

Government and Industrial Research Laboratories

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A common impression is that each of the many types of lasers was invented in an industrial research laboratory. While one can dispute the accuracy of that statement in a few cases, there is no argument that industrial and governmental research laboratories were the locations of much of the development of optics in the twentieth century.

The concept of an industrial research laboratory emerged just before the beginning of the twentieth century. The first industrial optics research laboratory was Carl-Zeiss Stiftung, founded in 1889, in Jena, Germany, by Ernst Abbe. It grew out of earlier collaboration by Abbe, Otto Schott, and Carl Zeiss, and quickly became the source of optical glass and precision optical instruments for most of the world [1]. This German success did not go unnoticed and helped to stimulate the founding of other laboratories. The contributions of industrial and governmental laboratories in the twentieth century were truly incredible, and this essay briefly reviews how these various laboratories came to be; but it will leave, for the most part, their enormous range of inventions and discoveries to be described in the later essays in this volume.

Several factors led to the rise of industrial and government research laboratories at the beginning of the twentieth century. The harnessing of steam power, and then electricity, led to mass-consumer-product industries that had sufficient resources to support basic research laboratories. In 1903 Bausch & Lomb sold 20 million spectacle lenses and 500,000 photographic lenses per year; Eastman Kodak sold 150,000 Brownie cameras in 1900, the first year it was sold; and by 1914 General Electric sold 88.5 million lamps in the United States alone [2]. The general public saw the night lit up by electric lights; radio, telephone, and motion pictures changed the way people lived and perceived the future. Thomas Edison, George Westinghouse, and Nikola Tesla captured the popular imagination as scientific geniuses who would develop new technologies that would revolutionize industry. Everything was aligned to enable and encourage large investments in basic research. Small laboratories for quality and process control existed before, but not industrial and governmental research laboratories whose task was to develop whole new technologies and products that had never existed.

Following the Civil War, industry grew rapidly in the United States. The new companies were receptive to change and optimistic about future technologies, so much of the early development of industrial laboratories occurred in the United States. In 1900 General Electric (GE) established the first industrial basic research laboratory in Schenectady, New York, an outgrowth of Edison's earlier laboratories.

General Electric characterizes the nature of this laboratory:

The lab was the first industrial research lab of its kind. Prior to the formation of the GE Research Lab the only industrial research labs were German pharmaceutical labs. In the German labs like Bayer scientists and researchers worked independently and competed with one another. At General Electric in Schenectady, New York engineers and scientists were encouraged to share information and assist with problem solving. They were given great financial support to buy materials. The best machinists and craftsmen were employed to help build prototypes. From the tungsten light bulb to the computerized hybrid car it is no wonder that the Schenectady lab produced a great proportion of our world's technology [3].

While the General Electric laboratory was not focused on conventional optics, it did work on illumination and the development of x-ray sources. William Coolidge's x-ray tube designs were instrumental in leading to the development of radiology, and his discovery of a method to make tungsten ductile provided a long-life filament for incandescent light bulbs. Soon GE was selling them by the millions, and Irving Langmuir's studies of monatomic films on filaments led to GE's first Nobel Prize. Most important, the GE Research Lab set the standard that other industrial labs used as a model.

In 1918 the Westinghouse Research Laboratory was established with goals and organization much like those of the earlier General Electric laboratory. In particular, this research laboratory was separate from any manufacturing facility. Again, the early work in this laboratory was not devoted to optics, although it was soon working in optical spectroscopy, a pursuit that it maintained for most of the century. One notable contribution to optics from this Pittsburgh laboratory was that it provided the first job for Brian O'Brien, who was the first permanent director of the University of Rochester's Institute of Optics. O'Brien, working with Joseph Slepian, developed the first lightening arrestors, which are commonly used today [4].

In 1915 the Eastman Kodak Research Laboratory was founded, and before World War I (WWI) broke out, laboratories were established at Dupont, Standard Oil (Indiana), U.S. Rubber, and Corning Glass. Bausch & Lomb did not have a formal research laboratory at that time but were soon central to the United States' efforts in optical research and development. After WWI Major Fred E. Wright wrote the following in a *Journal of the Optical Society of America* article [5]:

Before this country entered the war, it was realized that the making of optical glass might prove to be a serious problem. Prior to 1914, practically all of the optical glass used in the United States had been imported from abroad; manufacturers followed the line of least resistance and preferred to procure certain commodities, such as optical glass, chemical dyes, and other materials difficult to procure, direct from Europe, rather than to undertake their manufacture here. The war stopped this source of supply abruptly, and in 1915 experiments on the making optical glass were underway at five different plants: The Bausch & Lomb Optical Co. at Rochester, N.Y.; the Bureau of Standards at Pittsburgh, Pa.; the Keuffel & Esser Company at Hoboken, N.J.; the Pittsburgh Plate Glass Company at Charloi, Pa.; the Spencer Lens Company at Hamburg, Buffalo, N.Y. By April, 1917, the situation had become acute; some optical glass of fair quality had been produced, but nowhere had its manufacture in adequate quantities been placed on an assured basis. The glass-making processes were not adequately known. Without optical glass, fire-control instruments could not be produced; optical glass is a thing of high precision, and its manufacture, accurate control is required over all the factory processes. In this emergency the Government appealed to the Geophysical Laboratory of the Carnegie Institution of Washington for assistance. This laboratory had been engaged for many years in the study of solutions, such as optical glass, at high temperatures, and had a corps of scientists trained along the lines essential to the successful production of optical glass; it was the only group in the country with a personnel adequate and competent to undertake a manufacturing problem of this character and magnitude. A group of their scientists, with writer [Major Wright] in charge, was accordingly placed in April 1917, at the Bausch & Lomb Optical Company, and took over virtual direction of the plant.

The effort succeeded, and the United States became a serious player in optics and optical instrumentation, no longer depending on European supplies and technology.

The military importance of precision optics in WWI was enormously enhanced by two technological developments: (1) machining of artillery barrels was much more precise than ever before so that shells could be directed much more accurately—if you knew with enough accuracy where your target was located; and (2) military aircraft, which required bomb sights and aerial cameras for the airplanes and ground-based binoculars and telescopes for the anti-aircraft artillery. Another development that one does not usually associate with optics was the invention of camouflage to hide ships, airplanes, and land-based targets from the improved optics. Abstract artists were brought in to design the patterns,

and the company cafeteria building at Eastman Kodak was turned over to the military to develop camouflage, while other parts of the company developed aerial cameras.

These people and industries involved in American optics in WWI played a further enormous role in the development of optics. A group of them including representatives from Eastman Kodak and Bausch & Lomb met in the physics library at the University of Rochester in November 1915 to found the Rochester Optical Society, with an explicit intention of also founding a national optical society, which they did when they led the founding of The Optical Society at a meeting the following February in Washington. Perley G. Nutting (Fig. 1) of the Eastman Kodak Research Laboratory was the first society president, and the second president was the same Frederick E. Wright who led the glass effort at Bausch & Lomb. Adolph Lomb was the first treasurer of the society, and personally wrote checks to cover the budget deficits in the initial years. This connection between the early industrial research laboratories and the founding of professional societies and scientific journals was no coincidence. C. E. K. Mees, the founding head of the Eastman Kodak Research Laboratories, wrote in his history of the labs [6] that he and George Eastman discussed the nature of the industrial research laboratory that they planned to establish, and decided that if they wanted to have the best scientists on their staff they would have to encourage them to publish and to interact with other scientists. Good scientists need this interaction to be happy and productive. Furthermore, there needed to be professional societies and journals to support their efforts. The whole development of the optical research establishment owes a debt to this industrial initiative. Their contribution goes further. Mees and Eastman also decided that there needed to be an academic department to train optical engineers and scientists and to carry out basic optics research. They, along with Edward Bausch, approached the President of the University of Rochester about founding such a department. In 1929 the Institute of Optics was founded with a promise of an initial \$20,000 grant for equipment and continuing support of \$20,000 per year for five years, renewable for five more. Mees himself (Fig. 2) taught courses in photographic theory for many years in the Institute [7].

In 1925, Western Electric Research Laboratories and part of the engineering department of the American Telephone & Telegraph Company joined to form Bell Telephone Laboratories, Inc., as a separate entity. It was tasked to plan, design, and support the equipment that Western Electric built for Bell System operating companies. A few workers were assigned to basic research, and the results were rather spectacular, as essays later in this volume attest, and include 14 Nobel Laureates for work carried out in part or full at Bell Labs.

Another monopoly that led to the founding of an important industrial research laboratory was for radio communications. During WWI the Western Allies cut the German transatlantic telegraph cables and the Central Powers maintained contact with neutral countries in the Americas via long-distance radio communications. In 1917 the government of the United States took charge of the patents owned by the major companies involved in radio manufacture to devote radio technology to military needs. After the war, the War and Navy departments sought to maintain a federal monopoly of all uses of



▲ Fig. 1. Perley G. Nutting unceasingly campaigned for the establishment of a United States national optical society. He started the campaign while working as one of the first employees of the National Bureau of Standards and later as one of the first employees of the Eastman Kodak Research Laboratories. He led the successful effort to found The Optical Society and served as its first President. Courtesy of The Optical Society (OSA).



▲ **Fig. 2** C. E. Kenneth Mees. George Eastman wanted C. E. Kenneth Mees so much to be the founding head of the Eastman Kodak Research Laboratory that he bought the English company for which Mees was a part owner, Wratten and Wainright, and moved Mees and the company to Rochester, where he led the laboratories until his retirement after World War II (WWII). (AIP Emilio Segre Visual Archives.)

radio technology. Congress did not agree to continue this monopoly after the war, but the Army and the Navy negotiated with GE that if they bought assets of the confiscated American Marconi Company and founded a publicly held company in which they managed to retain controlling interest, that company, the Radio Corporation of America (RCA), would be granted a monopoly on radio communication. Westinghouse and AT&T joined in the forming of the company. So, by 1920 AT&T had a monopoly on long-distance telephone systems, and GE and Westinghouse, through RCA, had a monopoly on long-distance radio communication. By the mid-1920s short waves had replaced radio waves for long distance communication, the federal government broke up the monopoly controlled by GE and Westinghouse, and RCA became a separate and successful company. RCA made major optics contributions in photomultipliers, LEDs, CMOS devices, and liquid crystals, as well as in the development of sound recording, radio, and television [8].

If WWI greatly changed industrial research, and industrial optics research in particular, WWII completely redefined it and made it and governmental research a central component in the American economy. United States involvement in this war was more protracted than in WWI, and science and technology, particularly in the areas of radar and atomic bombs, were central to the nation's effort.

This short essay cannot cover all of the important developments lab by lab even within optics. Happily, many of the contributions of these labs are detailed in the chapters on individual technologies later in this volume. Therefore this essay will be limited to general trends and national initiatives. While the concept of industrial research laboratories grew out of nineteenth-century Germany, most of the major developments in the first half of the twentieth century were in the United States. After recovery from the devastation of WWII, Europe joined in with its own important industrial research laboratories. World War II not only was the genitor of many new industrial research laboratories, but it also led to a proliferation of governmental research labs. Their origins will be reviewed before the evolution of all of these labs during the second half of the century is discussed.

The Royal Observatory in Greenwich, England, was founded by Charles II in 1675. The United States got into the governmental laboratory business somewhat later with the establishment of the Depot of Charts and Instruments, the predecessor of the U.S. Naval Observatory, in 1830. But, it was in 1900 that Congress passed an act establishing the National Bureau of Standards (NBS), the direct predecessor of National Institute of Standards and Technology (NIST), whose scientists have received four recent Nobel Prizes in optics. These were among 13 Nobel Prizes awarded employees of governmental research laboratories in the United States. The climate that led to the forming of this laboratory is mentioned at the beginning of this essay and is nicely stated in the official history of NIST [9]:

The idea of a national bureau of standards was presented at an auspicious hour. America in the year 1900 thought well of itself. The hard times of 1893–95 were all but forgotten in the aura of prosperity and sense of achievement that energized the Nation. Industry and invention boomed and business flourished as never before. The prophets at the turn of the century unanimously agreed on the good years to come.

At the recommendation of the Secretary of the Treasury, Congress passed a bill, which the president signed, to form NBS, which was to aid “manufacturing, commerce, the matters of scientific apparatus, the scientific work of the Government, of schools, colleges, and universities.” It was not just in the United States that the need for such a government laboratory was felt; in England the National Physical Laboratory was founded in the very same year for these same purposes.

The staff of NBS in 1904 included in the Section on Light and Optical Instruments: Samuel W. Stratton, Perley G. Nutting, and Frederick J. Bates. This same Perley G. Nutting was already working to found a national optical society before he was lured away to the newly formed Eastman Kodak Research Laboratory, where he led the effort to found the local Rochester society, and then OSA, of which he was the first president.

We return our narrative to the onset of WWII when industrial and governmental optics research had a true phase transition in its development. As war broke out in Europe in 1939 a group of leading scientists and academic administrators including Vannevar Bush, President of the Carnegie Institution of Washington; James B. Conant, President of Harvard University; Frank B. Jewett, President of the National Academy of Sciences and President of Bell Laboratories; Karl Compton, President of MIT; and Richard C. Tolman, Dean of the Graduate School at California Institute of Technology, were concerned with the lack of technological preparedness of the U.S. for its likely entry in the war. They suggested a plan for the establishment of the National Defense Research Committee (NRDC), which Vannevar Bush described in four paragraphs that he submitted to President Roosevelt. At the end of ten minutes he had an approval from the President, and an order creating NDRC was issued on 27 June 1940. Some 30 years later in his biographical memoirs Bush describes the reasons for this initiative [10]:

There were those who protested that the action of setting up NDRC was an end run, a grab by which a small company of scientists and engineers, acting outside established channels, got hold of the authority and money for the program of developing new weapons. That, in fact, is exactly what it was. Moreover, it was the only way in which a broad program could be launched rapidly and on an adequate scale. To operate through established channels would have involved delays—and the hazard that independence might have been lost, that independence which was the central feature of the organization’s success.

Bush was appointed chairman, and the organization was established and expanded in 1942 to become the Office of Scientific Research and Development (OSRD), with Bush as director (Fig. 3). The OSRD had three principal subdivisions at that time: the NDRC, with Conant as chairman; the Committee on Medical Research (CMR), with A. Newton Richards as chairman; and the advisory Council, with Bush as chairman. The latter included the chairmen of the National Advisory Committee on Aeronautics (NACA), NDRC, and CMR, as well as representatives from the Army and Navy as a coordinating group. In addition, Bush was chairman of the Joint New Weapons Committee of the Joint Chiefs of Staff and, when the Manhattan District was created, chairman of its Military Policy Committee, which served as its board of directors [11].

Perhaps one might be tempted to say that the power grab was by Bush himself, but he had the confidence of the President and Congress so that he was able to coordinate and to smooth the inevitable friction between these varied groups remarkably well. Weisner summarizes quite nicely the organization that Bush set up:

The organization was a remarkable invention, but the most significant innovation was the plan by which, instead of building large government laboratories, contracts were made with universities and industrial laboratories for research appropriate to their capabilities. OSRD responded to requests from military agencies for work on specific problems, but it maintained its independence and in many cases pursued research objectives about which military leaders were skeptical. Military tradition was that a way had to be fought with weapons that existed at its beginning. Bush believed that World War II could be won only through advances in technology, and he proved to be correct. In some instances, the armed forces were enthusiastically cooperative. In others, resistance to innovation had to be overcome. Bush, himself, went to Europe to make sure that the proximity fuse was introduced to the battlefield and used effectively.



▲ **Fig. 3** Vannevar Bush watches as President Truman presents James Conant with the Medal of Merit and Bronze Oak Leaf Cluster in May, 1948. The nation was greatly appreciative of the leadership of Bush and Conant and other scientists during the war, allowing Bush and Conant to build a structure to continue government support of research after the war through governmental laboratories and research grants for university basic research.

The major exception to the policy of avoiding the building of government laboratories was in the development of the atomic bomb. After preliminary studies by NDRC and OSRD, it became clear that a colossal program would be needed, and Bush recommended to Secretary Stimson that the Army take over the responsibility. The result was the formation of Manhattan Engineering District by the Corps of Engineers. Bush with Conant as his deputy, maintained an active scrutiny of the enterprise.

This was the foundation of science and engineering administration in the U.S. as it exists up until now. All of the developments in optics in the second half of the century grew up in this environment. Optics during the war was overseen by Division 16, Optics and Camouflage of the NDRC. It was led by George Harrison. Paul Kelley describes elsewhere in this volume the optical developments during this period. Well before the war was over, Bush started to plan how the momentum of research could be sustained with new peacetime goals. President Roosevelt asked him to make recommendations on government policies for combating disease, supporting research, developing scientific talent, and diffusing scientific information. Four committees were set up to generate recommendations. On the basis of these recommendations Bush submitted a report titled “Science—The Endless Frontier,” which laid out the proposals for organizing post-war science and technology. The argument for the government to continue supporting research after the war was summed up in the report: “To create more jobs we must make new and better and cheaper products. We want plenty of new, vigorous enterprises. But new products and processes are not born full-grown. They are founded on new principles and new conceptions which in turn result from basic scientific research. Basic scientific research is scientific capital.”

The National Science Foundation was proposed, and a bill was introduced in Congress by Senator Warren Magnuson from Washington. After much argument in Congress and a veto by President Truman, a modified version was signed by President Truman in 1947. Vannevar Bush asked that Truman not name him to the board of the new foundation, suggesting that people were tired of his running things. Even before the NSF was launched, the Office of Naval Research was established in 1946 with the stated mission of “planning, fostering, and encouraging scientific research in recognition of its paramount importance as related to the maintenance of future naval power and the preservation of national security.” The Air Force Office Scientific Research would be formed in 1951 and the Army Research Office in 1957, and the Defense Advanced Research Projects Agency (DARPA) was signed into existence by President Eisenhower in 1958. Figure 4 shows the Laser Guide Star Adaptive Optics project, one of the technologies that came from the funding provided by those agencies. The National Aeronautics and Space Administration (NASA) grew out of the old NACA during the administration of President Eisenhower. At present the Navy operates one laboratory and seventeen Warfare Centers. The Army operates eleven labs, and the Air Force operates one laboratory and ten Technical Directorates.

The old Army-controlled Manhattan Project during the course of the war developed a number of secret sites including Los Alamos, Hanford, and Oak Ridge. There was also the reactor research lab at the University of Chicago that spawned Argonne National Laboratory. After the war the Atomic Energy Commission took over the wartime laboratories, extending their lives indefinitely, and funding was obtained to establish a number of new laboratories for classified as well as basic research. Each of the new laboratories was generally centered around some particle accelerators or nuclear reactors. At present, the organization in charge is the Department of Energy (DOE), and it administers 19 different national laboratories and provides more than 40% of the total national funding for physics, chemistry, and materials science. While the DOE directs most of its attention to nuclear, particle, and plasma physics, it supports major efforts in optics as well, especially through its high-energy laser fusion programs and its x-ray light sources.

Another important source of funding for optics research is the independent research and development funds that are provided by indirect cost charges to military contracts, allowing military contractors to carry out internal research programs and keep their scientists and engineers busy between contracts developing new technology. This supports long-term research efforts at many industrial laboratories.

This enormous research and development system that grew out of WWII is not without its detractors; many point to the address of Dwight David Eisenhower just three days before he left office. The President, who signed into existence many of the agencies that support this system warned, “In the councils of government, we must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military-industrial complex. The potential for the disastrous rise of misplaced power exists and will persist.” As you look over the essays in this volume that review the



▲ Fig. 4 The Air Force Starfire Optical Range for lidar and laser guide star experiments is tuned to the sodium D2a line and used to excite sodium atoms in the upper atmosphere. This provides what is essentially a point source of light in the mesosphere to use for adaptive optics to remove blurring of ground based imaging due to atmospheric turbulence.

progress in optical science and technology, particularly over the past half century in which optics has become an indispensable enabler in essentially every industry, it is hard to fault the model, given its evident success. But even today, some 50 years after this speech, many would argue that we need to keep our guard up to see that this enormously beneficial system of research and development is not corrupted.

References

1. “Carl-Zeiss-Stiftung—Company profile, information, business description, history, background information on Carl-Zeiss-Stiftung.” <http://www.referenceforbusiness.com/history2/79/Carl-Zeiss-Stiftung.html>.
2. R. Kane and H. Sell, *Revolution in Lamps: A Chronicle of 50 Years of Progress*, 2nd ed. (Fairmont Press, 2001), p. 37, table 2–1.
3. “General Electric Research Lab,” <http://www.edisontechcenter.org/GEresearchLab.html>.
4. C. R. Stroud, Jr., *Brian O'Brien, 1898–1992, A Biographical Memoir* (National Academy of Sciences, 2010).
5. F. E. Wright, “War-time development of the optical industry,” *J. Opt. Soc. Am.* **2**, 1 (1919).
6. C. E. K. Mees, “The Kodak Research Laboratories,” *Proc. R. Soc. Lond.* **8** 135, 133–147 (1948).
7. C. Stroud, *Jewel in the Crown* (Meliora Press, 2004), p. 18.
8. R. Sobel, RCA (Stein and Day, 1986).
9. http://www.nist.gov/nvl/upload/MP275_06_Chapter_I_-_AT_THE_TURN_OF_THE_CENTURY.pdf.
10. V. Bush, *Pieces of the Action* (William Morrow, 1970), p. 32.
11. J. B. Wiesner, *Vannevar Bush 1890–1974, Biographical Memoir* (National Academy of Sciences, 1979).