Chapter 2

Federal Scientific and Technical Information and the U.S. Competitive Edge

The drumbeat of political, economic, and environmental change around the world presents the United States with perhaps its greatest challenge since World War II. The global society is more competitive with respect to scientific and technological achievement, educational attainment, market development, and political leadership in addressing international issues. This Special Report examines in detail one key element in restoring U.S. competitive strength-the role of scientific and technical information (STI) developed by or for the Federal Government.

The importance of STI stems from its critical role in all phases of the innovation process. These include education, basic research, applied research and development, product development and manufacturing, and the application of science and technology to meet the needs in the commercial, not-for-profit, and governmental markets.

STI and Science and Technology Policy

STI policy is a component of overall Federal science and technology (S&T) policy. The latter includes the range of Federal actions that can influence the conduct of U.S. research and development (R&D) and conversion of R&D results into products and services to satisfy domestic needs and compete with foreign suppliers. Federal S&T policy is diverse, and includes: direct Federal finding (e.g., for basic research); the conduct of research in Federal laboratories; tax incentives for private sector R&D (e.g., accelerated depreciation and tax credits for technology investments); and rules or guidelines to waive antitrust laws for industry R&D consortia, among others; as well as policies and actions for collecting and disseminating STI.

This Special Report focuses primarily on the STI component of Federal science and technology policy. Related OTA studies address other aspects of S&T policy.[1] STI is an indispensable part of the R&D infrastructure. But more than that, it is a national asset that can contribute to strengthening the technological foundation of the U.S. economy. Debates may rage over the role of the Federal Government in promoting industrial competitiveness. But clearly it is incumbent on the government to improve the STI base on which many public and private R&D decisions are made. The challenge is to help STI more fully serve national priorities.

STI frequently has been lost in the broader debates over: U.S. technology policy; the role of science advice in the White House; and, in recent years, the need for and shape of a national information policy.[2] During the 1980s, the case for STI has been bolstered by considerable research (discussed later in this chapter) that has documented the role of STI in priming the pump of R&D and innovation. STI is, indeed, at the heart of the process by which science generates new ideas that in turn fuel technological innovation. The concern over U.S. competitiveness gives new impetus to the need for a sound STI policy.

Discussions of U.S. competitiveness typically are dominated by the international economic dimension, i.e., the ability of U.S. companies to compete

[1] See the ongoing U.S. Congress, Office of Technology Assessment studies, "Basic Research for the 1990s," scheduled for completion in winter 1991, and "InformationResearch and Technology: High Performance Computing and Networking for Science," scheduled for completion in fall 1990. Also see, for example, Office of Technology Assessment, The Regulatory Environment of Science, OTA-TM-SET-34 (Washington, DC: U.S. Government Printing Office, February 1986); Technology and the American Economic Transition: Choices for the Future, OTA-TET-283 (Washington DC: U.S. Government Printing Office, May 1988); Educating Scientists and Engineers: Grade School to Grad School, OTA-SET-377 (Washington DC: U.S. Government Printing Office, June 1988); Holding the Edge: Maintaining the Defense Technology Base, OTA-ISC-421 (Washington DC: U.S. Government Printing Office, April 1989); High Performance Computing & Networking for Science, OTA-BP-CIT-59 (Washington DC: U.S. Government Printing Office, September 1989); Computer Software and Intellectual Property, OTA-BP-CIT-61 (Washington DC: U.S. Gov ernment Printing Office, Much 1990); and Making Things Better; Competing In Manufacturing, OTA-HE-443 (Washington DC: U.S. Government Printing Office, February 1990).

[2] See, for example, J.M. Logsdon, "Toward a New Policy for Technology: The Outline Emerges," Technology Review, October/November 1972, pp. 36-42; U.S. Department of Commerce, Office of the Assistant Secretary for Science and Technology, U.S. Technology Policy: A Draft Study (Washington, DC: National Technical Information Service, March 1977); U.S. Congress, Office of Technology Assessment Computer-Based National Information Systems: Technology and Public Policy Issues, OTA-CIT-146 (Washington DC: U.S. Government Printing Office, October 1981); C.R. McClure and P. Hernon, United States Scientific and Technical Information: Views and Perspectives (Norwood, NJ: Ablex Publishing Corp., 1989).

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effectively in the international marketplace. STI is multidimensional and involves a "life cycle' approach to competition ranging from education to research to manufacturing to marketing and public policy. When viewed in a total competitive context, STI is the backbone of our competitive edge.

STI is linked with several national goals. STI resulting from Federal R&D is intended to promote the advancement of scientific knowledge and technical applications of that knowledge. It also serves other national goals, including: improving the ability of U.S. industrial firms to compete in the international economy; strengthening the U.S. defense and civilian technology base; improving U.S. science and engineering education; promoting international cooperation on global science and technology-related problems; and enhancing the free flow of STI required by an open, democratic society.

America's ability to achieve these national goals in part through STI has been limited by our inability to clearly define the contribution of STI to these goals and to reconcile the conflicts over competing goals that inevitably arise. The policy framework for STI dissemination must recognize and spell out the role of STI at each stage of education, research, and application. For example, STI about solar photovoltaic energy can be structured in terms of what is needed for: educating future solar energy scientists and engineers; supporting basic research on the physics and electronics of photovoltaic energy; facilitating applied research on photovoltaic cells; enhancing the development of prototype and commercial photovoltaic energy systems, and the manufacturing technology for production of such systems; encouraging the integration of photovoltaics into U.S. commercial and defense energy applications; and informing the national and international debate on alternative energy and environmental policies.

The U.S. competitive challenge is epitomized by the so-called "technology-intensive' industrial sectors, such as computers, telecommunications, electrical machinery, instruments, chemicals, and transportation. These sectors have been the mainstays of the U.S. post-World War II economy, due to high rates of growth in real output, productivity, and employment, and for many years contributed to a positive trade balance. Recently, even the strongest U.S. industrial sectors have come under intensified competition. This is due in part to the rise of the global economy and dominance of multinational companies (that operate across national boundaries), the continuing Federal budget deficit and negative trade balance and resulting effects on international monetary exchange rates, and the partially offsetting growth of the service sectors (where the United States competes strongly in some areas, notably information services). But the new competitive realities have spurred attention to other root causes.[3]

In a world of rapid technological change, successful competition is driven as much by the information skills of the work force and by the timing of information access, as it is by the brute intellectual, financial, and natural resources of the competitors. Scientific and technical advancements are information-intensive, and those who know how to obtain and use STI will have a competitive edge-whether the competition is over market share or over intellectual leadership on global issues.

In this context, the role of electronic technologies takes on significance, since the generation, location,

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[3]For a comprehensive analysis, see U.S. Congress, Office of Technology Assessment, *Technology and the American* Economic Transition: Choices for the Future, OTA-TET-283 (Washington DC: U.S. Government Printing Office, May 1988); and OTA, International Competition *in* Services, OTA-ITE-328 (Washington DC: U.S. Government Printing Office, July 1987).

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and retrieval of STI can be vastly speeded up.[4] STI users need to be better educated about how Federal (and other) STI may help, how and where Federal (and other) STI maybe accessed, and use of the tools that facilitate access (e.g., online databases, compact optical disks, and bibliographic and search and retrieval software). And science agency managers need to do a better job at including STI dissemination and use as integral parts of agency R&D programs.

STI and Science Education

Science and technical education is the foundation for the technological and economic competitive posture of the United States. Congress in enacting the "Education and Training for a Competitive America Act of 1988" noted:[5]

- "our [Nation's] standing in the international marketplace is being further eroded by the presence in the workforce of millions of Americans who are functionally or technologically illiterate or who lack the mathematics, science, foreign language, or vocational skills needed to adapt to the structural changes in the global economy;
- ''our competitive position is also being eroded by declines in the number of students taking advanced courses in mathematics, science, and foreign languages and by the lack of modern technical and laboratory equipment in our educational institutions;
- "restoring our competitiveness and enhancing our productivity will require that all workers possess basic educational skills and that many others possess highly specific skills in mathematics, science, foreign languages, and vocational areas. "

Recent OTA studies have identified a wide range of actions to improve science education: upgrade the quality of elementary, secondary, and higher education with respect to science and engineering; increase student interest in science and engineering; and expand the number of science and engineering students (and ultimately the pool of trained scientists and engineers).[6]

Several of these actions relate directly to Federal STI. For example, OTA found that "hands-on" computer-based science learning can increase student interest in the subject matter and enhance student learning. OTA also noted the growing role of computer-based science in science museums, science centers, and science fairs around the country. Overall, availability of Federal STI in low-cost, user-friendly electronic formats could add an important dimension to computer-based mathematics, science, and engineering education. School libraries can serve as a focal point for teacher and student training in the use of online and compact optical disk media, and can provide a shared computer resource available to support the science curriculum.[7] This could be an extension of the role already performed by library staff at many college and university libraries and at some of the larger and better-funded public libraries. In general, strong library media programs at the elementary and secondary levels

[4] See, for example, J. Bortnick and N.R. Miller, *The Impact of Information* Technology on Science (Washington, DC: Congressional Research Service, July 1985); National Academy of Sciences, Committee on Science, Engineering, and Public Policy, Information Technology and the Conduct *of Research* (Washington, DC: National Academy Press, 1989); and U.S. Congress, Office of Technology Assessment, High *Performance* Computing and *Networking* for Science, OTA-BP-CIT-59 (Washington DC: U.S. Government Printing Office, September 1989).

[5] Public Law 100-418, the "Omnibus Trade and Competitiveness Act of 1988," 100th Cong., 2d sess., Aug. 23, 1988, Title VI-Education and Training for American Competitiveness, sec. 6002(a) (3-5).

[6] See U.S. Congress, Office of Technology Assessment, *Educating* Scientists and Engineers: Grade *School* to *Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988); Power *On!* New Tools for Teaching and Learning, OTA-SET-379 (Washington DC: U.S. Government Printing Office, September 1988); *Elementary* and *Secondary* Education for Science and Engineering, OTA-TM-SET-41 (Washington, DC: U.S. Government Printing Office, December 1988); and Higher Education for Science and Engineering, OTA-BP-SET-52 (Washington, DC: U.S. Government Printing Office, March 1989).

[7] See, for example, J.W. Leisner, ''Learning at Risk: School Library Media Programs in an Information World," School *Library* Media Quarterly, Fall 1985, pp. 11-20; B.K. Stripling, ''Rethinking the School Library: A Practitioner's Perspective, " School Library Media Quarterly, Spring 1989, pp. 136-139.

School libraries can serve as a focal point for teacher and student training in the use of online and compact optical disk media, and can provide a shared computer resource available to support the science curriculum.

correlate with improved student skills in use of library and information resources, and in student achievement both overall and in specific science subjects.[8]

Pilot projects have shown that junior and senior high school students can readily handle computer-based bibliographic searches as an aid to course-work.[9] Teachers concluded that database searching enhanced student thinking and research skills. On-line searching was also used to augment the science education curriculum. For example, students conducted online searches on topics such as the Armenian earthquake, space sickness, and the climatic effects of tropical deforestation.

Integrating STI access, retrieval, and use into science education at all levels could improve the research skills and productivity of U.S. scientists and engineers in the long term. Various studies have highlighted the "inadequate information gathering and management skills of the R&D community' and the lack of skills and/or motivation to use available bibliographic tools.[10] Electronic dissemination of Federal STI could assist in attacking this problem.

Improving the "information literacy" of U.S. scientists and engineers must go hand-in-hand with upgrading STI. Even the best STI system would fall short if the users lack the skills to search bibliographic databases, retrieve and manipulate data, and scan documents. In many fields of science and technology, STI developed by other countries is increasingly important. Foreign patents now account for about 50 percent of all U.S. patents. The number of foreign scientific journals and articles is growing much faster than those published in the United States.[11] U.S. researchers must learn to utilize foreign STI, while making better use of domestic STI. The experience with Japanese STI suggests that U.S. researchers are, by and large, not well-trained in foreign languages and, generally, in techniques for accessing and utilizing foreign STI, and largely fail to recognize the need for doing so.[12]

STI and Research and Development

The creation of new information and knowledge is the major objective of R&D. This information takes many forms: information from basic research on AIDS conducted by Federal laboratories; design and testing of prototype photovoltaic solar energy cells by the Department of Energy (DOE); or the synthesis of satellite data collected by the National Oceanic and Atmospheric Administration (NOAA) to improve understanding of the interaction of the atmosphere and oceans in climate change.

Scientists and engineers involved in R&D often spend between one-quarter and one-half of their time

[8] See J.C. Mancall, "An Overview of Research on the Impact of School Library Media Programs on Student Achievement" school *Library* Media Quarterly, Fall 1985, pp. 33-36.

[9] See, for example, M.H. Bailey, J. Wieman, J. Newman, and N. Motomatsu, Research Goes *to School II: How To Go Online to the* Information Databases (Olympia, WA: Know-Net Dissemination Project, 1985); and N. Motomatsu and J.A. Newman, Research Goes to *School III:* Going Online *With* Students (Olympia, WA: Office of the Superintendent of Public Instruction, 1986). In Australia, a recent survey identified 20 schools (2 primary and 18 secondary) using online systems "as a source of up-to-date information for teachers and students and as a means of helping students to acquire information skills." See L.A. Clyde and J. Kirk, "TheUse of Electronic Information Systems in Australian Schools: A Preliminary Survey," School Media *Library* Quarterly, Summer 1989, pp. 193-199. In the United States, the Oakland County (Michigan) School District has successfully piloted the use of online bibliographic databases available from a commercial vendor. Students, teachers, and administrators from the participating schools (3 junior high and 3 high schools) enthusiastically embraced online searching. See Oakland County Schools, Educational Resource Center, "Database Searching Pilot Project," Pontiac, MI, Nov. 9, 1989.

[10] See C.R. McClure, "Increasing Access to U.S. Scientific and Technological Information: Policy Implications, " ch. 12 in C.R. McClure and P. Hernon, United States Scientific and Technical Information Policies: Views and Perspectives (Norwood, NJ: Ablex Publishing Corp., 1989), pp. 319-354.

[11] See D.W. King, D.D. McDonald, and N.K. Roderer, *Scientific Journals in the United States: Their Production, Use, and Economics* (Stroudsburg, PA: Hutchinson Ross Publishing Co., 1981).

[12] See C.T. Hill, *Japanese Technical Information: Opportunities To Improve U.S. Access*, Report No. 87-818 (Washington, DC: Congressional Research Service, Oct. 13, 1987); C.T. Hill, "Federal Technical Information and U.S. Competitiveness: Needs, Opportunities, and Issues," Government Information Quarterly, vol. 6, No. 1, 1989, pp. 31-38.

on information-related activities that include both analyzing and reporting on one's own research and searching for and applying the research results of others. Researchers in most disciplines spend about 15 to 20 percent of their time just on reading the STI literature, including scholarly journal articles, conference proceedings, and technical reports.[13] Researchers also find relevant STI through participation in technical conferences and activities of professional and scientific societies, and through informal letters, meetings, conversations, and, recently, electronic mail and bulletin boards.

Roughly three-quarters of researchers access STI literature in order to apply other research findings to a current project and/or for professional development or current awareness of STI trends. About half of the researchers read the STI literature to help prepare an article, book, or report, and about two-fifths to help prepare a lecture or presentation .14 Not surprisingly, empirical research in a range of government and private-sector settings has found that reading STI is positively correlated with productivity (e.g., number of reports or publications written and presentations delivered) .15

DOE estimates that federally funded energy researchers spend, collectively, the equivalent of over $1 billion per year of their time on STI (out of an annual R&D budget of over $5 billion). This is split about equally between generating new STI (e.g., writing technical reports) and reading other STI (e.g., journal articles), and amounts to roughly one-fifth of the total DOE R&D budget. In addition, DOE spends about $250 million annually on STI information management, libraries, technical information centers, and other STI-related activities. If the DOE estimate is extrapolated to the entire Federal R&D effort, then Federal researchers spend roughly 12 billion dollars' worth of time each year on STI.

The Department of Defense (DoD) has not made comparable estimates. But assuming that the roughly

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180,000 scientists and engineers doing DoD-related research work spend an average of 10 hours per week on STI, the annual time investment is 144 million hours. If time is valued, conservatively, at $30 per hour, then DoD researchers spend at least $2.7 billion per year worth of their time on STI.[16] The actual figure is likely to be double or triple (e.g., $5 to $7 billion per year, which would be consistent with the DOE estimates), and even this would not include STI time spent in connection with DoD test, evaluation, maintenance, and operational activities.

This kind of investment in STI is essential to scientific advancement and technical innovation that are, in large measure, built on the cumulative knowledge base of the scientific and technical disciplines. Breakthroughs may come slowly or, on occasion, may occur quickly as a result of ground-breaking research, anew interdisciplinary synthesis, or a "paradigm shift" where the cumulative knowledge leads scientists to revise their basic hypotheses—e.g., with respect to the susceptibility of the Earth to global change, and the role of the oceans, land, glaciers and ice sheets, biota, and the atmosphere in climate change. Geology, glaciology, oceanography, and climatology are among the several scientific disciplines that benefit from and contribute to Federal R&D and STI. Likewise, rapid advances in our understanding of human health depend on the extensive exchange of STI among researchers in

[13] See N.K. Roderer, D.W. King, and S.E. Brouard, "The Use and Value of Defense Technical Information Center Products and Services,' contractor report prepared by King Research, Inc. for the Defense Technical Information Center, Mar. 31, 1983, p. 20 and references cited therein. Also see E.R. Siegel, "Transferof Information to Health Practitioners, "in B. Dervin and M.J. Voight (eds.), Progress in Communication Sciences, Vol. *III* (Norwood, NJ: Ablex Publishing Corp., 1982), pp. 311-334.

[14] See, for example, Roderer et al., op.cit., footnote 13, p. 34.

[15] King Research Inc. has obtained *similar* results for numerous Federal and private-sector organizations. For a summary, see J.M. Griffiths and D.W. King, "Evaluating the Performance and Effectiveness of Information Services," paper prepared for the Mid-Atlantic Chapter, Medical Library Association, Rockville, MD, 1989.

[16] 180,000 persons × 10 hours spent on STI/week × 50 weeks/year (assuming 2 weeks vacation) X $30/hour = $2.7 billion. DoD officials have confirmed the 180,000 persons as a reasonable estimate.

disciplines such as biology, physiology, psychology, medicine, and nutrition.

Improving the use of STI could increase the return on the Federal Government's substantial investment in R&D, which is currently about $65 billion per year and represents roughly one-half of the total U.S. investment in R&D. Assessing the value of information dissemination services and products, whether Federal or otherwise, is obviously difficult. One technique is to estimate the savings (benefits) resulting from using an STI service or product. Using this approach, each dollar spent on Federal STI dissemination generates an estimated direct benefit of at least $2 to $5 to users in the research community (e.g., in terms of time saved, duplications avoided, etc.) and on occasion can reach into the hundreds to thousands of dollars.[17] Online databases are especially highly leveraged. If the cost of originating the information is not included (presumably funded out of Federal R&D funds), some databases generate an estimated value (savings or benefit in the eyes of the user) of $15 to $25 for each dollar spent.[18] This helps explain why many online users readily pay $15 to $25 per hour for online access to government databases (and up to $150 to $200 per hour for commercial databases).

Users of technical reports from DOE's Office of Scientific and Technical Information indicate significant savings for each report used, and that about 75 percent of reports used yield some savings.[19] Some typical examples of specific savings are:

- A basic energy sciences researcher saved over $50,000 by obtaining STI that eliminated the need to do a complete design from scratch of a double-effect absorption cooling system.
- A health and environment researcher saved $5,000 through STI that mooted the requirement for certain tests on disposal of wastewater from coal conversion.
- A fusion researcher saved a person-year of effort through STI that summarized prior related research on ion beam propagation and focusing.
- A nuclear researcher saved $1,000 through STI that provided calculations-that would otherwise have had to be redone-on steam electronic plant construction.

The benefits and savings from effective use of Federal STI include:

- time saved in locating other researchers doing related work;
- time and money saved in minimizing duplication of research effort;
- new insights or breakthroughs resulting from more complete awareness of related research;
- new information not available elsewhere;
- better understanding of relevant Federal R&D directions; and
- time and money saved in writing research reports, papers, and articles.

Federal science agencies face a major challenge in managing the already immense and rapidly increasing volume of Federal STI so that it is accessible and useful to researchers. For example, over 200,000 new technical documents are generated each year as a result of Federal R&D, adding to the base of an estimated 4 million existing documents.[20] Satellite data and imagery are contributing to an STI explosion in the space and earth sciences. The total earth sciences data volume managed by Federal agencies (primarily NASA, USGS, and NOAA) is roughly 100,000 gigabytes.[21] The total volume is projected to increase by two orders of magnitude over the next 5 to 10 years to 10 million gigabytes (or 10,000

[17] See Roderer et al., op. cit., footnote 13; and D.W. King, J.M. Griffiths, N.K. Roderer, and R.R.V. Wiederkehr, "Value of the Energy Data Base," contractor report prepared by King Research, Inc. for the U.S. Department of Energy, Mar. 31, 1982.

[18] For a good summary of relevant research issues and results, see B.C. Carroll and D.W. King, ''Value of Information' *Drexel* Library Quarterly, vol. 21, No. 3, Summer 1985, pp. 39-60.

[19] Ibid. The average savings per report was $1,300 (1982 dollars).

[20] The Department of Energy (DOE) has generated a cumulative total of about 800,000 technical documents that are estimated to represent about one-fifth of the governmentwide total. The National Technical Information Service (NTIS) clearinghouse includes about 2 million technical reports, estimated to represent about one-half of the governmentwide total. DOE generates about 30,000 new technical documents each year, estimated to be 15 percent of the governmentwide total; NTIS adds about 65,000 new documents to its clearinghouse each year, estimated to represent about one-third of the governmentwide total. These estimates are for technical documents and articles published in the technical literature, but exclude papers delivered at technical conferences. For DOE, the annual volume of technical articles equals that of technical documents (about 15,000 each).

[21] One gigabyte is equivalent to the volume of information contained in about 450,0(X) double-spaced typed pages of text. One terabyte equals 1,000 gigabytes or 1 trillion bytes; 100,000 gigabytes equals 100 terabytes. The current and projected earth sciences data volumes are based on estimates by the Interagency Working Group on Data Management for Global Change.

terabytes). When launched in the late 1990s, NASA's Earth Observing System (EOS) will generate in a few months more data than the total U.S. archive of Landsat satellite data collected over the last 18 years.

Electronic technologies can help the Federal science agencies manage STI and ensure that Federal data and documents are made available to users in cost-effective, timely, and usable form. The potential for electronic STI dissemination is especially great because-whether data, documents, or directories to data or documents—it is generally well suited to electronic formats. Electronic dissemination makes it possible to provide STI to researchers informs that are more convenient to retrieve and easier to manipulate. This could enable many potential new kinds of research and analysis. (See the appendix for a detailed discussion of technological opportunities.)

STI and Product Development and Manufacturing

STI is also a key element in the transfer of technology from the laboratory to the production line. The aerospace industry is a case in point. It is supported by a substantial Federal R&D investment, it has close collaboration with Federal agencies (civilian and military), industry, and academia, and it has a tradition of aggressively using the results of Federal aerospace R&D in commercial applications. A recent survey of aerospace engineers sheds light on the dominant role of STI in an industry with a successful track record of commercialization and international competition.[22]

Ninety percent of the aerospace engineers identified technical communication as very important. On the average, respondents spend about 35 percent of their workweek communicating technical information to others and about 31 percent of their week working with technical information received from others. Based on a 40-hour workweek, they spend roughly 26 hours on STI-related activities, a finding consistent with other studies.[23] These engineers produce on the average 1.6 government technical reports and 1.9 other technical reports every 6 months and use roughly 52 technical reports (about half generated from Federal R&D) during that time.

The aerospace industry has been successful at commercial utilization of Federal R&D because, for many decades, both government and industry have recognized the importance of Federal R&D and the highly leveraged role of STI and technology transfer mechanisms in the commercialization process. The National Aeronautics and Space Administration (NASA) has long-established relationships with academia and industry to encourage the use of STI. NASA has established a network of Industrial Application Centers as part of its Technology Utilization Program. The centers provide technical information to industry so that aerospace technology can be used in commercial applications. The effectiveness of this approach is illustrated by these examples:[24]

- A Western Springs, Illinois, firm specializing in high-resolution, oblique, aerial photography requested that NERAC research the NASA database for available information on film and cameras. Using the technology provided by NERAC, the firm improved the quality of its aerial photographs, which now sell for upwards of $2,000 each.
- A New York firm designed a computer-controlled robot using NERAC technology from its NASA database. NERAC rapidly gathered information on robot off-line programming methodology so that the fro's R&D staff could implement the concept by using a microcomputer system and graphics display.
- A firm dedicated to the development and manufacturing of testing equipment requested that NERAC research noise control technology. The search identified technical information that led to the development of a very high-performance hearing protector (with over 34 dBA of insulation) that will be marketed for

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[22] T.E. Pinelli, M. Glassman, W.E. Oliu, and R.O. Barclay, *Technical Communications* in Aeronautics: Results of *an Exploratory Study*, NASA Technical Memorandum 101534, Part 1 (Hampton, VA: U.S. National Aeronautics and Space Administration, Langley Research Center, February 1989). The survey instrument was sent to 2,000 randomly selected aerospace scientists and engineers (from the membership of the American Institute of Aeronautics and Astronautics). The response rate was 30.3 percent (606 out of 2,000). The affiliations of respondents were distributed as follows: academic (7%); industry (62%); not-for-profit (3%); NASA (12%); other government (16%). The professional duties of the respondents were: research (20%); administration/management (24%); design/development (37%); teaching/academic (6%); marketing/sales (6%); and other (7%).

[23] See Pinelli et al., op. cit., footnote 22; R.M. Davis, Technical Writing: Its *Place in Engineering Curricula—A Survey of the Experience* and opinions of *Prominent* Engineers, Air Force Institute of Technology Technical Report 75-5 (Wright-Patterson Air Force Base, OH: September 1975).

[24] Provided by one of the oldest Industrial Application Centers, NERAC, Inc.

use on aircraft flight lines, in airports, at rifle/pistol ranges, etc.—anyplace where full noise protection is required.

- A firm designed a water distillation system using solar energy, based in part on technical information provided by NERAC. The concentration of the Sun's rays causes a thermal reaction which initiates a distillation process that results in water vaporization. The water vapor is distilled and collected as a usable product. The solar system is expected to provide low-cost, fresh water supplies to remote, arid, and coastal towns.

Engineers rely more on their own knowledge and contacts with colleagues and inhouse experts to solve technical problems than on technical reports, journals, libraries, technical information centers, or online technical information databases. The 1989 NASA survey of aeronautical engineers confined the same pattern revealed in numerous other studies—personal, informal sources take precedence over the more formal, organized information sources.[25]

Engineers are likely to continue to rely in the first instance on personal, informal information sources. But there are significant opportunities to improve the effectiveness of technical reports, libraries, information centers, and computerized databases. For example, at present, less than half of aerospace engineers (44 percent, based on the NASA survey[26]) use electronic databases at all, and less than half (46 percent[27]) use a library or technical information center more than once a month. When electronic databases are searched, about two-thirds of the engineers use intermediaries (e.g., reference librarians) to perform the search. Engineers are generally open to the use of new information technologies. The four technologies receiving the highest percentage of 'I don't use it, but may in the future' in the NASA survey are:[28]

- laser disk/videodisk/compact optical disk (65 percent);
- videoconferencing (62 percent);
- electronic bulletin boards (54 percent); and
- electronic networks (53 percent).

Data on physical and chemical properties of materials are another form of STI that is important to industrial technology. The technical design of automobiles through electronic equipment must comport with a wide range of so-called "standard reference data' on the basic properties of materials and industrial processes used in manufacturing. The accuracy of this data is essential. Engineers include a margin of safety in product and process designs, but if faulty design data are used, the product or process could fail under certain operating conditions.

The Federal Government plays a major role in developing, maintaining, and updating standard reference data. This is accomplished through research conducted in Federal laboratories, Federal support for university and industrial research, government-industry cooperative initiatives, and Federal participation in a wide range of professional and technical standards activities. Topics range from radiation chemistry to thermodynamics to metallurgy to electronic properties to microwave spectral data.[29]

Private-sector managers recognize that the "cost of not knowing' can be very high. Employees can work hard, but if they do not work ''smart, ' the result can be losses instead of profits-whether conducting research, competing for a Federal R&D contract, or selling a safe, reliable, and competitive product in the marketplace.

STI plays a crucial role in the commercialization process by which the results of Federal and private R&D are translated into marketable products. The challenge is to increase the return on the Federal

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[25] See Pinelli et al., op.cit., footnote 22, p. 56; T.J. Allen, Managing the Flow of Technology: Technology Transfer *and* the *Dissemination* of Technological Information Within the *R&D* Organization (Cambridge, MA: MIT Press, 1977); H.L. Shuchman, Information *Transfer* in Engineering (Glastonbury, CT: The Futures Group, 1981); S. Ballard, C.R. McClure, T.I. Adams, M.D. Levine, L. Ellison, T.E. James, Jr., L.L. Malysa, and M. Meo, Improving the Transfer and Use of *Scientific* and *Technical* Information: The Federal Role (Norman, OK: University of Oklahoma, Science and Public Policy Program, 1986).

[26] Pinelli et.al., op.cit., footnote 22, p. 66.

[27] Ibid., p. 65.

'Ibid., p. 73.

[29] The National Research Council's Numerical Data Advisory Board (recently renamed the Scientific and Technical Information Board) has issued many relevant reports. For references, see National Research Council, Numerical Data Advisory Board, Improving the Treatment of Scientific and Engineering Data Through Education (Washington DC: National Academy Press, 1986). Also see minutes of the Sept. 21, 1989, NDAB meeting available from C. Carter, staff director, NRC/NDAB, 2101 Constitution Ave., N. W., Washington, DC 20418.

R&D investment through more effective utilization of the STI resulting from Federal R&D. This can be achieved by several means, including: improving the usability of government technical reports (e.g., formats, indexing, electronic retrieval); strengthening the capabilities of libraries and information centers to meet STI needs; sharpening the skills of scientists and engineers in using these resources; and continually upgrading the ability of technology-enhanced STI systems (e.g., online, compact optical disk) to provide affordable, user-friendly search and retrieval service. This is a challenge demanding the combined efforts of government, industry, academia, and the broader scientific and technical community.

STI and International Leadership on Global Issues

Another part of the competitive edge—in addition to education, R&D, and commercialization-is the ability of the United States to provide international leadership on a wide range of global problems. Providing and exchanging STI are important components of such leadership. The challenge is to maintain and strengthen the open flow of relevant STI in the face of greatly intensified global economic competition.

The United States has substantial information assets, and these are being augmented by use of electronic avenues of dissemination. A case in point is the MEDLINE (MEDLARS--Medical Literature Analysis and Retrieval System-online) database developed by the National Library of Medicine and offered online by NLM and several commercial vendors to the U.S. and foreign medical communities. MEDLINE is used for a wide variety of patient care, research, teaching, and administrative purposes.

Surveys indicate that MEDLINE is having a significant effect on medical decisions .30 Physicians use MEDLINE information to select the most appropriate tests and diagnose a wide range of medical problems in order to prescribe a treatment plan. MEDLINE's successes are well-known.[31] For example, a pathologist examining a supposed 'wart'

STI plays a crucial role in the commercialization process by which the results of Federal and private R&D are translated into marketable products. The challenge is to increase the return on the Federal R&D investment through more effective utilization of the STI resulting from Federal R&D.

used MEDLINE to confirm a diagnosis of skin cancer (polypoid melanoma) and develop a treatment plan. A physician treating an adolescent patient who collapsed during a foot race used MEDLINE to rule out exercise-induced pancreatitis as a possible cause, and prescribed rest and abstinence from food (which worked). And a physician used MEDLINE to locate information in a Swiss journal about a new treatment for aplastic anemia.

Medical problems and research know no national boundaries, and the effectiveness of databases such as MEDLINE depends on international collaboration in the collection and exchange of medical information. Computerized databases have become essential to this process, with both NLM and private vendors making global electronic access possible. User-friendly microcomputers are bringing access to MEDLINE to the grassroots. In the United States, medical personnel can access MEDLINE using "Grateful Med," a search and retrieval software package developed by NLM and sold by the National Technical Information Service (NTIS) for $29.98 per copy. Grateful Med runs on IBM-compatible and Apple Macintosh personal computers.

Another area of intensive Federal information activity with significant international implications is geographic information. Computerized geographic information systems ("GIS") make it possible to access and manipulate large volumes of natural resource, environmental, geologic, and other spatially referenced data. A 1988 survey[32] identified 35

[30]S.R. Wilson, N. Starr-Schneidkraut, and M.D. Cooper, "Use of the Critical Incident Technique To Evaluate the Impact of MEDLINE," contractor report prepared by the American Institutes for Research for the National Library of Medicine, Bethesda, MD, Sept. 30, 1989.

[31]Ibid., see app. G, "Impact of the Information Obtained From MEDLINE on Medical Decision-Making.'

[32]Federal Interagency Coordinating Committee on Digital Cartography, Reports Working Group, *A Summary* of GIS Activities in the Federal Government, August 1988, pp. 10-12.

Federal agencies with GIS applications, including, for example: the Agency for International Development (famine early warning, forestry); U.S. Forest Service (forest planning, gypsy moth suppression, fire behavior modeling); Soil Conservation Service (soil survey database, river basin and watershed planning, farm and ranch conservation planning); Census Bureau (all 1990 Census activities); NOAA/ National Environmental Satellite Data Information Service (atlases showing geographic distribution of ice, drought, temperature, precipitation, sunshine, length of day, etc.); Bureau of Reclamation (land classification, irrigation monitoring, baseline habitat); and U.S. Geological Survey (earthquake hazard assessment, national mapping program, water quality monitoring). Transportation is another emerging area of major GIS application, especially with respect to renewing the U.S. surface and air transportation infrastructure.

GIS-based activities require much greater coordination among Federal, State, local, and international government agencies. While Federal agencies collect and/or develop a large amount of geographic information, State and local governments are among the heaviest users and also generate geographic information as well. The same is true for foreign governments and international intergovernmental bodies (e.g., the United Nations Environment Program and Food and Agriculture Organization). The range of international GIS applications is shown below:

1. Preparation of thematic maps, with data on the socioeconomic, demographic, soil, water, and other characteristics of defined geographic areas.
2. Preparation of base maps, including the plotting and revision of quadrangle maps, aeronautical charts, marine navigational charts, ocean surveys, and the like.
3. Preparation of terrain maps, including topographic, elevation, slope, relief, and perspective maps, among others.
4. Data display and analysis, including the presentation and manipulation of map data and the merging. and integrating of map databases.
5. Environmental assessment and monitoring, including the use of geographic information in preparing environmental impact assessments and studies of irrigation, pollution, soil conservation, flood potential, and the like.
6. Land and water resource planning and management, including site and road designs, farm, forest, and wetland surveys, habitat and water quality studies.
7. Mineral resource assessment, including geographic maps, fuel and resource inventories, and geologic hazard analyses.
8. Navigational systems, including air traffic control systems and flight simulators.[33]

The role of STI and its dissemination varies depending on the area of science or technology. Historically, the Federal Government has encouraged the open exchange of Federal STI as a foundation of science and technology. Until recently, access to STI has been restricted only in narrowly defined areas of national security. This has been especially true in areas such as medicine and the environment, where health and safety considerations are paramount. But even in these areas, the changing competitive environment has led to increased sensitivity about open, international access to Federal STI (e.g., with respect to its use in commercialization of biotechnology, medical drugs and devices, or environmental mitigation techniques).

Over the last decade or so, intensified international technical and economic competition has led to additional restrictions on access to federally sponsored STI. These restrictions are based primarily on reasons of national security, foreign policy, and international competitiveness. Electronic technologies speed the transfer of information on national and global scales. Concern over this rapid, uncontrolled dissemination has fueled a debate over restrictions on access to STI.

This debate involves the balancing of competing interests. For example, in the area of export controls, the need to protect against export of militarily sensitive technologies and technical data directly or indirectly to U.S. adversaries must be balanced with the need to minimize adverse effects on international scientific exchange and on international trade opportunities. In domestic technology transfer, the need to encourage the transfer of technology (and related technical data) from the Federal Government to the private sector must be balanced with the need to

[33] Ibid.

minimize restrictions on access to unclassified Federal STI and promote a competitive marketplace (even though foreign companies may also benefit). Thus, the short-term interest of a solar energy company conducting Federal R&D must be weighed in the context of the long-term development needs of the U.S. solar energy industry as a whole and the interests of information vendors and users (e.g., librarians, entrepreneurs, policy analysts) who thrive on the open exchange of Federal STI.

In light of the political, military, and economic changes occurring in Europe and the Soviet Union, perhaps U.S. policies limiting the open flow of Federal STI should be reevaluated. It maybe that the justifications for the restrictive approaches of the 1980s are less valid as the world reaches the last decade of the 20th century.[34] A key step in restoring the U.S. competitive edge is to build on the strengths of the U.S. governmental, academic, and commercial information sectors. Federal STI must play an important part in the overall U.S. competitiveness strategy.

STI and International Competitiveness: A Summation

On the one hand, the world is becoming much more competitive in political, economic, and technological terms. The moves toward political democracies and market-based economies will open up many new opportunities for U.S. firms trading overseas and for U.S. Government leadership on key international issues. However, these same opportunities will similarly be available to other nations. Markets and competition rely heavily on science, technology, and innovation.

Evidence shows that STI is very important to scientists, engineers, and managers in technology-intensive government agencies and industries.[35] Why? Because maintaining an information advantage is crucial to achieving a competitive edge. In the rapidly changing global marketplace of ideas and products, information has become an essential competitive resource-along with technology, capital, labor, and management.

The challenge for the United States is how to strengthen and deploy our own competitive STI assets. The Federal Government supports the largest R&D complex in the world, and generates the largest volume of STI. The United States has a strong educational and library infrastructure, and the U.S. commercial information industry is foremost in the world. Also, the United States is highly competitive in assembling the technical infrastructure (e.g., online and optical disk systems) necessary to deliver information products and services, including STI.

Yet the United States does not have an overall strategy to capitalize on these substantial assets, and to overcome its weaknesses, e.g., the training of scientists and engineers in STI search-and-retrieval skills, or the consideration of STI user's needs in science agency planning. To realize the potential of U.S. leadership in STI will require reaching a strong consensus on overall Federal STI policy.

The stakes are high, as measured by market size and private-sector and governmental activity:

- The Western European database services market is expected to double in the next 5 years, to over $7 billion, with the online portion projected to increase from 60 to 70 percent;
- The European Economic Community is sponsoring a wide range of pilot projects for the European information services market, including, for example, a multimedia atlas of the Mediterranean region on compact optical disk (that combines data, images, digital maps, and graphics on Mediterranean geography, agriculture, environment, and industry);
- Two private companies (one U. S., one foreign) are planning cooperative STI projects with the U.S.S.R. Academy of Sciences and State Committee for Science and Technology (including the establishment of training centers to teach STI online search skills to Soviet officials and scientists);

[34] The Federal Government is already reevaluating the need for controls on export of a variety of computer and telecommunications equipment and systems to the Eastern bloc; proposals to relax export restrictions are being discussed with the Coordinating Committee for Multilateral Export Controls (COCOM). Also see H.R. 4653, the "Export Facilitation Act of 1990," 101st Cong., 2d sess., Apr. 26, 1990, ordered to be reported by the House Committee on Foreign Affairs, May 10, 1990.

[35] For recent results on STI in the aerospace industry, see T.E. Pinelli, M. Glassman, R.O. Barclay, and W.E. Olin, *Technical Communication in Aeronautics: Results of an Exploratory Study-An Analysis of Managers' and Nonmanagers' Responses,* NASA Tech. Memo. 101625 (Hampton, VA: NASA Langley Research Center, August 1989), and *Technical Communication in Aeronautics: Results of an Exploratory Study-An Analysis of Profit Managers' and Nonprofit Managers' Responses,* NASA Tech. Memo. 101626 (Hampton, VA: NASA Langley Research Center, October 1989).

- U.S.-origin databases still dominate the information markets of the industrialized nations, but many (especially the EEC and Japan) have explicit strategies to develop their own domestic information industries.

Perhaps the single most important step the U.S. Government can take is to recognize the important role of STI in strengthening U.S. competitiveness. In the immediate post-World War II years, the commanding across-the-board lead in science and technology meant that we could directly control the creation and dissemination of STI and needed to pay scant attention to foreign STI. Now, U.S. science and technology are under competitive pressure in many areas, and the U.S. lead in STI is no longer secure. Other developed countries-such as Japan and the European Community-are targeting STI as a key element of a national strategy, and seem committed to aggressively develop their own STI capabilities.[36] The imperative for a reinvigorated U.S. STI strategy is strong. As summed up by Dr. Lewis M. Branscomb of the J.F. Kennedy School of Government at Harvard University:

Perhaps the single most important step the U.S. Government can take is to recognize the important role of STI in strengthening U.S. competitiveness.

> Most other industrial democracies take information policy very seriously as an element of science policy and of strategies for competitiveness. In the U. S., for reasons I have never fully understood, information policy is the stepchild of economic policy and has lost its place in science policy. We spend our efforts discussing what information to keep, sell, or give away. The better question is how to create it, acquire it, and use it.[37]

[36] See McClure and Hernon, op. cit., footnote 2.

[37] Statement of Lewis M. Branscomb, Director, Science, Technology, and Public Policy Program, J.F. Kennedy School of Government, Harvard University, before a hearing of the U.S. Senate Committee on the Judiciary, Subcommittee on Technology and the Law, Mar. 16, 1988. Dr. Branscomb formerly seined as Chief Scientist of the IBM Corp., and as Director of the Nationat Bureau of Standards.