Midwest Computer Architect Struggles with Speed of Light

Chippewa Falls is the home of 12,351 people, about 50 small businesses, and Leinenkugel beer. Set among the dairy farms of western Wisconsin, it does not seem a likely spot for the development of the world's fastest computer. But it is also the home of a reticent 49-year-old engineer who grew up along the Chippewa River and has made a career of building ever larger computers.

Seymour R. Cray dislikes public speaking, seldom grants interviews, and for years has preferred to work with a small number of people in virtual seclusion. Since the 1950's, Cray has had a passion for building faster and faster machines as one computer generation succeeded another. Working late into the night in a small laboratory not far from his house, Cray has produced a uniquely designed supercomputer which appears to have won out against tough competition from some of the biggest names in the industry. Not everyone needs an $8 million computer that is four times faster than anything previously built. But for those specialized problems for which more computing power is indispensable, the unusual-looking Cray-1 computer is proving to be the world's foremost machine.

A half-dozen Cray computers have been built so far. The early ones have gone to scientific centers and government installations, such as the federal research center at Los Alamos, New Mexico, where the first computer was delivered. Subsequent "number crunchers," as the most powerful computers are referred to in the trade, are going to centers for long-range weather forecasting, to laboratories for advanced nuclear research, and to the Department of Defense—reputedly for code breaking. The tasks for which the Cray computer is well suited are important enough that in some quarters Cray himself is viewed as a "national resource."

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Just down the road from the Falls Bait Company and across a snowy field from the town's aqua-blue water tower, about 40 workers meticulously assemble Cray computers one at a time in a small steel manufacturing building. It is the only new building owned by Cray Research, Inc., and it is 6 months old. Before that the company had neither a factory nor a work force. (The first computer was built under a subcontract by a local electronics firm.) Cray Research has grown so fast that new employees are tucked away in odd lots of office space wherever it is available. Some work in the old Chippewa Falls Shoe Company building (the town's shoe industry declined after the early part of the century) and above the lobby of the First National Bank. Cray and the three or four engineers who have assisted him work at his research hideaway in the woods, which he calls Hallie Lab.

Inside the steel building, two finished computers are being tested and a third is being slowly assembled from some 200,000 integrated circuits that will be carefully placed and automatically soldered onto 1662 printed circuit boards. Every wire in the Cray-1 is cut to a precise length, and the assembly takes 3 months.

More than anything else, the finished product looks like a miniature version of the transporter on the television show *Star Trek*. The semicircular computer is about 6 feet in diameter, slightly taller than the average person, and has a narrow opening through which one can squeeze into the center. It is carefully assembled in three sections (none of the wires are color-coded and only the ones linking the three sections are numbered) and then the wiring is completed by a single person standing in the transporter zone. The circular construction was chosen so that the various components of the computer could be as close as possible to each other. No wire in the machine is more than 3½ feet long. The integrated circuits are of a type that takes only about one-fourth the space of circuits used by other computer makers. The printed circuit boards are stacked together in columns so dense that it is impossible to slip a finger between them.

Seymour R. Cray

There is a reason why everything is so densely packed. Signals cannot move from one part of the computer to another any faster than the speed of light, and supercomputers have gotten so fast that the time delay in long wires has become a limiting factor. The circular design was chosen so that wires could traverse the short inside radius. The feat that Cray achieved in getting all the necessary circuitry into a cabinet about the size of a Paris kiosk can be realized by comparing the Cray-1 with its two closest competitors, supercomputers built by Control Data Corporation and Texas Instruments. The Cray takes about 8 square feet of floor space. The other two take up most of a square room 40 feet on a side.

For all the speed that the compact design made possible, a price had to be paid. With so much packed into such a small space, keeping the circuitry from overheating was a monumental problem. (The computer uses 1/10 megawatt of electrical power.) The solution to the cooling problem is unique and was, in fact, the only aspect of the Cray-1 that was patented. Hidden in the massive aluminum uprights that hold the circuit boards are numerous cooling coils that are connected under the floor to a huge Freon cooling unit. Computers are often cooled with fans or tap water. The Cray machine is one of the few to have a built-in refrigerator.

With its unique features, the Cray computer has achieved a standard of performance that puts it in a class by itself.

There are only seven or eight types of computers that have enough speed and memory capacity (generally 1 million words) to qualify as supercomputers. The biggest computer ever built by IBM (the 360/195) falls in the supercomputer class, but IBM sold only a few and has discontinued production of this model. Favoring instead the larger markets that

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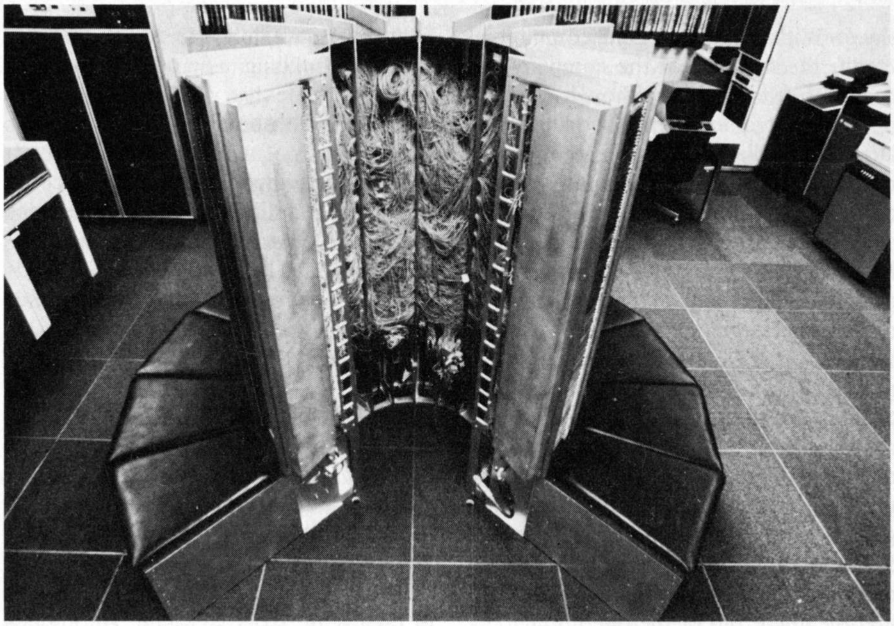
are available to machines just below supercomputer status, IBM has dropped out of the competition to build better big number crunchers. During the last decade, Control Data Corporation has cornered much of the scientific computer market, selling 400 of its CDC 6600 models and 75 of its CDC 7600 models. Even though the CDC 7600 is now 8 years old, it is still widely regarded as the workhorse of the scientific world and the standard by which further progress is measured. The Cray machine is equivalent to five of the CDC 7600's or out-of-production IBM 360/195's.

Another computer designer with a talent for entrepreneurship, Gene M. Amdahl, has formed a small company and built a large computer christened with his name. The Amdahl computer is powerful enough to compete with the biggest IBM model now made (the 370/168). But both the Amdahl and the largest current IBM machines are considerably below supercomputer status. According to the well-respected Auerbach Corporation, which publishes systematic reviews of computer technology, it would take 15 IBM 370/168's to match the Cray-1.

When Seymour Cray formed his company in 1972, he really faced only two competitors, Control Data and Texas Instruments. With large teams of carefully coordinated engineers, both companies were designing supercomputers in the early 1970's. Although they ran behind schedule, they beat the Cray-1 onto the market by a year or two. (Cray shipped his first computer to Los Alamos in April 1976.) Both computers were backed up by a large company's formidable expertise in designing program software.

Both the CDC Star and Texas Instruments' Advanced Scientific Computer were more expensive than the Cray. Each machine had a brief round of sales, but in spite of specialized capabilities that they had to offer, the overall computational qualities of the Cray proved superior. Control Data plans to upgrade the Star before selling any more than the four already built, and Texas Instruments is not actively promoting its supercomputer after building four for its own use and selling three others. Both machines have had more than their share of teething troubles. For a while they were clearly preferred because the Cray supercomputer was available only as a bare 5-ton piece of hardware without any program software. (It is said of Cray that he is the "ultimate engineer" who is happy to build and let others figure out how to use his computer.) Now that software is available for the Cray-1, customers are heading its way.



Inside look at the world's fastest computer.

The National Center for Atmospheric Research in Boulder, Colorado, installed one last summer. The European Center for Medium-Range Weather Forecasts (ECMWF) at Bracknell, England, is ordering one. A time-sharing computer company in Kansas City, Missouri, United Computing Services, recently gave the company its first order from the commercial sector, and the federal fusion research program is negotiating for one that will be installed at its computer center in Livermore, California.

* * *

Seymour Cray has been through the process of building up a small company before. He has been in the computer business from its beginning in the early 1950's, starting with Univac not long after graduating from the University of Minnesota with degrees in electrical engineering and mathematics. When a small group of people decided to split off from Univac in 1957, Cray was part of it. He became one of the founders of Control Data Corporation and quickly proved himself the company's most talented computer architect. He also convinced his colleagues that a small company could successfully build a large computer and proceeded to design a machine (the 1604) with the cheapest parts he could find ("semiconductor dropouts"). Produced in January 1960, it was the first solid-state computer to hit the market and it started CDC's success story.

As Control Data grew, Cray began to show signs of the penchant for isolation for which he is well known. Feeling increased discomfort with "large corporate structure problems" of the burgeoning company, Cray moved his 35-person research group out of the company headquarters in Minneapolis in 1962 and for the next 10 years worked in Chippewa Falls. He was, according to stories in the company, the only employee the chairman of the board had to make an appointment to see.

During the decade Cray worked for Control Data in Chippewa Falls, he designed the CDC 6600 and 7600 (renamed the Cyber 76 since he left), plus a still larger one that the corporation decided not to market. "It was a good deal for CDC and me," he says. But the company diversified into a service-oriented organization, while Cray maintained his single-minded interest in building bigger computers. By 1972, he decided he could support his research operation better through his own efforts. By all accounts, the parting was amicable. In fact, Control Data was one of the early backers of the new company.

Seven of the 12 founders of Cray Research came from Control Data, including the valuable engineer in the research group who developed the patented cooling for the Cray-1. The initial capital for the company was put up by Cray and the other original employees, along with private backers in the Minneapolis area. The company stayed small and the total expenditure up to the time the first computer was built was less than the purchase price of a single full-sized computer. In the spring of 1976, the company went public with a $10 million stock offering and later in the year negotiated a $10 million line of credit from Twin-Cities banks. The stock price has risen since. With six orders and commercial credit, the finances of the company appear to be stabilizing, although it is still operating at a loss. Because the parts alone cost millions of dollars, the company has not yet kept a computer for its own use.

To remedy the Cray-1's principal sales handicap, the company is building up its programming group. ("We now spend as much money on software as on hardware," Cray says.) The staff size has gone from 35 to about 200 in the last year through the addition of programmers and assemblers as well as service engineers and sales people. To coordinate the growth of the company, a young MIT engineer, who is a graduate of Harvard Business school, has been made president. Cray is the chairman of the board and the centerpin of the operation.

* * *

In an office overlooking the snowy parking lot of Spickler's recreational vehicle outlet, Cray is asked how one goes about designing a supercomputer. Except for a certain shyness, his manner and appearance belie his reputation. He is a large, handsome man, carefully dressed in leather moccasins, light blue corduroys, a plaid shirt, and a matching light blue sweater. He speaks of big computer building in an offhand manner, as if everyone has to have a job and that happens to be his.

"There is not much to designing really," he says, implying that anyone could do it if he practiced a little bit. He does not talk to other computer designers, although he says he reviewed the problems of other supercomputers. He does not use a computer to design a computer. He does not use any graphic aids to keep track of the pathways in his machine. Computer building is an abstract exercise, he says, for which his only aid is 8½ by 11 inch quadrille-ruled paper. The only peculiar preference is for "faintly ruled ¼-inch quadrille," and during the intense labor of creating a new machine he uses "about a pad a day." About his sources of creativity, Cray is vague. He implies computer building just requires attention to detail. Couldn't one say the same thing about designing sailboats? "I design computers about the same way I design sailboats," Cray replies. How is that? "For simplicity."

Those who know him say that Cray apparently builds a visual concept of an entire new computer in his head. There are no intermediate steps. He simply conceives it and then draws it. The result is the electronic organization of the whole machine: the wiring, the placement of each integrated circuit, and the design of the 113 different types of printed circuit boards used in the Cray-1. The logic behind this organization—the architecture of the computer—is the key thing, and Cray's success lies in the fact that he has consistently been a little more daring and aggressive than anyone else. He was the first to concentrate on the facets of computer architecture needed for science and he is a "genius at compaction," according to Sid Fernbach, who for years has been buying machines designed by Cray for use at the government's Livermore laboratory.

Rather than incorporate many specialized features in his machines, Cray concentrates on the basics. Whereas an IBM computer might be designed with a large set of instructions it could execute in order to have something to favor every sort of computer user, Cray's computers have a rather limited set of instructions optimized for scientific purposes. Anything that could slow down the machine is suspect. He reportedly once wanted to discard a standard error-checking feature widely used in the industry because it would slow the machine by 5 percent. Much of the architecture of super-

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Lederberg New President of Rockefeller University

After a search that lasted almost a year and a half, the board of trustees of Rockefeller University on 17 January elected Nobel laureate Joshua Lederberg to succeed Frederick Seitz as president. Seitz is retiring after more than a decade in the Rockefeller presidency (*Science*, 21 January 1977). Lederberg has been chairman of genetics at Stanford University School of Medicine since 1959. He also is professor of computer sciences.

The election of Lederberg, who has had virtually no administrative experience, comes to the surprise of many of his colleagues in biomedical research nationally. Even William O. Baker, president of Bell Laboratories and head of the search committee, acknowledges that choosing Lederberg is an "inventive and different move." According to Baker, whose committee collaborated with a faculty search group headed by Maclyn McCarty, the trustees will look to Lederberg more for his "intellectual contribution" to the university than for his skills as an administrator or fund raiser of proven talent. Reflecting the desire of the board to see Rockefeller concentrate its efforts on areas of genetics and molecular biology and virology in which it was long preeminent, Baker, in a telephone interview, cited Lederberg's "keen sense of strategy in developing new insights in highly traditional fields," as one of the qualities that make him attractive to the board. "We are looking for a new era of ingenuity at Rockefeller," Baker said, pointing out that Lederberg is not only strong in genetics but is also knowledgeable about computers and their application in biology and chemistry.

In 1958, Lederberg shared the Nobel prize for his discovery of the mechanism of genetic recombination in bacteria and has taken a consistently conservative stand on the recent furor over recombinant DNA research, arguing that it is being too restricted. At Stanford, he has coupled his work in bacterial genetics with an interest in life in outer space (he is said to have coined the word "exobiology"). He was instrumental in convincing the space agency to quarantine the moon rocks that were brought to earth on Apollo 11 in 1969 (no living organisms were discovered) and he had a hand in planning biological experiments on the Viking mission.

Lederberg's appointment at Rockefeller becomes effective 1 July.

Schmitt to Seek Commission on All Hazardous Research

During the past session of Congress, in the middle of unsuccessful efforts to pass legislation governing recombinant DNA research (*Science*, 20 January), freshman Senator Harrison (Jack) Schmitt (R–N.M.) took things one logical step farther when he introduced a bill ad-

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computers is designed to cope with the vector mathematics that occurs often in scientific problems, and the organization of the Cray-1 for vector problems is excellent. (Vector problems require the computer to repeat the same arithmetic with lengthy sets of numbers. The basic speed of a computer can be multiplied as much as tenfold by an architecture designed to anticipate the regularity of vector problems and to facilitate the processing of successive numbers.)

Cray claims that he does not know how to build a computer that is not simple, and this tendency is evident in the choice of basic components. In the entire Cray-1 there are only three kinds of integrated circuits—one for memory, one for logic, and one for addressing instructions. Other supercomputers have many more.

Throughout his career, Cray says that he has been "designing computers to do a better and better job of solving one problem." That problem is the numerical simulation of the physical effects of moving fluids. It is at the root of weather prediction, aircraft design, and many nuclear research problems. He makes no apology for the limitation, saying that "Cray Research is intended to stay in a narrow market" supplying specialized computers to large research institutions. But computational power is stilll insufficient to solve the problem fully. His computer designs, from the CDC 6600 to the Cray-1, have been intended to keep improving the solutions, first expressed in one dimension, then in two dimensions, and perhaps in three dimensions. Conceiving of fractional dimensions is difficult for many people, but computer users do not hesitate. Cray says that progress has been made to the point that "we are now about at 2½."

The problem that Cray has been tailoring computers to solve, at least in one of its realizations, is a central problem of the postwar era. Ironically, the detonation of a nuclear weapon is a problem in fluid simulation. It is a thought dark enough to cast a pall, even over Chippewa Falls, and Cray has considered it and come up with a simple and surprising justification. "The ability to test bombs on a computer seems to me to be the vehicle that led to the Test Ban Treaty," he says, "and as long as we can keep it on a computer no one will get hurt." Diplomats might contest the argument, wanting to take at least some of the credit for their treaties. And it puts a novel twist on the arms race—if computers could neutralize weapons, the Soviets might be parading computer printouts through Red Square on May Day. In fact, just the opposite is true. Supercomputers (Cray's in particular) are considered such an essential ingredient of the arms race that it is doubtful the company could export to any country other than Britain.

What will the future offer in the way of supercomputers? Still more power, Cray thinks. Historically, performance has been improving fourfold every 5 years, and Cray does not see any signs that this trend is flattening. True to his instincts, he does not place his hopes for future improvements on exotic innovations such as Josephson junctions (being studied by IBM) or other cryogenic technologies. He is even skeptical about magnetic bubble memories, which have been developed in prototype for many years. The big advance that has occurred in the last 5 years is in the number of components that can be packed onto a single integrated-circuit chip. The techniques of large-scale integration have reduced the cost of an equivalent number of transistors by a factor of 10, and that is the advance that computer designers will have to use in the future to improve their machines. (The Cray-1 did not use large-scale integration.) The semiconductor

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dressed to all "potentially hazardous research activities," not just recombinant DNA. The Schmitt bill—the first of its kind—calls for creation of a "National Science Policy Commission," to be composed of representatives of science, academia, business and the public interest, whose job would be to review all kinds of basic research.

An aide to Schmitt reports that the Senator introduced his bill out of concern for the narrowness of the recombinant DNA arguments. A scientist by training, Schmitt says he wants to "protect the public and foster scientific responsibility," without "unreasonably restricting the conduct of scientific research," hence his proposal for a national commission to formulate a comprehensive policy for research across-the-board.

Although the bill did not come up for hearings or discussion last year (it was introduced in November), Schmitt, a member of the subcommittee on science and space, intends to bring it up again during the session of Congress that has just been convened.

Firing of NIMH Head Brown Holds No Portent for NIH

The recent firing of National Institute of Mental Health (NIMH) director Bertram Brown for the ostensible reason that years on the job is long enough (*Science*, 20 January), has raised questions about whether Health, Education, and Welfare (HEW) Secretary Joseph A. Califano, Jr., will also ask for the resignations of long-term directors of the individual institutes of the National Institutes of Health (NIH). One director has been on the job for 15 years; another for a decade. Several others have held their positions for 4 to 5 years, so it is no surprise Califano's statement that "It is my policy that it's for the good of the government and the good of individuals for us to turn over these posts when people have been in them for a number of years," has left some people feeling a bit insecure. The prospect of applying such seemingly arbitrary management principles to institute directorships is particularly tricky in light of the fact that in recent years NIH has had increasing difficulty in recruiting individuals for the posts which pay considerably less than comparable positions in academe.

But the Brown episode apparently is not a portent for NIH. Julius Richmond, assistant secretary for health, says that rumors that Califano is thinking about personnel changes at NIH are "pure hokum, spun out of thin air." "The institute directors," Richmond told *Science*, "are [NIH director Donald S.] Fredrickson's responsibility. He hasn't requested any changes and we haven't asked him for any."

Souces close to the Brown ouster report privately that his dismissal came about as much because of the wishes of his immediate boss Gerald Klerman, new director of the Alcohol, Drug Abuse and Mental Health Administration of which NIMH is a part, as because of any general length of service policy of Secretary Califano's.

—Barbara J. Culliton

market is not driven by the needs of supercomputers but by the sales of hand calculators, TV games, and automobile electronic ignition systems.

Perhaps a man who has been notably successful at computer building would like to move on to other challenges. "I've had those thoughts," says Cray, who considered switching to a career in physics before he started Cray Research. He reviewed the status of particle physics but found his mathematics "terribly inadequate" and the statistical nature of everything in modern physics "disconcerting." For a man used to keeping mental company with 2.5 million transistors that must read either 1 or 0 without the slightest imprecision, such a sentiment is understandable. Cray says that he would "probably agree with Einstein," who argued for years against the uncertainty that most physicists of the 1930's found inevitable in the theories of quantum mechanics. Cray eventually concluded that he probably could not cope with particle physics, so it was "back to the grind, start another computer company and eke out a living."

More than he likes, Cray has been traveling, talking, and selling in the past 2 years. Now enough Cray-1's have been sold that the computer is becoming visible, and the company is evolving to provide a stronger administrative arm. Cray himself is returning to his late-night work schedule, buying quadrille paper pads by the gross, and starting to design his next computer back at the Hallie Lab. He is cautious in talking about it, saying merely that he expects to keep up with the industry's past record and come out with a machine that will be a better performer in the early 1980's (a schedule that would keep up the industry's pace of every 5 years). Others say that the next project will actually be a line of computers, including sizes small enough that not-so-well-heeled customers such as the universities can start with Cray equipment and expand later. The outlines are not quite clear, but it is expected to be even more versatile than the Cray-1 and at least twice as fast.

—WILLIAM D. METZ

Corporate Spying Prompts New Look at Trade Secrecy

Washington policy-makers are beset by complaints from industry and public interest groups that, under different federal laws, either too much or too little information about the composition and safety of new drugs, pesticides, and other regulated products is being released to the public. Now, as the result of several new initiatives in Congress and by the Carter Administration, they are moving toward the establishment of a uniform policy on the release of data that businesses provide in order to comply with federal rules and regulations.

The release of such data, long claimed by industry to be trade secrets of potential use to business competitors, has been a subject of debate in the capital since the enactment of the Freedom of Information (FOI) act in 1965. Although congressional sponsors envisioned then that it would be used primarily by private citizens to obtain information about the activities and policies of government, the act also enables individuals to request access to the files kept by federal regulators on thousands of companies and their products.

In recent years, more and more corporations have become aware of this, and have used the act to gain access to government files on their business competitors. Last year, for example, between 66 and 80 percent of the FOI requests received by the Food and Drug Administration (FDA), the Environmental Protection Agency (EPA), and the Federal Trade Commission were from businesses, seeking information about businesses. Corporate requests under the FOI act have become so frequent, according to several agency spokesmen, that the act has become a major instrument of contemporary corporate intelligence-gathering.

Accordingly, a small but growing number of companies, convinced that things are getting out of hand, are beginning to speak out about what they consider to be widespread release of sensitive commercial and financial data not intended by sponsors of the act and not desired by the firms at the time they provided the information to the government.

Nearly the exact opposite tack has been taken by representatives of public interest groups, many of which endorse the viewpoint of Claire Nader that "trade secrecy is a tool for producers that has served to hide a range of ills until the harmful consequences burst forth in a torrent of human pain and misery." For years, such groups have been pressing the FDA and the EPA to release the raw scientific data on which publicly given summaries of drug and pesticide safety and effectiveness are based; the groups want access to the data so they may independently critique the findings of industry and regulatory agencies. Naturally, businesses welcome this further disclosure about as much as they would the creation of a new agency for regulation.

Early last year, public interest groups won a major round when an interagency task force, set up by the Office of Management and Budget, proposed amendments to a bill on pesticide registration that will require all data on pesticide safety to be released to the public (*Science*, 30 September 1977). Although the proposal has been passed by both houses of Congress, the bill is awaiting final consideration by a joint conference committee. Even if approved, however, the amendments would only add to the confusing melange of existing laws relating to the release of what businesses claim are trade secrets. (Technically, trade secrets are strictly controlled data on the composition or manufacturing process of a unique product.) According to Edward Gray, an assistant general counsel for the EPA, in a recent study of trade secrets the agency "found that, in addition to the Freedom of Information Act and the criminal code provisions, there are at least eight statutes under which EPA operates that contain various specific provisions on trade secrecy. The Clean Air Act alone, for instance, has at least four separate rules for handling different kinds of alleged trade secret information."

According to spokesmen for several

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