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History and Activities of the Radiation Laboratory of the Massachusetts Institute of Technology

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THE Radiation Laboratory of the Massachusetts Institute of Technology, the largest wartime laboratory devoted to radar research and development and the largest single enterprise of the National Defense Research Committee, is demobilizing after five years of intense work heretofore shrouded by tight military security. Operating as a quasi-governmental agency, the Radiation Laboratory participated in one of the most extraordinary cooperative scientific efforts in history—an enterprise which included many British government and industrial laboratories, several U. S. Army and Navy laboratories, and a host of U. S. industrial laboratories, large and small. From the combined effort of all came the development of a radar industry which provided Allied fighting forces with an amazing array of radar equipments. Individually, each was far in advance of any radar the enemy nations possessed; collectively, our radar revolutionized many phases of modern warfare and contributed significantly to the Allied victory.

The full technical story of this whole enterprise will fill many volumes, and RL is now preparing such a series of volumes. Similarly, a complete analysis of the operation of the huge cooperative enterprise would be very lengthy. On the assumption that the readers of *The Review of Scientific Instruments* would be interested in a glimpse of the Radiation Laboratory itself, showing particularly the part played by the academic physicist in radar development, this brief statement has been prepared.

THE BEGINNINGS

The beginnings of military radar research and development took place almost simultaneously in several countries during the middle and late 1930's. By the middle of 1940, when the National Defense Research Committee was organized, the U. S. Navy and the Signal Corps had in production or ready for production radar equipments for air defense both of the fleet and of land bases. The British had a radar chain poised for the coming Battle of Britain, and had a large radar development and manufacturing program in full swing. It was already clear that radar (although this name had not yet been coined) was going to play an important part in the war.

While the NDRC plans for initiating development in this field were being formulated under the division headed by K. T. Compton, by a "Microwave Committee" headed by Alfred L. Loomis, a British scientific mission, headed by Sir Henry Tizard, arrived in this country to exchange information with U. S. scientific agencies. This mission quickly broke down security barriers between the U. S. and the British, and the era of cooperation was underway.

The British revealed that they already had several large civilian laboratories at work on radar development; these had been staffed to a considerable extent by bringing in physicists and engineers from the universities. They also made it clear that one of the big needs was for the development of microwave techniques for radar use, a field not then being covered in the U. S, NDRC thereupon decided to recruit a laboratory, drawing upon physicists and engineers from the universities, to undertake an intense development program in microwave radar.

Alfred Loomis enlisted the cooperation of E. O. Lawrence, also a member of the Microwave Committee,[1] to select an initial staff.

In mid-October, 1940, they asked the author to become Director of the Laboratory, and an active program of recruiting was initiated. Preliminary conferences were held during an Applied Nuclear Physics conference at Massachusetts Institute of Technology in early November, 1940, and an initial group of about 30 men began work at Massachusetts Institute of Technology on November 11. Massachusetts Institute of Technology had been chosen as the site of the Laboratory, after a thorough investigation of other possibilities, partly because of the microwave work already in progress there, partly because of its proximity to an available airport at East Boston, but mostly because it appeared to offer the best atmosphere for a laboratory of this type. The group decided to call themselves the Radiation Laboratory, in honor of E. O. Lawrence, and because the name did not reveal the nature of the work.

The group grew rapidly in 1940 through the enlistment of additional research men, and by January, 1941 it was very clear that the problems which had been undertaken were so great that a larger laboratory would be required. Consequently, F. W. Loomis was brought in as Associate Director and put in charge of personnel recruiting. He gradually assumed a very large share of the administrative burden of operating the Laboratory.

[1] The other members of the Microwave Committee, which later became Division 14 of NDRC, were: Ralph Bown, Bell Telephone Laboratories; Ralph Beal, RCA (later succeeded by Loren F. Jones); H. Hugh Willis, Sperry Gyroscope Company; G. F. Metcalf, General Electric Company (later succeeded by C. G. Suits when Metcalf accepted a commission in the Signal Corps); J. A. Hutcheson, Westinghouse Electric and Manufacturing Company; Melville Eastham, General Radio Company; E. L. Bowles, M.I.T., Secretary (later succeeded by J. G. Trump when Bowles went into the Office of the Secretary of War; Trump in turn was succeeded by J. R. Loofbourow); M. J. Kelly, Bell Telephone Laboratories; W. R. G. Baker, General Electric Company; L. A. DuBridge and I. I. Rabi, consulting members. Later F. E. Terman, Director of the Radio Research Laboratory, Harvard University, Ray Ellis, WPB, A. T. Waterman, Yale University and Assistant to Member, NDRC, and Warren Weaver, Chief of NDRC's Applied Mathematics Panel were added.

But no one in those days ever dreamed of the fantastic size RL eventually attained. By the end of the Japanese War, RL had 3900 employees, occupying two-thirds of a million square feet of floor space, located in one permanent and two huge temporary buildings on Massachusetts Institute of Technology's campus, in factory buildings leased or purchased in Cambridge, and in various field stations. In collaboration with all of the other radar research agencies, RL had by that time developed for combat use a whole series of microwave radars which fought on every warfront.[2]

THE EARLY DAYS

The Radiation Laboratory drew its first problems and its first technique directly from the British. Britain's greatest radar need at the time was an airborne set to enable nightfighters to detect enemy bombers. Crude forms of such AI (for "aircraft interception") radar were in use; the next step envisaged by the British was the development of a set using much shorter wave-lengths than the 1.5 meters of the early sets. Only at wave-lengths below 10 cm could an antenna be small enough for aircraft installation and still produce a sharp enough beam to give accurate location of the enemy.

The Microwave Committee had investigated microwave radar in the summer of 1940, but there was no oscillator tube which would give adequate pulsed power. The British brought the solution to that problem: a cavity magnetron developed by Drs. Oliphant, Randall, Sayers, and Boot at the University of Birmingham. It could produce pulses of 10 kilowatts peak power at a frequency of 3000 megacycles (10-cm wavelength). This instantly attracted the interest of the physicists. Such power at that frequency was then unheard of.

The physicists plunged into the problem with enthusiasm. The Microwave Committee, most of whose members were representatives of the large industrial research laboratories, had already made arrangements for close cooperation between the new laboratory and the industries. Bell Telephone Laboratories were asked to manufacture and improve the magnetron; Westinghouse was to design a suitable pulse generator; Sperry a

[2] See "Radar—A Report on Science at War," released by the Joint Board on Scientific Information Policy, U. S. Government Printing Office, Washington, D. C.

scanning antenna; General Electric a receiver, and so on. Drawing heavily on the experience of the engineers of these laboratories, the RL physicists also set about developing these and other components and soon collected and assembled the parts of the first U. S. pulsed microwave radar set.

Many knotty problems were presented by the new microwave art. The magnetron worked well, but no one quite understood why. RL and Bell Laboratories initiated a theoretical and experimental study of the device and soon enough was known to improve the efficiency considerably and to design models which operated at 3 cm. Later a large RL group, working closely with other U. S. and British Labs, brought to a high state of perfection a whole series of magnetrons for various power levels (up to 4000 kilowatts) at various wave-lengths down to 1 centimeter. The first magnetrons operated at an efficiency of under 10 percent; present models yield over 70 percent. Millions were produced by the industry for the Army and Navy.

Other military problems beside that of air interception came up in discussions with U. S. Army and Navy officers, and the physicists began dreaming up dozens of new ways in which microwave radar could help in the war. Radar-controlled anti-aircraft fire was the first, and intensive effort resulted in a highly successful equipment which has made blind AA fire as effective as optically controlled fire. Radar for anti-submarine work grew out of the AI work. Radar for ships was an instant success in its first demonstration on a destroyer. The development of a pulsed radio navigation system known as Loran was initiated and led to a system now in wide use throughout the world. By 1943 some 30 different radar projects were underway; eventually about 100 different types of equipment were developed and put into production. No less than two billion dollars worth of radar ordered by the armed forces came from Radiation Laboratory research.

A NEW INDUSTRY

By the end of the war, microwave radar had grown into a new industry larger than the prewar automobile industry. Starting up this industry rapidly under wartime conditions was not easy, and when the products of the new industry had to be introduced rapidly and effectively into combat at the earliest possible moment, the problem developed additional complications. Below are a few of the types of activities in which RL was involved.

1. Research

A vast amount of research in high frequency physics had to be undertaken. This ranged from fitting new mathematical solutions of Maxwell's equations to special microwave problems, to the accurate measurement of microwave absorption spectra in oxygen and water vapor. The useful radiofrequency spectrum was extended from its prewar limit of around 500 megacycles up to 30,000 megacycles, and the basis laid for even further extension. Pulse properties of thermionic cathodes, super-high frequency discharge phenomena in gases, antenna research in a field where radio and optical techniques come together, the study of crystal properties—these are but a few of the dozens of subjects in which startling advances were made. The free flow of ideas between all the U. S. and British agencies greatly accelerated this work.

2. Development

A war laboratory whose job is to develop instruments of warfare must go further than laboratory research. It must design equipment capable of use in airplanes, on ships, in trucks, wherever the battle requires. This means not only that each laboratory prototype equipment must be usable as a practical military weapon, but also that every part or component of the complete equipment must have gone through research, development, and pilot plant production, and must have passed dozens of temperature, humidity, shock, and other tests.

Equipment for testing the performance of various parts of a radar system originally occupied a whole laboratory bench; it was packaged into a portable box for use in the field. Precision potentiometers had to be designed which would stand millions of revolutions without change in properties, and a whole new art in potentiometer design was introduced. Even new types of shockmounts had to be designed. Dozens of different types of new vacuum tubes had to be developed for special purposes and nursed through their troubles in getting into production. OSRD finally organized a special Vacuum Tube Development Committee, with Dr. Rabi (Associate

Director of RL) as Chairman, to coordinate tube development throughout the industry and the Armed Services. All of this practical work was supervised by college physics professors!

Completed equipment had to be installed and flown in airplanes, tried out on ships, and taken to various Army or Navy bases for operational trials. The Army Air Forces turned over for experimental use the Bedford Army Air Base and over forty Army and Navy airplanes were assigned there for the sole purpose of conducting experimental flights of radar equipment developed by the Radiation Laboratory.[3] These extensive experimental flight and field-testing programs involved a huge effort, but meant that Radiation Laboratory equipment which had gone through such trials was as nearly adequately suited for combat use as it was possible to make it.

Radar design advanced as much in five years of war as radio receiver design advanced during the whole period from the crude home receivers of 1920 to the most modern sets of 1941. Indeed, it was clear at the end of the war that radar development had outpaced the development of radio communications, and a considerable pressure was placed on the Radiation Laboratory to swing over to the communication field. But RL realized that such an activity, started in 1944, could hardly be expected to yield results in time to have an effect on the war.

3. Manufacture

RL and industry worked together to solve the problems of introducing new equipment into manufacture, which were complex in the extreme. Army and Navy agencies were assisted in writing orders and specifications for new equipment and components. The normal radio industry of the country soon became loaded with radar and communication development and manufacturing, and RL scoured the country for other companies who could be educated and equipped to manufacture parts, components, and sets. These new manufacturers were educated in the new art, and were given educational orders in order to get their machinery and techniques set up and going in anticipation of larger Army or Navy orders. RL made monitoring tests on the manufactured products to insure they were meeting specifications, and provided the manufacturers with specialized equipment for making their own tests. Finally, RL entered the manufacturing business itself by making, in its own model shop,[4] small numbers of urgently needed items to go directly into combat use. Often, the first radar to reach the field for a particular combat use had been put together in RL, had been installed under supervision of members of the Laboratory, and was introduced to combat with the help of RL experts. All this happened months in advance of the time when production equipment became available from the factories. In anti-submarine war, in blind bombing, in the control of tactical aircraft, and in many other cases this procedure enabled radar to play a more critical role in the war. At the same time, intimate collaboration between RL and the manufacturer speeded radar design and production, so that production-model radar reached combat months ahead of normal schedules.

4. Field Service

Some of the most spectacular and exciting aspects of the work of RL had to do with introducing new equipment into combat. At the peak, there were over 150 RL members in the various combat areas assisting with a wide variety of Army and Navy radar problems. A branch laboratory was set up in England in 1943, and later a forward base was established in Paris. Members of the Laboratory worked at all military levels. Many a general has commented on the part these "civilians in uniform" played in increasing the effectiveness of his unit. Radar enabled the Air Forces to continue their operations through night and bad weather; during the filthy weather of the early Battle of the Bulge limited radar-controlled air operations were still possible and made all the difference in the world. RL experts were there working day and night to keep the equipment on the air. BBRL (British Branch of the Radiation Laboratory) became well known in all air force headquarters, and even the M. P.'s learned to know that BBRL vehicles (a fleet of about 30

[3] Radiation Laboratory members flew hundreds of thousands of miles in military and commercial aircraft during the war, including over 200 round-trip flights overseas. In spite of the fact that a great deal of this was experimental flying in military aircraft, not a single accident involving injury to an RL man occurred in such flights, although one RL member, Mr. Armand Herb, lost his life in a commercial airplane accident in Salt Lake City in 1942.

[4] This was Research Construction Company's Cambridge Division (RCC). It was set up by the Research Corporation under NDRC contract, and worked with RL.

cars and trucks was provided by the Army) could go about where they pleased.

Field work in the Pacific was directed by Dr. Compton's Office of Field Service, set up under OSRD. A radar advisory group was set up at Pearl Harbor, a development group was sent to cooperate with the Australian Radiophysics Laboratory in Sydney, and many individuals went to various other stations in the Pacific. As the war ended, a Pacific Branch of OSRD, under Dr. Compton, was being established in Manila with a large radar section just going into action. Never before have civilian scientists had such an immediate and profound effect on the day-to-day operations of the war.

5. Cooperation

Because of its position as a quasi-governmental, non-commercial enterprise, the Radiation Laboratory became a focus of the great international cooperative endeavor in the field of microwaves. The cooperation of the British, already mentioned, continued with ever-increasing effectiveness throughout the war. Dozens of Radiation Laboratory members went to England to discuss problems of mutual interest with the laboratories there, and there were many visitors from England to the U. S. OSRD and the Radiation Laboratory gathered information from British agencies and distributed it to all American agencies, and *vice versa*. The London OSRD office served as U. S. headquarters for the liaison effort abroad.

In this country RL maintained contact with all Army and Navy agencies and laboratories concerned with radar development and use. The Navy, the Signal Corps, and the Air Forces set up liaison offices at RL, which served as the site of many joint meetings where problems of mutual interest to all Services were discussed. During the peak of its activity an average of 50 Army and Navy officers came to the Laboratory each *day*.

Probably the most extensive cooperation work, however, was that between the Radiation Laboratory and the scores of industrial research and engineering laboratories who participated in radar. At the start of the war RL worked most intimately with the largest laboratories of the electrical industry: Bell Telephone Laboratories, General Electric, Westinghouse, Sperry, and RCA, all represented on the Microwave Committee. Bell Telephone Laboratories constituted the largest industrial radar development group, and there was extensive interchange of ideas between Bell and RL which did much to stimulate the work at both places. Scores of additional companies were later brought into the picture, and their engineers and the RL group worked together under an extensive system of mutual visits and collaboration. RL served as a catalytic agent for the radar industry, bringing all existing ideas to bear on each new problem. Smaller companies without research and engineering organizations of their own depended on RL for development, and took over RL designs for manufacture.

THE END

As the Japanese war ended, the Radiation Laboratory undertook the stupendous task of demobilizing. Dozens of projects being rushed to completion for immediate use were stopped. Others were of long range interest to the Army and Navy, and the task of transferring these to Army and Navy agencies was undertaken. A few rather long term basic research programs in the microwave field are to be continued on a small scale until the summer of 1946, or until taken over earlier by a permanent government agency. Nearly 1000 physicists and engineers, who, in the past three to five years, have been through the equivalent of ten to fifteen years' normal development experience, are now returning to their old jobs or to new ones. They will take to industrial laboratories remarkable new techniques which can stimulate industrial research for years to come. They will take to university laboratories new methods of working and new electronic techniques which can have similar effects on university research.

Most of these physicists are extremely anxious to get back to basic research. Universities must now step up their ideas of an adequate research budget, for these physicists have learned that their efforts can be enormously more effective, given adequate funds for equipment and technical assistance. They believe the experience and the prestige which physicists have gained on war projects will make it possible for American physics to enter upon a new era of progress and effectiveness. This may compensate in a small degree for the tragic five-year halt in basic physics which the war made necessary.