

HENRY H. PORTER

## RECOLLECTIONS ON THE DEVELOPMENT OF RADIO-CONTROLLED PROXIMITY FUZES

The fortieth anniversary of the founding of APL<sup>1</sup> provides an opportunity to recount the major features of its development and the evolution of current programs, and to recall events during the years prior to its formal establishment in 1942.

By 1940 we had been through the Great Depression and 1933, the year when Hitler came to power. In 1936 Italy overran Ethiopia, Hitler remilitarized the Rhineland in contravention of the Treaty of Versailles, and France and Russia formed an alliance. In 1938 Hitler, charging abuse of minorities, annexed Austria, threatened Czechoslovakia and Poland, and seized Danzig. He made a sudden pact with Russia and (as England and France declared war on Germany) on September 1, 1939, attacked Poland, which was vanquished in a month. Then came the “phony war” through the winter. Denmark and Norway were overrun in the spring of 1940. The major offensive on Paris through Belgium was opened in May, and France was forced to capitulate in six weeks.

The British army in France was evacuated from Dunkirk but lost most of its military equipment and supplies. England strained every effort toward building up defenses against an expected invasion across the English Channel. They had only recently taken rearmament seriously and had to build the necessary plants and facilities for furnishing their forces with weapons, whereas Germany had been preparing for a number of years. Much time had been lost, and Britain’s army, defeated in France, had to be built up to meet the expected cross-channel assault. But the German army had gotten ahead of itself and reached the position for the assault on England without having planned and prepared for it. Hitler’s reaction was to start an air assault, to get complete control of the air, and overwhelm the defenses largely by air power.

Britain remained as the only force left to face the Nazi might. Germany had the predominant air force and greater facilities for building it up. It was hard to believe Britain could prevail against these German advantages. Nor could she hope for any major outside help. Russia—with vast areas to be fought over but with untried troops, untrained and ill-equipped to meet the new type of warfare that had so easily humbled the best armies of Europe—and America,

with strong anti-intervention feelings, were weak reeds to lean on.

This was the situation as I saw it in July 1940, and I was very worried. I thought that America might be drawn into the conflict and that, even as individuals, we should start immediately taking steps to prepare ourselves to be as effective as we could. Therefore, I came to Washington to see what the situation was and where I could contribute. I had arranged a few meetings, but I was aghast at what I found. In the first place, the Navy did not appear to have any feeling of need or urgency. (As I learned later, this was not a universal opinion. The Naval Bureau of Ordnance had a group of younger officers who were actively pressing for action. Commander W. H. P. Blandy—later full admiral—was spot-promoted to rear admiral and chief of the Bureau of Ordnance and was largely responsible for getting Swedish Bofors 40-millimeter and Swiss Oerlikon 20-millimeter guns onto U.S. ships for air defense. The Navy was placing maximum priority and effort on air defense.) The Bureau of Standards had not been approached on any war work yet. At NACA they had nothing, but I took Civil Service exams, and about a year later got an offer. I also saw a number of friends, one of whom knew Dick Roberts, who talked to Merle Tuve. As a result, I came back to see them and joined Section T of the National Defense Research Committee a couple of weeks later.

The National Defense Research Committee had been established under Vannevar Bush in June 1940. In August of that year, Section T was established at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, with Merle A. Tuve as chairman. It was located a couple of blocks east of Connecticut Avenue and Military Road. We were assigned the old Experiment Building where the million-volt electrostatic machine was housed and adjacent to which a new five-million-volt electrostatic generator was in the final stages of being assembled. Just beyond this, a new building, having the 40-inch cyclotron and including office space, was being completed. This, we hoped, would solve our space problem in the spring, but in the meantime we were allotted space wherever it could be found—be-

tween the equipment, in passageways and corners—and often used the lawn for conferences and conversation.

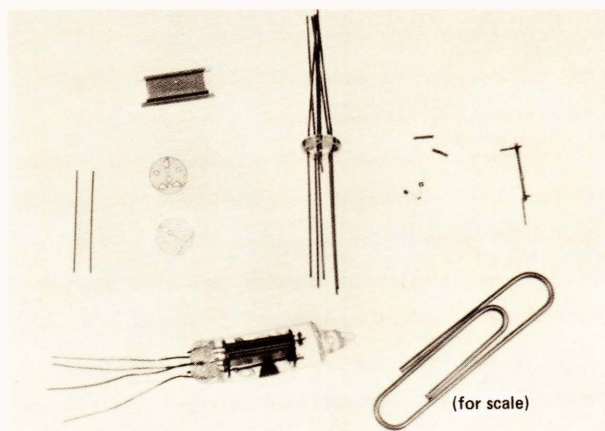
By this time the German bombers had moved closer to the Channel and were beginning their effort to cut down the RAF so that a cross-channel invasion could be mounted.

The British had expended a large amount of technical effort for improving the capabilities of their forces in battle, and the Tizard Mission was sent to Washington for discussions. The problems Section T had been assigned were “influence” or “proximity” fuzes. It seemed that if a fuze could be produced that would detonate the shell at the precise time when the beam of fragments would include the target, a great improvement in effectiveness would be achieved. Most people felt that this was a pipe dream and that the production of millions of fuzes that could withstand the acceleration of 15,000 g in a gun could not be done and would be a waste of time when time was so important. The general opinion was to strive for a fuze for rocket-launched bombs and accept the lesser effectiveness. But Tuve and Roberts were not willing to accept this without examining the validity of the premise. So they made drop tests on available small hearing-aid tubes, and found that in some directions the tubes showed great strength. In fact, one such tube tested in a centrifuge lent to us by Jesse Beams of the University of Virginia withstood forces of over 20,000 g.

At about that time a man came to see us who, as I remember, was president of Imperial Tubes, Ltd., of Canada, with an unconventional tube they had designed. It was very sturdy and was designed to withstand 75,000 g and a high spin rate. The plate was a small axial grid tube, the grid being a series of posts on which the grid wire was wound and supported by stacked mica discs. Outside of this, the filament was laid in a groove inside the stacked mica discs, which were assembled within a glass tube with metal end discs. The tube’s electrical characteristics were not good, but it would withstand firing in a gun: we could not damage it in either centrifuge or 37-millimeter firing tests.

We worked with the Raytheon and Hytron companies, who supplied us with limited batches of tubes modified for greater strength. The tubes were also made smaller because they became more rugged as their size decreased. We centrifuged and shot them for recovery, mostly from our 37-millimeter gun, but occasionally at Aberdeen in 5-inch, 25-star shells from which the tubes and their components could be recovered. We potted components and assemblies in cerumen wax and later in a hard thermoplastic that was very transparent, making it possible to see clearly if any motion had occurred and what types of assembly caused trouble.

Dana Mitchell from Columbia University joined in the tube effort. R. D. Mindlin, a stress engineer at Columbia University, joined Section T. His last consulting job had been to determine why the Tacoma



*Parts of a rugged triode*

Narrows Bridge had failed. He said that civil engineers did not consider time as a variable and, therefore, missed the interaction of resonances. Unfortunately, the resonant frequencies of the twist of the towers, the twist of the roadway, and the waves along the cables and roadway were near enough in phase so they did not damp out adequately. But it was a long step from the Tacoma bridge to the details of a sub-miniature tube. Mindlin appeared one morning with a series of graphs of grid structure and a system for computing their ability to withstand acceleration forces for the various shapes and materials used in tall structures. This largely solved the problem of designing a tube structure that would withstand the accelerations of the launching environments of guns.

While that was going on, other groups were investigating various ways to determine when and how the shell should be triggered. L. R. Hafstad was following the photoelectric path, keeping in mind that rocket launching might prove the quickest route to effective use. Roberts felt that the radio type of fuze had advantages and could probably be adjusted to the desired position of burst around the target. Acoustics and electrostatics were being followed, as others were working on them. Dick Crane was considering a ground command possibility, particularly for determining which shell should be detonated at a particular instant, and how to activate it.

Up to that time, we had been using a limited amount of drop testing and doing some firing with a 1-5/8 inch homemade gun and a Marine 37-millimeter launching gun, both adapted for vertical firing. We found that with proper care we could quickly bring the location of fall where we wanted it, find the impact holes, and dig up the test shells with posthole diggers. We developed easy ways to measure setback. One was by using small annealed-copper balls under a steel cylinder and then measuring the flattening of the ball in order to calibrate a curve. Another was by using a steel ball on a lead shim and measuring the diameter of the impression made by the ball. Mindlin modified this method by using a lead shim in the shape of a flattened figure 8 with a hole in the center.

The shim was held centered in a slot with steel balls above it. When fired, the two balls recorded the setback at the end of the lead piece. During the flight of the shell, the lead piece was centrifuged, thus separating the two ends; on landing, the ball recorded the setback. Thus, if there was an abnormally high landing shock it would indicate where the main damage was done. This was routine on all “proof tests.”

We had an even more sophisticated gauge for measuring dynamic effects, consisting of a piezoelectric crystal mounted in the shell. The lead from one side was electrically connected to one side of an oscilloscope through the shell rotating barrel and the gun barrel. The other side was connected to a brass cup on the nose of the shell to a bare wire stretched along the gun bore to the oscilloscope. This gave us a detailed trace of instantaneous acceleration at high frequencies. It was also possible to get measurements of shell base pressures and bore friction, but because these factors did not foreshadow problems, they were not pursued.

Jesse Beams provided us with an 8-inch centrifuge that would attain about 35,000 g and built us a 12-inch centrifuge that would exceed 20,000 g. They were used a lot in the early days and made possible rapid progress on tubes in the early work on ruggedizing components.

We began to see that testing by vertical gun firing would become an important part of the program as we got into the production, testing, and proofing of enormous quantities of fuzes being made in many sizes and various uses. Our first firing site had been a farm near Vienna, Va. Subsequently, we moved to Stump Neck, Md., which was near the Naval Powder Factory. There we primarily used a 47-millimeter naval gun, large enough to test standard 21-inch fuze components, so the tests were realistic. We had standard test shells into which smoke puffs and setback gauges were fitted; then regular detonator assemblies, batteries, amplifiers, and oscillators were added. These were fired in lots of 5 or 20 for trial shots, or lots of 20 to 100 for statistical information. At the height of the test firings, including developmental and production lot acceptance, we often fired and recovered over 600 rounds a day. The record was 785 in one day, with 770 recovered. It consistently took two days for the return of a lot from the test field, post mortem, decision by the APL engineers, telephone order to the Crosley Corp., preparation of the assembly line at Crosley for production the next day, production, shipping to Washington, receipt from railway, assembly of fuzes into test shells, trucking to the test field, and the next firing test.

Our final test field was a small peninsula in the lower Potomac where we had four recovery fields and could fire into two of them while recovering shells from the other two simultaneously.

By June 1941, progress with rugged tubes had reached the point where enough could survive so that experiments could be done with them. Dick Roberts had been working on the radio fuze circuit, Work-



*Field testing the VT fuze*

man on electrostatic fuzing, and Crane on command detonation. A number of circuits were fired, on the whole quite successfully. One of the oscillators operated throughout a flight, survived the landing shock, and continued to function while lying on the ground, to the surprise of everyone.

In July 1941, circuits were being assembled and fired in 5-inch guns at Dahlgren. Initially these firings were just to demonstrate the operation of components and circuits in a rugged environment, to show that they would give the expected results. I remember one test of 10 fuzes that Commander Parsons, Dick Roberts, Lorie Fraser, Blair Barghausen, and I witnessed. We had a few silent duds, some noisy duds, a few premature explosions during the flight, and, at last, a beautiful proximity burst as the shell approached the surface. Here was proof that radio-controlled fuzes were feasible. All that remained was to add the necessary safety and tactical devices, adapt them to the various guns and tactical uses, and produce the demanding devices by the millions. Roger Wise of Sylvania had included in the tube requirements not only that they have the requisite electrical characteristics and be adequately rugged, but that they be producible in enormous quantities.

Production was a very large job. The only battery available was the 2-inch dry cell. This dictated that the Navy 5-inch shell was the smallest that could accommodate the fuze. In order to save time, the fuze had been designed for that shell so it could be gotten into battle at the earliest moment. A good deal of



*Proving ground in New Mexico*

work had been done using a 1½-inch dry cell, but it had too short a shelf life to be counted on.

The test firings in the summer of 1941 showed that we were approaching the demonstration that VT fuzes could be made that would reliably give proximity bursts on attacking aircraft. Now we needed to know the fuze-triggering pattern about the target and adjust the fuze characteristics to optimize effectiveness. Tuve got Crane and Dennison at the University of Michigan to undertake model measurements and Workman at the University of New Mexico to undertake full-scale experiments using two 250-foot wooden towers at the New Mexico test area to suspend full-scale models of targets and fire shells past them. Models of German V-1's and Japanese Baka bombs were also tested at a later time. Thus we were able to optimize fuze patterns for all tactical situations and prove them in full-scale tests.

1942 was the critical summer to make crucial advances with the VT fuzes. Britain, almost defenseless against German air power, had at least survived the Battle of Britain. Germany and Italy were in the Balkans, and Hitler was getting embroiled with Russia. We could feel the pressure building up. There was much to be done, and people worked harder and longer. Often people worked at all hours of the night preparing equipment to be tested. The Enwood Company, which was amazing at finding equipment and tools for rush jobs, did a wonderful job of circumventing delays. A production contract was arranged at Crosley where the staff of design engineers set up a production line, with engineers to put pilot lines in operation. The tubes were pouring in for firing tests, often several batches a day, and experience was built up on how to design and assemble them into satisfactory structures. Quality and performance were rising. Interest everywhere was being felt. I remember one conversation with Commander Parsons on the im-

portance of the VT fuze in keeping esprit de corps at a peak. He said he wanted to discuss this with the Navy, and came back later with the statement that delays in the VT program were equivalent to the loss of a battleship every three months, the loss of a cruiser every month, and the loss of 150 lives a day. This gave some idea of the pressure felt in the Laboratory and of the effort and time that were willingly spent in trying to speed up the program.

Finally, the cruiser USS *Cleveland*, while deployed in Chesapeake Bay for ordnance trials, was scheduled on August 12, 1942, to carry out some VT fuze firing against drone targets. Six drones had been ordered for the trials. The first was a launching casualty. The second had a few bursts around the target, but near the end of the run it was hit and crashed. In the afternoon another drone was launched. Fire was opened at about 600 yards, and the drone was killed on an early salvo. The next morning another drone was provided, which also was immediately shot



*Quality control operation*

down. There being no further drones, the exercise was successfully completed with less than a dozen VT fuzes expended.

That opened the floodgates. Final diagnostic tests were made and ammunition was rush-produced and deployed on Navy warships. On January 5, 1943, the USS *Helena*, while on patrol north of Guadalcanal, shot down the first two Japanese planes in combat.

The USS *Cleveland* fuze tests, followed by the USS *Helena* success, started the feeling that a breakthrough in anti-aircraft effectiveness had been achieved. It had also been recognized that one of the greatest problems with fuze deployment would be premature detonations or other accidents. Therefore, a number of additional safety factors were included in the design to assure freedom from such events. As a result, no such incidents were traced to the VT fuzes.

The fuze effectiveness was so evident that they were eagerly wanted by the services. Since improvement in their manufacture was to be achieved by hands-on doing, weaknesses in production became known quickly from vertical firing tests, recovery, and post-firing examinations and could be corrected. Fifty percent operability had been recognized as an initial goal, and 80% was not thought exceptional. The program prospered. There were times when some production changes caused a spate of malfunctions, such as brittle glass in the radio tubes or large welding tabs on the filaments to improve their visibility for the welding; but, if serious, they were easily recognized and corrected. With experience, production quality improved rapidly.

The Mk 32 fuzes were used only on 5-inch gun shells, which were large enough to take 2-inch dry cell batteries as power supplies. About a year earlier, development was started on a 1½-inch wet cell battery when it was discovered that the 2-inch dry cell had too short a shelf life to be wholly satisfactory. National Carbon Co. proposed a battery consisting of a stack of plates cemented in plastic to supply the proper voltages after a liquid electrolyte flowed into place when a glass container was broken on firing. This design could be made in a 1½-inch-diameter size, and it would alleviate future shelf-life problems.

At APL, the development of the 1½-inch battery was well known; small fuzes for the U.S. Army and the British Army and Navy were being designed that could be used in shells down to 3 inches in diameter. While they were being developed as anti-aircraft fuzes, they were also tried out in airburst firings over the surface-effect testing fields at Fort Bragg, N.C. The fuzes were adjusted to burst 50 to 100 feet above the ground and could be used for barrages even on the reverse slopes of hills. They could be effective in foxholes against troops simulated by pine boards placed in shallow holes. It was clearly shown that



Several VT fuzes

troops would get little protection from shell fragments in such situations.

I was at Fort Bragg in 1944 when these fuzes were demonstrated to General Leslie McNair, who was going to Europe to command the troops in Normandy. Being less sensitive than the anti-aircraft fuzes because they were fired from howitzers with less acceleration than anti-aircraft guns, the fuzes had an operability of about 80% and a far greater effectiveness than the group had expected. One colonel remarked that even greater operability was being sought. I remember General McNair's reply: "Gentlemen, gentlemen, you are asking for all this and Heaven too?"

The massive use of VT fuzes during the unsuccessful German counteroffensive in the Ardennes mountains in the winter of 1944, their effectiveness against the German "buzz bomb" over England, and their incomparable performance against Japanese warplanes, kamikazis, and Baka bombs in the Pacific played a decisive role in the Allied victory in World War II.

#### REFERENCE

<sup>1</sup> *The First Forty Years—A Pictorial Account of the Johns Hopkins University Applied Physics Laboratory Since its Founding in 1942*, The Johns Hopkins University Applied Physics Laboratory (1983).