USING SANDIA TECHNOLOGIES TO IMPROVE NATIONAL COMPETITIVENESS

Venkatesh Narayanamurti and Dan E. Arvizu

Sandia National Laboratories was established in 1945 to provide engineering support for the United States nuclear deterrence program. Technologies developed for that and other federal programs are coupled with Sandia's industrial management roots. Together, they have resulted in a national laboratory whose systems engineering orientation is based on research and development processes modeled after those of AT&T Bell Laboratories. Recent dramatic changes in international relationships have redirected Sandia's role toward the transfer of its government-sponsored technologies to commercial and industrial applications in the private sector.

Venkatesh Narayanamurti *and* ***Dan E. Arvizu*** *both work at Sandia National Laboratories in Albuquerque, New Mexico. Mr. Narayanamurti is Vice President of Sandia National Laboratories, responsible for the area of Research and Exploratory Technology. He oversees research in physical and chemical sciences, microelectronics, pulsed power, materials, computing, and engineering science. He received a B.Sc. and an M.S. from the University of Delhi, India, and a Ph.D. from Cornell University, Ithaca, New York, all in physics. Mr. Narayanamurti joined AT&T Bell Laboratories in 1968 and transferred to Sandia National Laboratories in 1987. Mr. Arvizu is Director of Technology Transfer and Industrial Relations. In that capacity, he sets the direction of the technology transfer program, providing the framework and* (continued on page 9)

Introduction

Sandia National Laboratories, originally known as the Sandia Laboratory, was operated by the University of California from its founding in 1945 until 1949, when AT&T accepted responsibility for the Laboratory's operation at President Truman's request. Sandia Corporation, a wholly owned subsidiary of AT&T, continues to operate the Laboratories for the U.S. Department of Energy (DOE) on a no-profit, no-fee, no-cost basis. (See Panel 1 for definitions of abbreviations, acronyms, and terms.) Although DOE projects continue to receive its top priority, Sandia also does work for the Department of Defense (DOD) and other federal agencies. Sandia's headquarters and main laboratory are located in Albuquerque, New Mexico. Another laboratory complex is located in Livermore, California, with additional facilities near Tonopah, Nevada, and on the island of Kauai, Hawaii.

As a result of its work on components for the nation's nuclear weapons program, Sandia scientists and engineers have developed a broad base of knowledge in the fields of materials science, computational and engineering science (e.g., fluid mechanics, heat transfer, aerodynamics), solid state science, radiation-hard microelectronics (e.g., microelectronics whose functions are unaffected by ionizing radiation), and unique testing capabilities under harsh environments. These technologies have evolved during the past four decades, with increasing emphasis on nuclear safety, reliability, and security. From the beginning, this technology has been transferred to industrial contractors of the complex that manufactures the nation's nuclear weapons.

During the past twenty years, Sandia has evolved from a laboratory with a single mission to one with many programs. With the arrival of the energy crisis in the early 1970s, Sandia began to take on increasing responsibilities in the field of energy research for the DOE. Sandia's research has included fossil fuel recovery and use, and alternate energy technologies, especially nuclear and renewable energy sources (i.e., solar and wind). In the 1980s, Sandia also took on additional responsibilities for the DOD in areas such as advanced military technology, intelligence, arms control, and verifying compliance with arms control treaties. Much of this work relies on Sandia's interrelated capabilities in microelectronics, materials, and engineering science. In microelectronics alone, Sandia has had a broad impact. It designed the first laminar-flow clean rooms. It has also produced specialized, highly reliable, radiation-hard integrated circuits for space satellites.

Sandia's role as a national laboratory continues to evolve in step with changing conditions in the world's geopolitical, environmental, and economic climates. Many factors have affected Sandia's present and future role. They include:

- The end of the cold war
- The success of advanced technologies during Kuwait's recent liberation
- Revised requirements that will produce a reduced, safer national stockpile of nuclear armaments
- Demands for the development of environmentally benign manufacturing processes and the safe disposition of nuclear waste
- The likelihood of future energy crises
- Increased efforts to improve the ability of U.S. manufacturers to compete effectively with their international counterparts.

There is widespread agreement about the need to increase the rate at which our nation's efforts in research and development are transferred to the industrial sector. Much work is being done by the Departments of Defense, Energy, Commerce, and the Office of Science and Technology Policy to identify and develop plans for technologies critical to our nation's well-being. Although there is considerable overlap among these plans, common to all of them are areas such as high-performance materials, supercomputing, intelligent machines, microelectronics, and photonics. Sandia has unique strengths in each of these areas. It is well positioned to contribute significantly both to the nation's security and its economy. At this point in world events, national security and economic competitiveness are becoming increasingly intertwined.

Panel 1. Abbreviations, Acronyms, and Terms

CMOS — complementary metal-oxide semiconductor
CRADA — Cooperative Research and Development Agreement
CRF — Combustion Research Facility
DOD — Department of Defense
DOE — Department of Energy
LPS — laser plasma source
NCMS — National Center for Manufacturing Sciences, a consortium of 120 U. S. companies, large and small, formed to support U. S. industrial competitiveness in manufacturing.
SETEC — Semiconductor Equipment Technology Center
SMPC — Specialty Metals Processing Consortium
SRAM — static random access memory
VLA — very large array

Addressing Industrial Competitiveness

Though frequent reference is made these days to "economic competitiveness" and "technology transfer,"

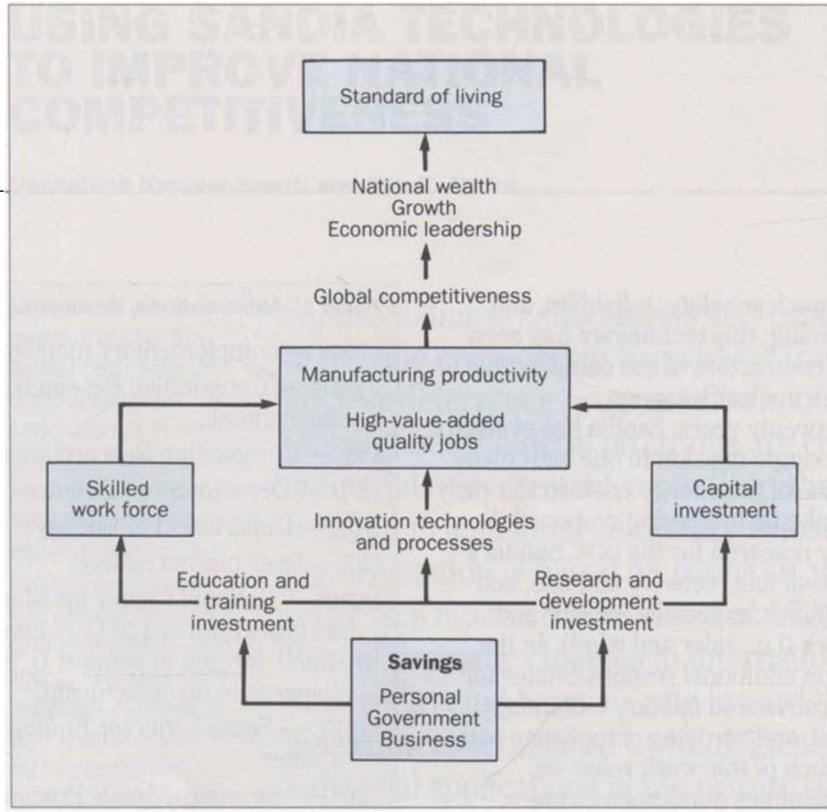

Figure 1. Sandia's perspective of an economic flow model of national competitiveness. This model was adapted from the 1990 Council on Competitiveness Index.

the exact meaning of these terms remains ambiguous. Typically, "economic competitiveness" is used in the context of U.S. industries' declining market share in the international marketplace. "Technology transfer" describes the process of moving science and technology from the laboratory to the factory floor. To focus public debate on these issues, several independent blue-ribbon commissions were charged by industry and government[1–6] to evaluate U. S. economic competitiveness and to determine government's role in enhancing technology transfer. The commissions reported that many U.S. firms are being outperformed in the design and manufacture of reliable, high-quality products. The commissions added that U.S. industry generally is ineffective in transferring technology from its own research and development organizations to its manufacturing facilities. The commission also noted a general lack of cooperation—perhaps even adversarial relationships—that accounts for ineffective technology transfer among government, the academic community, and industry. Changes on many fronts are necessary, the commission suggested, including improvements in education and work-force skills, lowering the cost of capital, reducing the time it takes for research to be translated into marketable products, lengthening planning horizons, and paying more attention to quality management principles.

Further understanding of the problems, and insight into potential solutions, can be gained by examining the economic flow model proposed by the Council on Competitiveness [7] (see Figure 1). This model suggests that, although a nation's standard of living is the final measure of its ability to compete internationally, the engine that drives economic growth is manufacturing productivity in key high-value-added industries. The engine's fuel comes from investments in technology and the work force. Given the government's huge ($70 billion) annual budget for research and development, primarily for national defense purposes, an important element of any national strategy should be to make this investment more beneficial to the private sector.

The National Competitiveness Technology Transfer Act of 1989 is the most recent of a number of legislative acts passed since 1980. It reflects our government's intention to create an environment that permits more cooperative working relationships among government, universities, and industry. Supplementing these laws, President Bush's recently published U.S. Technology Policy [8] supports a shift in the government's position toward federally funded research and development. The policy states that "it is government's role to provide an environment conducive to long-term economic vitality by promoting increased industry–Federal lab–university collaboration to help convert federally supported research and development into technologies that the private sector can then turn into commercial products and processes." The policy also states that federal research and development establishments should strive to reduce the time needed to transfer their research and development results to the private sector (or to their counterparts in the private sector) for commercial production. These federal establishments should seek industry input early and work with industry to develop useful core technologies that will form the basis for new commercial products. Most important, the policy encourages more collaboration in research and development among federal labs, universities, and industry.

Sandia's Technology Transfer Plan

In keeping with this new federally mandated mission, Sandia's primary objective for technology transfer is to contribute to the economic security of the U.S. by transferring commercially valuable technology to U.S. industry. We consider an improvement in our domestic economic security to be a national security issue—and a natural enhancement of Sandia's defense and energy missions.

Regarding the "how" of technology transfer, we are applying an array of mechanisms, including publications, workshops, seminars, technology news releases, and one-on-one interactions. We are also using several formal mechanisms, such as a variety of cooperative partnerships, contract work, work-for-others agreements, technical assistance, personnel exchanges, intellectual property licensing, and special-purpose facilities (e.g., unique test and scientific facilities such as a one-of-a-kind radiation effects laboratory, combustion research facility, or solar thermal test facility). All of these facilities represent millions of dollars invested by the U. S. government, investments that industry can take advantage of for a minimal usage fee.

If Sandia is to achieve its full potential as a national laboratory in today's geopolitical and economic environment, we must do more than merely respond to industry needs. We must aggressively seek out opportunities to form strategic partnerships with industry, from which benefits will accrue to the United States. Sandia's strategic plan targets industries in fields that are essential to national security and critical to solving problems of prime national importance. In technology transfer, we have identified six areas in which Sandia's strengths and capabilities potentially match critical market needs:

- Energy security
- Environmental quality
- Manufacturing processes
- Physical security systems
- Health-care cost containment
- Transportation.

Furthermore, because we believe the most effective technology transfer is based on "market pull" from existing and growing markets, we are emphasizing use of the Cooperative Research and Development Agreement (CRADA) in our negotiations with corporate clients. CRADAs are authorized by the National Competitiveness Technology Transfer Act of 1989. They contain provisions both for the disposition of intellectual property developed under the agreement and for withholding from publication information considered to be commercially valuable interactions for up to five years.

Sandia's Technology Transfers

Technology transfers from Sandia to private industry have a 40-year history. A number of them have already succeeded in the commercial marketplace. These include the laminar-flow clean room, improvements for polycrystalline diamond compact drill bits, the hot-air solder leveler, and rolamite as an acceleration-sensing switch for automobile air bags.

However, in today's more competitive international environment, the transfer of federally funded technologies must be managed so that their benefits accrue preferentially to U.S. manufacturers.

A review of Sandia's experiences with technology transfer has provided valuable insight into the primary elements needed to make the relationship between a large multi-program national laboratory and targeted sectors of industry succeed.

First, and most important, is to establish an atmosphere of cooperation and teamwork, and a sense of mutual trust and respect that continues throughout the effort.

Second, there must be recognized champions at the laboratory and in industry who act as catalysts and "barrier busters."

Third, there must be a significant element of market pull. *Market pull* is best described as applying technology to solve a specific known problem identified by a commercial partner. The converse is *technology push*, in which a technology is marketed as a solution looking for a relevant problem. In particular, everyone—from the top executive to the scientist and engineer at the bench—must recognize the value added by the laboratory's technology and participation, and the competitive advantages it will give the industry participant.

Finally, industrial clients must be thoroughly involved in all aspects of defining the additional research that may be required, and in developing the research and development agenda. In effect, there must be a full, cooperative partnership between the laboratory and its clients.

Recent Technology Transfer Successes

The Combustion Research Facility (CRF) at Sandia's Livermore location began operation in 1980. It is one of the DOE's most successful in terms of industry participation. It maintains a highly specialized set of laser-diagnostic and supercomputer-driven analytical capabilities for evaluating combustion processes that make possible high-value-added collaborative efforts with companies that manufacture products related to combustion processes (automotive, aerospace, coal and petroleum, and heating). From the time it began operations, hundreds of industrial visitors have interacted with CRF researchers. More than 50 long-term (i.e., longer than one month) visiting industrial scientists from 33 companies have collaborated with DOE-sponsored Sandia researchers. On average, the cost of the work is shared equally by the DOE and industry. There are currently 75 long-term visiting scientists from industry and academia at the CRF.

As one example of a CRF collaboration, the Rotary Engine Division of John Deere Technologies International in Livermore has completed a cooperative project to characterize the fluid motion in a prototype rotary engine. In addition to John Deere, this effort has been supported jointly by the Gas Research Institute and DOE's Energy Conversion and Utilization Technologies Program. John Deere complemented the CRF's scientific capabilities by providing expert knowledge about rotary engine design, development, and testing. The optically accessible test engine was designed and built in New Jersey, using window design technology developed at Sandia, and was then shipped to the CRF. John Deere sent a staff member to the CRF for the duration of a four-month experiment. The experiment involved the use of laser Doppler velocimetry to measure gas velocities and turbulence intensities in the engine's combustion chamber. This successful collaboration is expected to build a technology base that will lead to more cooperative efforts with other U. S. manufacturers of internal combustion engines. We have already worked with Ford Motor Company, General Motors, and Chrysler Corporation.

At one time, U.S. semiconductor manufacturing companies dominated the world's semiconductor equipment market. Today, competition from abroad is rapidly eroding their share of that market. To counter this challenge, Sematech, a consortium of 14 major U.S. semiconductor manufacturers, has entered into a major work-for-others arrangement with Sandia to develop a Semiconductor Equipment Technology Center (SETEC). SETEC's mission is to help manufacturers of integrated-circuit processing equipment develop advanced equipment and processing techniques. SETEC's long-term objective is to set up a methodology that can be used to design reliability into equipment. Sandia is well suited to respond to this challenge because of its extensive experience with semiconductor process modeling and measurements, and its reliability programs in nuclear weapon and nuclear power plant programs. In addition to a state of the art Microelectronic Development Laboratory (a 12,000-square-foot, flexible, class one clean-room facility), Sandia maintains an active research program in manufacturing processes such as chemical vapor deposition, plasma processing, and ion implantation.

The specialty metals industry produces alloys that define the high-temperature and high-stress limits of jet engines, chemical plants, valves and pipes in nuclear reactors, plus many other products. Although the specialty metals industry is small, its output is critical to much larger industries such as aerospace, petrochemical, and energy production.

Because material quality and price dominate the competitive position of products from this industry, new research tools are needed to improve current manufacturing processes. In October 1988, a group of U.S. producers and users of specialty metals formed the Specialty Metals Processing Consortium (SMPC), specifically to work with Sandia on precompetitive generic research that can lead to improved production processes. The cost of this work is being shared by industry and the DOE's defense programs, with industry picking up more than half the tab. Work began on July 18, 1990, when an agreement was signed by the DOE and SMPC. (Although this agreement was not formally a CRADA, as defined by the National Competitiveness Technology Transfer Act, it represents a pioneering effort that includes all essential features of the new CRADA instrument.) The research will be conducted at industry locations as well as at Sandia's vacuum arc remelt facility—the only large-scale, fully instrumented research furnace in the country. This facility has already been instrumental in developing a new control technique for fabricating high-purity, nickel-based super alloys. We expect the Sandia/SMPC research program to play a major role in keeping the specialty metals industry competitive in domestic and world markets.

New CRADA Partnerships

On January 22, 1991, AT&T, the DOE, and Sandia signed agreements that provided for Sandia's entry into CRADA partnerships with industry. With this authorization, a new era of Sandia/industry teaming has begun. Although this mechanism is new as of October 1991, 10 agreements have been approved by the DOE and work on those has begun. There are 5 more agreements in the DOE approval cycle, and an additional 20 agreements in various stages of negotiation. We expect to have a total of approximately 20 agreements in place by year's end. In these agreements, the relative cost share is typically 60-percent industry and 40-percent DOE, with most of industry's cost share spent in industry.

In these new collaborations, we will pay close attention to the four elements of technology transfer success stated earlier. We expect industry to judge our performance as a research and development partner by industry standards of performance, cost, and schedule. The rate at which the number of our collaborative efforts grow will be a good indicator of their value to industry and, therein, an indirect measure of their impact on U. S. industry's competitiveness.

Working with AT&T

Organizations within AT&T and Sandia have had many fruitful collaborations in the past, especially for government products. More recently, there has been increased interaction between the two companies on matters dealing with commercial products. A major new undertaking includes Sandia's participation in the printed wiring-board initiative under the National Center for Manufacturing Sciences (NCMS). Additional joint initiatives, in areas such as the Consortium for Superconducting Electronics and a CRADA to develop projection X-ray lithography, are in advanced stages of discussion.

More than 200 technical interactions have taken place in the 1990 calendar year, including informal visits, seminars and workshops, and major collaborations with over 80 Sandia technical organizations. In addition, we have had at least 70 administrative interactions with AT&T personnel from functions such as quality control, classification review, auditing, personnel, and the technical library.

Sandia/AT&T interactions are encouraged by the prime operating contract between the DOE and AT&T for managing Sandia National Laboratories. The contract also gives AT&T a nonexclusive, nontransferable, irrevocable license to all Sandia inventions, as well as nonexclusive use of all technical data. This includes inventions and data produced by Sandia under work-for-others agreements and CRADAs. However, any company—including AT&T—that collaborates with Sandia on research and development for a product or process it wants to commercialize can obtain exclusive rights to it with DOE approval. In cases where a company or organization other than AT&T wants to enter into an exclusive research and development arrangement with Sandia, Sandia may ask AT&T to waive its nonexclusive rights (through the prime operating contract) to intellectual property that results from the intended collaboration.

In This Issue

This issue highlights current examples of Sandia's technology that illustrate the dual-use concepts—defense and commercial—discussed earlier. Although special emphasis is given to several AT&T/Sandia collaborations, broad interactions with multiple users are common.

The paper by Eicker, Miller, and Strip describes research and development efforts to increase the level of automation in nuclear defense production facilities, which will control cost and enhance worker safety. Automated planning and programming and robot-independent object-oriented programming languages are important elements of current work. They have wide application to many industrial robotics needs.

Sekutowsky and Weissman's paper describes joint Sandia and AT&T interests in minimizing the environmental effects of manufacturing operations. It involves a paradigm shift from end-of-pipe control to meet environmental regulations to avoiding pollution in the first place.

Jorgensen and Yaney describe an example of the value added by joining Sandia and AT&T's scientific and engineering resources to develop a 1.25-micrometer radiation-hardened complementary metal-oxide semiconductor (CMOS) technology. It will be used in a new generation of 32-bit microprocessors and 256-kbit static random access memories (SRAMs). This technology has many diverse applications in nuclear power, defense, and space.

In their paper, Stulen and Freeman describe research collaboration on a technology of potential importance for integrated-circuit production in the late 1990s. Work on X-ray imaging by Bell Labs using a synchrotron has now been implemented in the laboratory using the laser plasma source (LPS), a compact source of X-rays developed by Sandia.

Peercy's paper tells about new methods to extend the current range of options available to device designers as they create future generations of optoelectronic circuits. The circuits have unique defense and commercial applications.

Supercomputing is critical to solving complex engineering science problems of importance to defense and energy. The paper by Benner and Harris describes the enormous progress achieved in getting exceptional performance from a new generation of supercomputers. Massively parallel computers and the software that supports them are rapidly coming of age.

Each of the final two papers in this issue deals with different aspects of security technology. Both have defense and commercial applications. Brickell and McCurley describe a method to verify the identity of an individual at a remote location. Methods of this sort have many potential applications, from providing more secure remote computer logins to providing more secure bank card transactions. Finally, Myoshi writes about Sandia's work in this area for the DOE and DOD, and its potential for commercial exploitation.

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operating policy, and supporting U. S. economic security by applying Sandia's developed technologies. Technology transfer is used to form strategic alliances with industry that both enhance U. S. industrial competitiveness in the global marketplace and support Sandia's core competencies for national defense missions. Mr. Arvizu holds a B.S. from New Mexico State University, Las Cruces, and an M.S. and Ph.D. from Stanford University, California, all in mechanical engineering. He joined AT&T in 1973 and transferred to Sandia National Laboratories in 1977.

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