History of Physicists in Industry
Final Report

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R. Joseph Anderson and Orville R. Butler, M. Juris, Ph.D.

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This report is also available on the AIP Center for History of Physics Website: http://www.aip.org/history/ . Contact us at (301) 209-3165, nbl@aip.org.

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Project to Document the History of Physicists in Industry

Executive Summary

This project is the first systematic study of the organizational structure, communications patterns, and archival records of industrial physicists in the U.S., and it provides general guidelines for understanding and documenting their work. The study confirms that the organization and management of industrial R&D is volatile, changing in response to economic cycles, new managers and management philosophies, and a variety of other factors. It also confirms that historically valuable records that document R&D are at risk and, in fact, are often scattered and lost.

The report is divided into two parts. Part I describes the recent history of research and development at the 15 companies in the study. Part II describes the archival findings of the study, including communication patterns and organizational structure relating to records and documentation, and it briefly describes information management programs at the 15 laboratories at 3M, Agilent Technologies, Corning, Eastman Kodak, Exxon Mobil, Ford, General Atomics, General Electric, Honeywell, IBM, Lockheed Martin, Lucent Technologies Bell Laboratories, Raytheon, Texas Instruments, and Xerox.

Part I traces the shifting funding and organizational structures of industrial research at the 15 corporations since World War II. The funding and organizational structure of R&D have undergone radical changes, mainly since the 1980s. We found a strong emphasis on development over research, but that relationship remains constantly changing. Physicists noted transformations in the nature of their work since World War II and particularly in the last twenty to thirty years. Those changes included shorter research time frames, shifts in the nature and source of R&D funding and sometimes a shift from knowledge creation to knowledge evaluation and acquisition.

Industry has not yet, and may never, arrive at a consensus on how to conduct its research or even the appropriate relationships among science, technology, and business interests. Companies are struggling to find the best mix of centralized long-term research focused on developing new basic and disruptive technologies, and distributed short-term research programs tied closely to current product improvements. Many remain unsure of the relative benefits and risks of government research and university collaboration. Others are forming research alliances similar to patent pooling programs that became widespread in the late nineteenth and early twentieth century.

Part II surveys the extent of record preservation and the changing nature of records used in industrial research. Company policies regarding research records vary widely. It particularly documents a decline in use of the lab notebook and the absence of an electronic replacement. The Sarbanes-Oxley Act of 2002 standardized financial and related business records that pubic companies must retain, but it does not cover records that document the R&D process or the resulting intellectual capital. As a result, the preservation of these records remains haphazard. The report analyzes the differing roles of corporate technical libraries and archives and describes academic and public archives where some companies preserve important records. Part II concludes with a list of best practices and recommendations.

Introduction and Methodology

Introduction

The AIP Project to Document the History of Physicists in Industry is a documentation research study designed to create a framework for identifying and preserving historically valuable records of physicists and allied scientists in American industry. The five-year study included 1) question set interviews with current corporate physicists, R&D managers, and information professionals at 15 major industrial laboratories; 2) identification and cataloging of extant corporate records, laboratory notebooks and other sources in the History Center's online International Catalog of Sources for the History of Physics and Allied Sciences (http://www.aip.org/history/icos) and the international OCLC database, and 3) a study of existing public and private archival programs that document the history of science-based industry in the U.S. and Europe. In addition to these components of the study, we conducted tape-recorded autobiographical interviews with 16 leading industrial physicists and will continue the interviews as resources permit.

The AIP Center for History of Physics conducted the study between 2003 and 2007. More than one-third of Ph.D. physicists in the U.S. are employed in the corporate sector, and the percentage is growing among physicists who received their Ph.D.s in recent years.[1] However, there is very little archival documentation on the work that physicists or others in industrial research and development do, and little information on how the work is structured and how it has changed over time. In conducting the study we selected 15 of the 27 major high-technology companies that employ the majority of physicists and allied scientists in industry. We conducted site visits at the central research laboratory or nearest equivalent at each of the companies and conducted structured question-set interviews with physicists (either senior bench scientists or R&D managers) and appropriate information professionals. We also visited public and private archives that collect business records in the U.S and Europe, and we did extensive background research.

The results of the study provide general guidelines for understanding and documenting the work of the physicists at the 15 companies.[2] They also illustrate the extensive changes in the nature of the work that physicists in the corporate sector have experienced during the careers of most of the interviewees, which stretch over the past 40 years. The median year for completing the Ph.D. for physicists who participated in this study is 1978, and most of the participants have worked in industry for the majority of their careers. Some of the changes, especially the development and use of computers, are ubiquitous in our society as a whole, and computerization has both speeded up the work of corporate physicists and changed patterns of communication and documentation. Another major force has been the volatility of corporate investment in R&D over the past 25 years, sometimes paralleling the economy as a whole and sometimes not. A third major issue, which appears as a recurring anecdotal theme in many of the interviews, is the change in organizational structure and management goals that the interviewees have experienced over the course of their careers.

Methodology

We began our initial inquiries into industrial research and development in the mid-1990s as an outgrowth of a documentation study of multi-institutional collaborations that we were then conducting. We visited industrial laboratories as opportunities allowed, included interviews with a few corporate physicists in the study, and in 1997 conducted a mail/phone survey of archives and library programs at large corporate research laboratories. In developing the methodology and work plan for this study we relied in part on the methodology that we had used in our earlier documentation research project, the AIP Study of Multi-Institutional Collaborations, and we sought input and advice from leading industrial physicists, historians, and archivists. We chose a qualitative approach—interviewing a smaller sample intensively—instead of a quantitative approach in order to investigate the large network of issues that help explain the nature of the work that corporate physicists and allied scientists do, and the documentation that grows out of it or in some cases fails to grow out of it.

We believe that qualitative methods are appropriate for this study since they have allowed us to raise research questions that are open and exploratory. Surveys and statistical analyses (*i.e.*, quantitative methods) are more appropriate for studies that have a limited number of clearly defined variables. Qualitative methods, on the other hand, are appropriate for inquiry that is exploratory, field-focused, process-oriented, inductive, and include data that are verbal and richly descriptive.[3]

We anticipated that texture and nuance would arise from our interviews, as respondents discussed the qualities and processes that describe and distinguish their roles in industrial physics and the records that document their work. In the interview format that we employed, respondents have had the opportunity to describe complex situations that cannot be represented in survey questionnaires. By hearing their stories in detail and considering them within the context of the interviewee's background and perspective, we have been able to appreciate how scientists' and companies' record-keeping practices are influenced by personal backgrounds, company culture, management and organizational trends, and technology.

We analyzed the interviews using Nvivo, a qualitative software program, and we assigned inductively created codes to flag concepts that could then be compared across companies, industry sectors, job types, and people. Because record-keeping by industrial physicists is so uncharted, we anticipate that an important byproduct of this qualitative study will be the identification of variables whose influence might be tested in future quantitative studies. Thus, in addition to providing information about the organization of industrial R&D and recommendations about documenting the work of industrial physicists, we hope that these interviews will provide a basis for additional research by others. The interviews will be made available to researchers at the conclusion of the study, except for the small number where the interviewees requested that their responses be destroyed after we analyze them anonymously.

We conducted site visits and interviews at 15 high-technology companies, choosing from corporations that employ the largest numbers of physicists. At each company we interviewed a minimum of two R&D managers, including at least one senior manager, and three or more senior bench physicists. In addition, we interviewed appropriate information professionals, including the head of the technical library, the person responsible for records management, and the archivist if the company had an archives. Two major components of the first stage of the project consisted of selecting the companies that we would invite to participate in the study and developing the questionnaire sets that we would use for the interviews.

We selected the companies from the 27 major U.S. high-technology companies that employed the majority of physicists and allied scientists in industry at the time. We chose from these companies because together they employ about half of all the physicists working in the corporate sector in the U.S., and because large companies are more likely to be involved in traditional physics/allied science research, which is our primary concern. We identified the largest employers by using the results of three biennial sample surveys (1998, 2000, 2002) of U.S. members of AIP's 10 Member Societies[4] conducted by AIP's Statistical Research Center. From the list of 27 companies, we selected a judgment sample based on the following criteria:

> *Size:* Our universe of 27 firms is comprised of large and very large companies. The five largest companies (Raytheon, Lockheed Martin, IBM, Lucent, and Boeing) employed significantly more physicists than the rest of the firms, and according to the AIP surveys more of their physicists/allied scientists were engaged in basic research. We included four of the five.
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> *Industry sector:* We selected firms whose products include all the industry sectors that are part of our universe: computer hardware, aerospace/defense, energy, transportation, telecommunications/internet, advanced materials, and photonics.
>
> *Product mix:* The 27 companies include firms that manufacture a limited number of related products concentrated in one or a few industry sectors, and diversified conglomerates that produce a wide variety of goods for many different sectors. We have included both in our sample.
>
> *Ownership:* Only three of the companies are privately owned, and we included one private company, General Atomics.
>
> *Archives:* We selected a few companies that we knew had active in-house archival programs.
>
> *R&D organization:* The 27 firms include companies that maintain centralized (headquarters) and decentralized research and development operations. We over-selected centralized R&D operations because they have traditionally done more advanced research.

We selected the following companies as our top choices, without first ascertaining if they would agree to participate: 3M, Agilent Technologies, Boeing, Corning, Eastman Kodak, Exxon Mobil, Ford, General Atomics, General Electric, Honeywell, IBM, Lockheed Martin, Lucent Technologies Bell Laboratories, Texas Instruments, and Xerox. In practice only one of the 15, Boeing, refused to participate. Boeing was one of the five largest companies in our universe, and we were able to replace it with another member of the top five, Raytheon, which is also an aerospace/defense contractor. The other change in our original selection was to substitute Agilent for Hewlett Packard. Agilent was spun off from HP in 1999 and represents the parent company's precision and scientific measurement units, and it was thus the sector that we were interested in investigating.

During the startup phase, staff developed separate question sets for each of the interview groups: senior bench physicists, R&D managers, archivists, technical librarians, and records managers (see Appendix A for the senior scientist question set). Developing the initial question sets was a major undertaking, and we received input and assistance from a variety of sources, including our consulting sociologist, Professor Wesley Shrum, John Armstrong (former head of IBM research and development) and especially Roman Czujko, head of the AIP Statistical Research Center. During the course of the project, we have revised and updated the question sets as needed on an ongoing basis.

Our results have been divided into two parts. Part I of this report describes the historical evolution of industrial research at the 15 companies in the study. Part II addresses the archival findings of the study, and it concludes with recommendations for documenting the history of physicists in industrial R&D. The study does not treat access to R&D records, which is an issue that must be addressed by individual companies. However, as many of our interviewees have pointed out, intellectual property in industry has a short shelf life because it becomes obsolete quickly, whether it takes the form of U.S. utility patents, which are issued for a period of 20 years and cannot be renewed, or trade secrets.

Endnotes

[1] A 2001 NSF study reports than one-third (36%) of physicists who received PhDs from 1946 through 1965 were working in industry in 2001, while almost half (49%) had jobs in academe. For physicists entering the job market in the late 1990s, the numbers invert. Of those who earned PhDs between 1996 and 2000, more than half (57%) were working in industry in 2001, while less than one-third (31%) had academic positions," online at (http://www.nsf.gov/statistics/issuebrf/nsf01332/sib01332.pdf).

[2] There is relatively little recent literature on industrial archives. However, noteworthy exceptions include James O'Toole, ed, "Special Issue on Archives and Business Records," *The American Archivist*, 60(1)(Winter 1997), 1; James O'Toole, ed*., The Records of American Business (*Society of American Archivists, 1997); and Bruce H. Bruemmer and Sheldon Hochheiser, *The High-Technology Company; A Historical Research and Archival Guide* (Charles Babbage Institute, 1989). In addition Karl Grandin, et al., eds. *The Science-Industry Nexus: History, Policy, Implications: Nobel Symposium 123* (Science History Publications USA, 2004) includes two articles on archives.

[3] For additional information, see J. W. Creswell, *Qualitative Inquiry and Research Design: Choosing Among Five Traditions* (Thousand Oaks, CA: Sage Publications, 1998), and M.Q. Patton, *Qualitative Evaluation Methods* (Beverly Hills, CA: Sage Publications, 1980).

[4] American Physical Society, Optical Society of America, Acoustical Society of America, The Society of Rheology, American Association of Physics Teachers, American Crystallographic Society, American Astronomical Society, American Association of Physicists in Medicine, AVS The Science & Technology Society, American Geophysical Union.

Part 1: History of Physicists in Industry

Orville R. Butler, M. Juris, Ph.D., Associate Historian, American Institute of Physics

Introduction

Several models of the relationship among "science", "technology" and "industrial research" have long been discussed in academic circles and to some degree have played important roles in the historical development of industrial R&D. The linear model, typically with its emphasis on a centralized R&D laboratory, can be traced back to the writings of Vannevar Bush after World War II. Other models include R&D outsourcing, collaborative research alliances, and particularly the "Triple Helix" model advocated by Henry Etzkowitz.[1] They all focus on different formulations of the relationship among "science," "technology" and "product development" that go beyond the realm of this report.[2] Industry, however, continues to search for the most productive interrelationship between research and product development.

The linear model, widely put forward in various forms by Vannevar Bush after War II, rarely had complete real world application in industrial research. Even Raytheon, with Bush as one of the founders, never focused its research program on "pure science." Bush's linear model derived, to a large degree, from the Manhattan Project where the best scientists were given free rein to apply the laws of physics to destructive ends. After the war, Bush asked, where would they find "objectives worthy of their best?"[3] Science, he argued, could create similar programs to develop artifacts for the benefit of humankind. Put the best scientists in a lab, give them free rein to make discoveries, and industry could create a "well supplied house" and teach humans "to live healthily therein." The concept was perhaps most forcefully put forward by the motto of the 1933 Chicago World's Fair—"Science Finds—Industry Applies—Man Conforms." He urged Manhattan-style projects where science could be applied to humankind's "true good."[4]

Physicists at nearly all of the companies we visited noted transformations in the nature of their work since World War II and particularly during the last twenty to thirty years. These changes include shorter research time frames, shifts in the nature of R&D funding and, in some cases, a shift from knowledge creation to knowledge evaluation and acquisition. In describing these changes our interviews document and occasionally add depth to the current literature. They show the interrelationship between the structure and funding of research and its impact on the role of industrial physicists, the documentation that social scientists might turn to in their study of industrial physics, and the ways in which physicists communicate and perform their duties within the corporation.

Several corporations transformed their research programs after World War II, at least in part to apply advances in science to industrial products, or in some cases to solve scientific questions that might provide utilitarian insights in the development of products. Science after the war was perceived as a potential solution to humankind's problems. Science could provide the solutions while industry could develop and apply them. While Bell Labs had been created as a distinct institution in 1925, many companies after the war developed independent research laboratories held apart from the corporations' day-to-day activities. However, recruiting scientists to go into industry or even government research labs was difficult. One interviewee told us of interviewing at a government laboratory in the 1950s where the manager told him that over 100 people had already turned down the position.[5] Most physicists we interviewed who entered industrial R&D during the 1950s and 1960s claimed to do so for personal reasons—family influence, a relationship with a recruiter, etc. One physicist hired by IBM in the 1950s suggested that he looked towards industry because his father had been an engineer at Bell Labs.[6] Another told us that he did not decide to work in industry; he decided to work at Bell Labs.[7]

By the mid 1970s motivation had changed for those entering industrial R&D. During the halcyon days of the Apollo program and other government-funded programs in the 1960s, bright students were encouraged to go into science. But by the 1970s competition for academic jobs became increasingly difficult. Most interviewees talked about the difficulty of getting jobs and many appear to have been forced by the job climate to accept what they could get, even though they planned to go back to academia eventually. Others mentioned—and this continues to the present—the factor of a two-salary difference between academia and industry.

Industrial laboratories created or modified during this time took on the trappings of academic research labs with academic style divisions—physics department, chemistry department, etc. One scientist who came to Bell Labs in the 1960s told us

> It really was an ivory tower. . . . You didn't have to go get government funding; you didn't have to do anything. They funded your research, they told you to do what you want. There was an atmosphere where it was a world class, if not the best place in the world to do things, probably pretty much the best place in the world. People would say it was the best except if you do high energy. … It was so stimulating and such an easy thing to do. In other words, you had no classes to teach, no responsibilities.[8]

Scientists at these labs were encouraged to publish and often permitted to do research in a field of interest to the company but with no known direct application to the company's current product line. When new ideas and concepts arose in the lab, they would be presented to the company—tossed over the wall, as several scientists described it.

Not every R&D laboratory interviewee mentioned the separation of research from development that predominated in the 1950s and 1960s, at least at the leading laboratories—Bell Labs, GE and IBM—and others that attempted to be little "Bell Labs." However, sufficient numbers saw this as an ideal characteristic that companies struggled with this view occasionally even into the 1990s.

Faas states that a primary change in the organization of industrial R&D over the last half century has been the gradual shift in control of innovation (*i.e.*, the creation and introduction of new or improved products or production processes) from individual workers to top managers. Following World War II, there was a strong belief that successful research and development depended on highly creative people who, given autonomy and adequate organizational and financial resources, would create new products on their own. Faas quotes a 1950 publication, *The Organization of Industrial Scientific Research*, as typical of the period: "The best person to decide what research work shall be done is the man who is doing the research, and the next best person is the head of the department. …" In contrast, the company's research director is "probably wrong more than half the time. …" According to Faas, this view began to change by the mid-1960s, when a major study of American R&D recognized that a scientist-centered approach risked sacrificing the technical needs of the company to the technical interests of individual people, and the authors concluded that organizational priorities should include cooperation with other R&D employees, work on multiple projects at the same time, and project/program selection by workers and managers together. These findings helped to shift autonomy from individual employees to the R&D department. By the time Faas was writing in the mid 1980s, however, he states that the dominant view had moved well beyond the individual department. This view, which remains dominant today, holds that for the innovation process to be effective, nearly all of the company's programs need to be involved, including R&D, marketing, and production. This in turn has increasingly moved control for R&D up the corporate ladder to the CEO and other top executives, resulting in less autonomy for individual workers.[9]

John Seeley Brown, former chief scientist and director of Xerox PARC, and Paul Duguid have focused on the problem of knowledge transfer within laboratories and within companies as a whole, and they use Xerox's failure in the 1970s to develop the graphical user interface (GUI), created at Xerox PARC, as an example. Tacit knowledge tends to "stick" within communities of practice, and they point out "the well-known path of resistance between a company's research labs and engineering." Because scientists and engineers, as well as market researchers, business managers, etc., represent different communities of practice, it's difficult to transfer knowledge between them, and this was exemplified by Xerox's failure to take advantage of the GUI. At the same time, knowledge that's tacit or "sticky" among scientists in one company may often "leak" to the same communities of practice in other companies. Brown and Duguid state that this happened with the GUI, which stuck in Xerox but leaked to scientists at Apple who were working on similar problems and were able to take advantage of it in developing the personal computer. They maintain that the system in place in Xerox and many other companies at the time gave "certain communities…the right to search for new knowledge. The others are strictly regimented and expected to follow routine." They propose that innovation, which makes products marketable, can be achieved only by integrating different communities of practice (physicists, engineers, chemists, computer scientists) into networks of practice within individual companies.[10]

Previous authors have pointed to a variety of effects from changes in industrial R&D organization and management, including especially a strong emphasis on development at the expense of research as companies attempt to create new products or improve old ones. One study notes that a result of this effort has been the decline in the importance of central laboratories, which are now dominated by individual business (*i.e.*, product) units or replaced entirely by labs operated by those units. Another outgrowth of the reorganization is that industrial inventions and industrial patents appear to have become less science-based over the past quarter century.[11]

If one result is clear from our study of physicists in industry it is that corporations continue to struggle to find the appropriate relation between research and development. While corporations have moved to integrate research more closely to their perceived business needs, they have not yet arrived at a consensus for a "best fit" between research, development and invention. The shifting relationship between research and the corporation's other operations might best be described as a shift from "invention" towards "innovation" where innovation focuses on integrating inventions into a completed process from the conceptual beginnings through manufacturing to customer acquisition and use.

No Customer for Research

Corporate R&D has changed significantly during the past 30 years. The 1980s were characterized by corporate takeovers, reorganizations, and the growth of conglomerates, and the first half of the 1990s saw downsizing and reengineering. While industry has continued to contribute the largest share of U.S. investment to research and development, major reductions in private R&D investment from 1985 through 1994 created "an unprecedented period of decline that affected nearly every major [industrial] research lab . . . and fanned fears that America would fall behind foreign competitors. However, the trend reversed during the second half of the 1990s, which witnessed a boom cycle. Private sector R&D grew by 0.7% per year in real (inflation-adjusted) dollars between 1985 and 1994; the growth rate increased to 7.6% annually from 1994 to 1998. Reflecting the boom, salaries for industrial physicists and related scientists began to surge in 1996 and rose 17% between 1996 and 2000. This rapid growth ended in the dot-com bust and economic slowdown of 2001-2002, followed by a gradual recovery. In terms of funding, the business sector's share of U.S. R&D spending peaked at 70% of the total in 2000, then declined for several years but recovered to 66% by 2006.[12]

Most industrial R&D labs through the 1970s were little concerned about the relationship of their research to the bottom line. As one interviewee described, in the "old days" GE, IBM and possibly Xerox did some basic research, although nothing on the scale of Bell Labs.[13] For most companies, that changed during the late 1980s through the 1990s. By the late 1980s, the utility of R&D or at least the research part of R&D increasingly came under attack as many of the leading companies faced growing competition and were disappointed that research was not providing adequate return on investment.

At Bell Labs the research transitioned after AT&T lost its monopoly in 1984. In November 1974 the U.S. Department of Justice filed the antitrust suit that would end ten years later with the breakup of AT&T. AT&T lost what became seven local "Bells" providing local and regional service. It retained its long-distance service, along with Bell Telephone Laboratories and the Western Electric Company. One researcher told us that the transition from the AT&T monopoly to competition was "the whole story of Bell Labs." When AT&T was a monopoly the view was "that you get a lot of good people in one place, and when problems come up they can come up with solutions and good ideas on things that do have something to do with the business." By implication the rest of the time they could spend doing their own research.

> Bell Labs was this wonderful place where they hired all these people and said, "Do what you want to do, and we won't bother you. We'll give you money and time and support to help you and a room, a small amount of room (not a huge amount), and then you will go and collaborate with people and set up a research program … and just do what you want."[14]

One former Bell Labs scientist asserted, "when AT&T was a monopoly, there was no bottom line in the company. … If they made too much profit they could always burn it away in Bell Laboratories." How research would "contribute to the business" wasn't "part of the culture of the organization that I was in." "We didn't look at the stock price on a daily basis because none of us owned any shares."[15] Another R&D manager at Bell Labs told us that Bell Labs "had a tremendous reputation, even though the impact of that research on the business of AT&T was relatively minor."[16] In the 1990s about 80% of Bell Labs research was unrelated to AT&T business. In the 1980s making the Labs relevant to AT&T, this manager suggested, was a matter of branding or placing AT&T in front of "Bell Labs." Only in the 1990s, she asserted, did they "need to understand what kind of impact we were really having on AT&T."[17] That created a great difficulty for "physical sciences, because we really didn't impact the larger company."[18] By the 1990s another physicist told us there was great pressure to make research relevant to company business.[19] She recalled that the spin-off of Lucent in 1996 was "a very exciting time for Bell Laboratories and physical sciences, because all of a sudden our company, Lucent Technologies, manufactured devices and everything that we did was relevant to the new company." But that too had its down side. "We didn't realize at the time that we were funded as a percentage of revenue, and that when you are a $20 billion company or a $30 billion company, that's a big number, but as the company shrinks, that number is shrinking on a yearly basis."[20]

Another remembered the transition more traumatically: "In 1995 we had a meeting offsite in which there was a serious crunch. AT&T had convinced itself to stop supporting Bell Laboratories, I think, at the highest levels." This physicist recalls a two-day meeting at Princeton in which an AT&T vice president explained the problem:

> When AT&T was a monopoly, every time some engineer at Bell Laboratories invented a way to double the bandwidth or get more phone calls per wire, AT&T made out because they didn't have to put more telephone poles up, they didn't have to make fatter wires, they just sort of used the idea and could make money from it. … When it became no longer a monopoly and we had competitors all over the place as a result of that decision, then every time we invented a new way to triple the bandwidth, the competition could use it as well, and did.

That resulted in "an incredible over-supply of telephone capacity" that drove prices through the floor. AT&T did not drop Bell Labs because they were not doing research relevant to the company, but because some of the research they were doing was actually harmful after the breakup of the monopoly. "So Bell Laboratories was in fact causing a problem for AT&T. … [E]very paper we published with a technical advance was in fact against the interest of AT&T." The interviewee told us, "I thought Bell Labs was over. And I think it wasn't so far from over. … [What] they decided to do was spin off Lucent, which gave us a little bit of a lease on life for a while."[21]

A number of scientists told us that the decline of monopolies was critical to the transformation of Industrial R&D.[22] One manager at Lucent asserted,

> You really can't do the fundamental stuff if you've got to sell the product units. ... I think there's an understanding that if you want this company to survive ten years from now, 15 years ago you need to have some people thinking about that. The product units may argue that, 'You can't do that. You're spending our money. This is our money. You should be doing base stations. We need to lower the cost.' So we do that.[23]

A Xerox R&D manager suggested that the creation of the company's Palo Alto Research Center (PARC) may have, in part, been viable because of Xerox's monopolistic status during late 1960s and early 1970s.[24] Another physicist at Kodak suggested that the loss of monopolistic status transformed not only Bell Labs, but also research at Kodak.[25] Similarly, one of Corning's R&D managers suggested that that company's virtual monopoly in the television picture tube business both provided a boon to the company and placed it at greater risk when it disappeared. After the loss of the TV tube "virtual monopoly" the company decided not to place all their research eggs in "one basket."[26] The increased focus on business came in part because of increased competition. "In the monopoly days, we were told there was 'no customer' for research. But now you are supposed to have customers for parts of the business you are in."[27]

One IBM R&D manager told us that the company went through a stage during the early 1990s where "we really did go from a state of not knowing if we're about to finish the death spiral or be able to stabilize somewhere to where we did stabilize."[28] Many within the company and division leadership questioned the value of scientific research. "It wasn't obvious what to do." "How do you make a story that makes sense for having a significant component of basic research within our organization?"[29] No longer was it adequate to conclude "Well, they let me do it, so it must be okay." In the end, he asserted, researchers had to be able to create a "story" of the utility of their research. It had to be consciously coupled to the interest of the company. The coupling could be "way out there somewhere" but researchers could no longer work "on something that has no prayer of ever having anything to do" with the corporate products and interests.[30] Everyone doing research had to come up with a story that justified how what they were working on had "potential of being important at some point to the success and profitability of IBM. That could be Charlie Bennett worrying about quantum computing. That was okay. But everybody had to think about it and have a story. That did a lot because there were people who couldn't come up with a story."[31]

It also changed IBM hiring practices. Rather than hire the best and the brightest, IBM increasingly focused on how their research might benefit the company. "It's not like, 'Well, he's a really great person and let's hire him and maybe he'll do something neat.' That story doesn't go very well. But it's not that much of a twist to come up with what he might do that's good. So, that's a game to be played to some extent."[32] Research metrics became more important. Milestones became increasingly important and if you didn't reach a particular milestone you again needed a "story why it didn't happen."[33]

Lockheed scientists and R&D managers, on the other hand, associate the decline of research in their industry with a decline in competition. The shift away from basic research, one research fellow at Lockheed noted, was one of the most dramatic changes in the Research Center over the last twenty years. Twenty plus years ago Lockheed and other aerospace companies spent some profits on basic research. In the mid 1980s there were, one fellow said, about fifty aerospace companies. Innovations would provide them a competitive advantage in gaining government contracts. By the late 1990s the industry consolidated, and since most research came from government contracts everyone knew as much as the potential competition. Today, he asserted,

> We are the government. There used to be five players for every major contract. Now there are only two players. … The contracts are spread out among the so-

> called competitors and there's no advantage to spending profits on basic research. The government used to score the aerospace industry on its IRAD (Internal Research and Development) projects and provide future contract fees based on those scores. Eventually the government stopped requiring that IRAD reports be collected by the Defense Technical Information Center (DTIC). [34]

Patents also had limited value in the aerospace industry, as one R&D manager pointed out:

> We are a monopsony, our customer is the U.S. Government, and the U.S. Government in all of its contracts routinely writes an authorization and consent clause. … The only people Lockheed Martin can go to for redress is the government, and so now we are going to bite the hand of our customer? … What a patent can really do for us, in cases where it is only for government use, is if we get a patent on a particular approach to a problem we can prevent other companies from doing pre-contractual work on it. [35]

But, he concluded, how do you know they are conducting IRAD on our idea prior to winning a contract? As a result fundamental research in the aerospace industry is no longer cost effective.[36]

Restructuring Funding

With the apparent exception of aerospace/defense contractors, growing competition, both within the United States and perhaps more significantly, from Asia, forced companies to re-evaluate the relationship of R&D to the company. One way of making R&D more "relevant" was to change the sources of funding for research labs. Another was to reposition labs within the company. Investment represents only one part of the pattern of change. A persistent theme in the interviews at nearly all of the companies is the significant changes that have taken place in how research is funded and structured, the kinds of work that corporate physicists do, and the people with whom they work, as well as how they communicate with others and the kinds of documentation that they produce.

Changes in the nature of the precise source of funding have profound implications for the research mix. Traditionally, centralized funding of R&D to a large extent removed the laboratories from the day-to-day pressures of business operations. While research was supposed to be in the interest of the corporation writ large, it was buffered from the concerns of the business units and addressed those specific concerns only to the extent that the central administration imposed those concerns on research. Centralized funding of R&D made research and development an outgrowth of the vision of the Director of Research, if not the CEO and/or the Board of Directors. Operational issues for which research could be a solution had to rise up through the business structure to the corporate level before they were likely to be addressed by the centralized R&D laboratories. Similarly, the innovations made by the centrally funded laboratories would be reviewed by the general corporation before being sent down the line to the operating companies for implementation into its products, which could be a long and imperfect process. While laboratories often researched issues of long-term interest to the corporation's business units, often the labs did not tie that research to the immediate interests of those units and their product lines. Research breakthroughs focused on new disruptive technologies and tended to ignore incremental improvements. The centralized research labs were unlikely to address production problems, quality control issues or the technological “fires” that the operating divisions regularly faced. Their research might produce new product lines but generally didn't produce refinements or improvements in current products or solve production problems.

For some companies, funding of the central labs came from overhead costs. That is, it came out of the corporate budget directly. For others it resulted from a corporate “tax” on the business units, where each business unit would pay up a percentage of its revenues to the corporation, which would then assign those funds to central laboratories. Funding R&D through the corporation effectively placed a buffer or middleman in the decision-making processes between R&D research and the operations of the company.

Two changes since the 1970s have sought to eliminate the corporate middleman between product and R&D. One broke up the centralized laboratory, placing research labs within the operating divisions that would both fund and manage them. Other companies retained the central lab, but shifted the funding from a corporate tax on the operating divisions to a contract-based research mechanism directly funded by the operating divisions. The central lab would have to get at least some of its funding by “selling” research to the operating divisions. The business units rather than the corporation as a whole would become customers of the laboratory. Such funding changes greatly increased the power of operating divisions over research agendas. With funding decisions and power coming from the business units rather than the corporation itself, the research laboratory obtained funds for addressing the specific needs of the business units. Laboratories were unlikely to receive funds for “blue sky” research when the limited funds an operating division might provide for research needed to address specific problems faced by that division or incremental improvements in their product line demanded by their customers. Placing funding under control of the business units effectively shifted research towards more immediate product development needs and sometimes even to “fire fighting” problems within operations.

One physicist told us in describing changes in R&D at General Electric, “Money is really the source of all the changes, the freedom or lack of it.”[37] Research funding began to evolve at GE shortly after Jack Welch became CEO of General Electric in 1981. GE remained a highly profitable firm, so research did not face a reduction of funds but a change in source. Previously 75-80% of research funding was provided, with little or no strings attached, from a corporate tax on the business units, which GE called “assessed” money. The laboratory director and his staff would then use these assessed funds to set their budget and allocate funds to various research projects according to their priorities. Most of the funding went to research that explored areas roughly applicable to GE’s lines of business. A small percentage of funding would be applied to specific business areas that “needed attention” and another small percentage was applied to longer-range exploratory work “not necessarily associated with any of the businesses.” Those discoveries would then be tossed “over the wall” to the business, which might find ways to incorporate the discoveries into its products and processes. But since research was not oriented towards the needs of the operating divisions, research output was as often as not irrelevant to those needs. One researcher who had started at GE in the 1960s told us,

> When I first started it [funding] all came from corporate . . . maybe 90 percent from corporate, maybe 10 percent from some government contracts. … You

> wouldn't be told things; you couldn't go to Hawaii and study whales or something like that. . . . We understood there had to be some kind of, some relation [to business] but … my first manager was here for thirty years and he never once visited a business. [38] [Another who started at GE in 1974 explained:] I had a lot of freedom. . . . But I was in a group that was working on particular things, so naturally I'm not going to run off in a random direction. That is like saying that someone in a physics department is going to do physics.[39]

By 1986, when Walter Robb took over as head of GE Global Research, many of the business units were questioning the need for a Central Research Lab. The laboratory, they argued, wasn't doing anything for them, but they were being taxed to pay for it. Concerned that the business units would pressure the corporation to eliminate the central laboratory, Robb changed the funding mechanism. Corporate would now provide about 25% of the central laboratory's funding but that would go to overhead—the maintenance of the laboratory rather than research. Researchers would have to turn to the business units for 100% of their funding. The business units were told that they had to contribute funds. They couldn't zero-base research, but they could determine where those funds went.[40] That transformed the nature of research in the Central Labs:

> Now we had to get money from people at a lower level who had lower resources but also shorter-term goals that they were responsible for. . . . When this new mechanism came in we had to spend more of our time preparing and presenting research plans to managers there, and they of course were people who had limited resources. They had to be quite selective at what they funded. And so it made it … more difficult. . . . It certainly wasn't impossible to remain funded all that time, but we had to put more effort into it and we had to learn . . . the critical path that each of the businesses had to use to plan their activities, and there was a strong … incentive for us to be on the critical path, because that was where they had … money to fund work.[41]

The researcher who told us that his first manager had never visited a business unit asserted "people go twice a week now."

When we visited GE in 2003, GE research funding was again going through a transformation. One of our interviewees said,

> Funding has changed in the last couple of years somewhat in that we are now again looking at or being funded on a longer-range concept. . . . We are able to focus more attention on our research activities, and we … take a longer-range view of what it is we are working on.[42] [But this had a downside.] I don't know the business as well as I did. … So I'm losing a little bit of my awareness of the business,[43]

Another R&D manager told us that the funding formula had again changed because new President Jeffrey Immelt felt they were doing "too much short-term stuff." "We probably do about 50% to 60% business funding and the rest is either internal funding or government funding." Similarly, the "businesses are being pushed to ask us to do longer term things rather than product development."[44]

Under Immelt, who became CEO in 2001, GE was developing a portfolio management approach to research, selecting specific areas, called AT [Advanced Technology] Projects for longer-range research. These projects were to be funded by the corporation rather than the business units. When asked if corporate funding had increased, one researcher replied, "Somewhat, not a lot, but somewhat."[45] Since our visit, it appears that GE has significantly expanded its AT Projects, opening central laboratories in Munich, Shanghai and Bangalore. In 2003, GE budgeted $2.7 billion to R&D, only a slight increase over the $2.6 billion budgeted in 2002. By 2006, however, that had increased to $3.7 billion with $1.2 billion of that dedicated to health care products such as MRI scanners and digital X-ray.[46] By 2004, many of GE's projects in its Schenectady Research Center were not expected to be translated into products or services by the end of the decade.[47]

By some estimates, GE corporate now funds upwards of 40% of its research, with the remaining 60% coming from the business units and government contracts. Yet when we visited in 2003, some researchers were still getting 100% of their funding from the business units.[48] Unlike the absolute control of research that GE divisions appeared to have under Jack Welch, division heads seem to have a more advisory role under Immelt. Scott Donnelly, who was the first head of GE Global Research under Immelt, each quarter, invited the CEOs from each GE division along with their top technology advisors and marketing people for a one-day strategy meeting with the top scientific specialists. Members of Immelt's "Commercial Council," made up of a dozen sales and marketing heads, must submit at least three "imagination breakthrough" proposals a year for review by Immelt and the council. Successful proposals receive significant development funding.[49] Decisions on what research to pursue has become more a matter of strategic development than purely contracting with the divisions.[50]

Even while it has increased longer-term research, GE still asserts, "The half-lives of technologies are very short" and views research and development as "a treadmill of technology and invention and innovation."[51] Donnelly declared that they place a premium on "trying to figure out how not to have people off working exclusively on 'wild blue yonder' kinds of stuff." While he admits that some such work is needed, the "ultimate measure of success," he said, is "the impact on our business." In 2005, GE committed to spending $1.5 billion annually in R&D in ecology-related developments by 2010.[52] By 2007, the company had introduced some 45 "ecomagination-certified" products with revenues reaching $12 billion. Still, Donnelly recognized that R&D impact might take 5 to 10 years to develop.[53] In 2007, *R&D Magazine* identified GE as having the best R&D facilities where scientists and technologists would most like to work and ranked it second out of 130 high tech companies as overall "best R&D Companies in the world.[54]

Kodak similarly changed its research funding. In 1982, money came from the corporation to fund the research laboratories, and the laboratories had extensive discretion over how the money was spent. There was a disconnection between research and the rest of the business. As one R&D manager told us:

> When I came, the research labs and the commercialization activities were completely disconnected. There was absolutely no linkage between them. Things were thrown over the wall. We would do research and when we invented something, we would go talk to some people and they would say that was nice.[55]

Another R&D manager, who received his Ph.D. in physics from MIT in 1973 and joined Kodak laboratory in 1976, told us that what one could research depended upon "which industry you were at."

> But back then you could do a few more things. . . . I don't believe I could have come here and chosen to study the distribution of stars as I could have at Bell say. … And I wasn't looking for that, so I understood what I was coming for. By the same token, there were some groups, especially in chemistry, at Kodak that were doing pretty far out things. And when cold fusion came along and room temperature superconductors, they were building them or attempts at them in those cases, so you know some fairly fundamental stuff that probably wouldn't happen today. . . .[56]

The shift towards more directed research appears to have come about in 1986 when Eastman Kodak reorganized from "large organizations" to "business units" and some groups within the central lab were assigned to business units. By 1992, all research reported directly to business units.[57]

When we visited in 2003, the corporation still funded 10% of the research at the laboratories; that research was "basic" but remained under "pressure to be quite relevant to the business unit."[58] The remainder was funded directly by the business units in labs set up in the old research center. Now many of the researchers questioned whether or not research was done at Kodak. Certainly, they argued, new researchers would not now come to Kodak because it had "a robust research program."[59]

Repositioning Labs within the Company

Forcing the central laboratory to contract research with the business units was only one way of increasing concern for product development and research relevancy. Another was to eliminate the central research laboratory altogether and place all research within the business unit organization. Two major effects of these changes is that scientists and science managers have less autonomy in setting research agendas, and they feel more pressure to create new products or improve existing ones in the near term. This means that there's little on emphasis on the kinds of wholly new technological breakthroughs that might result from long-term research. Another effect is that many of the interviewees said that today they work mostly with engineers, computer scientists, and other specialists instead of fellow physicists.

Research and development was in flux when we visited Raytheon. They had recently sold their interest in Hughes Research, which had played the role of central research for the company. Since the sale of Hughes, R&D was funded by the various business divisions and their concern was "What areas do we need to come up to speed" in order to win or maintain contracts in the company's areas of business. One manager said, "We will only go after R&D where we feel there's a gap in a need … that we need to have organically."[60] R&D at Raytheon was to serve expertise in developing a contract. Repeatedly, from the physicist researcher to the Chief Technology Officer, we were told that research was measured solely by whether or not it created "value for shareholders."

> When you decide what business you want to be in then you look at the gaps you have in comparison with your competitors, in comparison to what you have to do from a mission standpoint. And those gaps may fall into two categories again. So, should we buy the capability or team, or should we develop it ourselves as a discriminator against our competitors? Those are debates that occur at higher levels of management, but in general we all coalesce around an agreement that says, "Yeah, this is a good thing to do."[61]

Physicists at Raytheon similarly described two sources for their funding: IRAD (Internal Research and Development), which was funded on a year-to-year basis, and CRAD (Contract Research and Development) funded through government agencies such as the Office for Naval Research. Like other large defense contractors, Raytheon appeared to use a form of portfolio management where about 1/3 of their research was near term (1-2 years); 1/3 mid-term (3-5 years) and 1/3 beyond five years or far-term.

Texas Instruments gave up on the central research model in 1997, when they sold their Defense Division to Raytheon and their central research lab was eliminated. The other centrally financed labs were moved to their divisions. Some at Texas Instruments argued that originally Wall Street expected large companies to have a big central research laboratory and that once Wall Street dropped that expectation most corporations had dropped them.[62] Others argued that the relationship of R&D to product development was crucial in the decision to drop central research at Texas Instruments. Texas Instruments saw silicon research as within the purview of division labs. As a result the central lab primarily supported its Defense Division. When that was sold to Raytheon, Texas Instruments no longer needed a centralized research unit.[63]

Government Funding: Boon or Bane?

Many point to government investment in industry by foreign countries and suggest that the U.S. would benefit from increased government involvement in research. Our survey, however, suggests a far more complex situation where the benefits vary from company to company. Many industrial R&D centers that we visited limit their "government" research to between 10% and 15% of research revenues. Others seek government funding or collaboration for longer-term research projects where the outcomes remain too high risk to invest corporate funds. Finally, others have developed research labs as profit centers for the purpose of contracting government research.

After World War II, Bell Labs limited "government" research to less than 15% of revenues, until AT&T's president arranged for increased government research in return for leniency in anti-trust actions.[64] Agilent, we were told, limits government funding to less than 10% of research revenues and accepted no government funding till the mid 1990s. One senior R&D manager told us they would take government funding only for projects that might have potential for the business, but where they could not justify investing the company's own money. Such funding would accelerate high-risk product development.[65] Government funding would be used in areas where intellectual property issues were not of concern. GE similarly limited government research. "When I first started, it all came from corporate, maybe 10 percent from some government contracts. … I don't think they ever really exceed 15 to 20 percent. … There was always a feeling … that if you're on a government contract you're not really working for the company."[66]

Corning researchers and R&D managers claimed the company had discouraged government research since about 1990.[67] "Government has certain policies about intellectual property, and also policies about financial record keeping, and policies about how much money you can make off of anything that is developed with them. All of those things inhibit interactions," one Corning R&D manager told us[68]. But in 2003 the budget crisis resulting from the telecom burst changed their perceptions. "Things are changing. We're trying to get funding from the government to sustain some of our research," he concluded. "We don't have enough commercial activities to sustain the R&D expertise that we have, and so we're hoping that the government can help us sustain that." [69] For Corning, turning to government funding would help them through the desperate financial times immediately after the telecom bust. When we visited Corning in 2003, the company was ready to turn to almost any resource to stabilize research labs. By 2007, Corning's economy had rebounded and in April they announced a $300 million expansion of their R&D facilities. It would be interesting to follow up and see to what extent their rebound has again modified their attitude towards government funding.

Since our visit, Corning has continued to expand into global research and development and has invested heavily in R&D. The new CEO, Wendell Weeks, has again centralized control of R&D spending from the divisions and placed them at the corporate level.[70] As of 2005, Corning relied heavily on the production of LCD (Liquid Crystal Display) screens for laptop computers. In March 2006, it established its fifth R&D center at Taiwan's Industrial Technology Research Institute, in addition to its Sullivan Park laboratory in Corning, New York, founded in 1963, and other centers located in France, Russia and Japan.[71] In 2007, it began a six-year expansion of its Sullivan Park Research facilities with a goal of doubling its rate of "new-business creation from two to four per decade."[72]

In the 1990s, 3M turned to the government to help fund a number of programs that one R&D manager described as high-risk projects perhaps "looking too far ahead."[73] They took advantage of NIST's Advanced Technology Program, DARPA contracts and other government resources to fund these (often, they claim, research projects were funded 50% by 3M and 50% by a government funding agency). They concluded that government funding "defocused" their research programs and most of the government funded research projects did not pan out. As one R&D manager put it, if 3M researchers were working on ten programs and the yield was that only one of those would ever make it to a commercial application, it would be smarter to deploy them on projects that would have a higher return.[74] Relying on government funding led to programs that were less than a productive use of 3M's research talent. "Government funding was a way to fund activities that people wanted to go into, but that were too high risk. Getting government money mitigated risk," one R&D manager said.[75] 3M decided to focus on commercial applications and development over research and to severely limit government-funded research. "Right now very judicious use of government funding is applied to our projects." 3M would use government funding only "where it's something that's directly in line with what we [3M] want to do."[76]

At Honeywell several factors changed funding resources beginning in the early 1980s. "Twenty-five years ago, they [Honeywell] were willing to put money into areas that it wasn't clear where it was going. Research time frames might be 10 to 15 years out while today the research time frame rarely exceeds five years.[77] Until 2002 Honeywell

Corporation was providing centralized funding for the laboratories, but even then they sought the advice of the business units in deciding where the research money would be invested.[78] In the 1980s, Honeywell had turned to the Defense Advanced Research Projects Agency (DARPA) and other government agencies as a funding source for their atomic clock. Indeed Honeywell had two central laboratories, one for Honeywell commercial interests and another for government contracts.[79] One researcher recalled that the commercial business really valued patents, but on the military side of Honeywell you would patent ideas that the government could then take and give to a competitor to manufacture, only if "it were really important." [80]

By the late 1990s, Honeywell moved away from government contracts that one fellow maintained had not led "anywhere," and, like 3M, focused on developing technology "of commercial interest" to the company.[81] Now, this fellow said, there's a "pull for technology development. It's not like we were just pushing it from below all the time through government contracts." [82] Honeywell Advanced Technology Center brainstorms their research portfolio to cover areas of broad interest to one of the business units. If they foresee a product ready for the market in one to three years they will attempt to sell the research to one of Honeywell's business units. Where the time to market might be three to five years, they look for government funding.

The degree to which Honeywell depends on government funding remains unclear. One fellow told us that the government funded 70% of the research while 30% came from internal sources. Another put the ratio at 50% government funding, 50% internal sources, and an R&D manager estimated it at 40% government funding and 60% from the business units.[83] Since 2002, the central corporation has not played a role in funding research. Neither the business units nor Honeywell corporate leaders influence where the Advanced Technology Center, a part of Honeywell Aerospace, gets its external funding. Instead, it is required to go outside for research funding on technologies that won't reach a Technology Readiness Level (TRL) 6—a level that the government defines as a prototype demonstration in a relevant environment—within five years. This, R&D managers told us, forces the lab to compete their ideas for funding within the broader scientific and technological community. The lab director told us,

> I'm free to go after those areas that the agencies are willing to fund and that I can rationalize have a payoff to Honeywell. They don't tell me who to go to. If a government agency, DARPA or the Army Research Lab, for example, was willing to fund an area, Honeywell's Advance Technology Center would put a team in a room for four or five weeks throwing out ideas, brainstorming and laying out a potential research program. We've bid a couple of programs over the last couple of years where we're starting to do things like Bose-Einstein condensates, which the company would never invest in, but they're talking about using these things … for measuring rotation. That's something that we're definitely interested in, but it's very much a TRL 1 or 2 and a lot of work needs to be done.[84]

Often the Advanced Technology Center uses these research contracts as a means to form alliances with the leading researchers in the field. "Lots of times, we'll team in areas where we're missing the technical capabilities. Or if it's a brand new area where we don't have a lot of experience, we'll team … and use them as a way of coming up to speed and educating ourselves."[85] "Typically, we'll team with people [at] Berkeley or MIT or Stanford or the University of Michigan. … We've teamed with NIST on programs."[86] Honeywell used the NIST alliance to develop skills with atomic clocks. "Basically we taught ourselves, with their aid, all about the physics of atomic clocks to the point where we've got the expertise inside."[87] Since many of the patentable concepts come in taking the well-known physics through the manufacturing process, the concept of competing early ideas, and funding, within the broader scientific community, developing in-house expertise, then turning to business-unit funding to apply that expertise to its businesses products, had provided an ideal R&D platform for Honeywell.

R vs. D: Sea Change or Cycle?

The shortening timeline for industrial research and the abandonment of non-directed or basic research described here is not surprising or new, but some of our interviewees have argued that this is a temporary state of affairs. While no one would return to the alleged "Golden Age" of academic-style research centers doing research unrelated to, or at least disconnected from, the corporations' business interests, some argued for a cyclic view of research and development. As we have already noted, GE has returned to longer-term research to develop proprietary technologies for its future businesses. Others are considering or at least foresee the potential for increasing "far term" research.

The business cycle view of R&D organization argues that basic research did indeed result in new technologies and continues to do so. In this view, beginning in the 1980s there was a plethora of new, immature technologies that had derived from earlier basic research. These new technologies—the transistor, the silicon chip, and many others—resulted in a transformation in industry and industrial production. As businesses fed off this new technology, finding new products to develop, it resulted in a greater return on investment than did producing new research that companies need not yet assimilate. As a result corporate R&D turned to the development of these new, as yet immature, technologies, relegating basic and longer-term research to the academic realm. In those companies where the corporate intellectual property has matured there has been some renewed emphasis on "basic" research. Raytheon, for example, has opened a new laboratory and consolidated some of its research. Others, IBM for one, have renewed respect for academic-style research that they disparaged for a time.

However, other commentators, while admitting that an element of business cycle may play a role, see a fundamental sea change in the way business operates. A major component of this sea change has been globalization. Most businesses prior to 1980 had a strong vertical integration component. They made not only the final product but also most of the components, sometimes down to the screws that held together their products. Quality, it was once believed, was best maintained by controlling every aspect of the manufacturing process. But controlling every aspect of the process also drove up costs. One could not be the best and the cheapest at manufacturing small quantities of components for a product. Globalization brought with it increased pressure to build value for the shareholder, and the drive towards increased efficiencies resulted in a transformation of the business model. One might now set standards for components but would outsource the manufacturing of those components—which might be used in a wide variety of products—to companies that could build those components most efficiently. In the new global competitive environment, basic research was no longer cost effective so it too was outsourced.

One of the clearest enunciations of the cyclic view of research and development comes from Texas Instruments. In the 1980s Texas Instruments' Central Research Lab was "analogous to the organizations you had at IBM … or AT&T. You had people looking at a very wide range of things, a lot of which you just knew up front there probably couldn't be any real product application for quite a few years."[88] Between 1980 and 1982 the company split off its silicon work as a separate laboratory. It subsequently combined that lab with it's metal oxide semiconductor (MOS) silicon lab in Houston and decided that the central lab would abandon silicon research. As one R&D manager put it, "Since most of TI's business was in silicon and then military, the night vision and radar and such, so we ended up the central research labs mainly supported the defense division."[89]

Corporate research would run the SPDC [Semiconductor Processing Development Center] and do nearer-term development for the semiconductor division rather than the division having its own separate lab.

By 1982, development took precedence over research at Texas Instruments. One R&D manager said that the near-term R&D was "smaller R" and "bigger D" leading to products on the range of five years out.[90] Another researcher was even more explicit. "Probably 'D' was king for the last twenty years." Products had become smaller and smaller following Moore's law[91], he asserted, and

> When you fix the materials and simply make things smaller, that's . . . an engineering effort. That doesn't mean there wasn't some research going on, but there were a lot of research efforts to replace CMOS [Complementary metal–oxide–semiconductor], which never did happen. It looked like CMOS became the technology of choice and has been for 20 years. So a lot of managers started to become very critical of the big "R" and say, "Golly that looks like just wasted dollars." You know, maybe we threw a lot of money toward gallium arsenide; it didn't really replace silicon. So, people started to become fairly cautious of using the "R" term because it started to become synonymous with kind of wasted money.

CMOS will not be able to sustain Moore's law forever, however, and eventually new materials would need to be developed. Our interviewee added:

> If I look the next five years of research as opposed to the last five, [it will be] totally different. The last five dominated by development, I think maybe the next five years suddenly the "R" in R&D is going to become very important. … As soon as you start talking about changing the materials then you've got to say, "Well, I've got to look at charge trapping characteristics," and things like this which starts to sound more like physics. … So I think the "R" will start to come into play again and will suddenly become a nice word.[92]

Raytheon researchers also see a potential return to research as current technologies mature. Raytheon began as a Northeast business. During the 1990s it acquired a variety of defense businesses and merged them into Raytheon business units. So Texas Instruments Defense Division, rather than standing alone and reporting to corporate

Raytheon, was merged into Raytheon's lines of business. During the process of these acquisitions, Raytheon's Central Research Division based in Lexington, Massachusetts, was sold. Raytheon also acquired a portion of Hughes Research, and up until 2006 when it sold its interest in Hughes Laboratories, it played some role as a central research organization. But Raytheon distributed its research along its lines of business. Space Systems research labs were in El Segundo, the missile business in Tucson and the Defense Systems in Tewksbury (where we interviewed).[93]

Raytheon's strength, one physicist told us, lay in its ability to milk their existing technologies, with a result that the emphasis lay in product development. He asserted, "R&D was an exercise."[94] Indeed, most physics Ph.D.s there identified themselves as "engineers."[95] But some said that with the new issues facing the company from Homeland Security and other contractors, new research would be needed. In 2006, the Defense Division opened a new research lab. At the same time, Raytheon sold its interest in Hughes Research Lab; their Chief Technology Officer asserted, "We're going through a process right now of looking at whether or not we want to have a company-wide research division or if we want to do it in the businesses we do have."[96] Shortly before we visited Raytheon, Heidi Shyu was named as Vice President, Corporate Technology and Research, reporting to Taylor Lawrence[97] who explained that research had been included in her title "because … Raytheon needs to be viewing technology not just for sort of impact to current product lines but changing the nature of our product lines."[98]

The cyclic views of research and development were not necessarily mutually exclusive with the views of the larger group who saw a sea change in business that reduces the desirability of doing research within the company and focusing instead on development. In the competitive global environment facing most businesses since the 1980s, companies increasingly focused on their core business. For most, basic or far-term research was not a component of their core business. As companies emphasized their core business they would naturally shift from a focus on research to a focus on development. As a result, they argued that basic research ought to be outsourced as other non-core businesses had been outsourced.

Others argue that where research is done it ought to be closely associated with the company's core businesses. One of the R&D managers at Texas Instruments said, "All of the research and development is decentralized. We have completely gotten away from the mode of centralized research and development. Research is the driver for growth, and you have to make sure that it's focused on producing growth."[99] He continued:

> Some of our competitors that work in central research have a hard time getting their ideas accepted by the product groups. It just takes too long. In other words, the primary driver of research and development in our business is how quickly you can get an idea into a product, how quickly can you turn an idea into revenue, and if you have a research and development lab and then you have to transfer it and you have to transfer the technology to a product group and they have to reinvent it, it just takes too long.[100]

Insourcing Innovation

Despite what appear to be significant changes over the past 50 years, we found that corporate physicists and other scientists still have substantial autonomy. They may not be given the freedom to research whatever they like, but corporations continue to recognize the benefit of obtaining unsought ideas from creative minds. One Agilent interviewee recalled that Bill Hewlett claimed that if more than 30% of research resulted in a successful product, then the researchers were not asking hard enough questions. While emphasizing development over disruptive technologies and innovation, R&D managers continue to recognize that complete direction of researchers could be as destructive to the innovation process as the absence of direction. Research scientists continue to have significant influence, within corporate constraints, in determining the projects in which they participate. In addition, many companies set aside between 10 and 20 % of a researcher's time for projects of that researcher's choice, sometimes in consultation with his/her supervisors. For example, Agilent continues what was once called the "Hewlett Rule" where something between 10-20% of a researcher's time is supposed to be spent "thinking and developing something that you have no management support for but you think is in the best interests of the company." Agilent officially uses 10%, though researchers suggest that the time is often crunched by other research pressures. One Corning manager says he budgets 10-15% of his researchers' time towards somewhat unspecified projects. 3M has long had a rule in which technical researchers are encouraged to devote up to 15% of their time to independent projects. IBM doesn't appear to have a "rule" for each researcher, but around 2003 it budgeted about 15% of the research budget to long-term non-directed research.

Corporations that continue to advocate non-directed research do so for a variety of reasons. Non-directed research tends to lead more to new disruptive technologies likely to replace current products than to improve existing ones. At the same time having researchers publish in fields relevant to the company's product line but not likely to enter the product line in the near future remains a useful branding tool, identifying the company as a research leader in the field and therefore most likely to have products with the most advanced technology available. One IBM researcher admitted that his research was "this out-of-the way thing that we kind of believed in."[101] An R&D manager, on the other hand, argued that so long as he could tell a story showing relevance to IBM they would continue to support his research. The shift, he argued, was a matter of degree:

> We went through [a change], through the late '80s and the early '90s, that a lot of the people here didn't like. I think a lot of the people in physical sciences, it was enough for some people to leave over this issue, because, "What's this place going to become? Where's our great freedom?" or whatever. Well, Okay, we're not maybe quite as free, but its okay, we're still in business.[102]

A number of the interviewees, especially those who entered the workforce after 1990, said that working in industry was preferable to academic jobs for two reasons. First, physicists at academic institutions too often had to focus on fund raising and grant writing to the detriment of actual research. Second, the fierce competition for academic tenure required that young physicists work a grueling schedule with an uncertain payoff.

Outsourcing Research

Henry Etzkowitz, in "The Triple Helix and the Rise of the Entrepreneurial University," argued that universities either were or at least ought to play a crucial role with government and industry in "improving the conditions of innovation in a knowledge-based society." This, he claimed, would come through the entwining of government, university and industrial entities to create a "proactive stance in putting knowledge to use and in broadening the input into the creation of academic knowledge."[103] Etzkowitz's argument for a deterministic evolution of the entrepreneurial university may be historically flawed. Our discussions with industrial researchers and R&D managers called into question its desirability. That is not to say that we found no evidence in support of government-university-industry coalitions. But we also found a widespread critique of government-sponsored industry-university coalitions.

Industrial Funding of University Basic Research

A number of businesses turned to universities either to support more basic, *i.e.* longer term, research or to support research in parallel with that of their own labs. Agilent Technologies, for example, has a formal external research grant program for universities. It has two thrusts. One awards gifts to the universities with few strings attached. "We may know somebody [who is] doing good work and it's interesting and it may be of interest to Agilent in the long term, but there's no contractual arrangement."[104] A second thrust awards contracted research to a professor, and the collaborating researcher at Agilent becomes the "mentor" for the grant, interacting with the professor and the professor's students. According to one researcher, most Agilent groups larger than six people or so will have an external research grant and the grant is dovetailed with their research.[105] The head of one of the labs suggested that the university research grants took care of the basic research, the various divisions handled product development, and his lab as "an applied research lab" filled "the gap in the middle."[106] But, as another researcher involved with the universities pointed out increasingly "you're in conflict with the commercial interests of entities connected with the university … private operations on behalf of the university faculty, and it makes life a lot trickier." Thus the researcher maintained that the entrepreneurial university conflicts with the interests of the research university in its interaction with the industrial world.[107]

Ford, too, both funded and had reservations about university research. They have a corporate funded University Research Program. Ford has formal alliances with some universities that are "broad and span various science and engineering disciplines." In these alliances the company provides funding in wide-ranging "block grants" doled out within the university. They also fund programs between a "principal investigator" in the university and a "principal investigator" within the company. The principal investigators submit proposals that go through an internal review process that, as one physicist told us, "float up the food chain and eventually get approved and funded."[108] A Ford investigator can recruit a university investigator anywhere in the world to do research of interest to Ford. They develop a four-page proposal that a review board internal to Ford reviews and makes funding decisions about. These relatively small programs range from projects "further out" then Ford is willing to do internally to "dirty jobs" that researchers at Ford do not wish to do.[109] They also cooperate with other industries to fund specific research programs, such as the Northwestern Nanotechnology Alliance, which Ford funds jointly with Boeing,[110] and work with universities as co-investigators on grants from the Department of Energy and the National Science Foundation.

One researcher, while noting that the times were changing, asserted that many universities saw "our job in the automotive industry, especially, is just [to] give them money because we're all stupid."[111] Another told us that universities "may flatter you by saying they're interested in your intellectual things, but when it comes down to it, in almost every case what they're looking for is the money."[112] Universities had "gradually learned to talk more and get the important part" the first researcher told us, but it remained "hugely variable from one university to another. … Some are very easy to work with … and some are still just not getting it."[113]

Others sought to limit collaborations with universities to the "upstream" laboratories—those laboratories least focused on product development. "The closer you get to a product, the stickier it becomes working with universities," an R&D manager at 3M said. "A university's primary goal besides … getting funding, is to publish; whereas we have got this paradigm issue in industry, it is to make a profit, and often that requires protecting an idea."[114] Indeed, intellectual property issues themselves were frequently a problem. "Since we don't know how to value our information well, we'll try to put up a guard around everything," declared an R&D manager at Xerox, "that's almost an antithesis of the university structure."[115] An R&D manager at Lockheed concurred. "The best answer is to do things at the TRL 1 and 2 levels." "That work would tend to be pre-competitive, pre-weaponizable, and you wouldn't need to release a whole lot of proprietary information to the university. … It also frankly doesn't help the situation that universities have become very business—and intellectual property ownership—oriented over the past five or ten years."[116] Just giving money to the university and hoping for results was not satisfactory either. "We need to have a shadow program inside. … There has to be somebody inside doing it and we have to make sure that we specify some kind of deliverable."[117] Others at Lockheed were not even that optimistic. Jim Ryder in a 2005 Government-Industry-Academic Relationships workshop noted that "industry preferred to keep university work out of the critical path to technology development. Universities have a valid role, which does not, however, lend itself to being monitored for weekly or monthly progress or to achieving multiple milestones on a rigid schedule."[118]

Across industry, R&D managers emphasized the need for business to direct their funded research in academia. An R&D manager at GE noted particularly the problems of university collaborations funded by the government. "The company has the objective to try to make money and the university is trying to make publications." The two form an alliance to get funding from the government but they continue their own programs towards their disparate purposes. Successful university collaborations, he maintained, were:

> Where we're trying to make a business out of it, and someone in the university wanted to work on some of this stuff. We'd do some joint research together, but we weren't getting government contracts. The government has had these different plans with universities and industry to do joint [research]. … Both use it to get money from the government, but it doesn't really work.[119]

What did work, he said, were one-on-one, personal collaborations between a research scientist in the company and a researcher in the university where the company scientist could clearly direct the research program.

Others found university collaboration less problematic. "I can't think of too many programs we had that were not teamed with people in universities," asserted an R&D manager at Honeywell.[120] But if you listened carefully to the types of collaborations he enunciated, Honeywell was providing very clear directed research opportunities to do research, developing or testing products whose intellectual property Honeywell already controlled, not collaborations on basic research.

While corporations were encouraged by government funding sources and the downsizing of their own research departments to collaborate with universities, the fact that universities were increasingly focusing on intellectual property issues and patents created one set of problems. And where universities continued to focus on publication, working with academe created another set of problems for protecting and creating corporate intellectual property.

Knowledge Acquisition, Collaborative Consortia and Free Market Models

If, as those who argue for the "sea change" explanation of the decline of industrial R&D assert, research lies outside the core business of the corporation, then the establishment of businesses, alliances, consortia or "triple helix" arrangements from which the corporation can draw research and development would appear to be a natural extension of their position.

Some have turned to industry consortia to address fundamental technological problems in their industry. Texas Instruments funds external research to the tune of about $40 million annually. As one R&D manager put it:

> There is work that needs to be done that is exploratory on processes that are still five to eight years in the future. … That is where the external research is important. … There are research consortia and then there is just individual faculty, and we try to influence the kind of things they do and fund the things that we want to do, and get the results for long-range research that way. I would stop short of saying that that's fundamental research. It's not. It's very directed.[121]

One consortium they work with is IMEC (Interuniversity Micro Electronics Center) in Belgium. The results of the research are owned by the consortium, but Texas Instruments, as one of the members, gets a royalty-free license. Similarly Exxon Mobil funds research at a variety of consortia. They collaborate with Toyota and General Motors in a consortium doing work in combustion and hydrogen fuel cells. One of Exxon's R&D managers described that as "an industry collaboration."[122] Other collaborations are broader. Exxon Mobil, GE, Schlumberger, and Toyota, in 2002, funded Stanford University's Global Climate and Energy project.[123]

Finally, closest perhaps to Etzkowitz's "Triple Helix" model of government-industry-university collaboration, are the efforts of Xerox, Kodak and others to outsource research and development. In the late 1980s Kodak and Xerox and others formed the Rochester Imaging Consortium. They subsequently cooperated with the University of Rochester,

Rochester Institute of Technology and the New York State Science & Technology Foundation, subsequently the New York State Office of Science, Technology and Academic Research (NYSTAR), to form the Center for Electronic Imaging Systems. In 1996, Xerox created the Design Research Institute permitting its scientists to collaborate with faculty and students at Cornell University.[124] In 2001, Kodak and Xerox, with NYSTAR, formed Infotonics in an attempt to bring to commercial viability small scale Micro-Electromechanical Systems (MEMS) manufacturing. The Infotonics Research Center was formally opened in 2004. By 2006, however, Infotonics was losing $200,000/month. More recently, news reports have suggested an economic turnaround, but the ultimate success of the program remains undetermined at this time.[125]

Following along similar lines, IBM last year opened the Computational Center for Nanotechnology Innovations at Rensselaer Polytechnic Institute in an attempt to develop industry-wide collaboration with academic researchers in the development and manufacturing of nanoscale materials, devices and systems. Again, it is too early to determine the success of a program that seeks to be able to manufacture semiconductors on the order of 22 nanometers by 2015.[126]

Another important new trend appears to be the outsourcing of knowledge creation to the marketplace. Corporations recognize that new knowledge can be created anywhere and that internal knowledge creation applicable to a particular corporation's business needs has been notoriously inefficient. Several corporations in our study use a portion of their internal R&D to assess knowledge created elsewhere for possible acquisition rather than to create knowledge itself. As a result, they acquire more basic-level research in the marketplace.[127] As one corporate R&D manager told us:

> "The fundamental research will get done, the applied research will get done, the development will get done. … It's just that it may get done from different quarters. … Maybe by leveraging small startup companies more rather than trying to replicate everything they have. Research is not going to change. But it does change the question of what's done inside a corporation and how the corporation tries to position itself. Instead of doing some of that research now, many of us have to be aware of the existence of the research out in the rest of the community."[128]

Rather than inefficiently creating new knowledge through large-scale corporate R&D programs, several corporations in our study assign a portion of their R&D to assess knowledge created elsewhere for possible license or acquisition and development within the corporation. Lockheed, General Atomics, Xerox and others have researchers whose job it is to keep tabs on the small startups, many of which are affiliated with university research programs. They identify those whose technologies fit their company's portfolio and, where the fit is considered profitable, acquire the startups and utilize the parent company's larger R&D program to incorporate the technologies into the company's product lines. Others have established companies whose core business is intellectual property. Nathan Myhrvold, Microsoft's former Chief Technology Officer, has formed Intellectual Ventures (IV) as a specialized business to serve as an upstream intellectual property resource.[129] By July 2006, IV employed some 700 researchers.[130] Ross Perot has similarly established a $200 million private equity fund to purchase companies with "undervalued" patent portfolios.[131]

An increasing number of science-based startups, some coming out of university research, others spun off from corporate research programs or created by entrepreneurial scientists, suggests a market response to the outsourcing of knowledge creation. Beginning in the 1990s the number of new entrepreneurial startups increased dramatically. Some physicists have brought their understanding of the physical nature of the world to the creation and manufacture of new technologies. Others have focused on the creation and evaluation of intellectual property (IP) and its application across a broad spectrum of businesses, serving as consultants and licensors of IP, while companies like Agilent and Lucent have created spin-offs to exploit new technologies. In many respects using corporate R&D to evaluate external knowledge creation appears to be a free market counterpoint to the R&D constraints inherent in the Triple Helix model of collaborative R&D discussed above.

Recent Trends

Since we visited, many of the companies we surveyed have continued to adjust the role that R&D plays in the corporate business. Many since the 1990s have adopted Motorola's "Six Sigma" quality management methodology largely because of the success that Jack Welch had with it at General Electric. We found various versions of "Six Sigma" programs at GE, 3M, Raytheon, Honeywell, Agilent, and Exxon Mobil. While some companies enthusiastically promoted their versions of Six Sigma, others expressed reservations regarding its use and are beginning to move away from its more stringent aspects. One R&D manager at Agilent told us that the company did "follow Six Sigma" but it was "not a big part of R&D."[132] A physicist at Exxon Mobil noted that such programs played a role but primarily at the "decision stage" where technologies were transferred from R&D to the operating companies.[133]

One of Welch's assistants at GE, James McNerney, brought Six Sigma to 3M when he became CEO in 2000. However, R&D had a mixed review of the program. One physicist told us:

> What it results in is requirements that we spend time in training classes . . . for example, the latest one (and since it's here, I'm most familiar with it right now), they want everybody to have what they call a Greenbelt project, which means you're going to apply the Six Sigma methodology against something that you were going to be doing anyway. Actually, those are generally pretty worthless. … If you don't know the scientific basics of the problem, it doesn't make sense to do a statistical experiment on it. I've seen this happen a lot. It's not just Six Sigma. Corporate cultures tend to do that. [He concluded:] "I'd like to de-emphasize a lot of the formalism that's come in with the Six Sigma. It's just slowing us down. You cannot be slow in the display industry and survive, and we are struggling with that.

Design for Six Sigma, which focused more on R&D, was even worse. One physicist told us that "design for Six Sigma is this virulent scourge that has been unleashed on the corporation and is chewing up resources and excreting paper."[134] Recent news reports have suggested that McNerney's successor, George Buckley, has cut back on the focus on Six Sigma, particularly in R&D.[135]

Like Welsh at GE, McNerney paid close attention to R&D, holding its budget constant during his tenure. Buckley significantly increased R&D spending at 3M by 20% to $1.5 billion dollars. What effect this will have on 3M remains unclear. During McNerney's tenure 3M dropped from being the number one most innovative company, according to *Business Week,* to number seven. Now, one business director was quoted as saying, "We feel like we can dream again."[136]

Changing economic conditions and markets have led to reassessment of R&D's role within the corporation as well. In 2000, 65% of Corning's R&D spending went to fiber optics. Three years later when we visited, 70% of Corning's R&D spending went to non-telecom projects.[137] During the telecom boom of the late 1990s analysts urged Corning to focus on its fiber-optics business, but with the dot-com bust Corning's telecom sales dropped by two-thirds. When we visited Sullivan Park in 2003, Corning was in decline and the company was again seeking a new primary product line.[138] Changes in Corning's economic situation led it to reevaluate their utilization of government funding and globalize its R&D functions. The new CEO, Wendell Weeks, again centralized control of R&D spending, placing it at the corporate level and globalizing R&D functions.[139] As noted above, GE has also re-emphasized longer-term research programs, while continuing to emphasize business relevance.

IBM's new Director of R&D, John Kelly, reportedly intends to increasingly move research away from the company's traditionally centralized laboratories to what he calls "collaboratories." As head of IBM's chip business in 2003, Kelly hedged research costs by forming collaborative research alliances with other companies manufacturing chips or dependent on chip manufacturing. "The nature of research itself is changing," he asserted. "Great ideas are springing up everywhere." Collaborative research programs, he argues, will increase IBM's chances of having access to new disruptive technologies, which they could not afford to research and develop on their own.[140]

Conclusion

Our survey of physicists in industry suggests that industry has not yet arrived at, and may never arrive at, a consensus on how to conduct its research or the optimum relationship among science, technology, and business interests. Companies are still struggling to decide what mix of centralized long-term research, focusing on developing new disruptive technologies, and distributed short-term research programs tied closely to current product improvements, works best. They remain unsure of the relative benefits and risks of government research and university collaboration. Others are forming research alliances similar to the patent pooling programs that became widespread in the late nineteenth and early twentieth century. Each of those solutions has critical problems. But as applications of current technologies are reaching their limits, industries continue to change their mix of centralized laboratory research and distributed laboratory development as well as their mix of longer-term (but still highly directed) research programs and shorter term development programs. Texas Instruments' analysis of CMOS technology is telling. Can research provide new insights that permits Moore's law to continue, or have we reached a point where we will construct other perspectives?

If so, how can we even pretend to predict a vision of the future? How can businesses maintain or develop a competitive advantage? Original research? Technology acquisition applied to the company's core business? Or some other strategic form not yet envisioned? [141]

Our interviews with physicists suggest that they increasingly ally themselves professionally with corporate interests as much or more than the professional interests of their research field. One result of the reorganization in R&D is an apparent lack of a sense of community of practice among industrial physicists today beyond their coworkers. When we began the study, we assumed that the professional point of reference for industrial physicists would be the larger physics community. For example, when we asked physicists in corporate labs who the top people in their field were, we expected that they would name people at other labs in this country and abroad. We were surprised to find that most of the interviewees concentrated instead almost exclusively on physicists or other scientists in their own companies.

While nearly all of the physicists whom we interviewed said that they had less control today over the work they do than they or their counterparts had earlier, we found that corporate scientists still have substantial autonomy. Younger researchers, in particular, noted the burden that academic scientists have to fund their research, arguing that the increased direction imposed on corporate R&D by the business units is minimal compared to the requirements imposed on academic researchers by their funding sources.

Many companies are grappling with the issues of intellectual property and consortium research. Some appear to be outsourcing research programs or turning to "knowledge and technology" acquisition programs. They rely on the expertise of their research centers to assess and develop technologies created elsewhere that may have application to their core businesses, rather than to discover new science and technology on their own. Industrial R&D increasingly is driven by the dynamic needs of industry in a competitive environment. Industry is still struggling to find ways to effectively connect R&D efforts to both the short-term and long-term goals of the corporation. Given the influence of short-term profits on stock value, we should not be surprised that development frequently takes precedence over longer term, higher risk research. Nor should it be surprising that the longest research programs took place at General Atomics, the only private company we visited. As a private corporation it is less driven to respond to market pressures and can, at least occasionally, take a longer term view in its R&D investments. Even where industry engages in longer term research it can no longer afford, if it ever could, knowledge development and acquisition for knowledge's sake alone.

Endnotes

[1] The "triple helix" model is a descriptive, though sometimes also used as a prescriptive, model of the interaction and respective intertwined roles of government, education and business in knowledge generation and product development. See, for example, Henry Etzkowitz, "The Triple Helix and the Rise of the Entrepreneurial University," in *The Science-Industry Nexus. History, Policy, Implications*, (2004), 69-92.
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[7] David Bishop interview by R. Joseph Anderson and Sandy Johnson, Lucent Technologies, August 25, 2003.
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[14] Philip Platzman interview by Sandy Johnson.
[15] Anonymous interview II, Agilent Laboratories, July 2006.
[16] Alice White interview by Thomas Lassman and Sandy Johnson, Lucent Technologies, August 25, 2003.
[17] Ibid.
[18] Ibid.
[19] Anonymous interview III, Lucent Technologies, August 2003
[20] Alice White interview by Thomas Lassman and Sandy Johnson
[21] Anonymous interview III, Lucent Technologies, August 2003.
[22] See for instance Ed Furlani interview by R. Joseph Anderson and Thomas Lassman, Eastman Kodak, June 9, 2003; Anonymous interview III, Lucent Technologies, August 2003; Anonymous interview IV, Lucent Technologies, August 2003; Anonymous interview V, Xerox Wilson Center for Research and Technology, April 2003, and others.
[23] Eric Isaacs interview by Thomas Lassman and Sandy Johnson, Lucent Technologies, August 25, 2003.
[24] Anonymous interview, V, Xerox Wilson Center for Research and Technology, April 2003.
[25] Ed Furlani interview by R. Joseph Anderson and Thomas Lassman.
[26] Anonymous interview VI, Corning, May 2003.
[27] Philip Platzman interview by Sandy Johnson.
[28] Anonymous interview VII, IBM Thomas J. Watson Research Center, March 2006.
[29] Ibid.
[30] Ibid.
[31] Ibid.
[32] Ibid.
[33] Ibid.
[34] Pat Perkins interview by Orville R. Butler, Lockheed-Martin Advanced Technology Center, December 13, 2005.
[35] Jeff Newmeyer interview by Orville R. Butler, Lockheed-Martin Advanced Technology Center, December 13, 2005.
[36] Ibid.
[37] Anonymous interview VIII, GE Global Research Center, May 2003.
[38] Anonymous interview IX, GE Global Research Center, May 2003.

[39] Anonymous interview, VIII.
[40] Anonymous interview IX.
[41] John Schenk interview by R. Joseph Anderson, GE Global Research Center, May 5, 2003.
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[43] Ibid.
[44] Bijon Dorri interview by R. Joseph Anderson, GE Global Research Center, May 5, 2003.
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[56] Gilbert A. Hawkins interview by R. Joseph Anderson and Thomas Lassman, Eastman Kodak Research Laboratories, June 9, 2003.
[57] Ibid.
[58] Ibid.
[59] Ed Furlani interview by R. Joseph Anderson and Thomas Lassman.
[60] Anonymous interview XI, Raytheon Integrated Defense Systems, January 2007.
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[62] Richard Chapman interview by R. Joseph Anderson and Thomas Lassman, Texas Instruments, October 6, 2003.
[63] Ibid.
[64] Stephen B. Adams and Orville R. Butler, *Manufacturing the Future. A History of Western Electric.* Cambridge, 1998.
[65] Steve Newton interview by R. Joseph Anderson, Agilent Technologies, July 26, 2006.
[66] Anonymous interview IX.
[67] Anonymous interview VI. One R&D manager said the company was no longer involved in classified research, while another was unsure if they remained involved in classified government contracts.
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[78] Ibid.
[79] Ibid.
[80] Alan Cox interview by Orville R. Butler and R. Joseph Anderson, Honeywell Advanced Technology Center, November 11, 2005.
[81] Ibid.
[82] Ibid.
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[84] David Arch interview by R. Joseph Anderson and Orville R. Butler.
[85] Ibid.
[86] Ibid.
[87] Ibid.
[88] Anonymous interview XII, Texas Instruments, October 2003
[89] Richard Chapman interview by R. Joseph Anderson and Thomas Lassman.
[90] Anonymous interview XII.
[91] Moore's law is the popular restatement of a prediction by physicist Gordon Moore, that the number of transistors that could be placed on an integrated circuit would double approximately every two years. This rate has continued from about 1965 to the present.
[92] Anonymous interview XIII, Texas Instruments, October 2003.
[93] Taylor W. Lawrence interview by Orville R. Butler, Raytheon Headquarters, January 24, 2007.
[94] Anonymous interview XI.
[95] See for example Colin Whelan interview by Orville R. Butler, Raytheon Integrated Defense Systems, January 23, 2007 and Don Power interview, Raytheon Integrated Defense Systems, January 22, 2007.
[96] Taylor W. Lawrence interview by Orville R. Butler.
[97] "A Message from Dr. Taylor W. Lawrence Vice president of Engineering, Technology and Mission Assurance, *Technology Today*, No. 3, (2008) http://www.raytheon.com/technology_today/current/lawrence_message.html.
[98] Taylor W. Lawrence interview by Orville R. Butler.
[99] Dennis Buss interview by R. Joseph Anderson and Thomas Lassman, Texas Instruments, October 6, 2003.
[100] Ibid.
[101] Anonymous interview XIV, GE Global Research Center, May 2003.
[102]Anonymous interview VII.
[103] Henry Etzkowitz, Op. Cit.
[104] Curt Flory interview Orville R. Butler and R. Joseph Anderson, Agilent Technologies, July 27, 2006.
[105] Anonymous interview XV, Agilent Technologies, July 2006.
[106] Steve Newton interview by R. Joseph Anderson.
[107] Anonymous interview XVI, Ford Motor Company, June 2007.
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[127] Henry Chesbrough, *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Harvard Business School Press, 2003; Henry Chesbrough, Wim Vanhaverbeke and Joel West, *Open Innovation: Researching a New Paradigm*. Oxford University Press, 2006. P&G, for examples claims to source 50% of its innovation externally using what it calls "Connect + Develop". For a general discussion of sociological theories of entrepreneurship see Patricia H. Thornton, "The Sociology of Entrepreneurship," *Annual Reviews of Sociology*, 25(1999), 19-46.
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Part 2: Identifying and Preserving Historically Valuable Records

Records Keeping Practices of Physicists

Records keeping in industrial R&D faces a variety of obstacles. Like most groups, corporate physicists tend to keep only those documents they think will be useful to them or that their organization requires that they keep. Good record keeping also depends on storage and retrieval systems that are familiar, reliable, and easy to use. While corporate records management programs have become increasingly sophisticated over time, and especially since the enactment of the Sarbanes-Oxley Act of 2002, administrative and government regulations focus on management and financial accountability and generally don't address R&D records. Other major obstacles include changes in ways of supporting intellectual property claims, the replacement of paper by electronic records, and the preferred communication patterns among physicists. The ongoing process of reorganizing R&D presents yet another impediment to effective records management. When the organizational structure changes frequently, it's difficult for support programs like records management to keep up.

Only one-third of respondents were certain that they could recover records more than five years old. An additional 55% said they could recover some but not all significant records and 4% told us they could only recover personal records greater than five years old. There was even less consistency about what would happen to their records when they retired or left the company. Fifteen respondents told us that at least some records they maintained would most likely be trashed when they left. Nearly half told us that the records would be handled according to company policy--whatever policy was then in place. Thirty percent said they would pass on their records to their successor or to a supervisor, while 27% told us they did not know what would happen to their records. Seventeen percent indicated they would take at least some records with them.

Corporate records retention and disposition schedules are found at all of the companies in our study, but the extent to which they cover R&D records, beyond contract deliverables and materials required to support intellectual property claims, and the extent to which the schedules are followed by physicists, varies greatly from company to company. While 85% of respondents told us that their company has a records retention policy, 15% of these respondents said that they don't know what the policy is. A little over 7% indicated that they were aware of the policy but admitted that they don't follow it. The remaining 15% said, incorrectly, that their company doesn't have a records retention schedule. The library director at one of the companies who had in recent years been assigned responsibility for overseeing the company's records management program said:

> What I've discovered is there are federal . . . and state government rules for any kind of information that has to do with money. … There are rules about how long you preserve this information, how long you archive, and when you destroy it. And anything to do with personnel issues. … But there are no federal government rules governing intellectual capital. If you want to throw it away, you may. Internally you make your own rules.[1]

Given the lack of regulatory requirements, concerns for preserving records as part of the company's intellectual property vary widely. Some of the companies that we've visited no longer require that scientists keep laboratory notebooks, which have traditionally been a keystone of intellectual property claims, and they make no effort to assemble and organize those that do exist. A number of physicists at the IBM Watson Laboratory, for example, said that the company no longer distributed lab notebooks. One interviewee there explained that the current practice is to create a notice of discovery when he did work that he thought might be patentable.[2]

Electronic Records

Another major obstacle to records preservation is the advent of computers, which are at least as ubiquitous in corporate R&D as they are in other aspects of our lives. Current digital records may be easier to retrieve than their paper counterparts, but long-term preservation of electronic files is difficult and requires prior planning and ongoing technical support. Paper records, on the other hand, are uniquely easy to preserve and are generally tolerant of neglect and poor storage conditions. Short of fire, flood or intentional destruction, paper records that are left in a file cabinet by one generation are likely to be intact and useable by later generations. This is not true for digital files. In addition format affects content, and the new formats that computers present are changing the content of science records

As in all large organizations, most of the records that laboratories create today are born digital, and computers are changing the nature of the work. For example, a number of the interviewees talked about the effects of PowerPoint, which is widely used in corporate labs for a variety of purposes. Some of the effects included decreasing the free flow of information that had once occurred in meetings and simplifying and dumbing down reports to focus on graphics instead of data. A number of respondents said that computers were contributing to the decline in recorded information while speeding up the work that was accomplished. We've generally found that scientists, managers and information professionals are all struggling with the same issues that the rest of us are contending with, despite ambitious efforts by some of the technical libraries, including those at Xerox, Corning, and 3M, to make digital records more accessible. The issues are how to integrate different systems and to identify and preserve valuable records over the long haul.

Companies are investing heavily in a wide variety of document systems, but these are not records management programs and don't solve the problem of electronic preservation. For example, Exxon Mobil uses Globalshare, a Lotus Notes product, as an electronics records system for most of its records, but they print out those records that need to be available for the long term and keep them in paper format. Corning has extensive databases as a part of their Technical Information Center, but they do not permanently preserve electronic records. Instead, Corning requires that electronic records be printed out before delivery to the archives, thereby avoiding problems of maintaining appropriate hardware and software.[3] And Raytheon has extensive databases on DocuShare, which is an electronic storage system that allows researchers to share and comment on information. However, we were told:

> It's not easily accessible to folks. … It's all by program. There's hundreds of thousands of that. And I know because every now and then I'll get asked to help manage it. It's a big, huge mess, you know, knowledge management . . .

> and no one wants to fund it. No one wants to do anything, because it's too big.[4]

Nearly all the companies had similar distributed systems that allow project teams to work interactively online and to share their data, but they were intended to survive only for the life of the project.

The physicists and managers that we talked with routinely described "archiving" records, especially PowerPoint and important e-mail. However, it's necessary to define what's meant by "archives." As recently as the early 1980s, "archives" was a relatively obscure word, a noun that meant a repository for preserving institutional records. Since then, a new and far more common definition has grown up alongside the traditional meaning. In popular conversation archive is used today as a verb; it's become "a computer term meaning to transfer data from an active system to a storage medium, often tape or disk, for preservation. This type of archiving does not imply permanent retention."[5] So, while many of our interviewees talked about archiving records, from the context it's clear that they meant that they downloaded information to CDs or other media and stored it temporarily for their own use. At one of the defense contractors that we visited, an R&D manager said that all "laboratory reports are now done and entered into an electronic archival system, Word or WordPerfect or whatever the present system is." He added that "we've struggled the last few years in getting a…good archival system as we transition to electronics," but concluded that they hadn't succeeded thus far.[6] None of the companies had developed long-term storage for these or other digital media.

The change in the use of laboratory notebooks is one of the most striking transformations confirmed by our study. Although we had heard anecdotally before the project began that the use of paper notebooks has declined, we expected that they had been replaced by electronic substitutes. The laboratory notebook has long been considered the key document in recording experiments, and as a result it became an essential tool in the scientific method. Traditionally students are taught in introductory lab courses how and why to use notebooks, and scientists are expected to maintain them throughout their careers. Companies have long issued lab notebooks to their scientists who returned them to company custody when they completed them. A Swarthmore College website (http://www.swarthmore.edu/NatSci/cpurrin1/notebookadvice.htm) for biology students provides a succinct summary of the reasons for keeping good notebooks: 1) to provide the researcher with a complete record of why experiments were started and how they were performed, 2) to encourage sound thinking, 3) to share information with others, and 4) to "get rich" (*i.e.*, support intellectual property claims). The website describes a couple of the basic requirements of a lab notebook, including glued bindings and pre-numbered pages (to prevent surreptitious removal of pages) and coherent and legible entries. It neglects to mention two other traditional requirements: witnessing by a peer or supervisor and signatures.

Laboratory notebooks are seen as a vital source in investigating fraud and proving intellectual property. Historians of science have long used them as reliable primary sources in understanding how science is done and sometimes as a way of determining claims of primacy in findings or inventions.[7] However, only 52% of our interviewees told us they continue to use paper lab notebooks, and only one researcher reported using electronic notebooks. Physicists and R&D managers at several companies said that chemists are most likely to retain lab notebooks, while computer scientists are among the least likely. They said that physicists were far closer to the computer scientists than to the chemists in recording their work, and much of this has to do with the nature of their research. As one physicist told us, "If I've got to make a measurement or something, typically I'll have an instrument that records what's been done and you can type in or scan" the data. Chemists on the other hand have "a bunch of jars that people write something on,…and they're going to have to write this stuff. And they go back and look at it a lot."[8]

The rise of computerized research is clearly a significant factor in the decline of the laboratory notebook. In a 2002 article on the Hendrik Schön scandal at Lucent Technologies Bell Laboratories, the director of physics research there said that "the use of physical lab notebooks has declined in this computer age."[9] And a physicist at Ford explained that the use of computers had speeded up experiments so much that scientists no longer had time to fill in lab notebooks, a practice that in the past had been done in the intervals that were spent waiting for results.[10] A 3M scientist told us:

> I've had eight patents issued, and I've had the same notebook the whole time. I don't see where there's a particular need to [use one]. It's all documented in the Records of Invention. Between the Record of Invention, and other ways of recording electronically, it just seems like … a waste of time to be cutting and taping and writing longhand in the notebook.[11]

Another 3M scientist agreed:

> A notebook has two functions in industry. One is of course to keep good records, but so often that's done electronically now. If you're taking data it goes into a spreadsheet directly, for example. But a notebook's primary purpose in the eyes of our patent lawyers is to keep a record of a first invention or a first concept and then it's witnessed" "As more and more data is electronic the notebook becomes a bit of an oddball dinosaur. I don't know how that's going to evolve.

He added that "I don't go back and look at my notebooks. …" Instead, he uses the data on his computer. However, because the lab notebook is still a primary document for patent applications at 3M, whenever lab work became important for a patent application, "I print it out and stick it in my notebook. It's in an electronic file somewhere, but it also needs to be in the notebook."[12] Most of the physicists that we talked to said that they seldom went back to their own lab notebooks or those of others in the company. Instead, to find out if an experiment had been done or to learn the methods and results of work that they knew about, they'd review the published literature and talk to the oldest researchers, who represented the living memory of the lab. This conforms to some recent studies on the information-seeking behavior of scientists and engineers.[13]

Commercial electronic notebooks are widely available today, and the Millennium Digital Copyright Act of 1998 seems to have confirmed their legal standing. Electronic notebooks are reportedly used widely in pharmaceutical laboratories, but only one of the companies in our study claimed to be using digital notebooks, an in-house system.[14] In fact, however, only one researcher at the company said that he actually used the system. One reason, a 3M scientist suggested, is security. "For all of the benefits of communication and massive amounts of storage and communicating both visually and audibly all electronically now, it has also made information quite vulnerable. And that's a big concern in industry." Technical librarians in several of the companies reported that they had surveyed R&D staff and found that they weren't interested in digital notebooks. One librarian added that the scientists and engineers at her company were concerned that it would provide a means of more closely supervising their work. And the Information Management Program at Corning's Sullivan Park Laboratory did a survey of how researchers used paper notebooks. Their findings confirmed what we were told by a number of our interviewees: scientists seldom use either their own old notebooks or those of other researchers, instead relying more on oral tradition and published sources.

However, some companies still require researchers to maintain lab notebooks for intellectual property. Physicists at those companies cope with the problem of reconciling electronic data and paper notebooks in a variety of ways. Some record the process and briefly summarize the results. One physicist showed us the paper notebook that he kept in longhand with screen shots of data pasted in, and another said that he printed out data runs as an appendix to the paper lab notebook. At other companies, some physicists store a combination of narrative entries and data in conventional programs like PowerPoint or a combination of Word and Excel. Overall, the continued reliance on paper notebooks in an age of digital experiments reduces the quality and extent of the documentation. At the same time, companies that require notebooks, albeit in outmoded paper form, are preserving some record of the process of industrial research and development.

While more than half of the interviews were conducted in 2003, we should add that use of digital notebooks in our sample didn't increase over time. None of the companies that we visited in 2005 through 2007 are using them. The reasons for this seem to be lack of incentive by scientists and lack of initiative on the part of companies. Scientists don't express interest in them, even when they've been surveyed by technical library staff, and companies don't require them in most areas. The one exception that we found is pharmaceutical and biomedical research, which have very specific reporting and oversight requirements.

Email is an important new record format that has taken over some of the functions of both traditional letters and of telephone calls. Email is often relatively spontaneous and offers the opportunity to capture the process of science as practitioners are developing and working on projects and solving problems. However, few of the interviewees were concerned about preserving email as a historical record. Several told us they kept email "however long it is on the server," and very few maintained an active retention of important emails. Interviewees at four of the companies that we visited told us that the company automatically deleted emails off their servers after a specified period of time, ranging from 30 to 90 days. Even so, some scientists were not aware of that. One scientist whose company auto-deleted email after 90 days told us he thought it was retained indefinitely on the company server. A little over half of those we interviewed saved selected emails in a folder on their personal computer. Another 7.5% maintained personal email records on the company drive. Most who preserved email records did so for less than three years. As one put it, keeping email for two and a half years was easy but any longer became harder. Only six of our interviewees claimed with certainty that they could recover email records greater than ten years old, and only two said that they burned selected emails to CD when they no longer needed them actively on their computer.

Communication Patterns

The way in which physicists prefer to communicate with one another presents another important obstacle to a documentary record. One of the most revealing areas of our interviews with scientists and R&D managers is how they communicate with collaborators both within their own lab—those who worked with and for them—and collaborators working elsewhere—say in academia or at another laboratory. Scientists and R&D managers identified a variety of preferred forms of formal and informal modes of communication. Formal communication includes publications, formal presentations, reports, project documents, strategic planning documents, design reviews and formal meetings. Informal communication includes telephone conversations, incidental meetings, face-to-face conversations, voicemail, email and other means of corresponding with others about one's own and their work. While the number of interviews at each company makes statistical representations not that meaningful, the trends are revealing. In general, lab scientists prefer to use informal communication modes more than formal communication modes, while R&D managers seek a balance between formal and informal communication.

The ratio of informal to formal communication among lab scientists was 3:2, and the preference for informal communication grows the longer they've been in the work force. Lab scientists who got their Ph.D. prior to 1970 mentioned informal communication modes 77% of the time, versus 23% for formal modes of communication. For those who got their degree in the 1970s informal to formal modes of communication had a ratio of 64% to 35%, while those who graduated after 1980 expressed a ratio of 54% to 46%. This suggests that those with less time in a company tend to use more formal means of communication, and formal communication declines as they become more experienced and established in the company. A similar trend, however, did not appear for R&D managers. R&D managers mentioned informal modes of communication as a preference 49% of the time and formal modes 51% of the time. While those with Ph.D.s before 1970 utilized informal to formal 56 to 44, those with Ph.D.s in the 1970s mentioned formal modes as preferred 54 to 46. That ratio remained virtually the same for R&D managers with Ph.D.s since 1980.

The utilization of informal versus formal modes of communication varies widely from company to company and sometimes between R&D managers and lab scientists within the same company. A preference for informal communication on the part of lab scientists tended to correlate with the extent to which the lab has traditionally been viewed primarily as a research lab as opposed to a development lab. No lab scientist at IBM or Lucent Bell Labs, which have been seen as the most academic of industrial laboratories, mentioned utilizing formal communications in their work. Very few mentioned formal communications at Kodak and GE, although R&D managers at GE preferred formal communication modes to the same degree that their lab scientists preferred informal modes. Corning appeared to have a similar conflict between the preference for formal communication on the part of R&D managers and the preference for informal communication on the part of lab scientists.

Those companies that focused on development over research, on the other hand, tended to show a high preference for formal communication modes. Raytheon, where everyone is identified as an "engineer," had the highest ratio of formal to informal communication, followed closely by Texas Instruments. In the middle, Ford, GE, Exxon Mobil, Corning, Xerox and Honeywell utilized formal and informal modes about equally. Research labs at Agilent, Lucent (Bell labs), Lockheed, IBM, General Atomics and Kodak showed a preference for informal communication over formal modes. Agilent and IBM managers both balanced the two modes, but in the remainder even R&D managers leaned heavily towards informal modes of communication. These results suggest that science-based research is more informal and the participants have more autonomy, and it is therefore less likely to produce a documentary trail. Development, on the other hand, which involves engineering-style work, is more formal. Practitioners generally have less scope for autonomy, and documentation—which allows for formalization and repetition of the process—is more valuable. The difference in view between managers and scientists at GE is especially interesting. GE's central research laboratory had been a close third to IBM and Lucent in terms of scientific reputation after World War II, although the autonomy of scientists there decreased under CEO Jack Welch, beginning roughly in the late 1980s. As mentioned earlier, GE seems to be encouraging longer-term research under the new CEO, who arrived in 2002, but it's unclear what impact that may have on the autonomy of individual scientists.

A related problem in documenting industrial R&D is identifying what records the participants believe are likely to be important. Physicists and R&D managers consider a variety of records to be important, but they expressed no real consensus on what would constitute a set of important records. When asked what important records they created or were created by those with whom they worked, scientists and R&D managers included reports (65%), presentations (58%), publications and conference papers (31%), patent records (36%) including invention disclosure notices (26%) and patent applications (7%) and the patents themselves (8%), email (20%), lab notebooks (22%), or components of electronic records that once had been included in lab notebooks (50%). This latter could include electronic data, lab notes, experimental setups, results and measurements, drawings and text documents. Some (29%) mentioned some form of administrative records including meeting minutes (14%). Fewer (19%) considered project documents, including proposals (8%) and project reviews (4%) to be important. Only one thought, for example, that collective project data sheets were important records. Just a few included unpublished manuscripts (5%), memos (13%), technical papers and memos (9%) and contract records (8%).

Most physicists didn't take responsibility for preserving records that they identified as important unless the records were also of personal significance. Records important personally, for example selected email or reports, might be burned to a CD or saved on a personal computer hard drive. The physicists were unlikely to be concerned about saving records (patent applications, discovery notices, etc.) that they thought they could find elsewhere.

Company policies regarding retention versus disposal of records vary. Overall, legal departments tend to plan for the last war. That is, those companies that have been damaged by not being able to produce documentation during legal proceedings counsel retaining records. For example, in 1995 Hewlett Packard's legal department mandated that the company would formalize and enforce procedures for keeping laboratory notebooks permanently. Other companies counsel eliminating records as soon as they are not essential to the business. Potential historical value is generally not a criteria for preserving records.

Corporate Libraries, Records Management, and Archives

In considering the organizational structures that are designed to preserve and retrieve information—libraries, records management programs, and archives—there is an important distinction between the world of academic and government research, on the one hand, and corporate R&D on the other. In academic and government laboratories, the only unit that is likely to preserve laboratory notebooks or any other non-published materials on a permanent basis is the archives, typically the investigator's own university archives in the case of academic scientists, and a government archives, perhaps the U.S. National Archives and Records Administration, in the case of researchers in federal science agencies. This, of course, is not meant to imply that their records will actually be preserved, but only that if they are, they almost certainly will be preserved in an archives.

One of our first findings in this study was that here, as in other respects, business laboratories are different from other laboratory venues. Within most corporate R&D facilities the preservation of unpublished records including laboratory notebooks and technical reports of physicists—in-so-far as there is any organized program—is likely to be done by the technical library instead of archives, even in those companies that have an active archives program. Beyond that, among the 15 companies that we visited, we found no standard arrangement for preserving R&D records for the long term. However, the strongest programs were those that combined well-developed records management programs and strong technical libraries. When they exist, corporate archives tend to focus on the business functions of the company rather than research and development. As a result they are more likely to collect science and technology records at a high level, including records of vice presidents for research, along with corporate planning documents and reports, instead of the records of lower level R&D management and staff.

There are multiple reasons for the lack of standardization in identifying and making provision for preserving or eventually destroying science records. Two of the most important have been discussed earlier: lack of government regulations regarding science records and varying guidance and advice from the company's legal department. The value of history by itself is usually a weak motivator for preserving science records, since history and historic preservation are only occasionally significant concerns for most businesses. The one exception among the companies in our study is Corning, which was founded by the Houghton family in 1851 and whose CEO when we visited, Jamie Houghton, was a direct descendant of the founder. In addition there are occasional times—usually during major anniversaries—when many companies see their history as a branding opportunity to strengthen their appeal to customers and improve the morale of employees. Historical sources obviously can also be used for legal purposes, advertising and promotion, and to answer the questions of collectors who are concerned with its products.

Among our assumptions starting out was that 1) in-house archives are the exception rather than the rule in the corporate world, and 2) archives provide perhaps the only sure way of preserving the records of R&D. We knew of course that some of the companies that we selected had archives programs, including a few that seemed currently to be strong. And we also intentionally chose one company, Texas Instruments, which had developed a fairly strong archives program in the 1980s but then closed it after ten years or so. However, we've been surprised that more than half of the companies in our sample of 15 had an in-house program that was designated as an Archives when we visited or had transferred at least some company records to an external public or private archives.

In terms of structure and programs, corporate archives are the least standard of the information management systems that we encountered. They vary from programs that focus almost exclusively on product literature, sales brochures and other gray literature to a few programs that address the papers of scientists. As mentioned earlier, even among companies that have archives programs, the technical library is far more likely to be responsible for overseeing and sometimes preserving the R&D records of individual scientists and engineers. Archives, on the other hand, are more likely than libraries to preserve high-level records. These include the papers of top R&D staff, annual laboratory reports, and similar materials that may disappear if the company doesn't have an Archives. The difference is attributable in part to the different training and practice of archivists and librarians respectively. Another reason is that in-house archives tend to serve the needs of those departments—often legal, marketing, and public relations—that use their services the most.

It's important for historians and other researchers to realize that contacting a corporate archives or a technical library alone doesn't necessarily mean that they have explored all the possible sources for understanding the history of a company's science and technology. And while they may be told that records in the technical library or the archives are not available to outsiders, they should contact the responsible staff to explore access. It's also important to keep in mind that archives programs—either internal or external—do offer the potential for a dedicated program for preserving the company's intellectual as well as its administrative history.

The companies in our sample that had archives are IBM, Corning, Ford, Lucent, Agilent, and Xerox. In addition five companies—GE, 3M, Kodak, Exxon Mobil, and Texas Instruments—have transferred some business records to public or university archives. To a degree, the existence of an internal archives within a company may reflect the work or decision of one person, either an executive with the interest and authority to support an archives or, in some cases, a staff member who was able to successfully make a case for its utility. While there are many arguments for the practical value of corporate archives and history programs in businesses,[15] the company archives that we visited tend to reflect the instability of these undertakings in the real world of corporations. When companies face retrenchment, either because of economic downturns or administrative decisions, archives are often among the first to be cut back and, sometimes, entirely cut off.

Three of the companies—GE, 3M, and Kodak—had transferred some of their records to the archives of the Schenectady Museum, the Minnesota Historical Society, and George Eastman House respectively, before the study began. The 3M and Kodak collections consist of small, one-time or occasional transfers that don't include R&D records. However, the GE collection is comprised of 540 cubic feet of administrative files, company publications, photographs and some research and development records. At the time of our site visits, two companies, Exxon Mobil and Kodak, were planning to transfer sizeable collections to academic archives at the University of Texas at Austin and the University of Rochester respectively, and the records were subsequently transferred as scheduled. And after we visited, Texas Instruments transferred their archival collection, which had been closed in the late 1990s, to Southern Methodist University. Both Exxon Mobil and Texas Instruments included significant financial support to organize and prepare the collections for use. However, none of the three recent transfers included individual research and development records.

All of the companies that we visited have technical libraries except for Texas Instruments. Libraries have traditionally provided a necessary and important support function for research and development, but the library staff at virtually all of the laboratories that we visited had been downsized in recent years. Like libraries of all kinds, technical libraries are moving from being repositories of information to becoming portals for online sources. The rationale for downsizing libraries and library staff is based on the wide availability of online databases and other information sources. A number of the physicists that we interviewed reported that they are able to do literature searches online now, much faster than before and without help. Others, however, complained that online sources don't adequately replace the traditional technical libraries whose staff did comprehensive research and amalgamated the information. Also, some of the librarians reported that reduced budgets and staff make it harder for them to continue to deal adequately with non-published material like lab notebooks and technical reports. Nonetheless, companies are reducing their operating costs by reducing library budgets.

Appendix B contains a description of the information and records-keeping systems at the 15 companies in the study. In addition to this description, we are adding catalog records that describe the records that we found for the companies to AIP's online International Catalog of Sources for the History of Physics and Allied Sciences (http://www.aip.org/history/icos) and to the international OCLC database. To summarize our findings briefly, a few of the companies had well-developed systems to enforce traditional record keeping, including maintaining lab notebooks and other research records; 3M, Corning, and Agilent were especially impressive in this regard. Their success in maintaining a traditional paper system in the face of computerized research indicates that good record keeping follows from corporate retention schedules and enforcement/oversight programs. However, at many companies the record retention and disposition schedules or the enforcement mechanisms, or sometimes both, do not address experimental or R&D records beyond final reports and materials required for patent applications. Physicists often display an interest in their history, but on a day-to-day basis they're unlikely to be concerned about preserving the records of their past projects unless there are clear guidelines and requirements.

While the 3M, Corning, and Agilent libraries appear to be succeeding in retaining a system of paper laboratory notebooks, they are maintaining outmoded systems that don't reflect the way physicists do research today. In-so-far as researchers at these and other companies maintain regular records of their work in traditional notebooks, they're manually recreating documentation that already exists in digital form, usually in a much more complete way. Most physicists and information professionals alike say that researchers use far fewer notebooks today, meaning that they document far less of their daily work than in the past. Unless high-technology companies begin adopting electronic notebooks or equivalent digital systems that can be used to record and maintain the daily work of their researchers for the long term, it appears that this staple of the scientific method may disappear.

Before closing this section, it's important to add a word about the technical library and archives staff that we've interviewed. We've been impressed by the professionalism, knowledge and dedication of virtually all the information professionals that we've interviewed in the course of the study. As a group they are articulate, familiar with their company's programs and functions, and knowledgeable about current computer applications and other knowledge management systems.

Industrial Archives in Europe

The archival literature indicates that most countries in Western Europe have public or private archives that together preserve an extensive history of their industrial sectors. Denmark and some other Western European countries have developed government-supported units of the national archives that are specifically responsible for preserving business records, and the U.K. and Germany have privately-funded archives that document the industrial sector. Given the American archival tradition, where the pure view of the U.S. National Archives and Records Service is restricted to the records of the federal government, the Danish model is unlikely to be applicable here. The U.K. and German examples, however, seemed to offer the potential for providing insights for preserving the records of American industrial R&D, and we accordingly included site visits to selected archives there that collect industrial records. The Business Archives Council, a registered charity in the U.K., has reportedly promoted and helped to underwrite national surveys of corporate records, and it has worked to place records in local and regional repositories and especially at the Business Records Centre at the University of Glasgow. Less has been written about industrial archives in Germany, but our contacts with German historians and archivists indicated that there is a network of German programs that document business.[16]

We visited the Business Records Centre at the University of Glasgow in April 2003 and met with the senior archivist and other staff. The program describes itself as "one of the largest collections of historical business records in Europe." It was established by Sidney Checkland, a professor of economic history, who came to the university in 1959, and it moved to the University Archives in the 1970s. The Centre concentrates on the history of heavy industry that had once made Glasgow prosperous, along with Scottish banking, distilling and retailing. It does not include any high-tech industries or R&D records, and a planned survey of computer research in Scotland had not taken place. The Centre is funded by the university, grants, and some corporate support. At the time of our visit it was trying to obtain support from the Scottish National Archive and to become the Scottish National Business Archives.[17]

Through contacts with our counterparts in the German science archives community, we learned that there are several levels of well-established business archives in Germany, consisting principally of in-house repositories operated by a number of corporations and regional archives maintained by chambers of commerce and industry. In order to gain a broad understanding of how business archives operate in Germany, we conducted site visits at the chamber of commerce and industry repositories in Cologne and Munich and the Siemens and Carl Zeiss (Jena) corporate archives in April 2005, as well as the archives of the Deutsches Museum in Munich.

A new interest in social and economic history on the part of German historians led to the development of business archives there at the beginning of the 20th century with the establishment of the first ever in-house corporate archives at Krupp in Essen. Next came the first chamber of commerce and industry regional business archives, in Cologne and Saarbrücken in 1906, and two more in-house corporate archives, at Siemens and Bayer in 1907. Germany has since developed an effective and stable network of corporate and chamber of commerce and industry archives that document business throughout most of the country, and all of the early repositories mentioned here are still strong today except for the Saarbrücken archives, which failed in the immediate post-World War II period. There are six regional chamber of commerce and industry archives and 10-15 major in-house corporate archives. In addition, some smaller companies, including Carl Zeiss Jena, maintain their own archives, while others deposit records in regional or other repositories.[18]

The two corporate archives that we visited are very different from one another. Siemens AG is a global diversified high-technology company, and it maintains a Corporate archives at its headquarters in Munich. The Archives has 7.5 staff and holds four kilometers of records and one-half million photos, plus artifacts and a small collection of electronic records. Like most American archives, it tries to avoid accessioning electronic records because of the preservation problems they present. And like a number of American corporate archives it is administered as a part of corporate communications. The archives created the company's records retention schedule, and all business units are required to send records to the archives with two exceptions, research and development and legal, which means that the archives does not include R&D records. About 40% of their users are outsiders, mostly science historians doing the social history of science and technology.

Carl Zeiss GmbH Jena is a high-technology optical company that is much smaller today than its original incarnation through World War II or under the East German regime. However, it retains its own professional archives, operated by a full-time historian/archivist with temporary, part-time staff and volunteers. The Archives contains approximately 2.5 kilometers of records plus photos and artifacts and is open to the public. Some Zeiss R&D records were confiscated by the Allies following the war and remain missing, and a former archivist under the East German regime destroyed some others, but about 20% of the collection before 1990 consists of significant research and development records.

The directors of both archives said that their companies support the archives because history is seen as an important cultural value. The director of the Zeiss Archives added that when a company's products are competitive but not clearly superior, "history becomes a strong selling point." As a result, he works with salesmen to help them promote Zeiss' long tradition of high-quality optics.[19]

German regional chambers of commerce and industry are public corporations that represent the overall interests of industry and commerce in their district. Businesses were once required to belong to their regional chamber (we don't know if this remains true), and chambers in turn provide a variety of services, including in many cases archival programs. We visited the oldest surviving chamber of commerce and industry archives, the Rheinisch-Westfälisches Wirtschaftsarchiv in Cologne, as well as the Bayerisches Wirtschaftsarchiv in Munich. Both archives have professional staffs and resources. Their collections consist largely of records that are more than 50 years old and are mostly from companies that have gone out of business. They include some but not extensive R&D files. An exception is the Bavarian archives' chemical industry records, which include patents and R&D files. While both facilities are actively accessioning records as they become available, there does not appear to be an effort on their part to document the high-technology industries in their respective areas.[20]

The Cologne archivist said that his facility was founded 99 years earlier because archives had "come into vogue in Germany" at the time. He said that while some German companies today aren't concerned about preserving their records, many others are. And he added that history remains of strong popular and corporate interest in Germany today for a wide variety of reasons. The archivists at all four of the repositories agreed that companies preserve records for cultural and economic reasons, not because of legal requirements. While public organizations are required to preserve some records permanently, businesses and other private organizations are required only to keep tax-related records for a ten-year period. There is no requirement that they preserve these or other records permanently.

German archives present a strong contrast to American practice. In the U.S., academic archives have traditionally been the dominant sector, and the three corporate collections in our study that have been transferred to external repositories over the past five years (Exxon Mobil, Texas Instruments, and Kodak) have all gone to academic archives. Corporate archives in the U.S. have tended to be less stable over time, and there are no counterparts in this country to Germany's regional business archives.[21] The situation is reversed in Germany. The Siemens Archives director compared business archives in Germany to their academic counterparts, saying that professional archives at German universities are a relatively recent development and generally are small, often with only one staff member. In comparison, not only are there many stable in-house corporate archives and the six regional business archives, but in addition the Association of German Economic Archivists has 350 members. It provides professional training, works closely with other German archives sectors, and publishes a professional journal and a guide to German economic archives.

Germany's program for preserving industrial history is exemplary in many respects. However, the archives that we visited currently perform rather poorly overall in preserving R&D records, and the chamber of commerce and industry archives typically don't work with the large high-technology sector that has developed in post-war Germany. Nonetheless, the network of corporate and regional business archives is very impressive. Applying the lessons learned to American practice is difficult, however. In the same way that the Danish model of a centralized, state-supported national business archives isn't applicable in this country, the German system of a voluntary program based on the value that the people and companies alike place on history doesn't translate well to the U.S.

Conclusion

The results of this study do not provide easy answers to the difficult questions about how to identify records that are likely to be of enduring historical value and how to preserve them permanently. However, they do provide guidelines for understanding and documenting the work of the physicists and R&D managers employed in the 15 major high-technology companies in the study and, by extension, in other large high-technology companies. They also allow us to recognize dominant themes in the changing structure of corporate research and the creation and preservation of relevant records.

The study confirms that the organization and management of industrial R&D is volatile, changing frequently in response to economic cycles, new managers and management philosophies, spin-offs and other factors. All of the companies are trying to facilitate transfer of tacit information more effectively, and they have taken an increasingly direct role in promoting innovation (the development and introduction into the market of new or improved products or production processes) over invention (the creation of new instruments or ideas). These concerns have had an important impact on the work of nearly all the scientists in our study. It means that there is strong emphasis on development instead of research and on shorter versus longer-term projects. It also means that most of the physicists that we talked with no longer work primarily with other physicists. Instead they work mostly with engineers, marketers, customers and others in the innovation chain. In the words of John Seeley Brown and Paul Duguid, they have moved from a "community of practice" (*i.e.*, peers) to becoming part of "networks of practice."[22] All of these factors have progressively reduced the autonomy of industrial physicists over the past 50 years. At the same time, however, physicists in industry appear to have considerable autonomy within the constraints set by their organizations, and some physicists, especially those who entered the workforce after 1990, said that working in industry is preferable to academic jobs because of easier access to project funding and the strong competition for tenure in academic institutions.

Records keeping in industrial R&D has changed significantly over the past quarter century in response to computerization, physicists' preferred means of sharing information, and other factors. The biggest single change concerns laboratory notebooks. Only about half of the researchers we interviewed maintain lab notebooks, which were once ubiquitous in corporate laboratories. They appear to have been replaced as primary documents supporting intellectual property claims in some of the laboratories by records of invention. And physicists report that old lab notebooks, either their own or those of colleagues, aren't an important source of information for them. They're more likely to review the published literature and consult with other physicists, especially old-timers in their laboratory, to learn about earlier research that might shine light on new projects. We realized at the beginning that most physics experiments are conducted by computer today, and we expected that paper notebooks were being replaced by electronic equivalents better able to present and store digital data. However, only one interviewee reported that he uses an electronic notebook. The interviewees who still maintain lab notebooks cope with the limitations of paper by pasting in screen shots of data, keeping bound copies of printouts as an appendix, compiling experimental information in PowerPoint, etc.

The advent of computers has not only contributed to the decline in the use of notebooks, but it has speeded up the work that physicists do and created new forms of communication and reporting, like email and PowerPoint. These new formats change the content of the information that they contain, for better or worse. For example, several interviewees said that they believed that PowerPoint reports depended more on graphics than data, “dumbing down” and reducing the information content of the report. Unlike paper files, electronic records require prior planning and ongoing commitment in order to survive, and most of the physicists we interviewed do not make any effort to preserve electronic files, while those that do limit it to saving the files for a few years for personal use. The failure to develop satisfactory solutions for preserving the electronic information that we produce every day is common to all segments of society, but in the companies that we’ve studied it appears that electronic media are actually reducing the amount of documentary material like laboratory notebooks and technical reports that is being produced.

There are generally no state and federal regulations regarding R&D records as there are for financial and administrative records. So companies are largely on their own in deciding what R&D records to keep and what to destroy. Their responses vary widely. A few continue to mandate the use of laboratory notebooks and maintain effective methods for tracking them from the time that they’re issued to the individual scientist until they’re eventually filled and returned, typically to the technical library. For these companies, however, what happens next varies. A few preserve the records permanently, others keep them for a period of time and then destroy them, and two follow a middle course of trying to preserve the notebooks and other papers of their most distinguished researchers, who are designated as fellows. Other companies make little or no effort to track or preserve notebooks.

The typical function and responsibilities of business archives are different from their academic and government counterparts in a number of ways. Business archives have been traditionally less stable than technical libraries. They may exist largely because of the interest of an individual CEO or other top manger, and they’re one of the operations that are among the most likely to be cut back or even closed during hard times. In the companies that had both archives programs and technical libraries and that preserved some or all of the laboratory notebooks, it varied as to which took responsibility and custody of laboratory notebooks and lab reports. On the other hand, the corporate archives that we visited typically collected product catalogs and other gray literature and administrative records, including the records of the top R&D managers; none of the libraries that we visited collected these materials. One of the archivists said that technical records like notebooks and lab reports are probably safer in technical libraries than archives over the long run, because the libraries tend to more stable parts of the organization. That said, it’s important to note that nearly all of the technical libraries at the companies have also been cut back in recent years, some sharply, although only one company had eliminated the technical library altogether.

These findings and others described in the report represent real problems and may suggest that there’s little chance of preserving a record of the work of physicists and others who are employed in corporate research and development. However, other findings are more encouraging and, if action is taken, offer the promise of preserving some of their history.

First, a number of the industrial labs that we visited have a large core of extant science records in the form of notebooks and technical reports. This is certainly better news than what we found at some of the Department of Energy labs where we conducted our first documentation study in the 1980s, and often better than what exists for academic physicists. The bad news is that there's no structure or tradition for making these available to researchers. With the exception of historians who are doing an authorized history or are able to charm and negotiate their way into the technical library's resources, these collections are closed to outsiders. This is often, although not always, true even for materials that are many years old and have lost their intellectual property value.

Another positive finding is that high-tech companies do find value in their history, at least for branding purposes. Typically, major anniversaries are celebrated by extensive and sometimes relatively costly commemorations and events. They sometimes, although not often enough, even provide an opportunity for professional histories.

We have been surprised by the number of companies that make some kind of provision for archival programs. Six of the 15 companies in our study have active archives that range in staff size from one to five employees. These programs vary widely in terms of funding, mission, and the materials that they collect. But any archives program significantly increases the chances that general company information, often in the form of gray literature, will be preserved, and they provide the most likely opportunity to preserve higher-level documentation of research and development programs, including records of senior managers and CEOs. In addition to the six companies with archives programs, five of the companies have donated at least part of their inactive records, one to a state historical society, one to a private museum archives, and three to academic archives. The most recent examples, Exxon Mobil and Texas Instruments, have also made relatively generous financial contributions to help support their collections, which can be critical for archives. The downside of these archives and history programs is that they can be hit or miss, and in the past donations to outside archives have been static, mostly one-time efforts to unload records. In addition, in nearly all cases they have not included R&D records. Education and advice from professional archivists and historians represent one way of strengthening existing archives and history programs.

Finally, it would be difficult to exaggerate the importance of oral history as a tool and resource in studying the history of modern science and technology. This is true both in areas where the documentary record is fragmentary and in those areas, like some fields in academic physics, where researchers may reasonably expect that the records and papers of key participants may have found their way into institutional archives. In a recent review of a history of the Hubble Space Telescope, the reviewer noted that

> The human history behind Hubble is only known because the Smithsonian National Air and Space Museum and the American Institute of Physics arranged for hundreds of players to sit for exhaustive interviews about themselves and their work.[23]

Oral history is an especially valuable resource in understanding the history of industrial research and development because the documentary record is especially sketchy, and the oral histories that we've conducted are a rich resource for researchers and companies that want to understand their history. When we designed the study, we planned to use the question-set interviews as one of our primary tools in investigating the work and records of industrial physicists. As expected, these proved to be invaluable sources of historical information, providing insights that paper or electronic documentation couldn't match (although of course oral history has well-known problems of its own). As in other similar projects, we will make the interview tapes and transcripts available to other researchers, except for the very small number of interviewees who asked that their interviews be destroyed after being analyzed for our study. In addition, we conducted longer autobiographical career-length interviews with a small number of industrial physicists who have played especially important rolls roles in science or science policy. We've now completed 16 career-length interviews. These too are very rich in information, and we will continue to conduct career-length interviews with important corporate physicists as our resources permit. We also expect to work with interested individual historians, companies, and organizations to do additional interviews, providing both advice and material support. The existing oral histories and those that will be done in the future will all be cataloged and described in our International Catalog of Sources (online at http://www.aip.org/history/icos), and they will be available both in-house and on loan; some are now online and many more will be put online in the next few years.

Best Practices and Recommendations

The best practices and recommendations offered here are intended to provide modest and realistic guidelines for preserving the historically valuable work of physicists and other scientists and engineers who work in industrial research and development. None of them involve elaborate programs or large expenditures. Instead they rely on initial planning before records become scattered and disorganized, standardizing record keeping practices, and taking advantage of existing programs.

Best Practices:

1. Xerox, 3M, Agilent, Exxon Mobil, Corning and GE technical libraries distribute and permanently preserve laboratory research notebooks of each researcher.

    a. Prior to 1995 Hewlett Packard had an informal program for preserving individual laboratory notebooks, but in 1995 the legal department charged the library with purchasing and disseminating lab notebooks and collecting and preserving them when complete. Agilent has continued this practice since it was spun off from Hewlett Packard.

    b. 3M, Corning, and Agilent appear to have strong programs to insure that traditional lab notebooks are maintained for patent purposes.

    c. Xerox maintains lab notebooks in the original form and in microfilm. Technical reports were saved in the original and microfilm until 1988. They now are duplicated as PDFs.

2. Most technical libraries preserve technical reports permanently.

3. The archives at IBM and Lucent Technologies Bell Laboratories preserve the laboratory notebooks of company fellows.

4. IBM and Lucent archives preserve permanently the records of the senior vice president for research along with other top managers.

5. Corning's technical library preserves the laboratory notebooks and technical reports of all scientists; the Corning archives also preserves other papers of Corning Fellows.

6. The Corning Knowledge and Information Management Organization, which includes the technical library, is creating a Developed Technology Archive. This consists of videotaped interviews with scientists and engineers, shown with and discussing their invention.

7. 3M notifies users when a notebook is out more than five years from the time it was issued. Users who ask to review their old notebooks are given copies instead of the original and these are also tracked.

8. Ford and 3M include a records compliance audit as part of employee's annual performance reviews. As a result, all the staff that we interviewed at these companies said that they are familiar with the records management program.

9. Five of the companies in the study had transferred administrative and business records to external archives, and two recent transfers included financial support to arrange and describe the records. These arrangements can be beneficial for both the company and the archives and should include inactive R&D records.

10. Some companies—including several in this study—have supported important professional histories. These sometimes involved locating and preserving historical records and tape-recording oral history interviews.

11. Archival consulting firms can provide important assistance in building and strengthening archives or records management programs. In addition to Texas Instruments, several of the companies have contracted with archival consultants.

<u>Recommendations</u>:

1. All large for-profit organizations have formal records management programs in order to comply with federal and state regulations, and they should include R&D records as part of the program. A small number of records that document the R&D process and policies (listed below) should be saved permanently and preserved either by the company or in cooperation with external archives.

    - Laboratory notebooks are a traditional and important source of documenting the work that physicists and other scientists and engineers do and were once widely used in industry. In-so-far as they are still used, companies should preserve the originals or duplicates permanently as part of existing records management, library, or archives programs.

    - Like their counterparts in pharmaceuticals, high-technology companies need to develop electronic laboratory notebooks or the equivalent digital formats to replace the paper notebook.

    - Surrogates for laboratory notebooks in the form of invention disclosures are widely used today and also should be preserved permanently.

- Laboratory technical reports are a valuable resource for physicists and historians alike and should be preserved.

- The correspondence and papers of senior researchers (typically designated as "fellows") are likely to document the most valuable research conducted by the laboratory. They should be preserved either by the company independently or in cooperation with public or private archives.

- The correspondence and papers of senior R&D managers document the science and technology policies of the company. They should be preserved either by the company independently or in cooperation with public or private archives.

2. The preservation of essential R&D records depends on cooperation between a company's scientists and engineers and its information professionals. Physicists and science managers need to accept an active role in helping to identify and working to preserve the history of their programs.

3. U.S. utility patents are granted for 20 years and cannot be renewed. High-technology companies would benefit by allowing outside researchers access to intellectual property holdings whose time limits have expired.

4. A number of companies are establishing successful partnerships with public or academic archives. With financial support, existing archives may provide the expertise and facilities to identify and preserve historically valuable records, including the records of research and development. The AIP Center for History of Physics is available to help arrange and facilitate such partnerships.

5. Companies need to plan ahead for major anniversaries. Companies that commission histories, oral history interviews, or conferences have used these occasions to successfully enhance their brand with the public and build morale among staff.

<u>And two final recommendations to historians and other researchers:</u>

1. It is important to examine all of a company's potential information sources, including the technical library and the records management program. Going just to the archives when one exists is not enough.

2. Career-length oral history interviews with important corporate physicists and other researchers are an important and largely neglected area. Historians and other researchers are encouraged to conduct interviews and to eventually deposit them at an appropriate archives or library. Similarly, we recommend that companies encourage and help support oral history projects.

The AIP Center for History of Physics provides advice and assistance to individuals and organizations in identifying and preserving historically valuable records and papers. Please contact us at 301-209-3183, http://www.aip.org/history/.

Endnotes

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APPENDIX A

Center for History of Physics, American Institute of Physics

HISTORY OF PHYSICISTS IN INDUSTRY

Question Set for Senior Scientists

[When responses are vague or open ended, ask for specifics. For example, if the interviewee says things have changed, ask what changed, when, and how.]

Background, Education and Career

First, I would like to ask you some questions about your education and career:

1. You got your Ph.D. at ___________ in 19____. (In theoretical or experimental physics?)

2. What was the topic of your dissertation?

3. Who was your dissertation advisor?

4. How did you decide to pursue a career in industry?

5. How long have you been working for this company?

6. What is your current position and field of research?

7. Have you also worked in other research fields?

Organization and Institutional Structure of Research

This next set of questions will focus on the organization and institutional structure of research in your laboratory:

8. What is your institutional home within the laboratory (*e.g.*, unit, department, research group?)
   [Ask for an organization chart that shows the subject's position in relation to other research staff in the laboratory.]

9. To whom do you report and who reports to you (positions only)?

10. Where does research funding originate?

11. How is the research budget set?

12. Does the research staff participate in setting the budget?

13. How closely does management supervise activities at the laboratory bench and among groups of researchers?

14. How closely did management supervise activities at the laboratory bench when you started working at the company?

15. What is the time frame for your research?

Record Keeping

Now, I would like to ask you some questions about the records (such as notebooks, research proposals, professional correspondence) you create on a daily basis and what happens to them over the long term:

16. What kinds of records do you create as you work on research projects?

17. Which of the records you create or receive from other researchers do you think are the most significant?

18. How much of your communication with other researchers here is through e-mail? How much of your communication with researchers outside the lab is through e-mail?

19. Do you know if there is a records retention policy—that is, rules for keeping or discarding the papers that you and others create—in your laboratory?

20. Do you find it useful? Do you follow the policy?

21. What records does the policy cover?

22. What happens to your e-mail?

23. Are the records you accumulate periodically disposed of?

24. If yes, who decides what is destroyed and when?

25. Are lab notebooks used by you and other researchers in your laboratory?

26. If yes, who taught you to use lab notebooks here?

27. How do new scientists here learn to use them?

28. Were lab notebooks used by you and other researchers when you started working at the company?

29. Are there formal procedures for reviewing and approving notebooks?

30. If yes, who approves them?

31. How often are notebooks reviewed?

32. Were there formal procedures for reviewing notebooks when you started working at the company?

33. For notebooks and other records, what format is mostly used (*e.g.,* electronic, paper, audio, visual)?

34. What kind of system do you use to create and maintain your electronic records?

35. Is the system purchased off the shelf (*e.g., Oracle),* or is it homemade (in-house)?

36. **[Only ask if system is homemade]** Is the system you use also used throughout the firm or only in certain locations (*e.g.,* your laboratory, other research and development operations)?

37. **[Only ask if system is homemade]** What happens to outdated storage systems and to the records they hold? If you don't know, who does?

38. **[Only ask if system is homemade]** If multiple data handling systems are used in your lab, other labs, or throughout the company, how does this technological diversity impact the communication of research results?

39. Do all researchers in your lab have access to the records you create?

40. If not, what security measures are in place to restrict access to your records?

41. Can you retrieve records you created more than five years ago?

42. What will happen to your records when you leave or retire?

43. What role will you play in their disposition?

44. Does the laboratory (or the company as a whole) publish an in-house technical journal?

45. If yes, how are articles selected for publication?

46. Are you and your colleagues in the laboratory encouraged to publish your research in peer-reviewed journals?

47. If not, what restrictions prevent publication in peer-reviewed journals (*e.g.,* trade secrets, patent disclosures)?

48. Were you and your colleagues encouraged to publish when you started working at the company?

Current Research

I would like to get some more information about your current research and its relation to other operations within the company:

49. How did your current research project get started and where in the company did it originate (*e.g.,* research lab, manufacturing plant, headquarters, marketing department)?

50. How did projects get started and where did they originate when you started working at the company?

51. Do you usually work on one project or multiple projects? (If multiple, how many?)

52. Did you participate in multiple projects when you began working at the company?

53. How many staff members are working on your current project(s)?

54. Were they recruited from your lab or from other corporate divisions or research labs, outside firms, universities?

55. Did anyone decline to join your project?

56. If yes, why?

57. How do you communicate with other project members (how much of the communication is by e-mail? Other written forms-what form)?

58. What happens to your project related e-mail?

59. Have you experienced a tension between pursuing your own intellectual interests and the goals of the corporation?

60. If yes, how has the tension changed over time?

61. Do you spend all of your work time at the laboratory bench, or do you also have managerial/administrative responsibilities?

62. If you share research and management positions, how is your time allocated between them?

Current Research-Collaboration

63. Does your current project involve collaboration with departments and divisions outside the central research laboratory (*e.g.,* manufacturing, marketing, sales)?

64. Does your current project involve collaboration with external organizations (*e.g.,* universities, research institutes, government agencies or laboratories, other corporations)?

65. How does the level of collaboration on your current project compare to the level of collaboration on projects in which you participated early in your career?

66. How do you communicate with collaborators outside the central research laboratory?

67. What forms do the communications take (*e.g.,* e-mail, shared reports, staff meetings, conference telephone calls)?

68. Are these communications preserved?

69. If yes, where and for how long?

Current Research—Administration

70. What is the management structure at this laboratory? Is there a single line of command or are there multiple R&D managers?

71. How are responsibilities assigned?

72. Did the projects you worked on when you joined the company have one or multiple leaders?

73. Is your current project subject to periodic evaluation?

74. If yes, by whom and how often?

75. For what purpose?

76. What records/results are produced by the evaluation?

77. Are the records preserved for future use?

78. If yes, do you know who uses them?

79. How were projects evaluated when you joined the company?

80. Who are the lab's primary customers (end users, developers, business administration)?

Evaluation of Career

81. Are there aspects of your job that you would like to change?

82. What do you think is the most important change (*e.g.,* scope, direction, time-to-market) in research during your time here at the company?

Miscellaneous Questions

83. What other questions should we have asked you as part of this study to document the history of physicists in industry?

84. Are there other senior scientists and R&D managers you think we should talk to for this project?

    We will analyze this interview anonymously as part of a set of interviews for our study of physicists in industry. What you have told us may also be of interest to historians and other scholars in the future. Would you give permission for us to keep the transcript in the American Institute of Physics archives after the completion of this project? You may give us permission only for it to be analyzed anonymously, or you can allow future users to quote from it and cite it using your name.

APPENDIX B

Records Programs of the Laboratories in the Study

This section describes the records programs at the 15 laboratories in the study, beginning with the companies that have in-house archives. The Texas Instruments Archives provides a cautionary example of the rollercoaster quality of some corporate archival programs. Phillip Cantelon of History Associates, a consulting firm in history and archives, has said that the program began in the 1980s on a day when he was discussing a company history with the TI chairman. The chairman led him into the office of a former director to show him that person's records, only to find that they had already been disposed of. According to Cantelon, the chairman then returned to his office, "called somebody and said, 'You talk to this guy Cantelon; we're getting archives.'"[1]

History Associates did indeed establish an Archives for Texas Instruments in the 1980s and hired and trained a full-time staff member to operate it. By 1998 the collection consisted of about 1,000 linear feet of records stretching from the 1940s to the 1990s. However, they didn't include R&D records. And in 1998 the archives was suddenly closed, apparently as part of a cost cutting initiative. When we conducted a site visit at TI in 2003, the archives was in locked storage and was inaccessible, and we were concerned that the collection would be lost. Instead, in 2005, TI transferred the entire collection to the Special Collections Department at Southern Methodist University, along with $200,000 to prepare the collection for research use. SMU's Special Collections is one of the academic archives that is focusing on business history, and the director of the department told us that they are interested in acquiring other major business collections.[2]

Like other corporate repositories, the IBM Archives has traced the ups and downs of the company, and for a while during the early 1990s it appeared that the archives would be closed. IBM included an "archives" component in its records management program as early as 1962 and hired a corporate archivist in 1964, but a formal Corporate Archives Department was not established for another ten years. By the early 1990s the program seemed moribund, but late in the decade the company began investing more in the archives. When we did a site visit in early 2003, it had an active program with five IBM employees and several contract workers.

The mission of the IBM corporate archives today is to preserve material for the company's long-term legal business and historical needs. The latter category is largely based on the archives experience in answering reference questions. The IBM Archives does not have a formal administrative connection with the records management system, so the transfer of records to the archives depends primarily on selections by the archivist. At the time of the visit, the archives had negotiated with the Records Management program to transfer press releases, publications and other communications and related materials to the archives when they become inactive. Beyond that, marketing and advertising hold their own "proto-archives" and the corporate archives is negotiating to acquire some of these materials. In addition, there are a couple R&D records categories that are listed as "archival" on the company's records retention schedule. That is, they go first to the records management program for a designated number of years and then are transferred to the archives. These include records of the senior vice president for research. In 2001, a new category of records was added to the archives side of the list—the laboratory notebooks of the 60 or so research fellows at IBM. Notebooks in general are preserved for 20 years by the records management program and are destroyed after that, but the notebooks of fellows are now scheduled for permanent preservation. If a non-fellow researcher thinks his/her notebook is a valuable resource they can contact the archives to have it preserved. However, collecting lab notebooks at IBM is necessarily becoming a retrospective process, since it is one of the companies that no longer requires them.

The IBM Archives is one of only two archives programs that we encountered that routinely preserves any laboratory notebooks. Its work to preserve the records of the vice president for research is more typical of some of the other archival programs, and it also holds the papers and research files of two of the Watson Laboratory's most distinguished physicists, Rolf Landauer and Richard Garwin.[3]

Unlike a number of the companies that we visited, IBM Watson Lab's technical library has virtually no organizational connection with either the archives or records management, and it has no historical functions. It doesn't collect or maintain any technical reports or laboratory notebooks.[4] Like nearly all the companies that we visited, IBM has sharply reduced the number of libraries that the company maintains and has reduced the number of staff in the programs that have survived, including the Watson Laboratory's technical library.

Two of the archives, Corning and Ford, are responsible for records management as well as archives, which allows them to take a "life cycle" approach. This provides for the control of records from creation through disposition, and if used properly it means that the destiny of records for either permanent preservation or destruction is decided early on. However, it applies only to the activities that the archives takes responsibility for documenting.

Corning's Sullivan Park Laboratory has a Knowledge and Information Management Organization that shares responsibility with the Corning Archives for preserving R&D records. The archives was started in 1972, and the archivist told us that:

> The Corporate Archives program was developed because … the founding family has consistently had members in upper management positions, including the [current] CEO. … Since they were the founding family of the company, it was just natural for them to want to be able to preserve the documentation of the corporation, so they were very much in favor of starting a corporate archives program.

The mission of the Corning corporate archives is to acquire and preserve records of a historical nature to the corporation, and it has a small collection of early notebooks, including the recipe book of the son of the founder, containing both chemical formulations and food recipes. Beyond this, our interviewees reported that correspondence and some working papers of Corning fellows would go into the archives, although their laboratory notebooks and reports would remain permanently in the technical library.[5]

Corning's Knowledge and Information Management Organization contains the technical library, called the Technical Information Center. Although other Corning libraries have closed, the Knowledge and Information Organization remains strong and now serves as both the technical and the corporate library. It reflects the company's concern for its heritage and has primary responsibility for documenting science and technology at Corning. It maintains a lab notebook collection going back to the early 1900s—around 1917—and about 30,000 internal technical reports going back to 1946, when they were initiated.[6] Further, the library has created extensive databases as well as the Developed Technology Archive, which adds a new dimension to documenting the process of R&D. In the latter, the Information Management Organization staff videotaped interviews with:

> A scientist or an engineer with the artifact, have them talk about the artifact—because no matter how much they write about it, actually physically having them hold the artifact or whatever and describe it is far more valuable, because they just stream of consciousness, it just comes forth.

In addition to the archives and knowledge management programs at Corning Inc., physicists and other employees have the option of donating their papers to the Rakow Library at the independent Corning Museum of Glass.

Ford Motor Company began its archives in 1951 while planning for its 50th anniversary. The Archives has followed the ups and downs of the company's economy and administrations since. In the early 1960s funding slowed and a decision was made to destroy some of Ford's more controversial records. However, the destruction was halted when one of the archivists complained, and the corporate archives transferred the records to the Henry Ford Museum, which had earlier received from Ford records of other automotive companies. Three of the remaining archivists transferred as well. The Industrial Archives, as Ford's archives was called between 1964 and the mid 1990s, remained largely inactive until preparations for Ford's centennial began in the mid 1990s. When a new archives director arrived in 1996, the Ford Industrial Archives and the Henry Ford Museum each held about 10,000 cubic feet of records. Some 70% of the research requests were from scholars and academics outside the company. The Industrial Archives had not been systematically collecting product literature, sales literature and other typical mainstays of a corporate archive.

Since 1996, product literature has been the focus of the collection. The Ford Archives is now part of Ford's Global Information Management, which includes the archives and records management programs. The Archives concentrates on records supporting marketing, public relations and legal research requests, because those three groups most use the archive's services. Because the archives/records management director has implemented and enforced annual records management audits as part of individual performance reviews, Ford is one of the two companies in the survey that has the most complete compliance with its record management program. All of the physicists and managers whom we interviewed at Ford were familiar with the company's records management program. This was not true at many other companies that we visited. Ford

Global Information Management establishes the retention schedule for R&D records, but the retention periods are medium term and carried out by the Research Information Services Group, which includes the technical library.[7] Laboratory notebooks are distributed and returned to the library when completed but are not kept permanently. The same is true of technical reports.[8]

Lucent Technologies' predecessor, AT&T Bell Telephone Laboratories, boasted the largest corporate archives in the U.S. at the time that Lucent was spun off from AT&T. It contained over 50,000 laboratory notebooks and 70,000 volumes of project files associated with research and development. In fact, the AT&T Bell Labs archives, like the laboratory itself, rivaled the best funded of academic operations. At the time of the spinoff, the AT&T Archives kept the pre-1996 laboratory records, and one member of the archives staff moved to Lucent to create an archives that would document the new company from the beginning. As AT&T Corporation has declined during the past decade, there have been fears that the AT&T Archives would close. When SBC Communications, Inc., bought AT&T in 2005, some newspapers reported that the archives might be destroyed. However, the new company has maintained the existing collection, which had one staff member when we did a site in December 2006. And they were still accessioning at least occasional retrospective materials that documented the old Bell Telephone Laboratories.[9]

The Lucent Archives had five staff at one time and still had two people when we visited in December 2006, despite the sharp downturn in the company's profits since the late 1990s. Like IBM, Lucent's archive has a relatively tenuous relationship with its Records Management program, but again like IBM it does collect the laboratory notebooks of fellows. Records going through the records management program are "tagged" if the archives has an interest in them; tagging allows the archives to review those records when they come up for destruction. Most of the archives' acquisitions come as a result of the archivist networking with various corporate divisions, including personal contacts with the international divisions. The records that the archives collects is ultimately determined by the archivist individually. While records management feeds material for archival review, collections are as likely to be the result of the archivist requesting reviews when someone retires. Records the archivist pursues include biographies of executives ranked vice president or above, papers of Bell Labs fellows, product brochures and technical information and various artifacts and memorabilia. Lucent's archives serves business functions by doing research for legal, marketing and public relations.[10]

When Agilent was spun off from HP in 1999, the former HP archivist went with the new company, which pursues the test and measurement side of HP's former portfolio. Today "the Agilent History Center and Archives preserves materials that document the founding, growth, development, organization, management and achievements of the company."[11] While initially a part of Agilent, it is now a branch of the Agilent Foundation. The program contains the papers of HP founders William Hewlett and David Packard, the papers of some other top executives, and includes displays of HP/Agilent memorabilia and products. In an interview in 1999, just before the spin off, the archivist, Karen Lewis, an experienced professional with a background in academic archives, said that the HP Archives provided an important "heritage" function, working to convey both to customers and employees the original entrepreneurial spirit of what is now a major Fortune 500 business. She estimated that she spent 80% of her time in marketing, giving lectures and tours on company history to selected high-level visiting groups and staff. The status of the HP and Agilent archives are greatly enhanced by Lewis's role in the writing of David Packard's book, *The HP Way*. The holdings of the Agilent archives includes "annual reports, product catalogs, and company publications, such as the first weekly employee newsletter … visual collections that illustrate products, plants, activities and employees from 1939 to the present; and over one hundred interviews with former executives, scientists, engineers, sales people and office and factory workers." The largest component includes "the records of top-level planners, decision makers and scientists. This material is regularly transferred to the History Center's Archives for permanent preservation."[12]

Documenting the work of individual scientists at Agilent, however, as at Corning and Ford is the responsibility of the technical library/records management program. In a recent article, Cindy Alfieri, Global Manager of the Agilent Library, wrote that "laboratory notebooks, equipment manuals, application notes and technical reports … are the main archival documents that the library at Agilent hunts down … so that future researchers will have access to this trove of information." She added that "Nowadays this level of commitment is required in order to save materials before they are unthinkingly tossed out when people change jobs, office locations or employers. Part of the commitment involves educating people on the importance of retention. . . ." For many years HP had an informal process for maintaining lab notebooks, but it's especially noteworthy that the Library was charged by the legal department with creating a systematic and consistent program in 1995. Today the "library purchases the notebooks for the company, disseminates them and obtains them back for preservation." Like a number of other records programs, Agilent has recently investigated the prospect of moving from traditional print format to electronic lab notebooks, but they decided that the staff is not ready for the move. The exception is their bioinformatics group, which "does maintain digital notebooks … because of the large body of digital data they capture to document their experiments."[13]

The Xerox archives appear to exist in large part as the result of strong personalities—long-term employees who have assumed responsibility for the program and have been strong champions for the value of the company's history. Today the archives maintains its existence through serving other departments, especially public relations and legal. The program began in the 1970s. When Carl Elsberry took over the archives it became part of Records Management, and he became well known in the company for taking classic Xerox machines to trade shows. When Elsberry retired in 1998, the archives was turned over by a long-time Library indexer, primarily to catalog the collection and, she believed, to close it down. For her, the collection quickly became a passion. She said,

> I think it's a great collection and … I press so much for it and raise the level of awareness and value to a point where I think those that I work with really begin to recognize the value of getting the collection organized and they allow me to do that full-time.

The Archives contains primarily product documentation, including "service manuals, user manuals, sales files. … We can date Xerox machines from when they went out the door." She added that the legal department uses the resources of the archives and is a staunch supporter, as well as public relations.

The Xerox archivist added that legal records are held by Records Management, which in turn is part of Xerox's Technical Information Center"[14]. The Center has one of the more integrated records management systems that we encountered. While the Library's staff was reduced by half, from sixteen to eight, in 2000 they were able to maintain a strong core program by cutting off ancillary services like designing web sites for other divisions and providing editorial services. The Library has had long-term responsibility for maintaining the company's intellectual property in the form of laboratory notebooks and technical reports. These date back to those of Chester Carlson, the inventor of xerography. Technical reports and laboratory notebooks are kept both in hard copy and duplicates. Technical reports from 1988 forward are duplicated as PDFs; lab notebooks are still microfilmed as was true for technical reports before 1988. The Records Management program has a comprehensive records retention and disposition schedule based on periodic records audits, and the Information Center maintains extensive databases and has moved much of the technical records to an electronic format.

Xerox's Technical Information Center had begun looking at electronic records management tools a few months before our site visit in 2003. Like most other large companies, Xerox began using electronic information systems in the 1970s and over time more and more information is created digitally. After 2000 they developed a new database management system integrated with Docushare that became a document management repository that could handle electronic records from the experimental data stage through product development. However, from a preservation point of view the problem with Docushare is that it's not a records management tool. To exist within the Information Center as a document, a record has to be copied off Docushare, either in print form or on a CD. At the time of our visit, they were beginning to investigate systems that would integrate the company's existing database management system with the records management system. While the staff member we talked with about this process emphasized that Xerox is just beginning to look at digital records management, he said that in talking with peers at other large companies he felt sure that they were ahead of most others.[15]

In addition to the six companies that maintain in-house archives programs, several others either had or were planning to transfer inactive records to public or private archives. These now total five of the companies in the study. Three companies had transferred records in the past. General Electric had transferred 3,700 cubic feet of materials consisting mostly of internal publications and 1.5 million photos to the Schenectady Museum in 1997. 3M transferred a much smaller collection, about 100 linear feet, of company records to the Minnesota Historical Society after its 75th anniversary in 1977. These two collections have remained largely static after the original donations, and the 3M collection doesn't include records of individual scientists or engineers. In the 1980s, Eastman Kodak donated a large collection of photographic materials to the George Eastman House, and when we visited in 2003, they were planning to donate the remainder of their collection to the University of Rochester. Kodak had an informal archives program:

> Over time our organization has had some archival materials that the company has had for long periods of time, and there have been efforts to put together some kind of formal archives…, but ultimately the support for that was not there. So the materials have been primarily donated to other institutions. …[16]

Other collections, for example what was once known as Kodak's "patent museum," have been shifted from the library to various business units to preserve them for use within the company. As of our interview in June 2003, the company had three permanent collections—research notebooks, technical reports and patents. One R&D manager said that "we have a huge archive that is almost inaccessible because of its size."[17] Kodak transferred a large body of records to the University of Rochester the year after our visit, although these don't include the three permanent collections that document research and remain at the company.

Exxon-Mobil had announced that they were donating their archival collection to the Center for American History at the University of Texas-Austin shortly before our 2003 site visit, along with $300,000 to preserve the collection. The collection, which is made up of about 2,000 linear feet of records and over a million photos, comprised primarily of the former Mobil historical collection, was transferred to the university in 2004. In addition to the $300,000 gift, the company is funding an archivist and assistant archivist through 2010 to process the collection and put finding aids online. At this point, a partial finding aid is on the university website: http://www.lib.utexas.edu/taro/utcah/00352/cah-00352.html#did . These records, however, contain no files of individual scientists or engineers. Beyond the usual upper level R&D records, the files contain a small collection of research materials for an unpublished book, *The Leading Edge*, on research at Exxon that was proposed in the late 1970s, and some technical news releases.

Exxon Mobil has moved to an electronic records system for most of its records. However, records that need to be available permanently, which they defined as 50 to 100 years down the road, are kept in paper format. Exxon uses Globalshare, a Lotus Notes product that is an electronic storage system; it allows research groups to share and comment on information. Anyone who is a member of the group can submit documents ranging from PowerPoint slides to reports or a PDF file. Exxon scientists, however, didn't consider PowerPoint presentations to be an "archival medium" because most PowerPoint presentations don't capture details that would make up a scientific paper. Exxon preserves lab notebooks permanently.[18]

As mentioned earlier, Texas Instruments transferred their archives, which they had closed in 1998, to Southern Methodist University in 2005, along with $200,000 to support it. The original Archives has been transferred intact, and the former TI archivist is currently preparing it for research use at its new home. However, the Archives has never contained R&D records. The decision to transfer the archives, according to one of the people involved, appears to have been made by a top company officer on the spur of the moment, much as TI created the collection in the first place 20 years earlier. Texas Instruments is the only one of the 15 companies that has closed its technical library. The lone surviving library at TI is a one-person law library.[19]

A number of the companies that don't have archives are preserving technical reports and laboratory notebooks permanently in their technical libraries. However, none of these libraries are preserving general historical records, including the records of top-level R&D officials and high-level summaries like laboratory reports. These appear to be the special purview of archives in the corporate world. This is a significant omission in documenting R&D operations as whole. To highlight the programs of some these libraries:

The 3M technical library was one of the best organized programs that we visited, and since 1997 it has become the repository for selected records, including lab notebooks, records of invention, technical reports, videotapes of sponsored seminars and symposia, and since 2003 voice over PowerPoints. However, 3M had started a major reorganization the week before we visited, and the future of the library and, in fact of the library director's job, was unclear.[20]

GE has restructured its libraries into "Knowledge Centers" and they maintain technical reports and collect PowerPoint presentations within the company, as well as performing traditional library functions. And the Kodak InfoSource center collects formal technical reports, invention reports, patent applications, and project reports.

The Honeywell Library provides an interesting example of the unintended results of change. It had traditionally served as the means of promoting records management policy among the R&D staff and had transferred notebooks and other records to the company's records management program, where they were scheduled for permanent retention. The librarians reported that they had also served informally to link up scientists who were doing research on similar topics with one another. However, the library and the laboratory, which had been housed in the same building, moved to separate locations a few years before our site visit in 2005. Now the librarians said that they had lost their informal contacts with the R&D staff. One result was that the records management schedule, which specified laboratory notebooks and research reports for permanent preservation, had fallen into disuse, and nearly all the physicists that we talked with said that they didn't know of any means of preserving their records.[21]

Like other companies, Lockheed is grappling with reducing the size of libraries. One interviewee told us "Our documentation, I think, is our weakness … because they're reducing the size of our library by 80%. … They're saying not to worry, because it's all on microfiche. And I said, 'It's not.' Part of the tension is between technical management and the finance and business management. …"[22]

Raytheon, we were told "has always had libraries" back to the early 1940s, and every major IDS location still maintains a library. However, automation and more electronic resources have resulted in a reduction in staff. Currently all libraries have a staff of one, except for one that has two staff. Mergers in the mid 1990s appear to have changed the company's attitude towards preservation of the company history. We were told that "Since we've merged, it seems like the emphasis is on the new Raytheon, and they don't want to talk about the old Raytheon." Prior to the merger with Hughes, the libraries would have at least one copy of every proposal that went out for the facility the library served. Called technical memos, they were frequently used. After the merger however it became “no, we don’t do that anymore.” Similarly, the use of notebooks is in decline. “It’s been dying out over the last few years."[23]

At General Atomics records management is responsible for the Document Center, which preserves all GA reports. GA reports are all the contract deliverables to a customer, and they are retained permanently. They must be properly formatted and approved up through the VP of the initiating organization before they are sent outside the company.[24] Documents created since 1995 are formatted in PDF format and stored using a program called Nirvanna created by a division of General Atomics.

Endnotes

[1] "We're Getting Archives," *HAIpoints*, Spring 2006, 2.
[2] Meeting with Russell Martin, Director, SMU Special Collections, and Ann Howell, archivist, September 13, 2007.
[3] Anonymous interview, March 2003.
[4] Anonymous interview, March 2003.
[5] Anonymous interview, May 2003.
[6] Anonymous interview, May 2003.
[7] Anonymous interview, June 2007.
[8] Anonymous interview, June 2007.
[9]For a recent description of the new AT&T Corporation's archives, see: http://www.aip.org/history/newsletter/spring2007/att.html.
[10] Anonymous interview, December 2006.
[11] http://www.agilent.com/about/companyinfo/history/index.html?cmpid=4491.
[12] Karen Lewis, "Preserving the History and Heritage of Agilent Technologies, Part II," *AIP History Newsletter, Spring* 2007.
[13] Cindy Alfieri, "Preserving the History and Heritage of Agilent Technologies, Part I; The Meaning of 'Priceless' at Agilent," AIP History Newsletter, Fall 2006. Anonymous interview, Agilent, 2006.
[14] Anonymous interview, April 2003.
[15] Anonymous interviews, April 2003.
[16] Anonymous interview, June 2003.
[17] John Spoonhower interview by Thomas Lassman and R. Joseph Anderson, Kodak Research Laboratories, June 9, 2003.
[18] Anonymous interview, November 2003.
[19] Anonymous interview, October 2003.
[20] Anonymous interview, September 2003.
[21] *Honeywell Auditable Records Compliance Policy*, 2000.
[22] Malcolm O'Neill interview by R. Joseph Anderson and Orville R. Butler, Lockheed Martin Headquarters, November 11, 2005.
[23] Mark Baldwin interview by Orville R. Butler, Raytheon IDS, January 24, 2007.
[24] Anonymous interview, February 2006.