.
 Scott, Mary L.
 Seaton, Fred
 Seibel, Melvin H.
 Senn, Jurg A.
 Settle, Richard F.
 Shandor, Michael
 Shapiro, Nathan
 Shellenberger, Margaret
 Sherburne, Mary D.
 Sherry, Robert S.
 Showalter, A. B.
 Shudde, Evelyn
 Shuffer, Max
 Siggers, Edward G.
 Silsbee, F. B.
 Silsbee, H. B.
 Silverman, Richard A.
 Silverstein, Abraham
 Simpson, Dorothy
 Simpson, Joyce A.
 Singer, G.
 Sitton, Thelma
 Smith, Barbara Ann
 Smith, Barbara J.
 Smith, W. C.
 Smolen, Cecille F.
 Sneed, William D.
 Sorrells, John R.
 Souder, Wilmer
 Spinks, Almon W.
 Spokas, Otto E.
 Stair, Ralph
 Steiner, C. J.
 Stimson, H. F.
 Streib, J. F.
 Strickland, James
 Strickler, H. A.
 Strong, James C.
 Sutherland, James A.
 Suttan, Adrian
 Swanson, B. Mildred
 Sweet, Viola C.
 Sweetman, L. R.
 Sweger, H. M.
 Taylor, L. S.
 Taylor, L. S., Jr.
 Taylor, R. L.
 Taylor, T. L.
 Tedore, George J.
 Teele, Marion B.
 Theriault, Eileen
 Theriault, M. Annette
 Thomas, G. O.
 Thomas, J. L.
 Thompson, Dell T.
 Tobey, Royal G.
 Tucker, Mildred E.
 Tucker, Nancy J.
 Turner, James R.
 Ueberall, Ralph L.
 Untiedt, F. H.

Updike, Nancy	Walters, Ruth E.	Wilbur, Hazel H.
VanGelder, Johanna P.	Ward, Wm. K.	Wilimek, Fred D.
Veit, Katherine	Watson, Doran H.	Wilkins, Bernice J.
VerWiebe, Eleanor D.	Weinberg, Morris	Williams, Carl
Vinal, George W.	Weiss, Albert	Williams, Celeste S.
Vinikoor, David	Welch, Kathryn F.	Williams, Leola
Vogelsang, Edward A.	Welch, Ruth J.	Willyes, F. M.
VonSeggern, Ruby E.	Welch, W. B.	Wilson, B. E.
Vorkink, Rachel	Wells, Lola Margaret	Windham, Samuel B.
Wahler, Clarence G.	West, Janet M.	Wood, Eleanor I.
Wakefield, Wm. R.	West, Reeta I.	Worcester, Dean A.
Walker, Emil Carl	Wexler, A.	Wright, Wm. W.
Walker, J. A.	White, Clarence H.	Wycoff, H. G.
Wallace, Edward John	White, J. L.	Wynne, Eugene O.
Wallace, F. E.	White, Sarah A.	Yates, Wilfrid A.
Walleigh, Robert S.	White, Thomas N.	Zemko, Georgia G.
Walter, Henry R.	Whitson, W. L.	Zlotnick, Herbert I.

Division Personnel in Military Service

Becker, John C.	Johansen, Joseph	Scott, William B.
Boles, Maxwell	Lechter, Sidney	Stair, Gerald
Bowie, Everett G.	MacQuarrie, Horace	Stella, Karl H.
Bowie, Henry J.	Metz, William W.	Thomas, J. L., Jr.
Bowie, Norris T.	Miller, C. Maurice	Ullman, Maurice S.
Connor, Guy	Miller, Paul	Watts, T. E.
Cooper, Edmond F.	Morrison, R. F.	Weiss, Milton B.
Diehl, Lloyd G.	Pickles, Ralph K.	Wilczenski, A. M.
Donoghue, Harry J.	Rafferty, John F.	Williams, Wm. E., Jr.
Dorn, Martha L.	Reed, Judson D.	Wilson, Edgar H., Jr.
Evans, Alvin M.	Roudabush, Douglas E.	Zielinski, Norman E.
Ferguson, F. R.	Scneider, Bertram A.	
Horner, Charles R.	Scott, Donald W.	

Military Detachment Serving with the Ordnance Development Division

Arant, Eugene W., 2nd Lt.	Kunis, Manuel, Sgt.
Barrett, Carl A., T/5	Kurtz, T. W., T/5
Beamer, Scott, Capt.	Lansdale, B. J., Major
Bellew, Francis, Pfc.	Larson, Clarence N., T/4
Bennett, Wm., Capt.	Licata, Joseph P., T/5
Bibbs, J. C., Capt.	Loudon, Benjamin F., T/4
Biberman, David M., T/5	Maxwell, James R., T/4
Brooks, Walter L., Pfc	Melsheimer, Robert S., Pfc.
Brown, John I., Jr., T/5	Miller, Marion Hugh, T/4
Brumfield, Arthur E., Pfc	Miller, Paul, Pfc
Butterfield, Robert H., T/5	Morrison, Robert F., Pfc
Butz, Newton, Major	Nieder, Bailey H., 2nd Lt.
Carrroll, Maurice W., 1st Lt.	Norvig, O. V., Capt.
Carter, George H., T/4	Ohlenkamp, Robert M., T/4
Crawford, Thomas W., T/5	Pringle, Harold L., T/4
Cross, Robert D., Capt.	Rafferty, John F., Pfc
Cutler, Philip L., T/5	Roudabush, Douglas E., Pvt.
Danaher, James J., Jr., Capt.	Saroff, Harry A., Capt.
Day, John Leslie, T/4	Seegmiller, Robert, Pfc
Edwards, Howard D., T/5	Smith, McClain B., Jr., 1st Lt.
Fatout, R. C., T/5	Sniadecki, Raymond A., T/5
Field, Hubertus B., M/Sgt.	Steffen, Theodore G., T/4
Finch, Walter G., Capt.	Stillinger, Richard C., T/5
Furlani, Ermo, T/4	Thomas, Rufus L., T/5
Hittle, E. C., T/5	Underkoffler, Victor S., T/4
Hoffman, Lester, Capt.	Van Antwerp, Robert L., T/3
Hannum, William F., Capt.	Vernon, Robert C., Pfc

Wahlberg, Charles D., T/4
Warren, Joseph P., Capt.
Weiss, Milton B., Pfc

White, Charles E., 2nd Lt.
Wiehe, Warren, T/5

DIVISION 4, NATIONAL DEFENSE RESEARCH COMMITTEE

Members

Alexander Ellett
L. J. Briggs
W. D. Coolidge
Harry Diamond

H. L. Dryden
F. L. Hovde
John T. Tate

Office

The Staff of the Division 4, NDRC, which was located at the National Bureau of Standards, carried the large administrative and clerical load connected with the administration of the Division 4 contracts and of the work at the Bureau. They gave unstintingly of their time and effort to further the fuze program.

Benedict, Elizabeth J.
Bowker, Kathleen
Braithwaite, Margaret
Brekke, Edith
Butler, Martha
Cheyne, Julia
Clarke, A. S.
Cypert, Orine
Elliott, W. E., Major
Gatlin, Martha
Grant, Marion Jane
Gubersky, Jacqueline
Hosack, Emogene

LeHew, Josephine
Mowbray, Angela A.
Olmstead, Helen
Pike, Cathryn Holland
Rinehart, John S.
Ross, Doris
Schaefer, Charlotte
Schaeffer, Elmer
Thaden, Helen
Thomas, A. G.
Walchalk, Dorothy
VanCott, Emma

Voelker, Ione

PERSONNEL OF THE ENGINEERING AND TRANSITION OFFICE, OSRD, COLLABORATING WITH DIVISION 4, NDRC

Barrett, L. R.
Boelter, L. M. K.
Brown, Frank R.
Connell, J.
Ellis, H. B.
Hazen, H. F.
Hodgson, R. R.
Kennedy, T.

Mills, A. L.
Morrin, Earl
Sangster, R. F.
Schauer, C. H.
Scherer, Paul A.
Whiting, C.
Whitton, E. A.
Wood, F. C., Jr.