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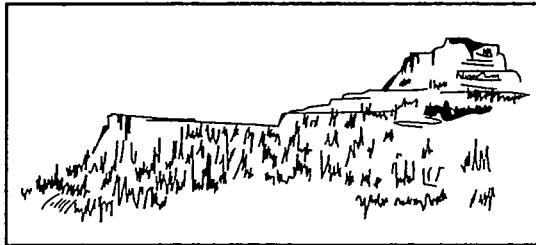
Technology Transfer: Half-Way Houses

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Technology Transfer: Half-Way Houses

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Introduction

In the fall of 1993, I was asked by the Center for National Security Studies (CNSS) of the Los Alamos National Laboratory (LANL) to study the ways in which technology transfer and defense conversion had been accomplished at General Atomics (GA) and Science Applications International Corporation (SAIC) by interviewing Harold Agnew, who had served as director of Los Alamos before becoming president of General Atomics in 1979, and J. Robert Beyster, who had been a staff member at Los Alamos and at General Atomics before founding SAIC in 1969.

Harold Agnew readily complied with my request for an interview and also suggested that I talk to Douglas Fouquet, who is in charge of public relations at General Atomics and is their unofficial historian. Robert Beyster was not available for an interview, but, through the courtesy of John C. Hopkins, a former director of CNSS, I was able to interview SAIC's executive vice president, Donald M. Kerr, who is also a former director at Los Alamos, and Steven Rockwood, a sector vice president at SAIC who was formerly a staff member at the Laboratory. Because Agnew, Kerr, and Rockwood are all familiar with LANL, as well as with their respective companies, the interviews became exercises in comparative analyses of technology transfer.

In what follows, I have tried to summarize both the interviews and some of the research which attended them. It is the historian's hope that by use of comparative institutional analyses, Laboratory administrators may learn something of value in directing their efforts toward the transfer of technology to private industry and other government agencies.

Technology Transfer at General Atomics

Los Alamos and the Origins of General Atomics

John Jay Hopkins founded General Atomics (GA) as a division of General Dynamics Corporation in 1956 to begin the commercial development of nuclear energy. He recruited as its first president Frederic de Hoffmann, who had been at Los Alamos and had worked on the Water Boiler reactor during and after World War II and had made important contributions to the Super Program. Hopkins's and de Hoffmann's backgrounds complemented each other; they were able to forge a shared vision.

The context within which that vision was successful was the Atoms for Peace Program, which sought to transfer technology for the development of civilian nuclear power from the commission to private enterprise, and from the

United States to underdeveloped nations. In the mid 1950s, as now, there was an initiative at the federal level to support technology transfer.

Hopkins had long been interested in nuclear propulsion and nuclear power; Time magazine called him “Mr. Atom” in 1953. General Dynamics Electric Boat Division made the first nuclear-powered submarines, and its Convair division had a contract for the NX-2 nuclear bomber. To pursue commercial nuclear power, Hopkins purchased the Nuclear Science and Engineering Corporation. The firm had been organized by former Atomic Energy Commission (AEC) Chairman Gordon Dean, who became a senior vice president of General Dynamics.

When the Atomic Energy Act of 1954 opened the door to civilian development of nuclear power, Hopkins created GA. He had also been inspired by President Dwight Eisenhower’s call to transfer America’s nuclear technology abroad. At the International Chamber of Commerce Meeting in Tokyo that year, he suggested that the developed world should donate “simple” nuclear reactors to the emerging nations.¹ A later director of GA’s research recalled that Hopkins loved the Japanese people, taught many of them to play golf, and wanted to see their lives improved by fission energy, perhaps as a sort of personal moral recompense for the bombs.²

In April 1955, de Hoffmann joined General Dynamics as assistant vice president of the Convair division. His appointment was suggested by Gordon Dean, who knew de Hoffmann well. In July 1955, de Hoffmann went to Geneva to help organize the Atoms for Peace Conference after having been appointed vice president of General Dynamics and general manager of its new “general atomic division.” Charles Critchfield, another Los Alamos veteran, had already become director of scientific research for the Convair Division of General Dynamics, so the appointment was not unprecedented.

A later president of GA, Harold Agnew, summed up de Hoffmann: “He had this idea: All this expertise in the nuclear era is just beginning, and he convinced John Jay Hopkins

of General Dynamics to start up a laboratory.”³ In order for de Hoffmann to accomplish what he wanted, he had to leave Los Alamos and join a commercial firm. This is an important means of technology transfer. As economist Tom Burns put it, “the mechanism of technological transfer is one of agents, not agencies; of the movement of people among establishments, rather than of the routing of information through communications systems.” Or, as Donald M. Kerr of SAIC stated, “the only effective technology transfer in my view is when the people move. You can read papers, you can understand theories, but in fact know-how is something that moves with people.”⁴

When he left Los Alamos, de Hoffmann believed that “technology in a field as complex as nuclear energy [could not] be separated from research and development.” So he and Hopkins created “a \$10 million research complex . . . the John Jay Hopkins Laboratory funded by General Dynamics Corp[oration]—one of the very largest privately financed general purpose nuclear research facilities in the world.” They “tried to marry a new philosophy into industry, of combining people with highly academic backgrounds, trying to do the same kind of thing that was done so successfully in the Manhattan District, where those people were married with engineers of a high capability and worked very well together. Our scientists and engineers are interested not in just one narrow line of work, but . . . try to move over a great fraction of the waterfront.” De Hoffmann argued that an enterprise like GA could accomplish the goal of producing nuclear reactors “quicker than it could be accomplished in a Government Laboratory . . . because . . . we can combine the fundamental research with . . . development with . . . production . . . and do it all under one set of circumstances” given “the framework [of] our industrial-government cooperation that has developed.”⁵ In short, he designed a Los Alamos for industry.

De Hoffmann invited a number of Los Alamos physicists to work with him at GA, including Ted Taylor, who had spent several years as a weapons designer at Los Alamos. These men

brought unique knowledge of nuclear technology to the new firm. As de Hoffmann put it in 1989: The guiding principle was to create an environment which would attract the best of scientists and engineers and particularly to regard the work at General Atomic as a continuum in which scientists and engineers could successfully tackle major problems.⁶ In particular, he sought defectors from Los Alamos and other nuclear laboratories. Among them were "many who had gone back and gone into other industries, other laboratories, universities, out of the atomic energy industry, because they did not have the proper framework in which to work."⁷

To plan GA's research, de Hoffmann invited a galaxy of experts on nuclear power to meet in GA's temporary quarters at the Bernard School in San Diego in the summer of 1956. Manson Benedict, Hans Bethe, Freeman Dyson, Glenn Seaborg, Alvin Weinberg, and Edward Teller led the group, which also included Los Alamos veterans Robert Duffield, Edward Creutz, whom de Hoffmann named director of research, Lothar Nordheim, Robert Richtmyer, Marshall Rosenbluth, and Taylor. To Freeman Dyson, this summer seminar resembled the lectures and conferences which accompanied the founding of Los Alamos in 1943.⁸ Rather than to develop a nuclear weapon, however, their intent was to determine the feasibility of reactors for commercial ventures.

The candidates which emerged were the "safe," the "test," and the "ship" reactors. The last was a closed cycle gas-turbine reactor system for ship propulsion. This marine gas-cooled reactor was found not to be economical for commercial shipping. The second, the high-temperature gas-cooled reactor, was an import from Harwell. The first, the "safe" reactor, was designed by Teller and Dyson. When a cooling system failed, the heat accelerated the neutrons in the fuel rods, causing them to escape into the surrounding water rather than to sustain further fission. The fuel thus had a negative temperature coefficient. Fuel rods composed of an alloy of uranium hydride with zirconium hydride were designed to accomplish this. It was, and remains, an intriguing technical solution.⁹

Having a good technical solution to the problem of reactor safety was not enough; it was necessary to find a market niche, and de Hoffmann found that niche in the production of short-lived radioisotopes for medical research and diagnosis. A one-megawatt reactor could supply radioisotopes that could not be shipped conveniently from Oak Ridge or other production centers. Such a reactor could also be used for training and research in universities. For neutron beam research, a ten-megawatt version was designed. These reactors were named TRIGAs, an acronym for Training, Research, and Isotopes, General Atomics.

The process of converting the technology into a product was much more complex than this narrative indicates. First, assembling scientific and technical expertise was expensive. Hopkins had committed \$10 million (about \$50.8 million in 1993 dollars) to the start-up of GA; therefore, de Hoffmann was able to pay attractive consultant salaries and to hire over 100 employees in 1956: "A whole gaggle of people joined him because he paid them a lot of money and challenged them."¹⁰ Second, land for the new center was obtained when Hopkins succeeded in persuading San Diego to donate city land for GA on Torrey Pines Mesa. He and de Hoffmann also helped found the University of California's San Diego campus: "General Dynamics Corp. made a \$1 million grant to the University of California to enlarge its San Diego facilities with the hope that it would become a great technological center of university training in the sciences and particularly in the technological sciences."¹¹ This infrastructure supported the articulation of the technology GA transferred from the national laboratories.

TRIGA

TRIGA proved that GA's vision of "simple" reactors for developing nations was not idle. Within three years, GA was marketing the research reactors abroad. The development of the reactor itself was straightforward. GA recognized that, because existing reactor types,

based on systems developed in the national laboratories, did not provide “complete and inherent safety,” governments, private industry, and educational institutions were cautious about developing them. “It was therefore felt that if General Atomic, as its initial contribution to reactor technology, could design and develop a novel reactor that was completely and inherently safe, such a design might not only be a technical achievement, but [might] also facilitate the training of scientists and engineers and increase popular confidence in the safety of nuclear reactors to such a degree that progress in the field would be greatly accelerated.” It was seen, not as an end in itself, but “only the pilot model for a new class of inherently safe reactors that should find wide acceptance for training and research and for power.”¹² In other words, the technical design was influenced by a long-range marketing strategy.

The technical means to inherent safety was the “prompt negative temperature coefficient” provided by the inclusion of a hydrogen moderator in the fuel rod itself, in the form of zirconium hydride ($ZrH_{1.2}$), the metallurgical and chemical properties of which were determined by Massoud Simnad. The theory of the reactor was based on neutron diffusion calculations developed at Los Alamos by Placzek and de Hoffmann. The behavior of $ZrH_{1.2}$ was measured at the Brookhaven research reactor. The first TRIGA reactor was built in 1958. Transient tests soon proved the concept of inherent safety.¹³

Marketing was crucial to the success of the reactor. William Whittemore, who managed TRIGA for GA for over thirty years, recalled that de Hoffmann had a banquet that year for several hundred participants at the Geneva Atoms for Peace Conference to promote TRIGA. Armed with a description of the reactor, which offered “10-kw, 30-kw-, and higher power levels,” versatile “training and irradiation facilities,” and installation “at a minimum of expense,” de Hoffmann was able to interest many of them in the reactor.¹⁴ GA’s experiment workbook demonstrated the reactor’s performance and its implications for studies in nuclear

and solid-state physics, radiation chemistry, and biology. A list of short-lived isotopes that could be produced with the reactor was also included.¹⁵

The promotion of TRIGA involved U.S. government officials at the highest level: President Eisenhower started up a TRIGA reactor at the 1960 World Agricultural Fair in New Delhi, India. The Atoms for Peace Program paid up to \$350,000 each to install reactors in Latin America, Korea, Indonesia, Pakistan, and Vietnam, where GA worked with U.S. State Department scientific attachés and the new atomic energy commissions in soliciting orders. In Japan, GA sold two TRIGA-II research reactors in the early 1960s, and the first was donated to Rikkyo University by the Episcopal Church of the United States.

Nor was the marketing industry overlooked. In 1959, de Hoffmann went to an advertising agency in New York to evaluate the world market for research reactors. There were ten competing firms in the energy range below one megawatt. They believed twenty to fifty such reactors might be sold. GA sold seventy TRIGAs, of which sixty-two are still operating.

The success of the program rested on the international enthusiasm for nuclear technology engendered by Atoms for Peace, which de Hoffmann tested in his “market surveys” at the 1955 and 1958 Geneva Conferences. His use of professional marketing organizations reinforced the impressions he gathered there. Moreover, the TRIGA reactor was “idiot proof,” and consequently was readily installed and operated in countries which did not have the nuclear expertise to build their own reactors. Whittemore recalled that a small team of GA workers usually accomplished the installation in a few months and that GA trained over 300 operators. They were certified by GA when there was no other certification authority (i.e., when there was no effective atomic energy commission in the host country).¹⁶ The TRIGA research reactor was eventually introduced into twenty-five countries, including Kenya, Morocco, and Bangladesh.

Transfer of Nuclear Reactor Technology

TRIGA reactor technology transfer demanded

- rapid development of the technology
- efficient installation of the reactor
- training of those who would operate it
- government channels seconding the efforts of GA salesmen
- market analysis.

Students of technology transfer have identified a variety of mechanisms used in international technology transfer. Among them are "(1) the flow of books, journals and other published information; (2) the movement of persons from country to country (such as attendance at conferences or emigration); (3) education and training at foreign universities or technical schools; and (4) exchange of information and personnel through technical cooperation programs of international organizations or individual governments." In one form or another, the transfer of TRIGA involved all of these elements. As one student of the process has pointed out, "individually, such non-commercial mechanisms are rarely important or effective means of transferring technology. However, their cumulative, long-term effect in raising the general technological level of a recipient country is undoubtedly quite significant."¹⁷ GA's most successful attempt at international technology transfer exemplifies the point.

International Transfer of Reactor Technology from the National Laboratories

Los Alamos Scientific Laboratory's contemporary efforts to transfer reactor technology to other countries, in contrast, were restricted to publications and presentations at the Atoms for Peace Conferences. No robust marketing and sales effort characteristic of the TRIGA reactor was made. Thus, the advanced reactors developed at Los Alamos as part of the AEC's Reactor Development program (PDRP) found no market. For example, the Los Alamos Ultra-High Temperature Reactor Experiment (UHTREX), begun in 1962 and completed in

1969, used the principle of passing hydrogen gas through a high-temperature reactor core. Louis Rosen claimed in 1983 that "the government really blew it when they abandoned that technology." He pointed out that GA was revitalizing it in their high-temperature gas-cooled reactor (HTGR).¹⁸ An examination of GA's efforts in this area shows the weaknesses of the GA model of technology transfer.

High-Temperature Gas Reactor

Although the technology transfer model associated with Atoms for Peace worked well for research reactors, it was less successful for commercial power reactors like the HTGR. Despite thirty-five years of effort, it has still not established itself, even though many have seen it as superior to conventional nuclear reactor technology. Its failure, and with it that of GA's main line of technology transfer effort, is instructive. In this case, however, the transfer was not from Los Alamos, but from one of its emulators abroad—Harwell.

Peter Fortescue came to GA from the Dragon reactor project at Harwell, after participating in the 1956 GA summer seminar, to begin the HTGR effort there. He brought with him the technique of coating reactor fuel in pyrocarbon, which had been developed at Farnborough for the Royal Air Force's rocket nozzles, and which had been applied to cover fuel columns in the DRAGON reactor. Los Alamos, however, patented an HTGR invented by R. Philip Hammond, Walter R. Wyckoff, and Harold M. Busey in 1960. The reactor was designed to use unclad uranium-impregnated graphite fuel elements and a helium coolant and produce three megawatts at a coolant temperature of 2400°F. The AEC, however, killed the project at the beginning of 1961, only to see it reborn in Congress that spring as UHTREX. UHTREX construction began in 1962.

The GA gas-cooled reactors were the product of the Power Reactor Demonstration Program (PRDP) established as a result of the Atomic Energy Act of 1954. The AEC asked that a gas-cooled reactor be included in the program and

secured legislation for it through the Joint Committee on Atomic Energy (JCAE). To the surprise of both, GA bid to build the reactor in concert with Philadelphia Electric Company for \$24.5 million. The AEC also provided \$14.5 million for research and development and covered the cost of up to \$2 million of fuel. For GA, the gas-cooled reactor, built at Peach Bottom, Pennsylvania, offered an end run into the reactor business around established giants like General Electric and Westinghouse, which had government subsidies. Fifty-three utility companies joined in the High Temperature Reactor Development Associates to support the project, for which Gulf General Atomic and the AEC did the research and development, presaging modern cooperative research and development agreements.

Although the Peach Bottom project suffered delays, the reactor was completed by the end of 1964 and began operation in 1966. It became the prototype of GA's HTGR. A demonstration plant was later built at Fort St. Vrain, Colorado, under the AEC's PDRP. Completed in 1976, with a capacity of 350 megawatts, the reactor suffered frequent leaks from its water-lubricated bearings and had to be shut down frequently to dry out. "It's an albatross around our neck," Agnew admitted.¹⁹

Gulf Oil Company, which took over GA from General Dynamics in the 1960s, pushed the HTGR line, and seven reactors were ordered. All but two of them were cancelled or delayed, however, and Gulf finally decided to get out of the reactor business in the late 1970s. After Harold Agnew was brought in to lead GA in 1979, he resurrected nuclear research and developed a new reactor based on GA's gas-cooled reactor technology.

By the end of the 1980s, the modular high-temperature gas-cooled reactor (MHTGR) emerged as a leading second-generation nuclear system. A private-sector initiative to investigate building a civilian lead plant has been undertaken by a prospective MHTGR vendor team, composed of GA, Bechtel and Siemens/Interatom, and Consumers Power Company, along with support from Gas-Cooled Reactor Associates.

As with other power reactors, however, the fate of the MHTGR rests more in the political sector than the market. Government regulation has replaced government subsidy as the chief aspect of the public-private partnership that markets nuclear energy, and GA, as a late entry into the market with a new technology, has suffered, not only because of the installed base, but also because claims of inherent safety for the MHTGR offend those who maintain that existing light-water reactors are safe.²⁰

Many utilities have abandoned nuclear technology because of the public fear of things nuclear, which has been exacerbated by the Three-Mile-Island and Chernobyl reactor accidents. This fear, as historian Spencer Weart points out, is unlikely to be overcome by rational argument or citation of comparable risks, because it is grounded in mental images which popular culture, as well as Hiroshima, Nagasaki, and the *Lucky Dragon*, have reinforced.²¹ The market for nuclear power was undermined by these images, many of which images had their genesis in Los Alamos.

GA has made some money from these safety concerns. The company is heavily involved, according to Agnew, in the "monitoring of power plants—all the safety and all their remote monitoring instruments throughout the plant. Kaman Instruments was a competitor and maybe Eberline was. But I think that the dominant supplier of the monitoring—the nuclear monitoring system—the power end was GA."²²

Fusion Reactor Technology

Other significant connections between Los Alamos and GA in the late 1950s occurred in the area of fusion reactor technology. The AEC's Project Sherwood, a classified program to develop controlled thermonuclear reactors, had attracted men like Marshall Rosenbluth, a Los Alamos consultant on the Super, and Donald Kerst, who had led the group which built the first water-boiler reactor at Los Alamos. Both Rosenbluth and Kerst joined GA to develop fusion reactors after the AEC made information on Sherwood available to industry in 1956 but

before it declassified the program in 1958. Ed Creutz, a group leader at Los Alamos from 1944-46, who had just finished a stint as scientist-at-large for Project Sherwood, recruited them after de Hoffmann and Hopkins made him GA's director of research. Creutz believed "that the problem of controlled thermonuclear reactions [was] becoming increasingly one of technology, even though there are, of course, many basic scientific problems not yet solved."²³

GA sent a team to visit Los Alamos in June 1957 to see the Columbus I, Columbus II, Tori (perhapsatron S-3), Totem Pole, and Turbulent Pinch systems, as well as many components. Los Alamos scientists such as F. Robert Scott, the Totem Pole project leader, subsequently joined GA, whose personnel made at least one additional visit to the Laboratory. Not surprisingly, Los Alamos fusion technology transferred to GA, which adopted the stabilized toroidal pinch design developed by Rosenbluth at Los Alamos and later pursued the multipole device suggested by James Tuck at Los Alamos.

The expanded fusion program at GA was another result of Atoms for Peace. Lewis Strauss, the chairman of the AEC, selected fusion for crash development in the mid 1950s, raising its budget from \$2 million in FY 1954 to \$29 million in FY 1958. He was determined to have a "Sherwood spectacular" at the 1958 Atoms for Peace Conference in Geneva. Like the research reactor featured at the 1955 conference, the fusion device planned for 1958 was intended to demonstrate American nuclear pre-eminence. Los Alamos alone had five separate experiments on display, including the Scylla, a new theta pinch device. Although experts continue to disagree whether Scylla produced true thermonuclear neutrons, it, together with the Livermore, Berkeley, Oak Ridge, and Princeton experiments, reinforced the impression that fusion energy was not far away.

For a time, it seemed that GA would serve as a successful way station for the transfer of fusion technology from the national laboratories to industry. As early as 1956, industrialists realized that fission presented economic and waste disposal problems. Fusion scientists were optimistic that controlled thermonuclear

generation could be demonstrated in four or five years and calculated that a demonstration fusion plant could be available in 1985. General Electric had a group under Kenneth H. Kingdon of the Knolls Atomic Power Laboratory working on fusion as early as 1955, and started a substantial research program in 1956 under Henry Hurwitz, a wartime staff member at Los Alamos. Westinghouse sent Don J. Grove and John L. Johnson to work on Princeton's Project Matterhorn in that same year, and Allis Chalmers won a contract to build the Model C Stellerator there in 1957.

GA also perceived the opportunity and, after a visit to the 1956 summer seminar by a delegation of the Texas Atomic Energy Research Foundation (TAERF), won private financial support for a fusion effort. Lewis Strauss later claimed to have personally brought GA and TAERF together.²⁴ The support was based on the Lone Star delegation's fear that private utilities would suffer if fission was dominated by public power suppliers and on de Hoffmann's assurances that fusion would eclipse fission. The result was a partnership between GA and TAERF in which each initially put up \$5 million. Eleven utility companies eventually provided more than \$10 million between 1957 and 1967; although this was a small amount compared with the cost of the projects in AEC laboratories, it sufficed to support an effort to understand the physics problems with relatively simple equipment and good theory.²⁵

By 1967, however, TAERF withdrew its funding of GA in order to support the work of GA veteran William Drummond at the University of Texas. GA asked the AEC to pick up the annual cost of more than \$1 million for the program. Like private funding, the AEC funding had also been reduced after 1958. Because Rosenbluth, Norman Rostoker, and Bruno Coppi, who had appointments at the University of California, San Diego, still contributed, the GA group was, in the words of DOE's historian of fusion, "one of the strongest, liveliest, and best-integrated fusion teams in the country." The AEC agreed to provide them with \$500,000 a year for a limited term to develop a toroidal multipole which had been invented by Kerst and Tihiro

Ohkawa. The invention of the tokamak by L. A. Arsimovich and his group at the Kurchatov Atomic Energy Institute and Ohkawa's success in confining plasmas for a similar amount of time in his toroidal multipole stimulated continued AEC interest in the GA program.

What had begun in hopes of short-term technology transfer became another government-subsidized research and development program at GA. By 1980, GA was receiving a larger annual budget for this purpose than Los Alamos's Controlled Thermonuclear Research (CTR) Division. Moreover, KMS Fusion, another private player, also was reduced to seeking government funding. Department of Energy (DOE) support of GA also expanded into tokamak and ICF development. Technology continues to be transferred from the national laboratories for new programs, for example, the eight neutral beam (NB) long-pulse sources mounted on four beamlines used on GA's DIII-D tokamak, a magnetic confinement fusion experiment, were developed with the assistance of the Lawrence Berkeley Laboratory. The Divertor Material Evaluation System (DIMES) at DIII-D is a collaborative program between GA, Sandia National Laboratories (SNL), and Argonne National Laboratory (ANL). It was initiated in response to the need for understanding the interaction between the plasma and divertor surface materials in tokamaks. GA has been assigned the conceptual design for the cryogenic target delivery system for the upgrade of the GA Omega laser at the University of Rochester's Laboratory for Laser Energetics, working with Livermore and Los Alamos and drawing upon their knowledge base in fuel layering and cryogenic characterization. GA won the General Atomics Inertial Confinement Fusion (ICF) Target Component Fabrication and Technology Development Support contract in the DOE Inertial Confinement Fusion program over the protests of KMS Fusion and with the assistance of Los Alamos target designers has transferred the technology developed here and at Livermore. DOE's Office of Fusion Energy has conceptual design studies of Inertial Fusion Energy electric power plants by W. J. Schafer Associates, Bechtel, GA, Textron Defense Systems, and the

University of Wisconsin for two 1000-MWe power plants: one driven by a KrF laser and the other by a heavy ion beam (HIB) induction accelerator.

Like the TRIGA project, fusion has benefited from a confluence of high-level federal, industrial, and international interest in the technology, which floated the market which General Dynamics exploited. Unlike TRIGA, fusion has yet to succeed as a commercial venture and has reverted to a government-supported enterprise. For GA, as for the DOE, which now subsidizes all of its work, its still Fusion in our Future.²⁶

ORION

GA's enthusiasm for nuclear technology development extended to the transfer of nuclear weapons technology. An early GA effort was the ORION project, which planned use of nuclear explosives to power an interstellar space ship. ORION was a product of Ted Taylor's enthusiasm and a byproduct of the Los Alamos spirit. As Freeman Dyson wrote to Oppenheimer: "You will perhaps recognize the mixture of technical wisdom and political innocence with which we came to San Diego in 1958 as similar to the Los Alamos of 1943."²⁷ It was also the product of a foreign challenge.

After the Soviet Union launched Sputnik in 1957, Taylor thought about ways to put large payloads into space. Rover offered a larger capacity than a chemical propellant, but Taylor dreamed of surpassing that by a factor of 100. The idea of nuclear explosives propulsion had occurred to a number of people after Trinity. In 1955 at Los Alamos, Stan Ulam and Cornelius Everett calculated the momentum transfer between a series of nuclear explosions and a mass of about 12 tons and found that a nuclear-propelled ICBM could provide very large accelerations.

Los Alamos participated in these studies, when "a group of theoretical physicists" apparently led by Stan Ulam, shared "ideas and information with the group at General Atomics."²⁸ Ulam testified before the JCAE in 1960

in support of the concept and reported that "a number of Los Alamos experiments have had bearing on the phenomena."²⁹

At GA in the late 1950s, Marshall Rosenbluth verified the feasibility of the notion of using nuclear weapons to propel an interplanetary spaceship by detonating a series of nuclear devices against a plate of steel and graphite on the bottom of a large ogival spacecraft. After Roy Johnson of the Advanced Research Projects Agency (ARPA) agreed to sponsor the project at GA with a million dollars, ORION received ARPA and Air Force support for seven years. It ended when the Air Force could find no military applications for it, even though GA formulated a plan to develop the engine without recourse to atmospheric testing.

It required an entrepreneur with a faith in the long-term prospects of nuclear propulsion to match the technological imagination of Taylor and his colleagues at GA. Both Hopkins and ARPA—which was created in the wake of the Soviet leap into space—were such entrepreneurs. The role of the entrepreneur in technological innovation is crucial. In most cases, a professional scientist does not play that role effectively. Ernest Lawrence and his University of California Radiation Laboratory are a significant exception to this rule, but, in general, studies have shown that scientists prefer the acceptance of their colleagues to the rewards of proposing such far-out projects as ORION, and that government bureaucrats also prefer to be safe rather than sorry in expending government funds.³⁰

Rover

The entrepreneurial spirit exemplified in ORION and other early GA projects was an essential component in the transfer of technology from Los Alamos and other national laboratories to the commercial sector. The laboratories, in contrast, pursued not commercial, but federal programmatic opportunities. After the Air Force Science Advisory Committee recommended that nuclear propulsion be pursued as a route to high specific impulse in 1955, Los

Alamos and Livermore undertook the Rover project, first as a means to a nuclear bomber, then as a vehicle for interplanetary flight. Though it used nuclear reactors rather than nuclear bombs for propulsion, Rover was a vision only mildly tamer than ORION and still arouses controversy today. Nevertheless, Los Alamos produced a viable technology that attracted the attention of President John F. Kennedy, who called for the development of nuclear technology to propel rockets.³¹ The project was terminated in 1973 because of "changing national priorities."³² It seems that Rover was a response to the growing need for delivery vehicles for nuclear weapons—as a backup for ICBM propulsion systems. The creation of the National Aeronautics and Space Administration in 1958 led the AEC to forge a joint program with the new civilian space agency, in which Rover was to furnish a means of nuclear propulsion to the moon and beyond.

Technology transfer in this program was accomplished through joint research with ACF Industries, a subcontractor in the development of the hydrogen bomb which built the KIWI experimental reactor vessels and nonnuclear components, and continued with Aerojet General and Westinghouse on the engine and the reactor, respectively, to develop the reactor concepts pioneered at Los Alamos. The NERVA reactor series was one result of this transfer of technology. Although it was not commercially successful, nuclear rocket propulsion produced a number of technological spin-offs that were. Among them were reactor fuels and HTGR technologies.

Reactor Fuels

It is claimed that the work done to provide high-power-density enriched uranium fuel elements for the Rover nuclear rocket propulsion program "led to the development of TRISO fuel heads used in commercial high-temperature gas-cooled reactors."³³ It is true that GA supplied fuel for the Rover reactors, but their fuels were based upon technologies developed at Harwell and in the AEC Power Reactor Demonstration

Program, specifically for the Peach Bottom reactor.³⁴ The exchanges between them may have enhanced fuel development in both laboratories.

Los Alamos developed a uranium dioxide Cermet fuel and a uranium carbide-graphite fuel element before perfecting a coated uranium carbide fuel in a graphite matrix. The carbide coating was supplied by niobium-carbide or zirconium-carbide, which served as a barrier to hydrogen reactions with the fuel. The UHTREX reactor used extruded graphite fuel elements, and the development of extrusion technology, as opposed to the molding technology previously used, as well as the development of high-temperature carbide coatings, made them suitable for very high temperature cores (~2000°C). GA developed coated fuel particles in a graphite matrix for the Peach Bottom reactor, and subsequently developed Triplex coated fuel particles with three layers of coating and BISO coated fuel particles with two layers. Their isotropic-structure high-density crystalline pyrolytic carbon coatings proved suitable for commercial reactors. GA supplied Los Alamos with a number of fuel elements for the Rover program as well.

According to Charles Baker, Los Alamos started "a very vigorous program . . . on uranium and plutonium carbide fuels for breeder reactors [and] worked for Argonne on uranium alloy fuels for fast reactors,"³⁵ after funding for UHTREX was cut off, but there was no transfer of this technology to the commercial sector.

Both Los Alamos and GA were also involved in the SNAP program. GA developed reactor fuels, while Los Alamos developed radiothermal power generators. Again, reactor fuels developed at GA found an application in commercial reactors, while the Los Alamos technology was transferred to Mound Laboratory in the nuclear weapons complex and found a variety of uses in the space program. The SNAP radioisotope thermonuclear generators (RTG) developed at Los Alamos were very successful space power sources: The SNAP-3B power source used on the Transit 4A navigational satellite operated for fifteen years, others even longer. The two Voyager spacecraft launched in 1977, for ex-

ample, have left the solar system but continue to operate using Los Alamos-designed RTGs that generate 4500 watts of thermal power that is converted into 300 watts of electric power. The Galileo spacecraft launched in 1989 also carried RTGs that provided all of its on-board energy.

In 1988, the Laboratory began fabricating fuel pellets for ground-testing of small nuclear reactors designed for use in space to produce many times the amount of power supplied by RTGs. The uranium-nitride pellets produced at the Laboratory's Uranium Nitride Synthesis Facility will be used for the Space Power Reactor program. These generators have also been used to power safety features in nuclear weapons.

GA, on the other hand, has followed a product-line strategy. Reactor fuels have been made at the Youngsville and Sequoyah Fuels subsidiaries of GA, which sold directly to industry. GA has also fabricated nearly 100 cores of nuclear fuel for both high- and low-enriched uranium for applications ranging from large power production reactors to space power systems. It has developed the TRISO fuel technology in the Fort St. Vrain Plant and elsewhere. Recently, GA and Babcock and Wilcox formed a joint venture to supply gas-cooled reactor fuels, including coated particle fuel using both high- and low-enriched uranium.

GA has continued to work with the national laboratories to develop this technology. Microspherical nuclear fuel particles of uranium dioxide using the sol-gel process have been developed by scientists at INEL, ORNL and GA for use in HTGRs. It has also refined the fuels for research reactors, as mentioned below.

Regardless of the precise origins of the technology, it is clear that in the case of reactor fuels, GA has taken a technology which has been extensively developed in the national laboratories and applied it in the commercial marketplace in a way that Los Alamos, stymied by programmatic changes, has not been able to do. As a half-way house, GA has been effective in the development of technology to the point of commercialization, even if the commercial use

of nuclear reactors has not provided the anticipated market.

The development of reactor fuels, however, has suffered from the same political and economic problems that have plagued the rest of the nuclear industry. Sequoyah Fuels has shut down, and former GA president Harold Agnew doubts that it will ever reopen.³⁶ Environmental and regulatory problems which led to the shutdown are comparable to those which now afflict the national laboratories and many reactor facilities.

Maintenance and Support

Even when the hardware has been transferred, the customer trained, and the product is in operation, GA has a responsibility for maintenance and support. It provides full-service support of extended and improved use for all types of research and training reactors. In the 1980s, for example, GA designed, developed, and tested the new digital control system as a standard system to upgrade its research reactor instrumentation systems. Although, according to Whittemore, the original design of the TRIGA makes such upgrades largely cosmetic, they demonstrate the importance of responsiveness to the ultimate customer, even thirty years after the product is developed; GA has retrofitted other manufacturers' research reactors with plate fuel matrixes which accept TRIGA fuel.³⁷

The support program at GA is dedicated to extended longevity of training and research reactor facilities. Such facilities include the new instrumentation and control systems, improved and upgraded nuclear monitoring and control channels, facility testing, and repair and upgrade services that cover (a) pool or tank integrity, (b) cooling system, and (c) water purification system. GA also supports fuel element testing procedures and replacement, control rod drive rebuilding and upgrades, control and monitoring system calibration and repair service, and training services, including reactor operations, maintenance, instrumentation calibration, and repair. It supports expanded or new uses such as neutron radiogra-

phy and autoradiography, isotope production, nuclear medicine, activation analysis, and material properties modification. With TRIGA, technology transfer is never quite done.

A national laboratory could not follow such an active strategy in technology transfer as GA has with the TRIGA program. Despite the Eisenhower administration's enthusiasm for peaceful applications of nuclear power, the national laboratories were expressly forbidden to compete with private industry in reactor development. However, in the nuclear weapons complex, the Laboratory has played a similar role. "It is a source of pride at Los Alamos that our prototype devices are so well engineered that few changes are required when they go into production."³⁸ The complex originally included Burlington, Iowa, and Amarillo, Texas, plants that produced shaped charges, the Mound Lab, which manufactured high-explosive detonators and neutron initiators, and the Kansas City plant, which assembled mechanical and electrical components. All of these activities began at Los Alamos during World War II and were transferred in the late 1940s and early 1950s. These "captive industries" were the result of the expansion of the nuclear weapons complex, entirely supported by government subsidy, and not unlike the subsidized reactor business.

Byproduct Technologies

Although GA's main line of business has been reactors, the company has produced a number of other technologies. Many of these have been transferred by defectors. Los Alamos veteran Robert Beyster, who headed GA's accelerator physics department, left in 1969 to start SAIC. He is reported to have "wanted to develop a corporation that was more conducive to scientific research than he believed traditional structured organizations to be." In many other cases, spin-off technologies seem to have been the direct result of individuals leaving GA with ideas. For example, GA's Jack Bokros developed pyrolite carbon for nuclear fuel particle coating into components for mechanical artificial heart valves and spun-off GA's

CarboMedics. This business was sold to Intermedics, Inc., in 1979.³⁹ Earnesto Gorte left GA's electronics division in 1980 to form Gamma Metrics to make neutron monitoring equipment and systems.

In other cases, GA has sold off lines of work that did not conform to GA's basic business interests. GA's Magneform magnetic-forming metal-working machines were developed in the fusion research program and sold to Maxwell Laboratories in 1969. Joe Bennett, the sales manager for Magneform, who went to Maxwell Laboratories when Magneform was sold to them, said that "Magneform seemed to fit in better with Maxwell's technologies."⁴⁰ Maxwell also acquired S-Cubed from GA after it spun off in the mid 1960s. A reverse-osmosis water purification system developed for HTGRs was sold to UOP Fluid Systems Division in 1974. GA's radiation technology division was acquired by Intelcom Industries in 1973 and subsequently was renamed Instrumentation Research Technology and later IRT Corporation. An IRT spokesman commented, "We didn't fit in with GA's long-term plans so that's why we spun off. Victor Van Lint, the Radiation Laboratory director, took 35 of us with him when he left."⁴¹ Another spin-off resulted from an industrial collaboration. Eric Oakes developed the Pyropower circulating, fluidized bed boiler for graphite reactors in collaboration with A. Ahlstrom Corporation, and the corporation subsequently took over the effort.

A number of these firms have done very well (e.g., over 700,000 heart valves have been made with components manufactured by CarboMedics Division of Intermedics). It is estimated that these high-technology companies annual sales have reached \$1 billion, about the same amount as GA's losses over the period 1956-86. The companies are summarized in Table I.⁴²

This is arguably the area of technology transfer where GA has been most successful. After the early period of entrepreneurship under Hopkins and de Hoffmann, the constricting leadership of Frank Pace under General Dynamics and the narrow focus on nuclear power by Gulf, Shell, and Chevron Oil Companies,

which successively owned GA, caused enterprising technologists to leave.

Recently, under Neal and Linden Blue, there has been an effort to staunch the flow of innovation. According to GA spokesman Doug Fouquet,

We have set up an Institute for the Development of Advanced Technologies, which is a small centralized corporate research laboratory that gets into the fields like the biosciences, which started there. But there's also a Business Action Team (BAT) which is a small crew where people come out of projects or even the business side and work together and study new business areas that GA might get into. I would say over the past 5 years many more new ideas have gone through the BAT than there have been defecting scientists. We've set up 4 or 5 new businesses, and most of them report to Toshiro Ohkawa.⁴³

By keeping some technology in-house for development at GA, the company either reaps the profits or produces an enterprise that can be sold to other firms for a profit. Several examples suffice to show the new trend.

Biosciences

The Biosciences Division at GA in conjunction with the Human Genome Center at the Salk Institute has been developing hardware and software to target many of the research components required for physical mapping and automated sequencing in the Human Genome Project. This response to the 1988 policy initiative of the DOE and the National Institutes of Health (NIH) originated at a conference held at Los Alamos in 1986 by Charles DeLisi, Director of the Office of Health and Environment at DOE, which he followed by allocating \$4.5 million in FY 1987 for a project involving Los Alamos, Livermore, and Lawrence Berkeley laboratories. This initiative, enthusiastically supported by Senator Domenici against considerable opposition in the Senate and the biological community, won \$39 million from Congress in 1988, rising to \$88

Table I. GA Spin-Off Companies, 1956-1986

Company	Year
Sharp Laboratories	1960
S-Cubed Corporation (Systems, Science, and Software)	1964?
Enviromed, Inc.	1968
Magneform	1969
Science Applications, Inc.	1969
Bass Engineering	1969
IRT Corporation	1971
Jaycor	1972
UOP Fluid Systems Division	1974
Management Analysis Company	1975
RAMCO, Inc.	1976
Carbomedics	1979
Gamma Metrics	1980
Advanced Energy Concepts	1980
Applied Microwave Plasma Concepts	1980
Base-Eight, Inc.	1982
GEA Power Cooling Systems	1982
Pyropower Corporation	1982
Emark, Inc.	1983
Nuclear Medicine, Inc.	—
Pacific Robotics	1986
Electro Technology, Inc.	1986
Ogden Environmental Services	1986

million in 1990 and \$135 million in 1991. Like earlier Big Science programs, Atoms for Peace and PDRP, the Human Genome Project provided opportunities for DOE contractors as well as national laboratories, and GA took advantage of these opportunities.

In 1989, Toshiro Ohkawa began a project to determine whether microwaves at 2-26 GHz were absorbed by DNA: This “question had long been a controversial subject within the biophysics community [and] seemed to be a fertile area to establish a name for GA and to begin developing a biophysics expertise within the company.” Researcher Skip Garner developed a number of biological measuring instruments while working to solve this problem, and GA formed its Helix Division in July 1990 to commercialize these instruments. Two months later, GA formed its Biosciences Division to pursue contract research funding and won a two-year \$260,000 grant from NIH in 1991 to study long-range electron transfers in flavocytochrome b2.

The long-term fortunes of biosciences at GA, as in the national laboratories associated with the Human Genome Project, are dependent upon sustained government funding in a program which, like reactor development, is controversial. GA has shown some of the same entrepreneurial enthusiasm for the project that Hopkins displayed for Atoms for Peace, and found a niche where they might prosper, but it is uncertain whether this will pay off in the long run.

Supercomputers

The “grand challenge” problems of science and industry that are driving computing and communications created corresponding challenges in information storage and retrieval. An industry-led collaborative project was organized to investigate technology for storage systems, and included GA DISCOS Division and Livermore’s National Energy Research Supercomputer Center (NERSC). The infor-

mation storage system developed for supercomputers at Livermore, UniTree, was commercially released by DISCOS. This was seen by DOE as an example of how valuable technology developed at a DOE laboratory can be transferred to US industry on a preferential basis, because by licensing the system to DISCOS rather than to the manufacturer of a specific brand of hardware, GA's UniTree would receive the widest possible distribution. At prices beginning at \$6,250 for an entry-level system and rising to \$95,000 for a system that handles up to 5,000 Gbytes, it was a limited distribution. For a time GA Distributed Computing Solutions division also sold a distributed file storage and management system developed at Los Alamos: DataTree, which was based on the Los Alamos Common File System.

As it had with TRIGA, GA chose a research route to leadership in supercomputing. It launched the California Education and Research Federation network (CERFnet) on a \$2.8 million grant from the National Science Foundation (NSF). Originally composed of California State University, University of California, the University of San Diego, Scripps, and several industrial organizations, the network expanded in 1992 to include federal sites in California using Pacific Bell Telephones new Switched Multimegabit Data Service (SMDS) to access the Internet over the Cerfnet backbone. The next stage on the information super-highway was also funded by NSF, which awarded \$12 million in contracts to three companies to help organize the ever-increasing flow of Internet traffic and took a step toward privatizing sections of its huge international NSFnet, part of the Internet. NSFnet is envisioned as the basis for a gigabit/second National Research and Education Network, and NSF contracts went to AT&T Co., Network Solutions Inc. of Herndon, Virginia, and GA to provide a seamless interface, called InterNIC, providing directory and database services, registry services, and information services. Thus GA got in on the ground floor in this new federal initiative.

In 1993, however, GA sold off this business to Open Vision in Pleasanton, California, although "it did a lot of good work in getting that system

commercialized and in winning a number of contracts with very major supercomputer centers and other large computing centers."⁴⁴ Here again, GA may be seen as a sort of half-way house between the national laboratories and the market, as it was in the reactor business. Having established the business, GA was able to sell it.

Jim Young's Torrey Pines Company made the Non-Aqueous Equipment Decontamination System (NAED), first a subsidiary of GA, then a spin-off company. GA continues to have an interest in this field, demonstrated by its involvement in transferring supercritical water oxidation technology from Los Alamos. The company is also designing casks for nuclear waste disposal under contract to DOE. It has designed a process to decontaminate chemical warfare rockets, land mines, and artillery shells by freezing them in liquid nitrogen, so that, without explosion or chance for gas to escape, they can be crushed into small pieces which are then dropped into a furnace and burned. At least \$50 million has been spent developing this "cryofracture" technology. Although the Pentagon has been attempting to stop funding for cryofracture development since 1985, Congress, responding to persistent company lobbying, has kept the alternative alive.⁴⁵

Internal and External Entrepreneurship

In an early study, Edward B. Roberts of MIT evaluated spin-offs from MIT-related-laboratories and one large Boston-area industrial electronics firm, demonstrating that "the flow of entrepreneurs out of advanced technical organizations into their own businesses can create significant technology transfer as well as impressive commercial and economic impact."⁴⁶ GA demonstrates this. The study also asserts that "companies ought to be quite concerned to discover why such people leave"⁴⁷ in view of the fact that entrepreneurs leaving the Boston electronics firm had generated over \$70 million in sales, just as at GA, defectors have made billions.

Although GA has been marginally successful in stemming this undesirable (from its point of view) technology transfer, one of its spin-offs, SAIC, has created a system for internal entrepreneurship which has the opposite effect. That is, it results in the transfer of technology into the firm, and the technology then subsidizes the entrepreneurs who bring it with them.

SAIC Technology Transfer

If General Atomics is a half-way house between the national laboratories and industry, SAIC would appear to be further down the chain of technology transfer. Unlike GA, SAIC has diversified into many areas from its original focus on nuclear-weapons-related technologies. The architect of this diversification, J. Robert Beyster, worked at Los Alamos at the 12-Mev Van de Graaff from 1951-56 before leaving to join GA shortly after it was founded. He was chairman of the department of accelerator physics at GA, where he ran a linear accelerator facility from 1957-69, when he left GA to form Science Applications, Inc., with a \$20,000 contract from the Defense Atomic Support Agency (DASA) to analyze neutron and gamma ray output. According to Agnew, "Beyster...took 20 or so guys with him and they started SAI."⁴⁸ The company reorganized as Science Applications International Corporation (SAIC) in 1984.

Beyster's support from the DASA included a number of studies that Los Alamos was reluctant to support, including nuclear weapons effects studies.⁴⁹ Although Los Alamos became more willing to take on such work for the Defense Nuclear Agency in the 1980s, and SAIC began to be perceived as a competitor, SAIC had already exploited the niche and established a role for itself as a government-service contractor to the Department of Defense (DoD). Beyster himself became a member of the Joint Strategic Target Planning Staff Science Advisory Group in 1978. The company also won support from NIH, the Safeguard Systems Command, the Joint Cruise Missile Program Office, NATO, and the Army. The growing business deployed over 100 offices at home and abroad in

its first decade. Among many other fields, it became involved in the development of high-energy gas lasers for defensive applications. In 1979, it won a systems integration contract for a foreign C³I system and a real-time control system for the U.S. Army National Training Center.

Diversification into Defense Department Projects

SAIC landed a number of defense contracts and became a "principal player in President Reagan's drive to develop an antimissile shield." The company garnered more than \$50 million in Strategic Defense Initiative (SDI) work in the 1980s. These included system architecture studies worth about \$50 million. It also expanded into the development of emergency response and stack monitoring systems for the nuclear utility industry, and began a major program of support to the DOE evaluation of Yucca Mountain.

By 1991, Beyster predicted the company's revenues would reach \$1 billion. He was accurate; SAIC's overall revenue grew by 10 percent to \$1.28 billion in that year, and hiring increased by 11 percent, despite a recession and the limited funding for government contracts. SAIC signed major multi-million dollar contracts with other non-military organizations (e.g., a \$15.4 million contract with Florida's Orlando-Orange County Expressway Authority and a \$100 million contract with the federal Environmental Protection Agency). It also expanded its system integration activities and outsourcing business which, together, brought in about 25 percent of the company's revenues in 1991.

This growth continued in 1992, when SAIC's information systems revenues increased 25 percent to \$533 million, out of total revenues of \$1.3 billion, mostly through its military contracts (e.g., a \$7.6 million contract for the Defense Supply Services WARBREAKER simulation system, a \$16 million contract for controls and displays in automated aircraft cockpits, a \$25 million subcontract for the Army's Close Tactical Trainer Program, and a \$200

million systems integration contract for the Army's Missile Command (MICOM). SAIC also integrated wireless local area network (LAN) technologies with Personal Digital Assistants (PDA) for commercial customers. The company succeeded at "defense conversion." Ten years ago, 80 percent of its revenue was from defense contracts; now, that figure is 50 percent. Its revenue has increased 17 percent a year since 1989, to \$1.5 billion today, and in 1992 it hired 2,500 new employees, for a total of 15,000—impressive for a firm with ties to declining defense appropriations.

Defense Conversion

The transformation of SAIC to the civilian sector began in the mid 1980s. The larger scale work for SDI required putting more people into project units and assembling a new top-level management (a new chief financial officer, a treasurer, and a controller). As Beyster put it, "the importance of skilled project managers is becoming extremely obvious to the company."⁵⁰ The government was tightening contracting procedures and Beyster tried in this way to ensure that SAIC did not lose money: "We have placed a much greater emphasis on risk aversion," said Beyster. "It is hard to perform fixed-price contracts in a research and development environment, in which costs can escalate rapidly due to the experimental nature of the work. The standard cost-plus-profit margin contracts of the past have grown fewer, forcing the company to pay closer attention to the bids it submits."⁵¹

SAIC was also in a more competitive environment. Its contracts, which had been largely sole-source agreements for specialized services for the DoD and DOE, were increasingly competitive: from 75 percent, the number of sole-source contracts had slipped to less than half. Like GA, SAIC faced increasing competition from its own spin-offs. While continuing to bid on a large number of small government projects, SAIC also began to look outside the government for new business. It had researched a number of energy supply technology methods, especially nuclear, relying on its prior expertise,

but, as Beyster noted at the time, "energy [was] not growing the way it was during the energy crisis." Like GA, the company also had projects in toxic waste disposal, but this also seemed to have only moderate growth expectations.⁵²

Beyster retained the focus on national security in his efforts to diversify SAIC. The company's competence in computer hardware and software, developed in a series of contracts for DoD, facilitated an initiative to supply the Army with a portable lap-top computer and an integrated hospital information system. This project, to computerize the medical records at some 700 military hospitals and health clinics around the globe, won a \$1 billion DoD health-care system contract and led to a \$100 million contract from the U.S. Veterans Administration (VA) for a decentralized health-care computer system. The Integrated Data Communications Utility contract called for SAIC to provide integration, software, and management for a system to link 400 VA locations nationwide and in Puerto Rico to the VA headquarters in Washington, DC, and provide military veterans with speedy access to information about their eligibility for benefits. It led to a \$1.2 billion contract for VA for its Composite Health Care System.

Expansion of Core Capabilities

SAIC acquired new core capabilities by purchasing them: the software services division of Control Data Corporation, the M/A Com, Inc. Systems Engineering Center, Falcon Associates, and Médecine et Systèmes Informatiques Intégrés in France were all strategic acquisitions in the late 1980s. It also has teamed with systems vendors but "is not interested in having a long list of strategic alliances and subcontractors on projects. Rather, the company prefers to develop and leverage its own resources, and pursue projects in which most of the contract revenue stays within the corporation."⁵³ In this way, SAIC maintains not only cost but also quality control. It guards its independence as "a contract research organization, a loosely organized one, with relatively autonomous units,

abilities to make commitments of people and facilities without interference."⁵⁴

SAIC diversifies in a particular way: "Most of the company's employees are technicians or contract officers with government experience who are supported by the company during their first year. Afterwards, they must bring in the contracts to support their positions or be released, but they have wide latitude in choosing the types of projects they pursue."⁵⁵ As Don Kerr noted of one such employee, Steve Rockwood, a sector vice president:

Steve Rockwood doesn't need me to succeed in his business. I may be able to do some things to help him, but in fact he's going to stand or fall on his efforts in this company based on what his colleagues do in the groups that report to him, and yes, there could be some corporate support for initiatives he wants to take, there can be help in collaborations and teaming and so forth, but he really runs his own business to some great extent.⁵⁶

A number of these in-house entrepreneurs, like Rockwood, are LANL veterans, and SAIC personnel also go to the laboratories so, as at GA, there is a flow of information and expertise between the laboratories and the company. Many in the Laboratory have seen an opportunity to do at SAIC what they cannot do at Los Alamos—run their own enterprise.

Employee Ownership

The ownership is not just figurative, but also literal. Beyster credits employee ownership for SAIC's success. Its workers and directors own 46 percent of SAIC's shares outright. Another 41 percent are reserved for the company's executive stock option and 401(k) plans. "If there is a problem with a contract that could make the stock go down," says Beyster, "employees sound off about it. The fact they are concerned puts teeth into management." SAIC's stock price has climbed at a 27 percent annual compound rate for twenty years. Employees recommended by their managers for their performance can buy

stock on SAIC's quarterly trading days. According to *Fortune*,

Tying employee welfare to corporate results has overcome institutional lethargy and helped make SAIC surprisingly nimble. While many defense contractors struggle to diversify, SAIC has made the move with grace and speed. Just six years ago, more than two-thirds of its sales came from providing technology, analysis, and engineering support to the Pentagon for Star Wars, arms control verification, underwater surveillance systems, electronic warfare, and the like. While that business continues to grow, defense now accounts for just over half of revenues.

SAIC's new growth markets are health care and environmental cleanup:

The same geologists, hydrologists, and other environmental experts who once contemplated the chilling prospects of a nuclear winter are now working for NASA on the problems of global warming. Others are developing innovative technologies to help the EPA clean up the worst of the country's hazardous waste sites. One of the most promising—using bacteria that gobble up waste—was employed on two-thirds of the beaches of Alaska's Prince William Sound that were polluted by the Exxon Valdez.⁵⁷

The bootstrapping of resources developed in defense-related contractual work, rather than the creation of new capital facilities, has been essential to this strategy. As Rockwood explains,

We've stayed a very lean company, loosely knit, which is sometimes a problem, but most of the resources are given to the first-line managers, and they are expected to serve their customer in Idaho Falls, or wherever they are located, as if they are his sole support. They are focused on his needs. That makes the customer happy and coming back. So it's a very successful formula for the sort of government-service business that we've been in.⁵⁸

In the past, such activity has been referred to, derisively, as "job-shopping," and has been

resisted by the national laboratories, although both Argonne and Oak Ridge, faced with the loss of their reactor development missions, turned in this direction in the 1950s and 1960s. By the 1980s, Oak Ridge was describing itself as "a multiprogram research and development laboratory having a variety of energy-related missions of national importance," and, like Brookhaven and Argonne, was considered by the Energy Research Advisory Board as among the original multi-program laboratories. Indeed, when Oak Ridge was taken over by Martin Marietta in 1982, the focus of the entire laboratory was shifted to accelerate technology spin-off to industry through Martin Marietta Energy Systems, Inc., a division of the corporation formed to operate Oak Ridge.

Decentralization

Other studies have found that organizations which are more decentralized, like SAIC, were more likely to innovate and that more innovative individuals were more likely to transfer technologies across institutional boundaries. The decentralized firm, however, runs the risk of losing control of its subsidiary organizations. Both Steven Rockwood and Donald Kerr agree that the national security mission of LANL will continue to be the most important focus for its activity; and rather than further decentralization, they recommend spin-offs of functions that are no longer relevant to that mission. This is also what GA has learned to do. Ideally, such a course would provide Amtech- and Cell Robotics-like high-technology businesses for former Laboratory employees to run.

That leads to a focused business to develop and deploy the technology and get it to the marketplace, where if it stays within the laboratory the expertise to do that is typically not present. The interest in doing it is less because there are other interesting things to work on and diversions of all sorts. I think the spin-off is, in fact, the preferred way to go.⁵⁹

Steven Rockwood observed of Laboratory efforts that, "a lot of the Lab's projects, even when

they're looking at a commercial market, start out as a technology push without knowing if the commercial market is really there."⁶⁰ Research has shown that "approximately three out of four commercially successful industrial good innovation projects are initiated in response to a perception of user need for an innovation, rather than on the basis of a technological opportunity to achieve them."⁶¹

Spin-offs from Los Alamos

Spin-offs, however, face their own problems. Although GA's and SAIC's founders both had clear markets in mind when they left Los Alamos, there was a kind of technology push involved. Amtech was founded by Gary Seawright after the Departments of Agriculture and Energy decided that the technology, which used microwave transponders and readers to identify and interrogate cattle and vehicles, did not have commercial potential. Amtech had to learn a good deal about industrial technology and markets in order to succeed, even with abundant capital from Ross Perot, and despite the promise of the technology, it is still losing money. Even though the company has successfully marketed its technology for identification of ships and railroad cars, the loss of California and mid-Atlantic contracts for automated toll collection using Amtech technology will not improve this situation. Amtech, like many Laboratory spin-offs, faced another problem. As Kerr puts it,

It's partly location. I remember talking to Ed Knapp who at one point left the Lab to try and commercially exploit some of his ideas for accelerator design. He found very quickly that he couldn't do it in New Mexico because there was no industrial infrastructure to support him, and did it in Los Angeles, instead, where he could go a few blocks and there would be a company to do the plating, go a few more blocks and there would be people who could do the brazing, so that he didn't have to put as much money into the start-up as he would otherwise have had to recreate all that infrastructure in, say, Albuquerque.⁶²

Amtech, which has moved from Los Alamos's small business incubator to Santa Fe's industrial park, to Albuquerque, followed an analogous path to that of Knapp, Cell Robotics, and other Laboratory spin-offs. Cell Robotics, which moved to Albuquerque successfully, found difficulty in raising capital there. "It's been a learning experience for us," says Ron Lohrding. "The toughest part is getting it funded in New Mexico . . . There's no venture capital in the state, and those [venture capital firms] on the east and west coasts prefer firms to be nearby."⁶³

Although Amtech did succeed in raising venture capital through the local Cook family, as the company grew, Ross Perot and other capitalists who bought in took control. As Tom Thornhill, president of New Mexico Technet, remarked, "you don't have to go to the coast to get venture capital; I've tried to help some start-up firms myself. One of the things I've found is that anyone giving venture capital to a project will tie a lot of strings to it, want an interest in your business and a voice. That kind of has a tendency to scare the small entrepreneur."⁶⁴

If spin-offs move away from the Laboratory, however, they may lose the benefits of the infrastructure it provides for research and development. The infrastructure provided by other centers of industrial spin-offs from government-funded, defense-related research, like Route 128 and Silicon Valley, has been the subject of considerable study. Such an infrastructure might be provided in Albuquerque, where Sandia National Laboratories, which has been a conduit for nuclear weapons component technologies to industrial manufacturers, could supply similar expertise to Los Alamos. In a sense, GA and the University of California, San Diego, built up a regional infrastructure for the development of high technology in the San Diego area. SAIC could then be seen as the most successful spin-off of that infrastructure.

Whether New Mexico can create the kind of regional infrastructure that has grown up in California, Massachusetts, North Carolina, and Texas may be the subject of considerable doubt. The cost of doing business in Los Alamos is high, and although software development, which requires minimal capital resources, has pro-

vided some alternatives for growth, it is not likely that the Laboratory could sustain a high-tech community in the way that Stanford, MIT, the Research Triangle, and the University of Texas have.

Without a local industrial infrastructure, the Laboratory has traditionally relied upon other means to shop its wares. Numerous publications have described technologies available for development from Los Alamos. As Steve Rockwood remarked, however,

Ninety-some percent of the investment is yet to be made when the Lab sends out this glossy brochure and says here it is. The judgment of the market is such that most of those glossy technologies aren't really needed to serve the consumer market.⁶⁵

Indeed, under Donald Kerr, a Control Data Corporation study identified approximately ninety Laboratory-developed technologies ripe for transfer to industry, and although more than 200 companies received a copy of this inventory, only 10 visited the Laboratory for more details.⁶⁶

Cooperative research and development agreements (CRADAs), the hoped-for results of such advertising, are currently fashionable. Kerr initiated a staff exchange program beginning with Techtronics; and cooperative agreements with Westinghouse, IBM, ARCO, 3M, and Schlumberger-Doll involved more than 200 staff members engaged in private consulting through the Los Alamos Economic Development Corporation. Asked about its success, Kerr replied, "My feeling is that if there is a return and a benefit it's going to be seen over a period of decades."⁶⁷ The enumeration of such agreements, or counting CRADAs, as it is now termed, is not an adequate measure:

You can measure the height of the papers published, you can measure the recognition given to professional staff members, you can . . . count the number of CRADAs, you could maybe count the amount of money that companies are willing to match with the government, but none of them go to the guts of the enterprise which is motivating people to perform and succeed. There's just no present way to do that.⁶⁸

Unlike SAIC, Los Alamos does not have a profit-based performance system. The Lab doesn't have that equivalent of a single parameter to judge itself by as an institution, not just as individuals, but as an institution, Rockwood pointed out, "I think that's going to continue to be difficult."⁶⁹ Moreover, the rewards for performance are, not, as in the case of SAIC, a share of those profits. As an employee-owned firm, SAIC rewards its high-performers with more stock. As Kerr suggested, only half facetiously, "how about an employee buyout for some building and capability? George Cowan could finance it through the bank!"⁷⁰ Rockwood details the scheme:

The entities that were privatized would still reside in Los Alamos county, along with the employees, but now the county's economy is strengthened by increasing the diversity of its employers. The employees would benefit by being part of an organization strategically focused on a business area for which their skills are mainstream. The Laboratory, as a national resource, would be helped because it could better focus its attention on those tasks the nation can only get from a LANL. Finally, industrial competitiveness would be helped because industry would be a more responsive and cost-effective connection to talent it can use in business development.⁷¹

Conflicts of Interest

Questions have been raised, however, about the ways in which SAIC has performed as a government contractor. Even *Business Week's* glowing praise notes that it has had the help of board members such as former Defense Secretary Melvin R. Laird and Bobby R. Inman in landing contracts spanning a wide range of technologies.⁷² Several years ago, senate investigators discovered that SAIC has evaluated weapons systems that it produces. As Republican Senator William Roth of Delaware said at a June 1989 congressional hearing, the company was "being asked to support testing assessments for [the Strategic Defense Initiative].

At the same time SAIC [was] the 26th largest SDI contractor. Tell me that is not a conflict of interest." On December 10, 1991, DOE announced it was hiring SAIC to evaluate programs even though there was "a potential conflict in that SAIC . . . could [be] reviewing its own work."⁷³ Deputy Defense Secretary William Perry, contracting chief John Deutch, and contracting deputy Anita Jones, not to mention Inman, have all served on SAIC's board, which raised questions of conflicts of interest again before Inman declined Clinton's offer to him of the position of Secretary of Defense although not, apparently, in the case of Perry, who accepted the offer.⁷⁴ To this, the current executive vice president of SAIC responds, "sure, the board of directors provides some assistance, in terms of people who have access and knowledge, but the board of directors isn't any different in that part of their function than some of the advisory committees to the Laboratory."⁷⁵

SAIC, which with 4000 federal contracts has more than any other firm, is already successful but may be able to go much farther than Los Alamos and other national laboratories in pushing the envelope of federal law, particularly when it relates to conflicts of interest.⁷⁶ The long struggle to amend the technology transfer act must be seen in the light of a century-long debate over the intellectual property rights inhering in publicly funded research. The formation of the Research Corporation, which used the proceeds of a smoke precipitator invented at the University of California in 1912 to fund scientific research, the Wisconsin Alumni Research Foundation, and other such instruments have traditionally been used to channel profits from university research back into that research while safeguarding the public interest. When German chemical patents were acquired by the Alien Property Officer in World War I, a private foundation, the Chemical Foundation, was established to make them available to industries. Federal funding for university research of benefit to industry, however, has legitimated the kind of investment in which the DOE is now participating. NSF's industry-university cooperative research centers (IUCRC) program was designed to fund basic university-based research

on strategic and commercially important areas through industrial sponsors. The successful 20-year-old program currently funds some 50 IUCRCs involving 1,100 faculty members, 1,000 graduate students, and 78 universities through 700 sponsoring industries, government agencies, and national laboratories. University work that industries support includes research on polymers, glass, sensors, biodegradable materials, software engineering, and composites.

In the DOE's national laboratories, until a few years ago, things were quite different: "Let's say that the people who believe that if the taxpayers paid for it, there shouldn't be exclusive licenses given were rather more in control than they are today," Kerr recalls.⁷⁷ SAIC executives see the transfer of technology to private industry as in the public interest:

If, in fact, U.S. companies become more competitive, their sales increase and their profits go with them, there's a return to the taxpayers. So we don't necessarily have to look for a direct return to the Laboratory to justify the activity . . .⁷⁸

Support of Spin-Offs for the Laboratory's Traditional Mission

The formation of small firms to develop Laboratory technologies would also support the Laboratory's traditional mission:

Let's assume that the Laboratory is still in the same geographic area but the Laboratory's main mission—Los Alamos's main mission—is the nuclear weapons part, which is going to be mostly engineering maintenance over the next ten years or so. Then, when a new weapon is to be developed, one has a periphery of technical talent that you could bring back into the program, perhaps, if there's something that kept those good technical people in that area.⁷⁹

Conclusion

The advice from SAIC, not surprisingly, mirrors the company's success. If SAIC is viewed

as a collection of small, autonomous firms owned by their employees, oriented toward the customer in government or, to a far smaller extent, in industry, much of that success can be attributed to the kind of strategy which Kerr and Rockwood have suggested for the Laboratory. The ownership of the Laboratory, however, vests in DOE, not the University of California, and, apart from patent rights, it is unclear what equipment or facilities could be sold off to entrepreneurs who want to transfer technology to the marketplace.

Despite the examples of local firms that have spun off from the Laboratory, it is not clear that this approach can contribute materially to the goal of devoting 20 percent of the total Laboratory budget to industrial partnerships. However, it seems clear that technology transfer works most effectively when individuals are the agents of transfer. SAIC has institutionalized the transfer of technology from the federal sector to the private sector by hiring those human agents. Although this practice has raised questions of conflict of interest, since the principal customer remains the federal government, it has been effective in propelling the firm to a leading position among those involved in commercialization of technologies arising in the national laboratories.

The establishment of the Los Alamos Economic Development Corporation and of the first technology business incubators in the nation helped launch employee-owned small businesses like Cell Robotics and Amtech. Southwest Medical Ventures (SMV) of Albuquerque, New Mexico has emulated their success. Molecular Technologies, a firm that is attempting to transfer DNA-sizing technology, is one result. Further encouragement of the incubator mechanism, in addition to the pursuit of DOE's Small Business Initiative with particular attention to Laboratory employee-owned firms may enhance this mechanism of technology transfer, especially with special user facility access.

Neither GA nor SAIC, however, has faced the overwhelming bureaucratic obstacles to technology transfer that have burdened the national laboratories. Indeed, they were created in large part to avoid them. The evolution of legislation

and policy in this area during the past fourteen years had lightened the load, but not removed it.

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