Review Essay

THE SCIENTIFIC TRADITION IN AMERICAN INDUSTRIAL RESEARCH

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In the past decade industrial research has been a focus of activity in the history of technology. This new generation of scholarship distinguishes itself from earlier work in a number of ways.[1] First, it is based on documentation that provides an inside view of the evolution of industrial research. Second, it has benefited from numerous detailed case studies that demonstrate that innovation is not synonymous with invention.[2] Finally, the organizational approach to understanding big business developed by Alfred D. Chandler, Jr., has given historians a framework within which to place the research laboratory.[3] Companies develop strategies and create organizational structures to carry them out. Research laboratories, however, once in place, develop their own organizational identities and research agendas, seeking direction from science as much as from business.

A long-standing, science-based research tradition is the key factor uniting the histories of the companies that have been extensively

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[1]Many thirty-year-old studies are still useful. These include John J. Beer, "Coal Tar Dye Manufacture and the Origins of the Modern Industrial Research Laboratory," *Isis* 49 (1958): 123–31; Kendall Birr, *Pioneering in Industrial Research: The Story of the General Electric Research Laboratory* (Washington, D.C.: Public Affairs Press, 1957); Richard R. Nelson, "The Economics of Invention: A Survey of the Literature," *Journal of Business* 32 (April 1959): 101–27.

[2]On the relationship between invention and innovation, see Neil Wasserman, *From Invention to Innovation: Long Distance Telephony at the Turn of the Century* (Baltimore: Johns Hopkins University Press, 1985), and John K. Smith, "The Ten-Year Invention: Neoprene and Du Pont Research, 1930–1939," *Technology and Culture* 26 (January 1985): 34–55.

[3]Chandler's concepts are developed in *Strategy and Structure: Chapters in the History of American Industrial Enterprise* (Cambridge, Mass.: MIT Press, 1961); *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, Mass.: Harvard University Press, 1977); and *Scale and Scope: The Dynamics of Industrial Enterprise* (Cambridge, Mass.: Harvard University Press, forthcoming).

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studied. We now know a great deal about R&D at General Electric, AT&T, Du Pont, RCA, and Alcoa, and the outline of the story at Kodak and Westinghouse.[4] David Mowery has pointed out that industrial research before World War II was centered primarily around chemistry and chemical technology and to a lesser extent the application of engineering and physics to mechanical and electrical phenomena.[5] Once established, a science-based research tradition evolved in the laboratories, which achieved a degree of autonomy by the 1920s because it had shown that investment in science could pay large dividends. Having secured its position, the research laboratory often set its own goals, which sometimes conflicted with those of the corporation. Occasionally, however, the tension between science and business proved to be creative and led to important new technologies such as those of polymers and semiconductors.

The popular image of industrial research at mid-century was that of scientists inventing new technologies in a systematic and predictable fashion. Through the medium of science, invention had ceased to be the concern of wild-eyed individualists.[6] This interpretation was challenged in the late 1950s by John Jewkes and others, who concluded that the sources of invention were diverse and that corporations frequently prospered on the basis of technology that had been invented elsewhere.[7] Jewkes's work led the next generation of historians to a new interpretation of industrial research.

[4]General Motors is omitted from this list because we do not know much about the development of research as an institution within the corporation. I suspect that the development of R&D at GM followed a very different path than that of the science-based laboratories because there is no strong correlation between automobile manufacturing and a scientific discipline. Stuart W. Leslie shows how research at GM was dominated by Charles Kettering for decades, but we do not know what traditions of research Kettering left for his successors; Leslie, *Boss Kettering: Wizard of General Motors* (New York: Columbia University Press, 1983). An important area for further inquiry is industrial research in companies whose business fields do not closely correlate with scientific disciplines.

[5]David C. Mowery, "The Emergence and Growth of Industrial Research in American Manufacturing, 1899–1946" (Ph. D. diss., Stanford University, 1981), p. 104.

[6]For the general view of industrial research in the 1950s, see "Why Industry Lures Pure Scientists," *Business Week* (January 12, 1952): 40–44; "The New World of Research," *Business Week* (May 28, 1955): 128–36; and Francis Bello, "Industrial Research: Geniuses Now Welcome," *Fortune* (January 1956): 96–99, 142–50. In 1954 Robert Jungk wrote an essay about a visit to the Du Pont research laboratories in which a scientist with a sign "A.D. 2000" on his door confidently told Jungk that the future was being hatched in his laboratory. Jungk, "Discoveries to Order," in *Tomorrow Is Already Here* (New York: Simon & Schuster, 1954).

[7]John Jewkes, David Sawers, and Richard Stillerman, *The Sources of Invention* (New York: St. Martin's Press, 1958); and Willard F. Mueller, "The Origins of the Basic

Influenced by New Left scholarship that emphasized the control that big business has exercised over American politics, society, and technology, David Noble argued that corporations used their scientific and technological resources to harness technology to corporate ends.[8] The true sources of creativity were independent inventors, but the major accumulators of capital were corporations. In this view, the story of industrial research became the appropriation of the work of the inventor by whatever forces a corporation could deploy.[9] Industrial research was seen as having an essentially defensive character.

What corporations were trying to defend was their investment in existing technology. Through their research laboratories, they sought to control innovation rather than to promote it. Leonard Reich provides perhaps the best example of this phenomenon in his study of AT&T and the development of radio.[10] The key, the three-element vacuum tube, had been invented by an independent, Lee De Forest. The new device had the potential to solve the telephone company's critical problem, long-distance telephony, or to make the entire telephone system obsolete. Reich argues that AT&T did research not to promote radio but to gain a strong patent position in order to influence how it would be used. Of course, radio escaped the tentacles of AT&T to become enormously successful, but it did not replace the telephone network.

The insight that industrial research was not institutionalized invention proved to be critical in understanding the origins of corporate laboratories, origins that were not in invention but rather in science. Industrial research evolved from attempts to improve existing technologies by pursuing a more fundamental understanding of underlying phenomena. Beginning in the 1870s, companies in businesses ranging from railroad transportation to paint manufacturing discov-

Inventions Underlying Du Pont's Major Product and Process Innovations," in *The Rate and Direction of Inventive Activity: Economic and Social Factors* (Princeton, N.J.: Princeton University Press, 1962).

[8]David F. Noble, *American by Design: Science, Technology, and the Rise of Corporate Capitalism* (New York: Knopf, 1977).

[9]In *American Genesis: A Century of Invention and Technological Enthusiasm 1870–1970* (New York: Viking-Penguin, 1989), chap. 4, Thomas P. Hughes sees the history of industrial research as a conflict between heroic inventors and powerful corporations. His section on industrial research begins with the tragic story of Edwin Armstrong and his battles with AT&T and RCA. Over time Hughes sees the system-sustaining corporations suffocating the independent inventor whose radical inventions could have led to entirely new systems.

[10]Leonard S. Reich, *The Making of American Industrial Research: Science and Business at GE and Bell, 1876–1926* (New York: Cambridge University Press, 1985), chap. 9.

ered the usefulness of professional scientists in systematic problem solving and rationalization of industrial operations.[11] By the turn of the 20th century, science and industry had become partners and were ready to formalize the relationship.

The pioneers of American industrial research, General Electric, Du Pont, AT&T, and Kodak, set up formal research laboratories before World War I. These laboratories were part of the larger rationalization of big business in the wake of the merger movement of the late 1890s and the rigorous enforcement of the Sherman Antitrust Act after 1900. Previously, companies had protected their businesses through patent monopolies or through informal market-sharing agreements. When the patents ran out and when Theodore Roosevelt decided to enforce the antitrust laws, a number of large companies that had dominated their respective industries established research laboratories as part of a more general reorganization of their operations. The goal was to maintain market share in established product lines by continuous product improvement and overall organizational efficiency. This turned out to be an effective strategy; the companies that made this transition remained industry leaders for decades.[12]

The experience of these pioneers suggests that research laboratories were not invented by one organization and then diffused to others but rather that they arose from similar conditions in a number of "science-based" industries. The two contenders for credit for the "invention" of industrial research have been the German dyestuffs producers and Thomas Edison; however, neither had much influence on GE, Du Pont, and others. According to Georg Meyer-Thurow, broad-ranging research in German dye companies began in 1890, a decade before the establishment of American laboratories,[13] yet these research programs do not appear to have been a model that American companies emulated. Edison could not be a genuine precedent for industrial research because he was the epitome of the independent

[11]One source estimates that there were thirty-nine laboratories in the chemical industry before 1900. Arnold Thackray, Jeffrey L. Sturchio, P. Thomas Carroll, and Robert Bud, *Chemistry in America, 1876–1976* (Dordrecht: Reidel, 1985).

[12]These common themes emerged from the papers presented at the R&D Pioneers Conference, Hagley Museum and Library, Wilmington, Delaware, October 7, 1985, which featured papers on General Electric by George Wise, Du Pont by David A. Hounshell and John K. Smith, Kodak by Jeffrey Sturchio, AT&T by Neil Wasserman, and commentary by Richard S. Rosenbloom. For a summary of the papers, see my conference report in *Technology and Culture* 28 (April 1987): 340–42. See also Reese Jenkins, *Images and Enterprise* (Baltimore: Johns Hopkins University Press, 1975).

[13]Georg Meyer-Thurow, "The Industrialization of Invention: A Case Study from the German Chemical Industry," *Isis* 73 (1982): 363–81.

inventor, generally characterized as being temperamentally unsuited for work in large organizations.[14] Even if they had been good team players, inventors would not have been desirable researchers because big business strategy in this era emphasized protecting established products, not producing new ones. Edison was not interested in the kind of work that industrial research would stress—ongoing process and product improvement. On balance, building new things, not improving old ones, was what inspired Edison.[15]

Lacking models to emulate, American corporations began research in a cautious and experimental manner. The process by which it became a permanent part of their operations has been explored by George Wise in his biography of Willis R. Whitney, the pioneer research director at General Electric.[16] The new GE laboratory, set up in 1900, was not part of a grand design; the goal of the work was simply to thwart competition by improving the company's existing technology.[17] After the expiration of the original Edison patents, the laboratory's first major project was to save GE's light bulb business. As the interface between the laboratory and the front office, Whitney had a new type of job which required expertise in both science and business. Wise explores how Whitney tried to focus the efforts of his researchers on problems that needed solving while at the same time selling these projects to the staff on the basis of intrinsic scientific merit. Preventing his laboratory from becoming "a philanthropic asylum for indigent chemists"[18] took an enormous toll on Whitney, but his initial efforts were successful beyond expectation. Whitney's laboratory secured its future when chemists William D. Coolidge and

[14]An interesting example of an independent inventor and a company was the case of William Stanley and Westinghouse. George Wise, "William Stanley's Search for Immortality," *American Heritage of Invention and Technology* 4 (Spring/Summer 1988): 42–49; Ronald Kline, "Engineering R&D at the Westinghouse Electric Company, 1886–1921," paper presented at the Society for the History of Technology annual meeting, Pittsburgh, October 25, 1986.

[15]On Edison as an inventor, see Thomas P. Hughes, *Thomas Edison: Professional Inventor* (London: Science Museum, 1976). On the failures of Edison as a manager, see A. J. Millard, *Edison and the Business of Innovation* (Baltimore: Johns Hopkins University Press, forthcoming).

[16]George Wise, *Willis R. Whitney, General Electric, and the Origins of U.S. Industrial Research* (New York: Columbia University Press, 1985).

[17]Wise argues that, in addition to applying science, the new GE laboratory would also do science, an activity that was novel for an American laboratory. Irving Langmuir turned out to be a rare type of researcher who could do and apply science simultaneously. Ibid., pp. 77–79, 149–58. Whether science was being applied or being done, the goal was still to improve existing technologies, not to invent new ones.

[18]Whitney quoted in ibid., p. 91.

Irving Langmuir improved the light bulb dramatically and preserved GE's position in this lucrative market. Langmuir's approach to the light bulb problem was so innovative that it won him a Nobel Prize in chemistry.[19] Having saved the company's most profitable product, Whitney was able to diversify his research program.

The experience of the other pioneers was similar to, if less dramatic than, that of GE. When scientific research proved its worth by improving long-distance telephony, dynamite, and photography, research directors sought freedom to move in new directions.[20]

In the period before World War II, American industries cast a wide net for new technologies but in general did not expect to invent them. Rather, they made use of the work of independent inventors who quite often did not realize the technological or market potential of what they had created.[21] Besides independent inventors, Europe was an important source of new technologies, especially chemicals. The R&D laboratory helped to transfer new products from Europe.[22]

This new emphasis on *innovation* led to the golden era of American industrial research in the interwar years. The success of industrial research was based on two ingredients: the use of science to understand and improve technology, and the possession of organizational

[19]Langmuir is an extreme example of the blending of science and industry that industrial researchers represent. Wise categorizes the industrial laboratory as a new work setting rather than as a university-in-exile or a factory-like operation. George Wise, "A New Role for Professional Scientists in Industry: Industrial Research at General Electric, 1900–1916," *Technology and Culture* 21 (1980): 408–29. Although Wise places his argument in a historiographic context, what he really seems to be attacking is the idea that industrial researchers are second-rate scientists who could not get more desirable academic jobs.

[20]Smith, "R&D Pioneers Conference" (n. 12 above). A similar pattern of evolution occurred at Alcoa. For a short history of Alcoa research, see Margaret B. W. Graham, "Corporate Research and Development: The Latest Transformation," *Technology in Society* 7 (1985): 186.

[21]Lee De Forest invented the three-element vacuum tube but did not perfect the device or develop its various uses in telephony or radio. With the important exception of the discoveries of Edwin Armstrong, scientists at AT&T and GE made the vacuum tube a successful technology. On De Forest and the vacuum tube, see Hugh G. J. Aitken, *The Continuous Wave: Technology and American Radio, 1900–1932* (Princeton, N.J.: Princeton University Press, 1985), chap. 4.

[22]On the European influence on American technology, see David A. Hounshell, "Rethinking the History of 'American Technology,' " in Stephen H. Cutcliffe and Robert C. Post, eds., *In Context: History and the History of Technology* (Bethlehem, Pa.: Lehigh University Press, 1989); David A. Hounshell and John Kenly Smith, Jr., *Science and Corporate Strategy: Du Pont R&D, 1902–1980* (New York: Cambridge University Press, 1988), chaps. 3, 8–11; Sheldon Hochheiser, *Rohm and Haas: History of a Chemical Company* (Philadelphia: University of Pennsylvania Press, 1986).

capabilities to develop and commercialize new products. Du Pont cellophane, GE refrigerators, and Kodak color film were all based on technology that had originated outside of the firm.[23] Wise has called this process leapfrogging; that is, acquiring nascent technology and then using corporate capabilities to hop over the competition.[24]

By the late 1930s, however, science was becoming widely regarded as the driving force behind the process of innovation. A shift from leapfrogging to science-based invention had begun in the 1920s, when two of the research pioneers, Du Pont and AT&T, began to do university-style research in fields of interest to their respective companies.[25] Instead of just applying science, industrial researchers would "do" science. Polymers and solid-state physics were just emerging as disciplines, and Du Pont and Bell researchers made major scientific contributions. More important for the future of industrial research, this work led to nylon in 1934 and the transistor in 1947, two products that opened up large new fields of technology.[26] In between these two events, World War II solidified the developing relationship between science and invention.

It would be difficult to overstate the importance of World War II in the relations among science, technology, and industrial research. From the perspective of 1945, the list of wartime innovations was an impressive one: penicillin, radar, synthetic rubber, the atomic bomb. This burst of innovation resulted from cooperative R&D by government, universities, and industry; what the war did was to increase the

[23]On Du Pont cellophane, see Hounshell and Smith, *Science and Corporate Strategy*, chap. 8. On GE refrigerators, see George Wise, "R&D at General Electric, 1878–1980," paper given at R&D Pioneers Conference (n. 12 above). On Kodak color film, see Laurent Hodges, "Color It Kodachrome," *American Heritage of Invention and Technology* 3 (Summer 1987): 46–53. The latter story is one of the most unusual in the history of industrial R&D. The color film process was developed by two musicians, who were employed by Kodak to perfect their process. After completing the project the musicians left Kodak and returned to music.

[24]Wise, "R&D at General Electric, 1878–1980" (n. 23 above).

[25]In 1927, U.S. Steel decided to jump onto the science bandwagon and establish a central research laboratory. The company hoped to be able to hire Nobel Prize–winning physicist Robert Millikan to head the laboratory. The transcript of a board of directors' discussion of Millikan shows how little understanding the U.S. Steel executives had of research or science. Paul Tiffany, "Corporate Culture and Corporate Change: The Origins of Industrial Research at the United States Steel Corporation, 1901–1929," paper presented at the Society for the History of Technology annual meeting, Pittsburgh, October 25, 1986.

[26]On Du Pont, see Hounshell and Smith, *Science and Corporate Strategy* (n. 22 above), chap. 12. On AT&T, see Lillian Hoddeson, "The Roots of Solid State Research at Bell Labs," *Physics Today* (March 1977): 22–30.

speed of the innovation process by bringing resources together.[27] Government removed the risks of innovation by paying for the R&D and plants and by assuring markets for the products. This, however, was not how the scientific community saw it. Vannevar Bush argued that the key to the wartime developments was basic science, which was *the* source of new technology. Many people, including corporate managers and research directors, were persuaded by Bush's arguments that basic science led directly and rather quickly to new technology.[28]

After World War II, American industrial research entered a new era. If basic science was the seed of new technology, then the entire innovation process could be contained within the firm; reliance on unpredictable outside sources of technology was no longer necessary. Making this concept even more attractive to corporate management was the late New Deal antitrust attack on big business that continued into the 1950s and made corporate acquisitions or cooperative activities highly suspect. Companies now had to rely on internally generated technology, but the Bush concept reassured executives that in-house science would generate an adequate supply of inventions.[29]

The new research orthodoxy raised the status of the research laboratory and gave it an unprecedented autonomy. Corporate management believed that, if innovation was the product of science, then the process was best left to scientists. In the 1950s, industrial research, especially in central research laboratories, moved toward academic-style research. In part this reflected the fact that the demand for Ph.D.'s far exceeded the supply, so unhappy researchers could readily find employment in other companies or in academia. Sociological studies on professionalism and the new discipline of research management legitimized the scientists' need for autonomy.[30]

[27]John Kenly Smith, Jr., "World War II and the Transformation of the American Chemical Industry," in E. Mendelsohn, M. R. Smith, and P. Weingart, eds., *Science, Technology, and the Military: Sociology of Science Yearbook* 12 (1988): 307–22.

[28]George Wise, "Science and Technology," in Sally Gregory Kohlstedt and Margaret W. Rossiter, eds., *Historical Writing on American Science: Perspectives and Prospects* (Baltimore: Johns Hopkins University Press, 1985), pp. 229–33.

[29]On postwar research strategy, see Hounshell and Smith, *Science and Corporate Strategy* (n. 22 above), chap. 16; Wise, "R&D at General Electric, 1878–1980" (n. 23 above); and Margaret B. W. Graham, "Industrial Research in the Age of Big Science," in *Research on Technological Innovation, Management and Policy* 2 (1985): 47–79. Graham explains that Alcoa, after the government put other companies in the aluminum business, moved away from fundamental research and toward customer-service research as a response to competition.

[30]Hounshell and Smith, *Science and Corporate Strategy* (n. 22 above), chap. 17; Wise, "R&D at General Electric, 1878–1980" (n. 23 above); and Graham, "Industrial Research" (n. 29 above), pp. 61–69.

This literature was aimed at a new generation of research directors who, unlike their predecessors, defined their jobs more narrowly by insisting that the laboratories were responsible only for research, not innovation. They had grown up in a research culture and saw their job as sustaining a tradition, not as supporting corporate goals. Not surprisingly, their labs became increasingly isolated throughout the 1950s. The physical manifestation of this was laboratories built in suburban country-club settings far from the plant and corporate headquarters.[31]

By the end of the 1950s, management began to lose patience with the denizens of these ivory towers.[32] What was the source of this discontent? Had the promise of science-based invention raised expectations so high that only new nylons and transistors could keep management happy? Was research just a scapegoat for a general slowing of economic growth as the European economy recovered and gained strength? Regardless of the underlying factors responsible for the problems, management concluded that, while laboratories had produced many scientific breakthroughs, the translation of them into new technologies had not occurred, in part because the scientists were unwilling to undertake the mundane tasks of development and commercialization. To remedy this situation, in the 1960s and 1970s companies emphasized development and commercialization of new products, forcing reluctant scientists into new molds.[33]

To get research back on track, management hoped to repeat the successes of the past with new blockbuster innovations. Du Pont introduced Corfam synthetic leather into the high-priced shoe market in 1964.[34] Similarly, RCA tried to repeat its earlier triumphs in consumer electronics—radio, black-and-white television, and color television—with the videodisc system in the late 1970s.[35] But consumers preferred Japanese videotape systems and real leather shoes, and management soured on innovation in general, cutting back on R&D programs.

[31]Hounshell and Smith, *Science and Corporate Strategy* (n. 22 above), chap. 17; Graham, "Industrial Research" (n. 29 above), p. 67.

[32]Hounshell and Smith, *Science and Corporate Strategy* (n. 22 above), pp. 381–83, 509–15, 574–78; Graham, "Industrial Research" (n. 29 above), pp. 68–69; and Wise, "R&D at General Electric, 1878–1980" (n. 23 above).

[33]Norman Fast, "The Evolution of New Venture Divisions" (Ph.D. diss., Harvard Business School, 1977); Hounshell and Smith, *Science and Corporate Strategy* (n. 22 above), chap. 22; Graham, "Industrial Research" (n. 29 above), pp. 69–72; and Wise, "R&D at General Electric, 1878–1980" (n. 23 above).

[34]Hounshell and Smith, *Science and Corporate Strategy* (n. 22 above), pp. 536–38.

[35]Margaret B. W. Graham, *RCA and the VideoDisc: The Business of Research* (New York: Cambridge University Press, 1986).

It is remarkable how similar the postwar experiences of the research pioneers have been. Perhaps these companies were evolving along parallel lines or just following wider trends set by a few outspoken executives or management consultants. A major difference between Du Pont and electronics firms was that the latter became heavily involved in military research, whereas Du Pont consciously avoided government R&D contracting. Historians are just beginning to assess the effect of government spending on corporate R&D. Generally, government funding policy has encouraged competition in research instead of funneling money to the dominant firms.[36] More specifically, Thomas J. Misa has shown how important the military has been in the development of the semiconductor industry.[37] As in World War II, the government financed the risky and expensive development and commercialization phases. Perhaps the biggest success story was the silicon transistor. Even though it was more expensive than germanium ones, the military promoted its development because of its ability to operate at higher temperatures. This led to the discovery of the diffusion technique, which proved to be the basis for integrated circuits and computers on a chip.[38]

Much of the development of semiconductors was done by entrepreneurial firms that have been touted as the successors to large bureaucratic R&D organizations. Had technology broken loose from its century-long corporate fetters and returned to the age of the heroic inventor? Not really, because these new firms depended on two large institutions: the Pentagon (for funding development) and Bell Laboratories (for technology and personnel). The latter was as close to a national laboratory as the United States has ever had. The family tree of the Silicon Valley companies has numerous branches that go back to Bell Labs.[39] When the federal government turned AT&T into just another company, Bell Labs became just another corporate research laboratory.

In recent decades, as AT&T, General Electric, Du Pont, and the other companies have redefined their businesses away from the

[36]David C. Mowery, "Industrial Research and Firm Size, Survival, and Growth in American Manufacturing, 1921–1946: An Assessment," *Journal of Economic History* 43 (December 1983): 979.

[37]Thomas J. Misa, "Military Needs, Commercial Realities, and the Development of the Transistor, 1948–1958," in Merritt Roe Smith, ed., *Military Enterprise and Technological Change* (Cambridge, Mass.: MIT Press, 1985).

[38]Ernest Braun and Stuart Macdonald, *Revolution in Miniature: The History and Impact of Semiconductor Electronics,* 2d ed. (Cambridge: Cambridge University Press, 1982), pp. 88–89.

[39]Ibid.

traditional disciplinary foci, the research organizations have found themselves searching for new roles. Businesses can be bought, sold, reorganized, or redirected very quickly, but changes in research orientation occur more slowly. The expertise that exists in American industrial research laboratories has been accumulating for a century. At this point it is unclear how science-based research of the past will fit into the corporate structure of tomorrow.[40] With respect to historical scholarship, however, it is this very uncertainty that has induced corporations to become interested in the history of their R&D programs and has led to the creation of a new body of literature for historians of science, technology, and business.

[40]One possible scenario is for laboratories to become independent businesses. Recently, General Electric sold the former RCA central laboratory to the RAND Corporation. *New York Times,* April 30, 1989.