Supplementary Content

The Legacy of Dale R. Corson

Post-Publication Supplement One
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Preface

This supplementary collection is an on-going effort to expand the initial book, The Legacy of Dale R. Corson. This supplement will be expanded from time-to-time – breaking the usual limitation of a single definitive terminal point for a traditional book edition.

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Preface

This is a personal account of my role in the development of airborne RADAR during World War II – from the time I was summoned to join the staff of the MIT Radaiation Laboratry, through testing and implementation to the end of the war.

Dale R. Corson

23 February 2003

Microwave Radar In World War II

Microwave Radar In World War II

Dale R. Corson, March 1, 2008

Speaking at Saturday Night Club, or anywhere else, is difficult for me now because I'm doing nothing worth speaking about. I can only revert to the past and that is what I am doing tonight. I will talk about microwave radar as it was used in World War II, focusing on my own 4½ year involvement.

There's not a great deal of literature about radar's role in the war, but in the early 1990s the Sloan Foundation commissioned a young science writer, named Robert Buderi, to write a history of the MIT Radiation Laboratory, the principal WWII American radar development organization. Buderi called me one day, right out of the blue, to ask some question and, as time went on, I became a general hand holder for him, clarifying technical points he did not understand and commenting on his manuscript. Henry Guerlac, who came to Cornell after the war and became one of America's eminent science historians, was the official historian of the MIT Project. The Guerlac papers in our library provided material available nowhere else.

What I say tonight comes from material I pulled together 15 years ago for Buderi, from the Guerlac papers, from some other sources and from my own memory.

Detection of ships by reflection of radio waves had been demonstrated as early as 1904 but no one was interested until 1935 when the British began to worry about Hitler.

In 1934 an assistant administrator in the research arm of the British Air Ministry, A.P. Rowe, surveyed all possible air defense systems and concluded that Britain had no air defense. The Air Ministry decided to act.

They created a Committee for the Scientific Survey of Air Defense, chaired by Henry Tizard, Rector of Imperial College of Science and Technology of the University of London. It was a committee of six people including Mr. Rowe and P.M.S. Blackett, a distinguished physicist at the University of London.

In the late 1930s I worked in exactly the same field of physics as Blackett did and he was the mentor of my Berkeley professor. I came to know him during the war. He was a Nobel laureate in 1948 and later he was President of the Royal Society, Britain's most distinguished scientific body.

The minutes of the early meetings of the Tizard Committee are in the Guerlac papers, copied there in Henry's handwriting. In its first meeting, on January 28, 1935, the committee discussed all possible means of air defense. Searchlights with direction determined by sound locators. Not much hope there. Visual detection. No hope at all. Detection by infrared--to be taken up at a later meeting. Dr. Robert Watson-Watt, superintendent of the Radio Department of the National Physical Laboratory (the British equivalent of our Bureau of Standards) had been asked earlier about the possibility of using radio waves as death rays. He reported that the idea had no merit but there was a possibility of detecting aircraft at a considerable distance by reflected radio waves. The committee was interested and plans were made to establish a laboratory, under Watson-Watt's leadership, to explore the detection idea.

The system adopted for experimentation included the transmission of a short pulse of radio waves, a bit of which was reflected from the target, measuring the time for the reflection to return and then transmitting another pulse to repeat the process. Radio waves travel at the speed of light and by measuring how long it takes for the echo to return one can determine the distance to the reflecting body. If the antenna that transmits the radio waves transmits in only one direction, then that is the direction to the target.

It takes about 10 μs (i.e. 10 millionths of a second) for a pulse to travel to a target a mile away and return to where it started. It was easy to measure a fraction of a microsecond even in World War II days; so distance could be measured with some precision if the pulse was short enough.

TV CRT picture tubes, just now going out of style with the advent of the new flatscreen displays, are cathode ray tubes (CRT is the common designation) in which an electron beam is scanned back and forth from left to right, making the screen brighter wherever the electron beam strikes it. The radar monitor was the same type of picture tube except that the electron beam normally scanned radially from the center of the screen in the direction the antenna was pointing. The echo made the trace brighter for a few seconds so that it painted a map of anything in the field of view.

The Watson-Watt group was extraordinarily successful right from the beginning. Before 1935 was out they achieved detection ranges of about 50 miles using a 25 m wavelength and 25 μs pulses with 100 kW of pulse power. A 25 μs pulse gave only a two or three mile distance precision.

From the beginning there was a big drive for shorter wavelengths. There were two reasons for this: 1) the shorter the wavelength the easier it is to make short pulses and therefore greater distance measuring precision and 2) the shorter the wavelength the easier it is to make a narrow beam of radio waves and the greater the directional precision. The wavelength in the airborne systems I worked with was 10 cm and the antenna was a circular aluminum parabolic dish about 3 feet across, producing a beam width of about 10°. Later systems had a 3 degree beam.

The word "radar" for "radio direction and range" was invented sometime in middle or late 1940.

By 1938 the British had installed a chain of early warning radar stations, known as CH (for home chain), along the east and south coasts of England, using wavelengths of 6 to 15 m. At these wavelengths the antennas were enormous structures, 200 or 300 feet high, visible for miles. I believe that complete coverage of the South and South West coasts was not complete until the fall of France in June 1940, barely 2 months before the Battle of Britain began.

The stations were critical in the defense of Britain during that terrible time. As the German formations took shape over France they could be detected and their track determined early enough for the small Fighter Command squadrons of Spitfire and Hurricane planes to fly from their home bases to other bases in the track of the incoming raid, refuel and be at altitude to meet the raid when it arrived.

The Watson-Watt laboratory operated throughout the late 1930s with a tiny but highly productive staff. One staff member was E.G. Bowen, a young Welsh physicist who had just completed his Ph.D. at the University of Wales in Swansea when he was recruited for the Watson-Watt effort. He became a dominant figure in the British work at that time and later exerted heavy influence on the American effort at MIT, where he was known as Taffy.

Toward the end of the war Bowen moved to Australia where he founded the rather remarkable Australian radio astronomy program after the war. Nellie and I visited him and his wife in Sydney in 1968.

Bowen was the central figure around whom Bob Buderi built his story of the MIT laboratory.

In this country both the Army and the Navy had radio detection programs from the late 1920s on, without either telling the other. This work appears to have been about on a par with the British work right up to the late 30s--except that the British had a war to fight. The British told no one about their work, not even the other Commonwealth countries, until 1939 or 40.

After the fall of France in June 1940 it was becoming clear that we were going to be involved in the war and the scientific establishment began to get itself organized. The organizers were James Conant, a chemist and President of Harvard, Karl Compton, a physicist, and President of MIT, Frank Jewett, President of Bell Telephone Laboratories and President of the National Academy of Sciences, Ernest Lawrence, a Berkeley nuclear physicist and my former boss, and Vannevar Bush, an electrical engineer from MIT who was President of the Carnegie Institution of Washington. On June 27, 1940, a year and a half before Pearl Harbor, Vannevar Bush met for 15 minutes with FDR to outline a National Defense Research Committee (NDRC) the group wanted to establish and Roosevelt initialed Bush's short paper "O.K. FDR".

11 days later FDR received a letter from Churchill, offering to disclose the British secret research program and seeking cooperation. Roosevelt accepted at once.

The Vannevar Bush group gave air defense a high priority and they knew that the radio detection program would never go far without a move to microwaves, given the small size, particularly of antennas, and the precision that went with microwaves. So creation of a Microwave Committee was one of the first acts of the National Defense Research Committee.

The Chairman of this committee was Alfred Loomis, a remarkable amateur scientist who was a member of the National Academy of Sciences and who had his own laboratory in Tuxedo Park, New York. Loomis was a Wall Street lawyer and investment banker, who was an MIT trustee and who was widely acquainted in the scientific world--with Compton, Conant, Lawrence and through Lawrence the whole Berkeley entourage. He also knew Edward Bowles, an MIT electrical engineer specializing in communications and experienced with microwaves. Bowles was appointed to the Microwave Committee, along with Lawrence and scientific leaders at Bell Labs, GE, RCA, Westinghouse and Sperry Gyroscope.

Historian Henry Guerlac writes "the group was experienced in scientific administration, versed in current radio development, well placed to coordinate scattered work and fitted to administer funds."

Every one knew that microwaves were central but they also knew that they had to have a microwave generator much more powerful than the fractional watt generators current technology provided. The British had already set about finding such a generator in the fall of 1939 at Birmingham University and by February 1940 they had succeeded. Various approaches were undertaken, with two scientists, named Boot and Randall, investigating magnetrons. The magnetron, in which a vacuum tube was placed in a magnetic field so the electrons followed curved paths as they moved from one side of the tube to the other, was well-known in a simple form and was used to produce fractions of a watt of power at wavelengths in the centimeter and even millimeter range. On a hunch Boot and Randall tried building on some 50-year-old work by Heinrich Hertz, a German pioneer in radio wave research. Hertz had used a metal ring with a gap arrangement to produce radio waves and Boot and Randall extended the idea to a series of cylinders with slits, produced by drilling cylindrical holes parallel to the axis of a cylindrical block of copper, with slits connecting the holes to the hollow center of the block. The magnetic field was parallel to the axis. This is the cavity magnetron of your microwave oven--and of microwave radar. They produced 1 kW of power at a wavelength of about 10 cm and then 10 kW and later 100 kW. By war's end magnetrons capable of a megawatt, i.e. a million watts, were available. Your microwave oven produces about 0.7 KW.

Following the US-British agreement to share war research secrets the British organized a mission to come to Washington and to bring the magnetron--that no one outside the inner circle of British officials and scientists knew about. The mission was led by Henry Tizard, the Rector of Imperial College of the University of London, with two other civilians, Bowen and John Cockcroft, a distinguished physicist, plus several military officers. The mission departed England on August 20, 1940. On Sunday, October 6 the magnetron, operating at a wavelength of about 10 cm, was demonstrated at the Bell Telephone Laboratories. To the astonishment of the Americans, it produced 10 kW of power. The American air defense effort, thwarted to this point by inadequate microwave power, was ready to take off.

When the Tizard mission returned to England Bowen remained behind and in early October, following the demonstration of the magnetron and with Bowen playing an influential advisory role, the American civilian microwave laboratory was organized, following the British model to a considerable degree, including staffing primarily by physicists. Why physicists? I don't know. There was the British success to point to. There was the physics influence on Alfred Loomis' Microwave Committee. Physicists were better equipped to deal with microwave technology than were chemists but why not electrical engineers, who were more directed to radio lore and engineering?

MIT was chosen as the site of the laboratory. Ernest Lawrence, the Berkeley physicist, was the key personnel recruiter. Lee DuBridge, the 39-year-old Chairman of the Physics Department at Rochester, was recruited as director of the laboratory.

In late October 1940 there was a three-day symposium on applied nuclear physics at MIT and 600 physicists attended. The conference turned into a briefing and recruiting session for those invited to join the lab. I was at the University of Missouri in the fall of 1940, without travel funds so I stayed home.

Before October was over DuBridge was on the job. 12,000 $ft.^2$ of space had been assigned and a first-year budget of $455,000 had been adopted. A lab or 50 people, including technicians and secretaries, was projected. At VE Day, Laboratory personnel numbered about 4000. The laboratory was named the Radiation Laboratory, a name intended to disguise its purpose.

The British Watson-Watt work had embraced AI--air interception--and Bowen had concentrated on airborne radar for this purpose. When the MIT laboratory was organized it had three primary missions: navigation, precision gun laying (that is, aiming and firing antiaircraft guns) and, under Bowen's influence, air interception.

Lawrence made a recruiting trip around the country in November and I received a telegram from him asking me to meet him in St. Louis in connection with something important. I met him on the specified date and he asked me to sign up for the MIT lab, which I did. I was granted a three-month leave from the University and Nellie and I moved to Cambridge over the 1940 Christmas and New Years holidays. We never returned to Missouri and after 5 1/2 years of war work we came to Cornell.

I reported for work at MIT on Monday morning January 6, 1941. The laboratory was organized along component lines, following the British example: a transmitter group, a receiver group, an indicator group, a modulator group, an antenna group and a systems group. I was assigned to the systems group in a plywood building on the roof of one of the MIT buildings, the plywood building having been built during December. That systems assignment dictated my radar career, right up to the middle of 1945.

The first operation of an American microwave radar was on Saturday, January 4, 1941, 11 months before Pearl Harbor and only about 2 1/2 months after the lab was conceived. When I went to work the following Monday morning I was shown the Boston skyline as viewed with microwave radiation. Developments and improvements came rapidly and within days we were seeing aircraft echoes among the building echoes.

The Army Air Corps (the Air Force was not created until after the war) supplied an aircraft for flight tests of an airborne configuration and I was assigned to that project, under the leadership of Edwin MacMillan, my former colleague at Berkeley and a Nobel laureate after the war. The aircraft was a B-18, a military version of the DC-3. We joked that in a steep dive it could do 120 miles an hour.

The official record is confused about the early operation of this system in March 1941 and I should say a word about Henry Guerlac's history. He did not come to the lab until it had been operating for two years and he had to reconstruct those first two years by reading reports and talking to busy people. The result was a story whose details diverged from my memory. He was always hesitant about publishing his work and questions about what he reported as facts probably increased his hesitation. It was not until 1987, shortly before he died, that the American Institute of Physics decided to publish his monumental two volume history. I wrote the Foreword after his death.

Henry writes about the B-18 equipment: "on March's 6-7 it was installed in a B-18 plane, equipped with a special Plexiglas nose transparent to hyper-frequency radiation. The equipment was first flown on March 10 with poor results." He says the first successful flight was on March 27 with Bowen present. I remembered a successful flight on March 10 without Bowen. The antenna for all the early aircraft tests was a parabolic aluminum reflector about 36 inches in diameter. It rotated about a vertical axis and could be tilted up and down. On that first flight the rotation mechanism was not yet operational and we had to point the antenna by hand and when we pointed it at our target airplane, a fraction of a mile ahead of us, we saw the reflected signal on our cathode ray tube indicator. So I claimed that the first American success with an airborne microwave radar was on that day. By pure coincidence the first successful flight of the British microwave equipment was also on March 10.

From the first days of flight testing it was clear that echoes from ships were going to be useful and the Systems Group undertook an airborne radar project to detect ships. It was known as the ASV (air to surface vessel) project. There was also a shipborne project and I was transferred to that at New London, Connecticut.

While I was stationed at New London DuBridge called me one night at the hotel where Nellie and I were staying and said: "How would you like to go across the water?" He proposed that I take our latest AI equipment, then installed in a Boeing 247-D, the 14-seat air line predecessor to the DC-3, to England for comparison tests with the corresponding British equipment.

Bowen, Fred Heath (a Canadian engineer) and I spent 10 weeks in the summer of 1941 working at the Telecommunications Research Establishment (TRE), the British equivalent of the MIT radiation laboratory. TRE was then at Swanage in Dorset on the South Coast. We flew our equipment and we flew experimental British equipment with the RAF. Our airfield was in Hampshire near Christchurch and we spent many hours flying back and forth along the Sussex coast, between Selsey Bill and Beachy Head.

We were able to determine which of our components were superior to the comparable British components and which were inferior. In the end we married the best of the British equipment with the best of ours and a hybrid system was manufactured by Western Electric for combat use by both British and American night fighters. It remained the standard RAF night fighter equipment until 1957.

After Pearl Harbor, Radiation Laboratory attention turned to antisubmarine warfare. The military wanted help with the submarine threat and I was assigned to the project, along with a number of other people.

I believe my first assignment was to take our radar equipped B-18 to Panama to help protect the canal. I started on this only to be shifted to the Aleutian Islands. I had tickets in my pocket and arrangements made to get to Attu and Kiska when interest shifted to the west coast of the US. By this time I had a panel truck with a great deal of test equipment and spare parts ready to operate. I dispatched my technician and the truck from Cambridge to San Francisco. When he arrived there he telephoned, saying: "Here I am. What do I do now?' I took a deep breath and said: "Go to West Palm Beach, Florida," where submarines were attacking ships right on our doorstep. When he arrived there I met him and dispatched him to Jacksonville, where there were even more submarines.

By this time we had a squadron of B-18s all equipped with laboratory ASV equipment and we actually hunted submarines from Jacksonville. The submarines had to surface to recharge the batteries that provided their propulsion power while submerged. They did their surface recharging at night. The first night out the crews found three surfaced submarines but they failed in reporting the contacts to base. This kind of disorganization and failure of procedures plagued much of the early war effort involving complex equipment and even equipment that was not so complex, such as radios.

By the time we reached the Florida part of this story I had a partner named Byron Havens, a Caltech undergraduate who came straight from his BS to the lab. He was a brilliant electronics engineer who made major contributions before the war ended. His postwar career was all with IBM.

Soon after the Jacksonville flights we were transferred to Langley Field Virginia, across the Bay from Norfolk, where I spent much of the summer of 1942. There were plenty of submarines to find there. Havens and I were on easy terms with everyone, from enlisted technicians to the commanding officers. We flew with the crews, maintained the equipment and gained experience.

One of the problems that soon became evident was the inability to hit anything with a bomb once the submarine had been detected. During early 1942 about one submarine sinking per 40 contacts was the official score. After various technical and operational improvements, particularly by the British, the kill ratio improved greatly and in the end the submarine threat ended. I will say more later.

Working with one of the more imaginative bombardiers, Havens and I experimented with the idea of giving the bombardier a radar indicator to use in conjunction with his visual bomb sight. Out of these experiments we devised a system known as LAB, low altitude bombing. The target signal was centered on the screen by turning the appropriate knobs and by heading the plane to keep the target squarely lined up. As the plane proceeded, the signal, which was a bright blob on the radar screen, moved up or down the screen and the operator turned another knob to make the target stand still right in the middle of the screen. Meanwhile a horizontal line moved up from the bottom and when it reached the target the bombs were released automatically. This system became the model Bell Labs used to develop their own Low Altitude Bombing system, based on the MIT concepts and experience but with detailed circuit designs of their own. It was used with great effectiveness against Japanese shipping in the Pacific.

One digression about the LAB development tests, which took place in Florida. Early in his career S.C. Hollister, the longtime dean of the Cornell College of Engineering, designed ships made of concrete. Two of those ships were long ago sunk, with parts extending above the surface, in the Bahama Islands, near North and South Bimini, about 60 miles off Miami. Most of the tests were conducted from West Palm Beach (Morrison Field) using a B-24, a four engine bomber aircraft, with the concrete ships as targets. We dropped 100 pound live bombs flying at an altitude of about 1000 feet.

In operational use in the Pacific about one night attack in three produced a direct hit on the target.

Now back to the submarine war. The first British ASV radar, operating at a wavelength of 1.5 m, was nearing operational status when the war began in the fall of 1939. Attempted use against submarines began in 1940 but the most dramatic use was against the battleship Bismarck in May 1941, a month before I went to England to work at TRE. The Bismarck had sunk the British warship Hood on May 25 and was itself damaged by the British Prince of Wales, but managed to escape and was lost for many hours. It was finally found with a radar equipped Catalina, an American flying boat used by the RAF. The British Fleet closed in and finished off the Bismarck. I arrived at TRE around the first of July and my first activity was a seminar on the Bismarck Engagement.

The first airborne radar submarine sighting came in May 1940 in the Bay of Biscay, off the coast of France, but the first attack on a submarine did not come until November 1940. During 1940 the subs had full sway. During the first nine months of the war about 10 ships were sunk for every submarine destroyed and things deteriorated from there. During December 1940 and January and February 1941, 96 ships were sunk and not a single submarine. Part of the trouble was in the use of radar equipment without adequate training and without adequate search procedures. Finding submarines was a difficult job at best and finding them in the North Atlantic in bad weather was nearly impossible.

Improved ASVs were installed on a large number of planes, the number eventually reaching 400. Sightings increased and the first damage-inflicting attack came in February 1941. With increasing numbers of attacks the U-boats were frightened and remained submerged for longer periods and their movements were restricted. Shipping losses began to fall and by the end of 1941 losses had fallen to 10 ships lost for each submarine sunk, back where we were in early 1940. Night attack by aircraft became more common.

In the spring of 1942, with the US in the war, the Germans attacked shipping along our east coast and losses started up, reaching 20 ships sunk for each sub destroyed.

I pointed out earlier the difficulty of hitting a surfaced submarine at night even though the radar could find them. The bombing had to be done visually and the bombardier could not see the target. This all changed with the installation of searchlights on British aircraft. By the summer of 1942 the lights were in widespread use and were extraordinarily effective. The plane closed on the submarine entirely on radar guidance and at the last moment turned on the searchlight and aimed the bombs visually.

From mid-42 on shipping losses fell and although the battle continued right on through 1943 and 44 the Allies had the upper hand and the ratio of ships lost to U-boats sunk fell to a small number.

In 1943 both the British and the Americans undertook large blind bombing operations against German industrial targets, the British by night and the Americans by day. Equipment much like the anti-submarine radars were adapted for land bombing use. Industrial areas could be distinguished from residential areas but it was nearly impossible to do anything that could be called precision bombing. A common technique at night or above the clouds was to employ "pathfinder" squadrons who could identify the target, make a carefully controlled bomb run using the radar signals, releasing their bombs and at the same time releasing flares with parachutes. The following planes released their bombs when they reached the flares.

The massive blind bombing attacks must have seriously damaged German morale but they were less than totally successful in destroying German industrial capability.

From late 1942 on I worked in Air Corps headquarters in Washington as a technical advisor to a General responsible for overseeing the development, production and introduction into combat of new equipment, primarily electronic equipment. I was dispatched to North Africa and Italy and then to England in the winter of 1943-44 to make an assessment of the efficacy of the blind bombing effort. In tests in Florida or in the Mohave Desert in California, in good weather, with skilled operators and with the equipment in tip-top condition it was difficult to hit anything from an altitude of 20,000 feet, even with an optical bombsight. Move this to a theater of war, in terrible weather, with the enemy shooting at you, with inadequately trained crews, with the equipment in far from top condition, and you did not often strike targets. I had trouble making people back home believe that the blind bombing was as inaccurate as I said it was, based on analysis of photo reconnaissance pictures.

When B-29s began missions against Japan from Sichuan, far inland in China my colleague and I, in the Pentagon, undertook a "radar intelligence" program. We actually planned the first mission ourselves and we trained an intelligence unit to perform the same function in the field. The first mission, probably in the summer of 1944, was against Japanese steel works in Yawata on the Shimonoseki Straits between Honshu and Kyushu. We laid out a bomb run, using easily recognizable islands or land features, guaranteed to give them maximum probability of hitting the target. We drew pictures of what the radar operators would see at given points. Commanders in the field, however, elected not to use our plan because it exposed them to Japanese fire for a few minutes longer than they liked. They made their own plan, hit nothing at all, and lost six B-29s and their crews.

As a matter of interest: Bill Brown, a post-war Cornell entomologist, was stationed in Sichuan at this time and operated all over eastern China, rescuing the crews of downed planes. I startled him once by giving him a list of targets for the first dozen of those raids, how many planes were involved in each raid, how many crews were lost, and what success the raids achieved.

The Radiation Lab staff from the beginning included people who were brilliant inventors and the most brilliant of all was Luis Alvarez, future Nobel laureate at Berkeley. You probably know him for his asteroid theory of dinosaur extinction. He made three major inventions at the Radiation Lab, each involving an antenna based on the principles of visual optics every physics undergraduate studied in depth in those days.

Visible light has a wavelength of something like a thousandth of a millimeter, compared to the 10 cm wavelength we were working with at MIT--a factor of 100,000. The optical phenomena a physicist is familiar with, such as refraction, diffraction, reflection, dispersion, and interference all have their counterparts with microwaves except on a scale 100,000 times bigger. Alvarez used these principles to design an antenna that produced a narrow beam of intense microwave radiation. When it was incorporated in a 25 foot long rotating system it was capable of detecting aircraft with precisely known distance and direction up to 200 miles. This became the standard early warning system for the later stages of the war. It was known as MEW, for microwave early warning.

Through a clever arrangement of some moving parts in the antenna structure he could make the narrow beam sweep back and forth from right to left through a total angle of about 60° with the antenna stationary. Put this in a wing-like structure underneath the fuselage of a bomber and one had a high-resolution blind bombing device. This equipment was called Eagle. For a time it was designated EHIB, for every house in Berlin. City streets were readily visible.

The Alvarez Eagle blind bombing equipment on B-29s was introduced in the Pacific rather late and had little effect on the war.

Now, a personal experience with this equipment. I was working at an air base in the Mohave Desert where some of the final training of crews going to the Pacific took place. One Sunday morning, for some important purpose that I cannot now remember, we made a test flight in a B-24 four engine bomber, with me as the radar operator. I was "under the hood", that is, in a small compartment where I could see nothing but the radar screen. We flew up the San Joaquin Valley to Sacramento and then reversed our course back to our base at Victorville, following directions I gave the pilot over the intercom.

On the way back south the pilot asked me repeatedly where the mountains were and I kept telling him "25 miles to the left" or "50 miles straight ahead" according to what I was seeing on the screen in front of me. As we approached our base I gave him instructions for "letting down", that is, beginning the approach to our airfield. His inquiries about the mountains became more and more nervous and I did not know what was bothering him. Finally when we came down to a couple of thousand feet above the ground he relaxed. When we landed, and I exited from the hood, I learned that the cloud ceiling had lowered to 2000 feet during our flight and we were in the clouds all the way home. When I realized I had been entirely responsible for the safety of the crew and of the aircraft in getting us down through the clouds, through the mountains and lined up with the runway for landing, I went limp. But I made a believer out of that pilot--and out of me.

I want to return briefly to the control of anti aircraft guns. This developed into a highly successful operation using a 10 cm radar installed in trailers the size of a large truck. The central feature of these radars was the ability to "lock on" the target and follow its every move. Computing equipment, which we would consider crude today, calculated the target's track and aimed the antiaircraft guns. I believe the equipment had been used in a minimal way in North Africa following the landing there in November 1942 but by far the most important early use was at Anzio, just south of Rome, in March 1943. The original landing in Italy was at Salerno, south of Naples. After bitter fighting the allies sought to leapfrog the enemy with a second landing at Anzio but they were pinned down on the beach for weeks. In the first air attack following the deployment of the radars, five of 12 attacking German planes were shot down. 63 confirmed "kills" were credited to the equipment by the end of the month. On average, one in five attacking planes was shot down during the Anzio period.

Later, the same radars played decisive roles in destroying V-1 missiles attacking England in 1944. The missiles were faster than the defending fighter planes and the antiaircraft gun became the weapon of choice.

Now, one final example. The advantages of going to shorter and shorter wavelengths were obvious and there was a push to go all the way down to 1 cm. The actual wavelength chosen was 1.25 cm. The results were great. I remember flying with the equipment and seeing individual streets in Boston and Providence. We had reached Nirvana. There was just one trouble. Radiation of 1.25 cm wavelength proved to be strongly absorbed by water vapor so that the microwaves could not penetrate clouds and performance was fatally degraded. It was a highly successful effort in every respect-- except that it was good for nothing.

Altogether, more than 100 different radar equipments for many different purposes were developed, many of them produced in large numbers. I have discussed only a few of the major ones and ones I happened to have had something to do with.

How important was radar in World War II? Let me quote from the I. I. Rabi and John Rigden introduction to Henry Guerlac's history: "Radar altered the course of the war and, in so doing, it changed the course of the world." I have heard it said many times: "the atomic bomb ended the war but radar won it."

It is useful to look at the World War II technical effort from today's vantage point and ask if, in a similar crisis, we could find equally effective ways to respond. Would it be possible to organize a laboratory to tackle some vital problem and do it so effectively? Maybe, depending on the problem and the degree of urgency. Are there ways today to make national science policy which are as effective as were the ways in the Vannevar Bush days? The answer is certainly "no". Are those making science policy today as obviously the best and the brightest as were the Bushes, the Conants, the Comptons and the Lawrences of more than half a century ago? Almost certainly "no". Are there leaders of the DuBridge caliber to guide whatever efforts we undertake now? The answer is surely "yes". The world is filled with highly competent young people.

Overall, we have vastly superior technology today, yet we seem less capable of bringing it to bear effectively on our national needs. Perhaps it is only that I am too much out of the action and lack adequate vision.

2-23-08


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