Oak Ridge National Laboratory

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ORGAN IMAGES

ORNL Influences Radiation Protection

A Look at Inventing

Revolutionizing Electron Microscopy

REVIEW

Volume 23 *Number One, 1990*

Oak Ridge National Laboratory is a multiprogram, multipurpose laboratory that conducts research in the physical, chemical, and life sciences; in fusion, fission, and fossil energy; and in energy conservation and other energy-related technologies.

ON THE COVER

This computer graphic, generated at ORNL from diagnostic computerized axial tomographic (CAT) images provided by Thomas F. Ferron of Children's Hospital, Washington, D. C., shows a cross-sectional view through the lungs and heart of a child. In this view, the lungs are shaded green, the bones of the skeleton are white, and the heart and other soft tissues appear blue. The half-moon-shaped object below the subject is the bed upon which the patient lies in the CAT scanner—the shape being determined by the circular field of view of the scanner.

The computerized anatomical models of children (see back cover for two more images) are used to improve estimates of the radiation doses to children's organs for various levels of radiation exposure. For details, see the article by Keith Eckerman and Alan Hawthorne on "ORNL's Impact on Radiation Protection Guidance," on p. 64.

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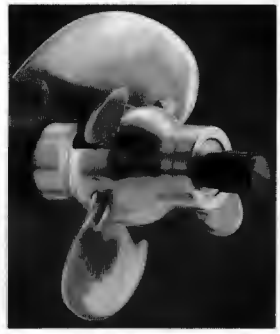
Features



Departments

Eureka!
A Look at Inventing

By H. C. (Chet) Thornton, Jr.

This reversible and self-adjusting variable-pitch propeller, co-invented by the author, operates more quietly and efficiently than a conventional fixed-pitch propeller.

The author holds a model of the new propeller he co-invented with Cliff Hall, a retired ORNL machinist who devised the first version in an attempt to reproduce the motion of a falling maple seed.

"The world's improved quality of life has been heavily dependent on American inventions."

Inventing, inventor, invention—to me, even the words are exciting. They make us curious. How does it work? Is it useful? Who invented it? Many Americans have been inventors. The world's improved quality of life has been heavily dependent on American inventions—for example, the telephone, the electric light, the electrical distribution system, the phonograph, movies, the airplane, television, the office photocopier, magnetic recording tape, satellite communications, the personal computer, the cardiac pacemaker, and many therapeutic drugs. Many different devices have been made possible because of a few key American inventions, such as the transistor and the laser.

The motivation behind these inventions has usually been to solve identified problems, although some inventions spring from the occasional "flash of inspiration" or the serendipitous recognition of a solution to an unrelated problem. American pioneers had to "make do" with the limited tools and materials that were available, much like independent inventors do now. Fairly often they came up with new ideas and improved designs. Robert Gundlach, holder of numerous patents on the photocopying process, said in Kenneth A. Brown's *Inventors at Work*, "Desperation is the mother of invention."

Some of our American heros have been, and are, inventors. What school child has not heard of Thomas Edison or the Wright brothers? The names are not as well known, perhaps, but some outstanding current American inventors include

Gordon Gould (who invented the laser), Wilson Greatbatch (the implantable pacemaker), and Robert Jarvik (the artificial heart).

Today, however, America's inventive spirit may be declining. We seem to be losing our technological edge to other nations, particularly Japan. In 1986, more than 45% of U.S. patents were granted to foreign nationals, and more than 22% went to the Japanese alone. In 1988, the total number of U.S. patents declined to 83,584 but the share of U.S. patents awarded foreigners increased. In fiscal 1989, the number of issued U.S. patents rose to a record 102,712 and the foreign share dropped slightly from 47.3% in fiscal 1988 to 46.7%.

Closer to home, Tennessee inventors received only 551 of the 102,712 U.S. patents issued in 1989. Although our state has 2% of the nation's population, we received 0.5% of the issued patents.

In 1988, 5.5% of all U.S. originated patents were held by women. Of all government organizations, the Department of Energy ranked first in woman-inventor patents for 1977–1988. One notable woman inventor is Mary Spaeth, who invented the tunable dye laser and helped develop laser isotope separation as research director for DOE's Lawrence Livermore National Laboratory. Does this low percentage indicate that women are less inventive, that our educational system fails to nurture creativity in female students, that women have different background training (set of basic tools), that women have fewer opportunities in their work environment to develop their innovative ideas, or that their traditional responsibilities attract most to nontechnical professions and leave them little time for inventiveness?

Can innovativeness be taught? If not, how can we encourage the creative spirit once prevalent in our nation? These are important questions that our educational institutions are only beginning to address.

I believe everyone has an "inventor's toolbox" filled with all the knowledge and experience acquired in life from family, friends, education, reading, innate curiosity, hobbies, and jobs. Successful inventors also need a gift for mechanical visualization. All of these tangible and intangible attributes enable a person to develop a new concept or invent a new product or process. People can provide valuable assistance. Otto Wheeley, a native of Lafayette, Tennessee, and general partner of Venture First, says, "Successful people will always stop and help you." I have found this to be true. It is also important to recognize the help you receive (e.g., my article has been improved by the editing of the *Review* staff). A little luck helps, of course. Recall the old sayings "Luck is when preparation meets opportunity" and, of course, "There is nothing sadder than a missed opportunity."

Inventing is a stimulating activity and gets easier with practice. It happens best when you are well prepared to identify a problem, state it in a realistic way, and then develop the best solution. All of us have some motivation for inventing because we would each like to achieve that small measure of immortality that comes from having our own flash of inspiration turned into a real invention. All of us would like to have that "Eureka!" feeling experienced when you realize that you may have invented something new and useful and, again, after a patent search reveals that your proposed solution to a problem is unique and may be the best solution ever developed. The "Eureka!" feeling, I believe, is one of the most exciting of human experiences.

"Inventing is a stimulating activity and gets easier with practice."

Hard Realities

The inventing process does have its perils and pitfalls, however. Besides worrying that others will steal the new concept, independent inventors are saddled with a heavy workload to bring their concept to fruition—research, prototype development, consulting with patent attorneys, applying for a patent, product design and manufacturing, and marketing the invention. Funding to develop a new product or process is often hard to find.

An Investor's Worst Nightmare

The following story, told by Vansant Coryell, was published in Complete Speakers' and Toastmaster's Library: Human Interest Stories *by Jacob M. Braude (Prentice-Hall, Inc., Englewood Cliffs, N.J. 1965, p. 69).*

One afternoon Mark Twain, who lost more than one hard-earned fortune by investing it in harebrained schemes described to him in glittering terms, observed a tall, spare man with kindly blue eyes and eager face, coming up the path with a strange contraption under his arm. Yes, it was an invention, and the man explained it to the humorist, who listened politely but said he had been burned too often.

"But I'm not asking you to invest a fortune," explained the man. "You can have as large a share as you want for $500." Mark Twain shook his head; the invention didn't make sense. The tall, stooped figure started away.

"What did you say your name was?" the author called after him.

"Bell," replied the inventor a little sadly. "Alexander Graham Bell."

"Luck is when preparation meets opportunity."

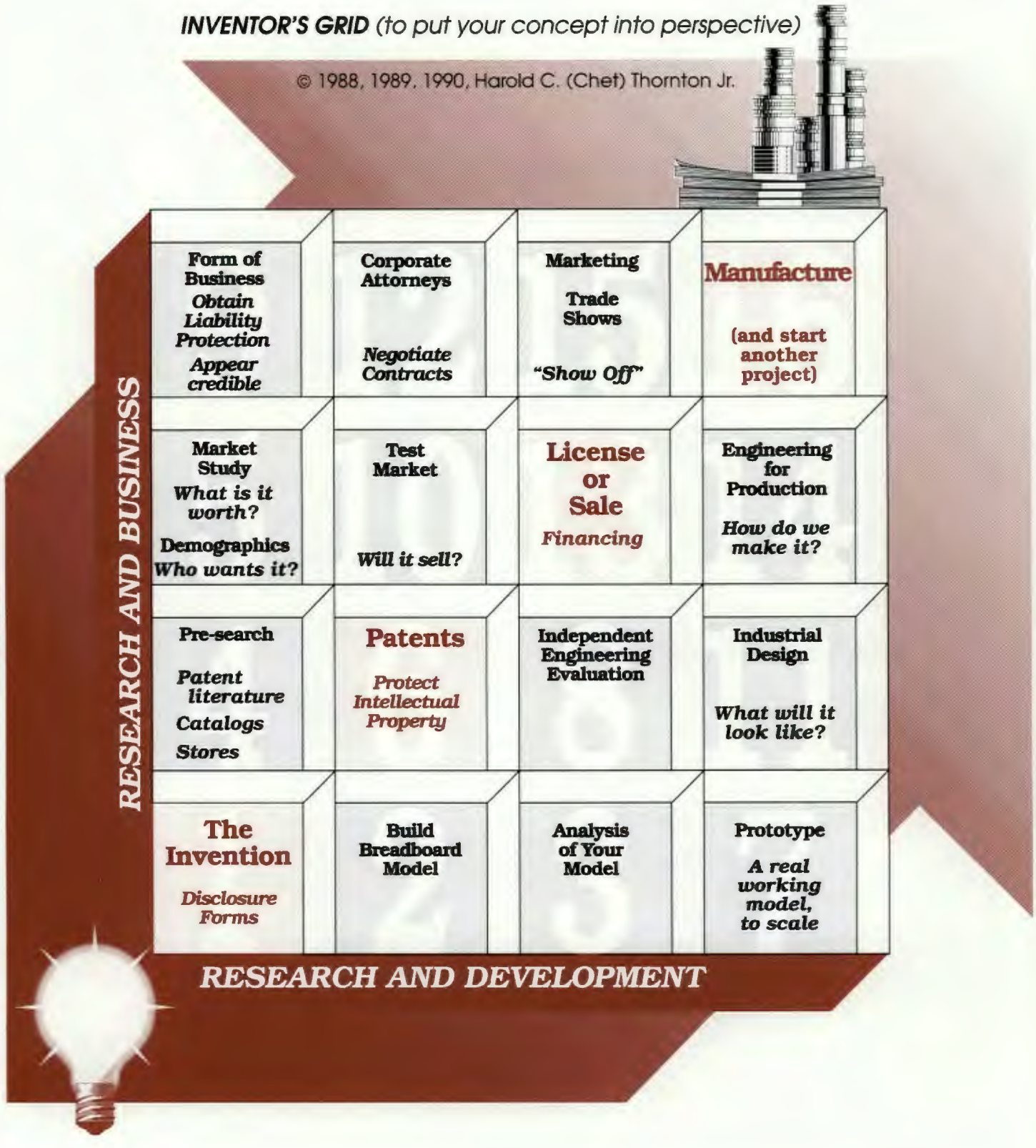
Inventors usually find that the patenting process needed to protect an idea is costly and complex. This process ideally involves a patent search to see if your idea has already been patented, filing for a patent application, and paying for the patent once it is issued. The initial cost of a patent ranges from $1000 to $1300 for "large entity" status just for the U.S. Patent and Trademark Office (PTO) and about half as much for "small entity" status; patent attorney (agent) fees range from $2000 to more than $5000, and PTO maintenance fees total as much as $2700 over the next 12 years. A patent gives the inventor the exclusive right to an invention for 17 years; during that time, anyone wishing to make, use, or sell this patented invention must pay royalties or licensing fees to the patent owner. (However, a patentee is responsible for monitoring the usage of the patented invention to determine if any rights are being violated.) A patent is real property; it can be bought, sold, or mortgaged.

There are other stresses, too. Jealousy and the attitude that the inventor is "a little eccentric" may develop among the inventor's peers. Inventors risk losing friends and partners because of the conflicts and intensity of trying of commercialize an invention.

Even very creative persons are often under tremendous pressure exerted by the managers within their work situation to be even *more* innovative—the syndrome in academic and research and development (R&D) circles known as "publish or perish!" in which career advancement or even continued employment depends on the number of publications one has.

"The 'Eureka!' feeling, I believe, is one of the most exciting of human experiences."

Admiring the wheelchair and remotely controlled swing-away footrest are, from left, Bob Gundlach, who holds numerous patents on the photocopying process; Kenneth Brown, author of *Inventors at Work;* Sandra Newsom, former director of the Patricia Neal Rehabilitation Center in Knoxville; Wilson Greatbatch, inventor of the cardiac pacemaker; and Thornton.



The number of steps actually required for an invention to become a useful product greatly exceeds the number of obvious steps (in color) known to every beginning inventor-entrepreneur. Developing a concept successfully requires the systematic execution of at least 16 steps in the general order shown in this grid. Drawing by Bobbi Lee.

However, because filing patent applications in some organizations may take several years and publication about the new concept may be forbidden until that process is complete, the inventor is caught in a real bind. In the United States a patent must be filed within 1 year of public disclosure, and filing for a foreign patent is barred if information about an invention is published ahead of time.

What are the financial rewards of creating new inventions? Only 1 out of every 100 patented inventions is commercially successful. "The reason for this low percentage is that many people patent ideas in areas in which they have little knowledge," says Martin Skinner, retired patent agent from ORNL. When the patent is granted, the inventor usually must use his own or borrowed funds for fabrication of a prototype and product development. Any royalties that accrue from a new invention depend on its commercial licensing and application. Unfortunately, some of the basic research at ORNL and the other national laboratories does not lend itself to commercially licensable products or processes. However, ORNL's recent emphasis on technology transfer has led to a number of successful licensing agreements.

In the past, most American work organizations have done little to encourage the invention process. Inventors in most places (including ORNL, until recently) were given the token sum of $1 for each patented invention developed on the job; in the past, ORNL inventors received the $1 as an indication that the invention had been assigned to DOE. After Martin Marietta Energy Systems, Inc., assumed management of ORNL, a system was instituted that rewarded the inventor more generously. The inventor receives a one-time award of $500 when he/she assigns patent rights to DOE or Energy Systems. If the invention is licensed by Energy Systems to a commercial organization, the inventor receives a share of the royalties. Originators of some unlicensable inventions (for example, classified processes or devices) may also receive financial awards from a shared-royalty fund set up by Energy Systems. Some Energy Systems inventors who file a patent application and receive the $500 award later receive a Statutory Invention Registration (SIR). (In 1989 there were five SIRs issued to Tennesseans, all of which went to Energy Systems employees.) As defined by the PTO, a SIR is defensible but not enforceable; it has all the problems of a patent but none of its assets.

Another problem for inventors in our litigious society is liability. An inventor is held liable for his inventions, and the primary concern, of course, is the possibility of physical injury resulting from use of the new product or process. For example, the developer of a new alloy might be liable if it is used in an airplane component that fails, leading to a fatal crash. In addition, liability concerns include financial losses to assignees or licensees that might be incurred from errors or omissions in development of a new technology. Also, a more personal, professional liability could result if the invention turns out to be, in fact, a dud. If the new concept is in any way concerned with the handling of hazardous materials, the inventor is held personally responsible by all the applicable regulations of the Toxic Substances Control Act and the Resource Conservation and Recovery Act (RCRA). Under recent RCRA regulations, in fact, persons working with hazardous materials can be held criminally liable for any violations occurring retroactively for 10 years.

Entrepreneurship

Inventors must do more than come up with creative, practical ideas; they must frequently become involved in the development of those ideas—what we call "entrepreneurship." Besides being responsible for patenting personal inventions, the innovator must stay abreast of due dates and assume financial responsibility for maintenance fees to preserve a full 17 years of coverage. If a prototype and product development are needed to market the new invention, personal funding or the ability to attract investment in the invention is required.

Venture capitalists use what they call "due diligence" in appraising a new technology, and one factor they strongly consider is the degree of commitment the inventor has made to his/her own creation. When you, the inventor, have

"Inventors must do more than come up with creative, practical ideas; they must frequently become involved in the development of those ideas."

In late 1989 at a press conference at the International Hall of Fame in Atlanta, Thornton displays a wheelchair equipped with the remotely controlled swing-away footrest invented by his class at Pellissippi State Technical Community College. Behind the table is Don Wolfenbarger, a class member and Thornton's supervisor at ORNL.

cashed in your certificates of deposit and "mortgaged the farm" to pursue the future of an invention, venture capitalists assume you are committed to the project. Of course, if the invention is the property of the inventor's organization, that organization must be relied on to champion the ideas, submit proposals to funding agencies, file patent applications, and license the new technology. The degree of success depends on how well the invention competes with those of other employees for funding.

The R&D work needed to develop any new concept is usually very expensive. When an individual must carry out this stage with his or her own resources, it is not uncommon to utilize materials at hand, borrowed from friends, found at a junkyard, or purchased at a flea market. Usually, hard cash is also required. If the inventor is working for an organization, the project or idea may sometimes have to be abandoned altogether because funding support fails before development can be completed. Besides causing professional disappointment, this loss may also cause the inventor emotional pain because, as ORNL consultant and University of Tennessee Professor Igor Alexeff says, "A new idea is very much like a child and giving up a child is very difficult."

It may be hard to believe, but competing for an award can kill your project. Consider, for example, the coveted R&D 100 Award given each year by *Research & Development* magazine to the top 100 innovations. To be eligible for this award, the new technology must have been offered for sale or licensing within the preceding calendar year. If it has been offered for sale, the funding agency may assume that the new concept is ready for commercialization, when, in the scientist's or inventor's opinion, the development process may be only beginning. Rushing the concept into the market before it is ready in order to be eligible for an award normally will curtail its research funding immediately, unless an understanding has been negotiated in advance. Lacking such an agreement may cause the project to die on the vine, so to speak, because the additional expense of the necessary R&D may deter companies from being interested in licensing it.

Protecting Your Invention

The system to protect inventors is complex and, unless care is taken, the rights to the invention may be voided inadvertently. An inventor is justifiably proud and wants to show and tell others about the new "baby." To guard against premature release of the information, however, the wise inventor will require a signed nondisclosure statement, clearly specifying that this information is not in the public domain and is to be kept strictly confidential. Failure to require secrecy could allow others to copy the new concept and patent it before the inventor can. Anyone unethical enough to steal an inventor's new idea will certainly have no scruples about signing the patent office's oath swearing to be the true inventor. A complete, annotated, and properly dated laboratory notebook kept by the inventor during the concept's development may be the only defense against such an eventuality. The notebook must be witnessed by someone who signs a statement such as "I have read and understood pages 1–10 on January 29, 1990."

Courtesy of INVENTORS' DIGEST

Thornton displays the new propeller at the National Inventors Expo '88.

"Anyone unethical enough to steal an inventor's new idea will certainly have no scruples about signing the patent office's oath swearing to be the true inventor."

New inventors would be wise to ignore such well-meaning but useless advice as the popular recommendation to establish ownership of an idea by writing it in a letter and then mailing the registered letter to themselves. A self-addressed letter does not constitute legal proof of invention because mail is too easily subject to tampering. It is better to spend time and money on obtaining good legal advice and establishing a good relationship with a patent agent or attorney.

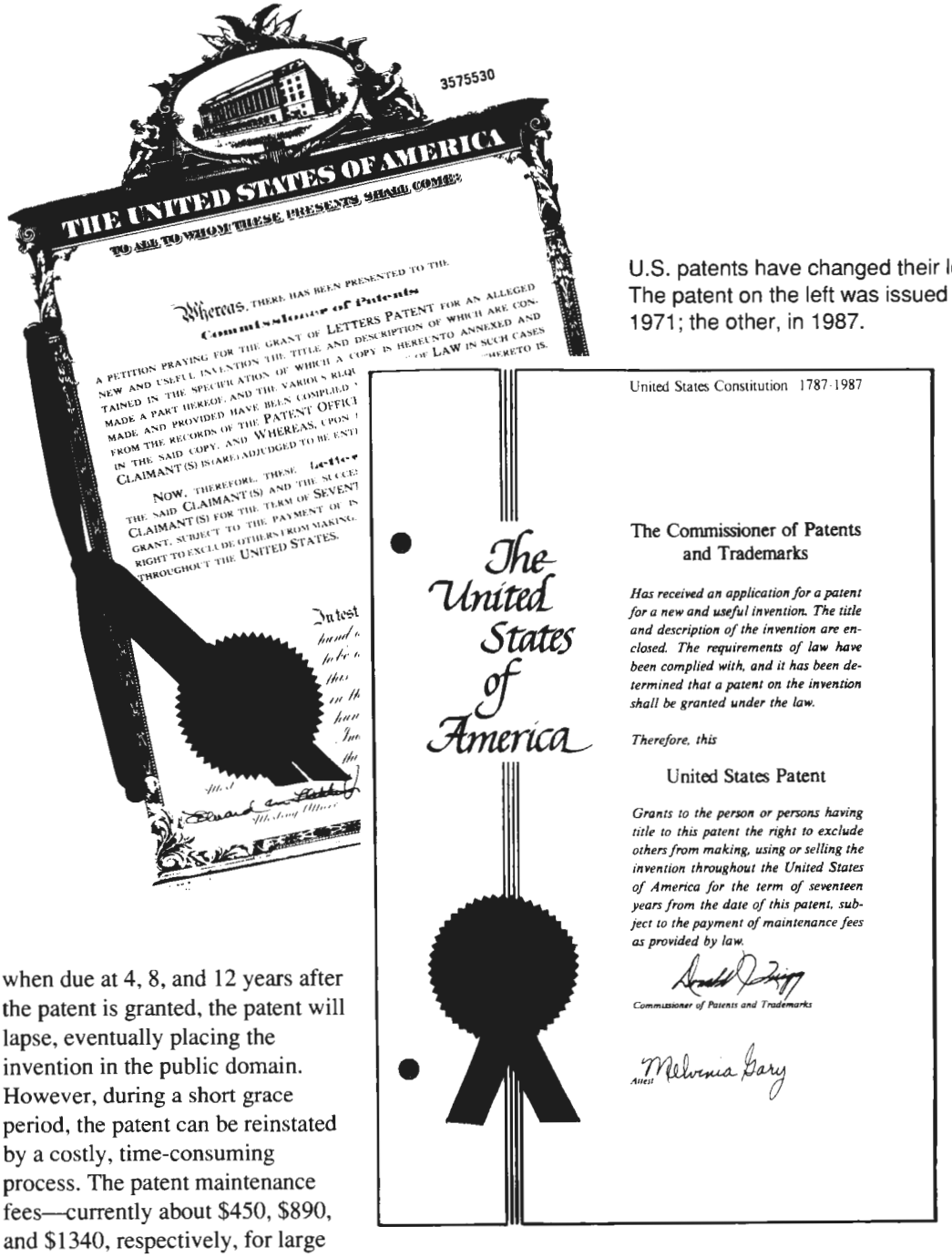
Failure to observe these precautions to protect an invention before patenting is completed can often lead to large legal fees (if the inventor's rights are challenged) or loss of the invention altogether. Gordon Gould, who invented the laser in 1957 as a graduate student in physics at Columbia University, spent $6 million dollars and waited 28 years before his first patent application cleared all the legal barriers (his first patent expires in 2004). His final legal victory was mainly the result of perseverance and his habit of keeping a well-documented and witnessed inventor's notebook. Because of the maturity of the laser industry and the widespread use of lasers, Gould's 20% share of the 1989 royalties was worth at least $45 million. Over the years, he traded off the other 80% of his royalties to obtain funding for litigation. His 1989 multimillion-dollar royalty check barely compensated him for the loss of the 1964 Nobel Prize in Physics, which was awarded to the American physicist Charles Townes and two Soviet physicists for their work on optical masers.

Other problems related to protecting an invention can arise from simply missing important patent application deadlines (called bar dates), or failure to pay maintenance fees on already-issued patents. Unless the fees are paid

Cliff Hall shows a working demonstration model of the continuously variable hydrodynamic transmission he and Thornton designed and fabricated.

Gordon Gould, inventor of the laser, examines the propeller co-invented by Thornton.

Thornton's class included many Energy Systems employees, including Joyce Francis at center.



U.S. patents have changed their look. The patent on the left was issued in 1971; the other, in 1987.

when due at 4, 8, and 12 years after the patent is granted, the patent will lapse, eventually placing the invention in the public domain. However, during a short grace period, the patent can be reinstated by a costly, time-consuming process. The patent maintenance fees—currently about $450, $890, and $1340, respectively, for large established businesses (approximately half these amounts for small entities)—must be paid to the PTO at specific times. The inventor should hire a patent attorney or agent to keep her/him informed of patent filings, fee due dates, and other issues for both domestic and foreign patent applications.

Is it really worth the effort to protect a new invention? It's very important, in my opinion, for several reasons. The inventor must protect the new concept from infringement by another person or institution, large or small. Infringement is a serious problem for inventors in two ways: someone could steal an idea and use it to make money, and the inventor could spend time and money on developing an idea only to learn that such an invention has already been patented. Remember, a patent search is needed to determine absolute novelty.

For example, my consulting firm, R&D SOLUTIONS ™, recently was hired to conduct an

apparently routine evaluation of a new product being considered for investment. During an interview with the entrepreneur who developed the product, he told us that he had previously lost money on patented inventions and would not invest in protecting this one. Instead, he used his funds for product development and packaging. Because he had avoided the patent process, we felt it necessary as part of our evaluation to perfom a preliminary patent search. At the University of Tennessee Law Library we discovered that a patent had recently been issued on this particular invention. The patented device was almost identical in appearance to and served the same function as the product we were evaluating. As a result of our report, the lender withdrew all support and the entrepreneur lost $22,000 in development and marketing costs, an enormous amount of time, and credibility as an inventor. Because he had manufactured and sold several items of this already-patented invention, he might wind up being the defendant in a patent infringement lawsuit. The lesson: a wise inventor first invests about $400 for a diligent patent search.

Another way to protect original work is by copyright. According to Energy Systems patent attorney Bruce Winchell, all derivative works should be protected by copyrights. People who publish documents and produce original software should consider obtaining a registered copyright on their work, for a fee of $10, from the Library of Congress. (See Inventor's Grid on p. 6 for an example of a copyrighted item.) Large companies are often suspected of attempting to pirate the ideas of unsuspecting and naive inventors. Although this is not often the case, inventors should take all precautions for protection for their work because, otherwise, it is difficult to license or market it for commercialization. Established companies are usually quite willing to pay for a good idea or technological advance—but only if it is well-protected by the intellectual property laws and protection measures available to the inventor. Businesses are unlikely to invest in funding the development and manufacture of any unprotected concept, no matter how innovative or promising it may seem. The risk of having the same product or technology marketed simultaneously by a competitor is simply too great if protection measures have not been taken by the inventor. When a large company tries to break a patent (legally circumvent patent claims or omit one of its elements), it is usually only to ensure that the competition will not break it. By breaking a patent, the competition can copy the concept without undergoing the risk of development.

Rewards of Inventing

Despite the problems, inventing has its rewards. If you ask inventors about the motivation and rewards that stimulate their desire to think of new ideas, the financial aspects are usually not primary. Some might say it is the challenge of the unknown. Others might talk about improving the quality of life, creating new jobs, or improving our nation's competitive stance in world trade. Usually, though, it's the excitement, the adrenalin rush, the "high" of thinking up a new idea or a new solution to a problem that most inventors say is their greatest reward. From personal experience, I know the thrill of inventing can be so stimulating that I can stay awake all night and not be tired the next morning, as I hurry to get all the details worked out and recorded. Inventing can be a very "heady" experience because of the sense of accomplishing something others may have thought impossible. Most good inventions appear, in hindsight, to be such simple, obvious ideas, but no new concept is truly obvious until someone actually does the mysterious, creative intellectual processing that leads to "Eureka!" ornl

Helpful Hints for Inventors

1. Read books such as

- *Inventors at Work*, Kenneth Brown, Microsoft Press.
- *Patent It Yourself*, David Pressman (patent attorney), Nolo Press.
- *A Handbook for Inventors*, Calvin D. MacCracken, Charles Scribner's Sons.
- Ask your librarians for other titles.

2. Join organizations such as

- Inventors Clubs of America (60 clubs, 6000 members)
  P. O. Box 450261
  Atlanta, GA 30345
  (404) 938-5089

- Tennessee Inventors Association
  P.O. Box 11225
  Knoxville, TN 37939-1225

(Open meetings at 10 a.m. on the third Saturday of each month except January at the Tennessee Innovation Center, 701 Scarboro Rd., Oak Ridge.)

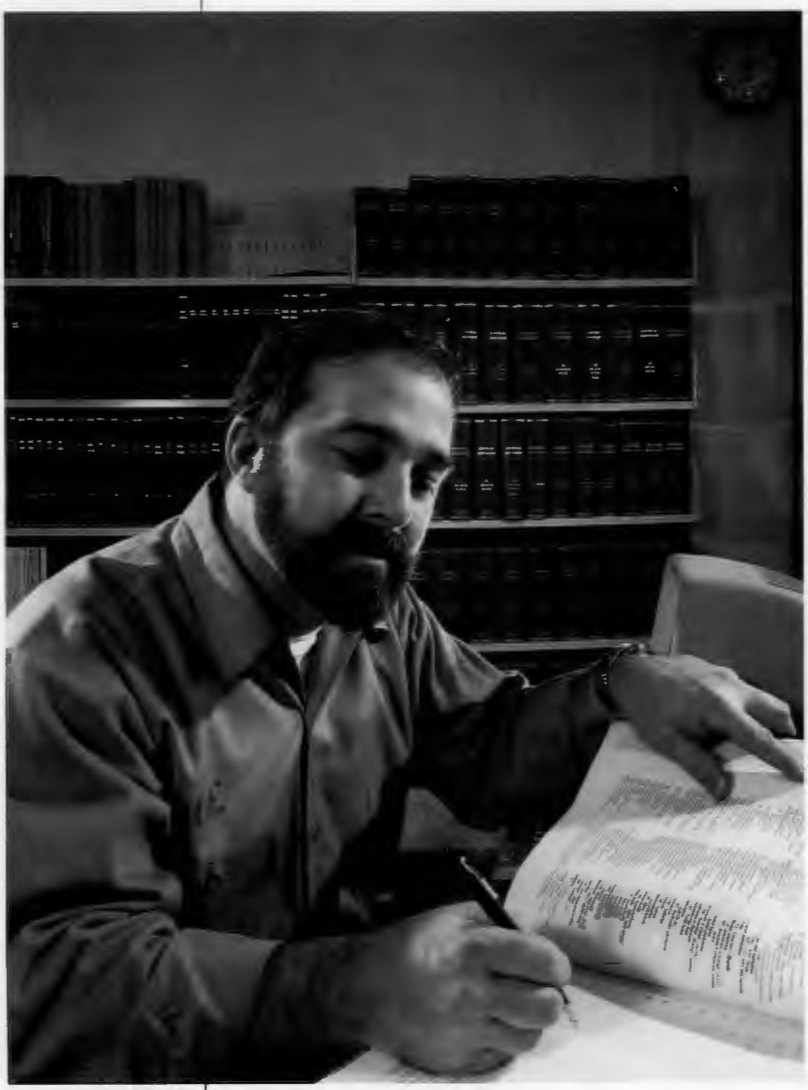
- Venture Exchange Forum
  P.O. Box 23184
  Knoxville, TN 37933-1184
  (615) 694-6772

3. Consult with

- U.S. Small Business Administration
- SCORE (Service Core of Retired Executives)

4. Enroll in college continuing education courses. Participate in seminars and workshops.

Profile of the Author as Inventor



During his lunch hour, Chet Thornton looks up a patent in ORNL's Central Research Library.

By day he works as a pipefitter at ORNL, wearing the familiar khaki shirt and slacks. At night and on weekends, he wears many different hats. He is an inventor, an entrepreneur, a college instructor, a chairman of several boards (including Inventions for the Disabled™), and a consultant. He is especially proud that he was twice inducted into the International Hall of Fame sponsored by the Inventors Clubs of America and was recently named the Inventor of the Year for 1990 by the Tennessee Inventors Association.

Harold C. (Chet) Thornton, Jr., of ORNL's Plant and Equipment Division is the co-inventor of the reversible and self-adjusting propeller device, which could be used for submarines, helicopters, windmills, and boats and as a new continuously variable hydrodynamic transmission for automobiles. (For more details, see the sidebar on p. 23.) Although he has not yet successfully marketed the patented product, he has gotten considerable "mileage" out of it. In March 1988, he unveiled the propeller to the public as one of 50 American inventors selected to exhibit a patented invention at the Inventors Exposition of the U.S. Patent and Trademark Office in Washington, D.C. Because of the invention of the propeller, he was inducted into the International Hall of Fame for inventors on November 2, 1988, in Atlanta (along with Gordon Gould, for his invention of the laser, and Robert Bruce Hagman, for his mathematical breakthroughs involving binary numbers). The propeller received the International Hall of Fame New Product Award sponsored by The Inventors Clubs of America.

In an attempt to learn how to market the propeller, Thornton joined the Tennessee Inventors Association and the Venture Exchange Forum and received some funding from Steve Parker of the Small Business Administration. He read all he could about patenting, licensing, manufacturing, and marketing new products. He also took college courses in small business management and entrepreneuring from Kitty G. Grubb, now his corporate attorney. Having established himself as somewhat of an authority on these subjects, he was invited to develop and teach two courses, "Inventing: How To Protect and Develop Your Concept" and "Inventing: The Business Development of Invention," at Pellissippi State Technical Community College. As an adjunct faculty member there, he developed the curricula for his classes, or as he puts it, "I invented the courses."

Thornton has taught the inventing course to almost 70 students, including a number of Energy Systems employees. Many of these students already

had received patents and awards for their inventions (e.g., I•R 100 or R&D 100 awards). However, several of his students are now in the process of obtaining their first patents using the knowledge they acquired in the inventing classes. Thornton is particularly proud that his classes have invented devices to aid disabled persons. The staff of the Patricia Neal Rehabilitation Center in Knoxville identified for the class some needs of disabled persons.

The most successful invention to come out of this cooperative venture has been the Remotely Operated Wheelchair Footrest Moving Device. Some partially paralyzed persons risk falling if they move their footrests manually and must rely on another person to do it for them. The new device allows these individuals to move these footrests by remote control while seated so they can stand to transfer to the toilet or bed without assistance. The device has been well received because it enables wheelchair-bound folks to be more independent. The invention received the International Hall of Fame New Product Award, which was presented in November 1989 to Thornton and his students.

Thornton is an entrepreneur as well as an inventor. He is president and chief executive officer of TRAMTEC CORPORATION™, which conducts research in propulsion and powertrain transmissions. He formed R&D SOLUTIONS™, a consulting company that develops and conducts seminars and advises, evaluates, and performs R&D for inventors, entrepreneurs, small businesses, and investors, using contract consultants. He also helped organize Hall-Thornton Ventures, Inc.™, of which he is chairman of the board; this company's goal is to market the variable-pitch propeller.

Thornton credits his parents for his inventive and entrepreneurial spirit. His father is a highly skilled craftsman who used to build state-of-the-art houses that incorporated his own problem-solving innovations. From his father he learned mechanical skills and developed make-do and can-do attitudes—the belief that materials available can be used to solve problems. His mother taught him to love art, literature, and nature; as a result, he became an avid reader, majored in biology, and took journalism courses at West Virginia State College, from which he graduated in 1990. She also taught him how to cook and sew. "My mother," says Thornton, "explained that people who do any craft—sewing, carpentry, cooking, or welding—do the same thing. You cut to a pattern and hook it together. For inventors, the pattern may be in your head, so you must learn new skills and use different materials to join everything together and make it work."

Although he used the kitchen only for cooking when growing up in St. Albans, West Virginia, Thornton later found his Oak Ridge kitchen useful for laboratory work. In their quest to invent a better propeller based on an early design patented by Cliff Hall, a retired ORNL machinist, he and Hall made breadboard models in the kitchen before they fabricated the prototype propellers in Hall's machine shop. Says Thornton: "We made our early models by cutting them out of celery, carrots, and oranges." What did they do with their mistakes? "Cliff is so intelligent that we didn't make many mistakes, but if we did, we ate them!"

Thornton is also involved in organizational work related to inventing. He is chairman of the board of Inventions for the Disabled™, a fund-raising group that consists of business leaders from East Tennessee and Atlanta as well as students from the inventing class responsible for the wheelchair device. He is also faculty advisor and member of the board of directors for the Edison Group, which comprises past students of his classes who desire to finish their projects, including enabling inventions for people with various disabilities.

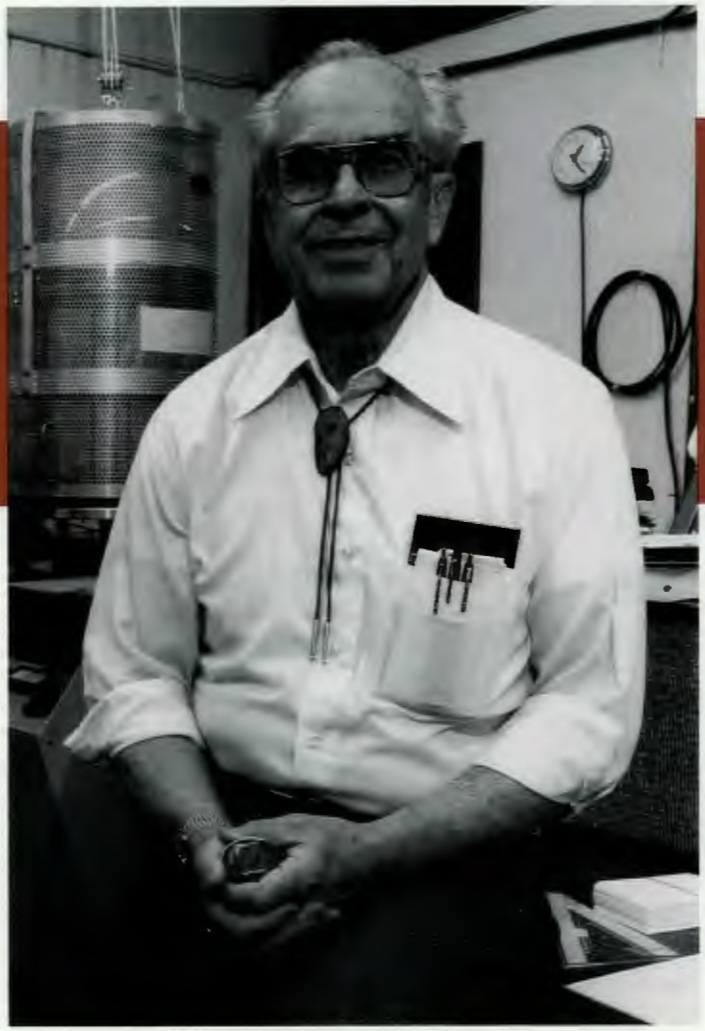
Thornton is a member of the executive council of the Inventors' Forum of Martin Marietta Energy Systems, Inc. For several years he has been a director of the Tennessee Inventors Association. He was recently named to the Advisory Board of the International Hall of Fame.

Thornton probably could wear even more hats if, as he puts it, "I had more days in my hours." So far he hasn't figured out how to invent a longer day.—*Carolyn Krause.*

"We made our early models by cutting them out of celery, carrots, and oranges."

Wayne Clark

Three East Tennessee Inventors



Wayne Clark takes a break in his laboratory at Syn Crys, Inc.

G. Wayne Clark is well known in Oak Ridge as a landowner, businessman, and entrepreneur. He is one of the owners and chairman of Adroit, Inc. (office supplies and printing), Adroit Computers, and Syn Crys, Inc., a start-up research laboratory for developing advanced materials based on synthetic crystals. Many ORNL employees remember his work as a crystallographer in the Metals and Ceramics Division, from which he retired in 1985. However, Clark is also an inventor; he holds eight patents—five U.S., one British, one German, and one Japanese—and should have more but for two unfortunate events. He has co-invented new methods for making synthetic crystals, such as an improved star sapphire and magnetic iron oxide crystals, and for growing single crystals of uranium oxide.

As an employee of the Linde Division of Union Carbide Corporation in the early 1950s, Clark was given the task of improving the asterism of the star sapphire being grown there. His job was to make the star-shaped figure seen when light is reflected from the crystal appear even more like a six-pointed star. He was so successful that Linde executives expressed concern that the improved synthetic star sapphire might not be marketable as jewelry because it was too perfect (desirable

Developing "the materials of tomorrow."

(desirable synthetic gems closely imitate the natural ones, and nature is not perfect).

The Linde Division, whose mission was to develop "the materials of tomorrow," also asked Clark to investigate a class of iron oxides, commonly called ferrites (e.g., magnetite, or lodestone). Company executives thought this black ferritic substance would be an important material of the future. So Clark and three other team members began experiments with nickel ferrite ($NiOFe_2O_3$) and obtained good results.

"We obtained 13 different structural combinations in our magnetic oxide crystals, which were confirmed by X-ray analysis," says Clark. "Because of all the obvious variations of our basic invention, the patent attorney suggested that we apply for 13 different patents."

The number 13 may have been unlucky for Clark. "The patent attorney quit his job at the Linde Division, leaving the company's Intellectual Properties Section in a mess," he said. "All 13 of our patent applications were lost in the shuffle."

During the late 1960s at ORNL, Clark and Ted Chapman worked on a project that led to Clark's "most exciting invention." They grew single crystals of uranium oxide using a new method they invented. This "internal melt zone growth" technique melted the inside of the material, not its surface, and grew crystals from the molten material. "The most exciting part of this method," says Clark, "is that the material acts as its own crucible. This method works with high-temperature materials, such as semiconductors and ceramics."

Clark and Chapman filed disclosures for patents on this method, but the Department of Energy and Union Carbide Nuclear Division, which operated ORNL for DOE at that time, did not file a single patent application on this new technique. "By the time we hired patent attorneys to attempt to protect the invention, the legal time period had elapsed. I was crushed. Our invention went into the public domain."

Despite this setback, the scientific community recognized the importance of the new technology. Clark gave invited talks in Marseilles, France; Geneva, Switzerland; and three U.S. cities on using this technique to produce binary and ternary eutectic materials. In addition, the internal melt zone growth technique received an I•R 100 Award in 1976 from *Industrial Research* magazine. Because the rules of the competition stipulate that the invention must be offered for sale, it is not surprising that the research phase of Clark and Chapman's project was considered over and that its funding was halted.

Clark acknowledges that inventing and making disclosures can be fraught with pitfalls and perils, but he takes satisfaction from his basic research on crystals. He notes, for example, that basic studies of nickel ferrites led to two important applications. "These materials," he says, "have reduced the size and cost of radar systems because nickel ferrite allows the rotation of the plane of polarization of microwave radar. In addition, nickel ferrite is ideal for making 'donuts,' electrical devices used for computer memories."

Clark continues to work on techniques to make better materials at his Syn Crys laboratory. Although his business activities occupy much of his time, the former ORNL researcher has not retired from science.

Terry Tiegs

Terry Tiegs holds three patents for his work in developing whisker-reinforced ceramics used for cutting tools and other applications. Here he conducts ceramic research in ORNL's High Temperature Materials Laboratory.

Only 1% of all issued American patents are profitable. One ORNL inventor who has found inventing financially rewarding is Terry Tiegs, a ceramicist in the Metals and Ceramics Division who was named Inventor of the Year in 1988 by Martin Marietta Energy Systems, Inc. He holds three patents (with other ORNL researchers) on the development of whisker-reinforced ceramic composites, which have been commercialized; as a result, he has received royalty checks from Energy Systems.

He also finds it rewarding that this ceramic composite is widely used for cutting tools and that the economy, nationally and locally, is benefiting from the advanced material. Eleven U.S. companies representing more than 80% of the worldwide market in cutting tools now hold licenses to use this ceramic composite. Cercom, an affiliate of Coors Ceramics, Inc., which is licensed to use a patented silicon-carbide-whisker-reinforced ceramic co-developed by Tiegs, recently announced it will move some its manufacturing activities to Oak Ridge. Also using the material is Hertel Cutting Technologies, Inc., the first company to lease a facility in Martin Marietta Corporation's Commerce Park.

Ceramics such as aluminum oxide, or alumina, are useful because their mechanical properties are retained even at very high temperatures, making them candidate

1988 Inventor of the Year.

materials for energy-producing devices that will be operated at high temperatures to increase their efficiency. However, these materials are normally brittle and can suffer catastrophic failure if subjected to stresses. Ceramicists at ORNL and elsewhere found evidence that reinforcing alumina with microscopic ceramic whiskers made of silicon carbide could increase the crack growth– inhibiting quality of the material, a property known as toughness. Increasing the toughness of materials makes them less prone to catastrophic failure.

"In the beginning, the chief method used to determine which ceramic the silicon carbide whiskers reinforced the best was one of trial and error," says Tiegs. "Mostly, a lot of development work was done. It was found that the silicon carbide whiskers doubled the toughness of the alumina matrix."

Ceramicists at Arco/ Greenleaf recognized that the composite had superior mechanical properties that would make it an excellent material for cutting tools.

The development of the whisker-reinforced ceramics by Tiegs, Ron Beatty, Paul Becher, and George Wei resulted in an I•R 100 Award in 1985 for Arco/Greenleaf for WG300, which is being used to make metal-cutting tools. Arco/Greenleaf has developed new applications for this ceramic—die punches for aluminum soft-drink cans, woodcutting tools, and stonecutting blades.

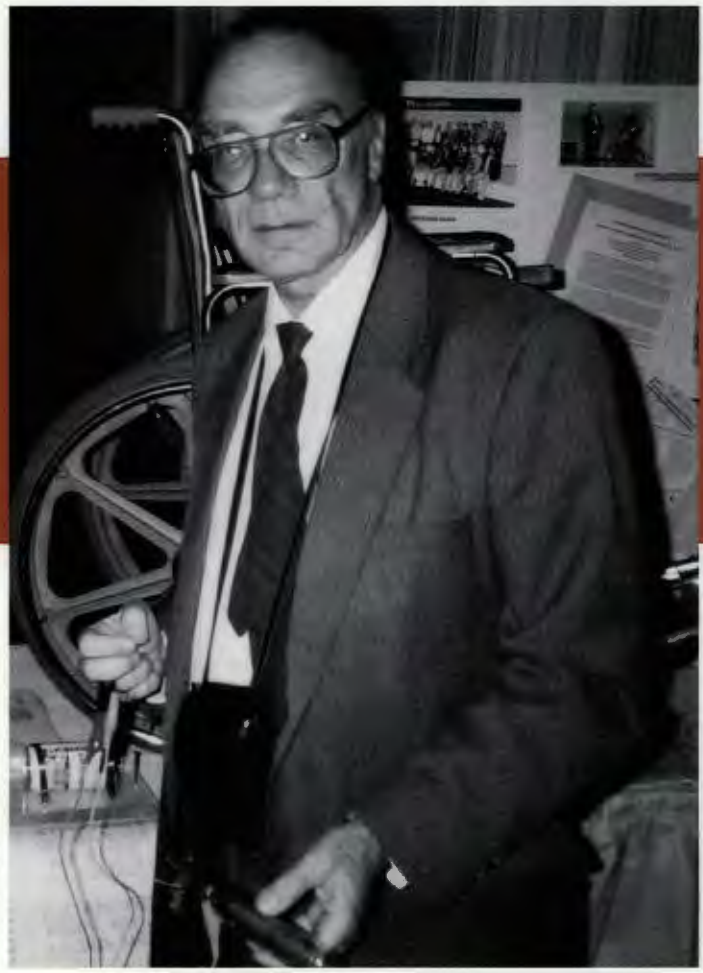
Tiegs, who has an M.S. degree in ceramic engineering from the University of Illinois, started his career at ORNL in 1975 studying nuclear fuel oxides for the High-Temperature Gas-Cooled Reactor Program. He also examined corrosion of ceramic materials for their use in chemical- process-heat applications and the storage of nuclear waste in underground fractured shale.

By working at ORNL, Tiegs has some advantages not shared by the independent inventor: the availability of expensive materials and equipment, the possibility of borrowing needed materials and equipment to continue the research, and the technical support for all phases of the work. "All types of support—from librarians and industrial hygiene staff to craftsmen and engineers—are available to us," he notes. "At least 20 persons, from a variety of disciplines, were involved in support of our whisker ceramic project. When we had equipment problems, repairs were quickly made or replacements were quickly loaned so we could keep our project going. Without this quick response and willingness to share, we could have been slowed down by an inadequate material supply."

Tiegs says his most exciting invention is always "the one I am working on right now." He regrets that funding priorities will not allow him to spend much time on improving or finding applications for the whisker-reinforced ceramics.

Tiegs is an advocate of Energy Systems' technology transfer program. Because of this program, says Bill Carpenter, Energy Systems vice president for Technology Applications, the number of invention disclosures filed and licensing agreements signed with respect to ORNL-developed technologies has risen significantly. In fact, DOE's Oak Ridge facilities lead all other DOE national laboratories and facilities in the number of technologies licensed to industry.

Igor Alexeff



Courtesy of Marty Garrison

Igor Alexeff demonstrates the orbitron "beer can" maser displayed at the International Hall of Fame along with the wheelchair device invented by Thornton's inventing class from Pellissippi State Technical Community College.

Igor Alexeff, a world-renowned expert on high-frequency microwave technology and co-editor of the 1987 book *High-Power Microwave Sources*, has one of the most inventive minds in East Tennessee. In 1989 this ORNL consultant and professor of electrical engineering at the University of Tennessee at Knoxville (UTK) won several awards for his inventions. He received an R&D 100 Award from *Research & Development* magazine for the gasless atomization nozzle, and he received the Advanced Technology Award from the International Hall of Fame (sponsored by the Inventors Clubs of America) for his tunable maser. In addition, he was named 1989 Inventor of the Year by the Tennessee Inventors Association. "I see all my inventions as children, to be loved and nurtured, to worry about, and sometimes to watch fail, but always to be proud of," says Alexeff, who worked as a researcher at ORNL's former Thermonuclear Division from 1960 to 1971.

Alexeff worked with David Hobson and Vinod Sikka of ORNL's Metals and Ceramics Division to develop the gasless atomization nozzle, which uses magneto-

"I see all my inventions as children, to be loved and nurtured, to worry about, and sometimes to watch fail, but always to be proud of."

accelerate a flowing molten stream of metal and then atomize it into minute individual droplets. The resultant metal powders from the device could be used to manufacture a wide range of automotive, aerospace, and household products more economically than by conventional means. This development received attention by the local media and the trade press (e.g., an editorial in the January 1990 issue of *Industrial Heating*).

Most people in the technical community are familiar with tunable lasers, which have been around for at least a decade. However, until Alexeff's invention in 1982, an easily tunable maser did not exist. The maser (acronym for *m*icrowave *a*mplification by *s*timulated *e*mission of *r*adiation), invented in 1953 by Charles Townes, became the basis for the laser, invented in 1957 by Gordon Gould. In 1958, Townes and his brother-in-law Arthur Shawlow developed an "optical maser."

Townes developed the first maser by bombarding ammonia molecules that had been excited to a high-energy level with microwave photons. When an incoming microwave photon strikes an excited molecule, it falls to a lower-energy level and releases a microwave photon of the same energy and in the same direction as the incoming photon, which is also released. Thus, each stimulated molecule produces two microwave photons, thus amplifying the incoming microwave radiation.

Unfortunately, the ammonia maser invented by Townes cannot be easily tuned—that is, it normally gives off only one frequency of microwave radiation. Only by using magnetic fields can the frequency be changed, but high frequencies cannot be obtained by this method.

About 10 years ago, Alexeff began thinking about the possibility of developing a tunable maser. The idea of how to make it work came to him in 1980 at home. "The idea just kept popping into my mind," he says. "I visualized a way of trapping orbiting electrons around a wire, producing super big atoms in which a wire replaces the nuclei. The orbiting electrons produce microwaves. That's why I call it the orbitron microwave maser. But it is also a tunable maser because the microwave frequency can be altered by changing the voltage applied to the electrodes in a small tube."

Using a beer can with a wire through the center, he and Fred Dyer at UTK tried to make a plasma switch that was invented and patented by Alexeff behave like a maser. A plasma switch uses an ionized gas, such as that in a neon sign, to open and close an electric circuit; this high-voltage, controllable device concentrates electrons. "I was using a beer can as a microcavity for a plasma switch and adding 10 times more power than I had ever used before. Fred had been looking for microwaves from the plasma switch. Then, when he accidentally left a diode microwave detector turned on and aimed at the beer can, he saw an indication of very intense microwaves. This was our lucky day—we had proved that a plasma switch could be turned into a maser!"

The tunable maser, which does not require a magnetic field, can be operated at a range of frequencies, even ones high enough to fill the gap between radio waves and light. Alexeff sees many applications for such a

Courtesy of W. L. Cochran, Sr.

Alexeff presents a plaque to Thornton honoring him as 1990 Tennessee Inventor of the Year.

"Inventing—is it worth all the agony that can result?"

device: high-resolution wide-band radar for military and transportation uses, satellite-to-satellite communication, and short-range radar for aircraft carriers. High-frequency microwaves, he notes, would be superior to radar in guiding antiaircraft missiles. Because radar "sees" two aircraft flying close together as a single object, military officials are concerned that radar-guided missiles will fly between the targets, missing them both. Missiles guided by high-frequency microwaves, says Alexeff, are more likely to hit their targets.

Strong interest in the prize-winning invention has been expressed by research groups from Israel, the People's Republic of China, and the Naval Research Laboratory (NRL) in Washington, D.C. When UTK asked an invention evaluation firm from New York to provide a market value on the tunable maser, a representative asked Alexeff, "Can you cook a steak with it?" When Alexeff answered no, the man said he could see no use for the tuneable maser unless it could be built for $2 less than a magnetron, the typical source of microwaves in microwave ovens. The firm advised UTK to not seek a patent but to waive the rights to Alexeff.

Alexeff was frustrated in his attempts to interest companies in developing and marketing the orbitron maser. Only one of the large American microwave companies exhibited initial interest and then proclaimed the device unworkable. "American companies resist developing new technologies," he says. "They would rather wait for a small firm to assume the risk of developing the technology and then take it over."

Alexeff encountered other problems with the orbitron maser. After UTK waived the rights to his invention, he hired an attorney to seek patent protection. After his patent application was rejected twice by the U.S. Patent and Trademark Office, he made a trip to Washington, D.C., only to be rejected a third time. The patent examiner said that the tunable maser is essentially the same as an X-ray generating device patented by the NRL. Alexeff shared his drawings with NRL staff, who subsequently wrote letters to the patent office in support of Alexeff, stating that his device was not like the patented NRL invention. Finally, he was awarded a patent on the tunable maser.

His invention-related problems did not end there, however. He was audited twice by the Internal Revenue Service for claiming patent costs as a business expense on his personal income tax form. He won his case after the second audit and a great deal of personal inconvenience.

Inventing—is it worth all the agony that can result? "Sure it is," he says. "My inventions are all worth it." Just like children.—*Chet Thornton and Carolyn Krause.*

A Revolutionary Propeller

Typical propellers for boats, helicopters, airplanes, submarines, and windmills are based on an invention more than 150 years old. The mechanism involves two or more blades that rotate on a shaft to produce a useful thrust. In a boat, for example, as the propeller rotates, the water is pushed away from it and the boat is thrust forward, satisfying the first law of physics: for every action there is an equal and opposite reaction.

In Oak Ridge in 1986, a revolutionary new "reversible and self-adjusting variable-pitch" propeller was invented by retired ORNL machinist Cliff Hall and Chet Thornton. In 1988, it received the New Product Award of the International Hall of Fame sponsored by the Inventors Clubs of America and was one of 50 American patented inventions selected for display in the 1988 Inventors Exposition of the U.S. Patent and Trademark Office.

The new propeller is superior to the conventional fixed-pitch propeller and other variable-pitch propellers in a number of important ways: it operates quietly, resists propeller stall or cavitation, and offers greater fuel economy and efficiency of operation. It can also be used as the propulsor in a continuously variable hydrodynamic transmission (CVHT) for automobiles. Because of its ability to change speed ratios and direction of thrust, the CVHT can do the work—transfer power from the engine to the wheels—that now requires numerous automobile drive train parts. A car equipped with a CVHT would be potentially more efficient and less costly to operate and maintain.

At the Inventors Exposition, Thornton exhibited a prototype CVHT designed to operate with noncompressible fluids. "As an automobile transmission," Thornton said, "the CVHT could replace the fluid-driven torque converter, the automatic transmission with its several hundred parts, the drive shaft, and the differential, all of which are now used in automobile powertrain transmission. Because of the low cost of the CVHT, this automobile transmission would probably never be repaired, just replaced."

Thornton says a car using a CVHT would accelerate quickly and perform better than many of today's automobiles because the engine would operate at peak power output as the self-adjusting CVHT changes ratios in response to varying load and speed conditions.

In addition to its applications to automobiles, the reversible and self-adjusting variable-pitch propeller could be used for submarines, boats, bicycles, and helicopters. "The CVHT can replace gears in bicycles, and the propeller would give helicopters improved fuel economy, quieter operation, and great takeoffs," says Thornton. Canadian researchers have expressed interest in using it for electricity-generating wind turbines, and the U.S. Navy has been offered the opportunity to use the technology for quiet submarine propulsion.

The new propeller has two large thrust blades, each of which is connected to a small control blade. The paired blades operate in dynamic balance. Whereas ordinary propeller blades stand at a fixed angle to the hub of rotation, the new device's thrust blades pivot at an angle that changes as needed to maintain a constant horsepower input while varying the output. By remotely changing the angle of the control blades, the operator can make the propeller work in forward, neutral, or reverse while the input shaft turns in the same direction at all times.

In discussions of propellers, an important parameter is pitch, the distance a propeller travels forward in one rotation (normally in inches); the higher the pitch number, the farther the distance traveled. The reversible and self-adjusting variable-pitch propeller automatically and continuously provides the best propeller blade pitch for all load and speed conditions independent of torque.

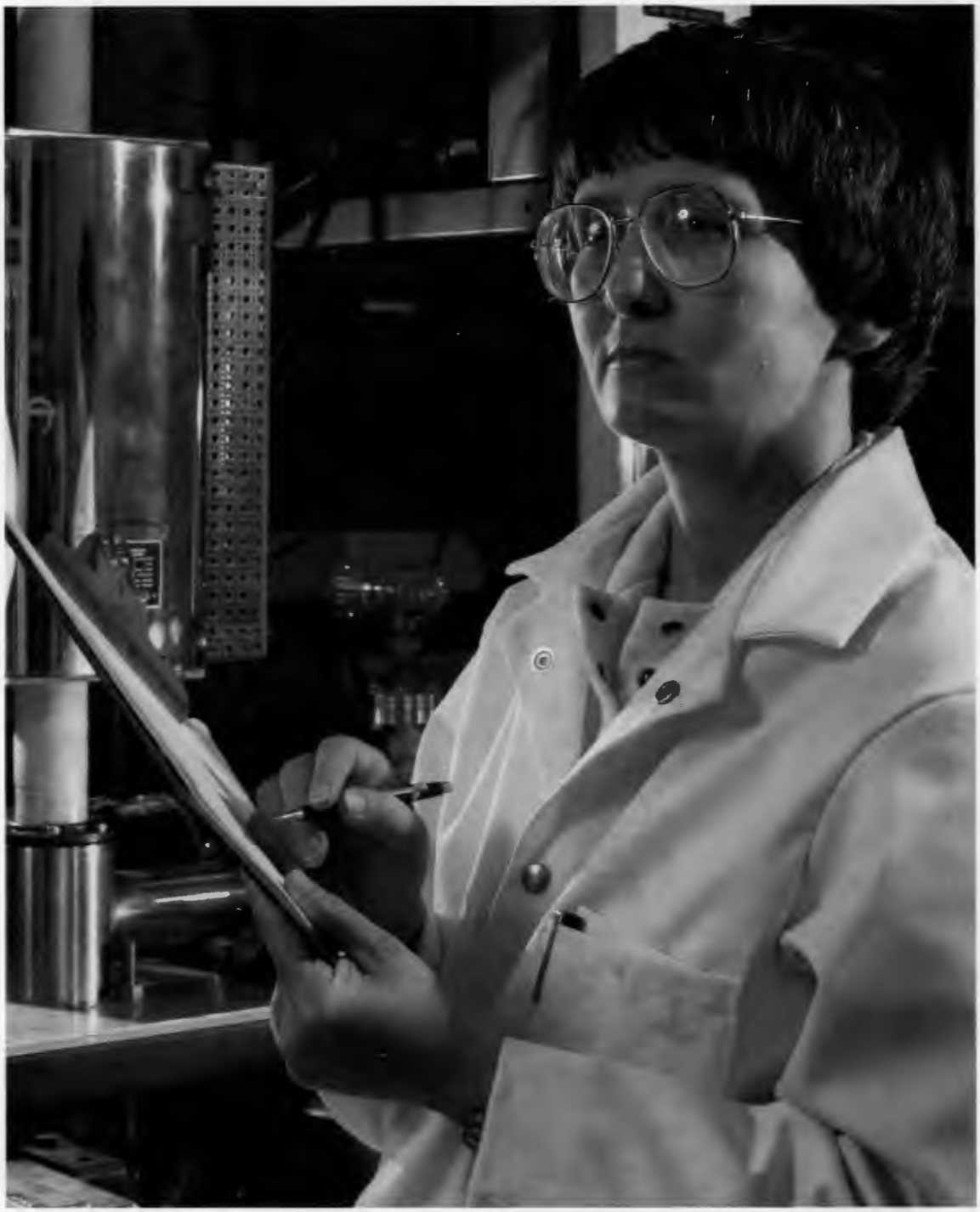
Ronald A. Porter, a former graduate student at the University of Tennessee, wrote his master's thesis in 1974 on the early variable-pitch propeller invented by Hall. He found that its operation is up to 86% more efficient for a wide range of speed and load conditions when compared with a fixed-pitch propeller. In no case was the reversible and self-adjusting propeller worse than the best design point of the fixed-pitch propellers.

Even though the cost of manufacturing the new propeller would be higher than that for the conventional fixed- or variable-pitched propellers, Thornton believes this device will be successful when companies begin to see the economic advantages of further developing and marketing it. Right now, the revolutionary propeller's development is not moving as fast as he and Hall would like, but Thornton is optimistic that some enterprising organization will soon give it a whirl.—*CK*

Iron Aluminides and the Inventor of the Year

By Carolyn Krause

"Interestingly, McKamey, who grew up in Anderson County coal-mining country, is working on alloys that could benefit the coal industry."



Claudette McKamey ponders the results of a creep test to determine the strength of an iron aluminide alloy developed at ORNL.

Twenty years ago, Claudette McKamey was a secretary in ORNL's Metals and Ceramics (M&C) Division. In the fall of 1982 she began work at ORNL as a metallurgical engineer, and in 1985, she started work in a fossil energy materials program to improve the metallurgical properties of iron aluminide alloys. For her successful efforts, in May 1989 she was named Inventor of the Year of Martin Marietta Energy Systems, Inc., and in June 1989 she was awarded a Jefferson Cup by Martin Marietta Corporation.

Interestingly, McKamey, who grew up in Anderson County coal-mining country, is working on alloys that could benefit the coal industry. These alloys could be used in advanced technologies for burning coal more efficiently or converting it to liquid and gaseous fuels. Iron aluminide alloys are of interest to the fossil fuel industry because they are highly resistant to the corrosion induced by the sulfur-bearing gaseous effluents of coal combustion and conversion. As a bonus, iron and aluminum, the key components of the alloys, are inexpensive and readily available in the United States.

How did McKamey become an expert on iron aluminide alloys? A daughter of a mechanic and granddaughter of coal miners, she came to ORNL as a typist in 1968, shortly after graduating from Lake City High School, and was hired as a secretary in 1970. McKamey soon became bored with typing and decided to take classes at the University of Tennessee at Knoxville (UTK) in hopes of eventually obtaining a better-paying job. "I came from a rural, low-income family, and I wanted to make enough money to live on my own and support my family when they needed help," she said. "So I took classes all sorts of ways—evening classes, correspondence courses, part-time day classes, classes on a full-time basis. I started to major in geology, then biology, then chemistry." By 1981, after taking a full range of science courses, she earned a B.A. degree in physics from UTK.

In 1974, while still a student, she left her secretarial position and became a technician. Her job was to prepare specimens for electron microscopy studies. She worked with researchers such as Jim Stiegler, now director of the M&C Division, for whom she once had been a secretary.

In the fall of 1982, she became a research staff member in the M&C Division's Materials Science Section—the section for which she had also worked as a secretary and technician. Three years later, she earned her master's degree in metallurgical engineering from UTK and took charge of the iron aluminide alloy project started in 1983 by Henry Inouye, who had retired. Her task was to improve the ductility of a brittle alloy so that it could be rolled and shaped into components that do not crack, break, or otherwise fail at room temperature.

Improving Ductility

Coal combustion and conversion plants produce hot, sulfur-bearing effluents and products that are moved through the plant by pipes and tubes. Iron aluminides (Fe_3Al and FeAl) are favored materials for these conduits because they will not corrode when exposed to sulfur-bearing gases at temperatures as high as 500 to 700°C. However, iron aluminides have poor room-temperature ductility and, therefore, cannot readily be shaped into pipes and tubes.

McKamey focused her attention on Fe_3Al. Her supervisor, C. T. Liu, a recent winner of the Department of Energy's prestigious E. O. Lawrence Memorial Award, worked on FeAl, which has better corrosion resistance but poorer ductility and fabricability than Fe_3Al.

To improve the room-temperature ductility of Fe_3Al, McKamey tried alloying it with other elements to control the deformation mode, surface composition, dislocation characteristics, and microstructure of the alloys. She investigated the effects of adding elements such as boron, carbon, cerium, chromium, manganese, molybdenum, niobium, vanadium, and zirconium in various proportions. Specimens of each alloy

"Her task was to improve the ductility of a brittle alloy so that it could be rolled and shaped into components that do not crack."

"Iron aluminide alloys could be less expensive than steels."

Using a micrometer, Randy Howell measures the diameter of a modified iron aluminide ingot. The ingots shown here are either 1.5 cm (4 in.) or 2 cm (5 in.) in diam.

composition were tested under tension to determine room-temperature strength and ductility.

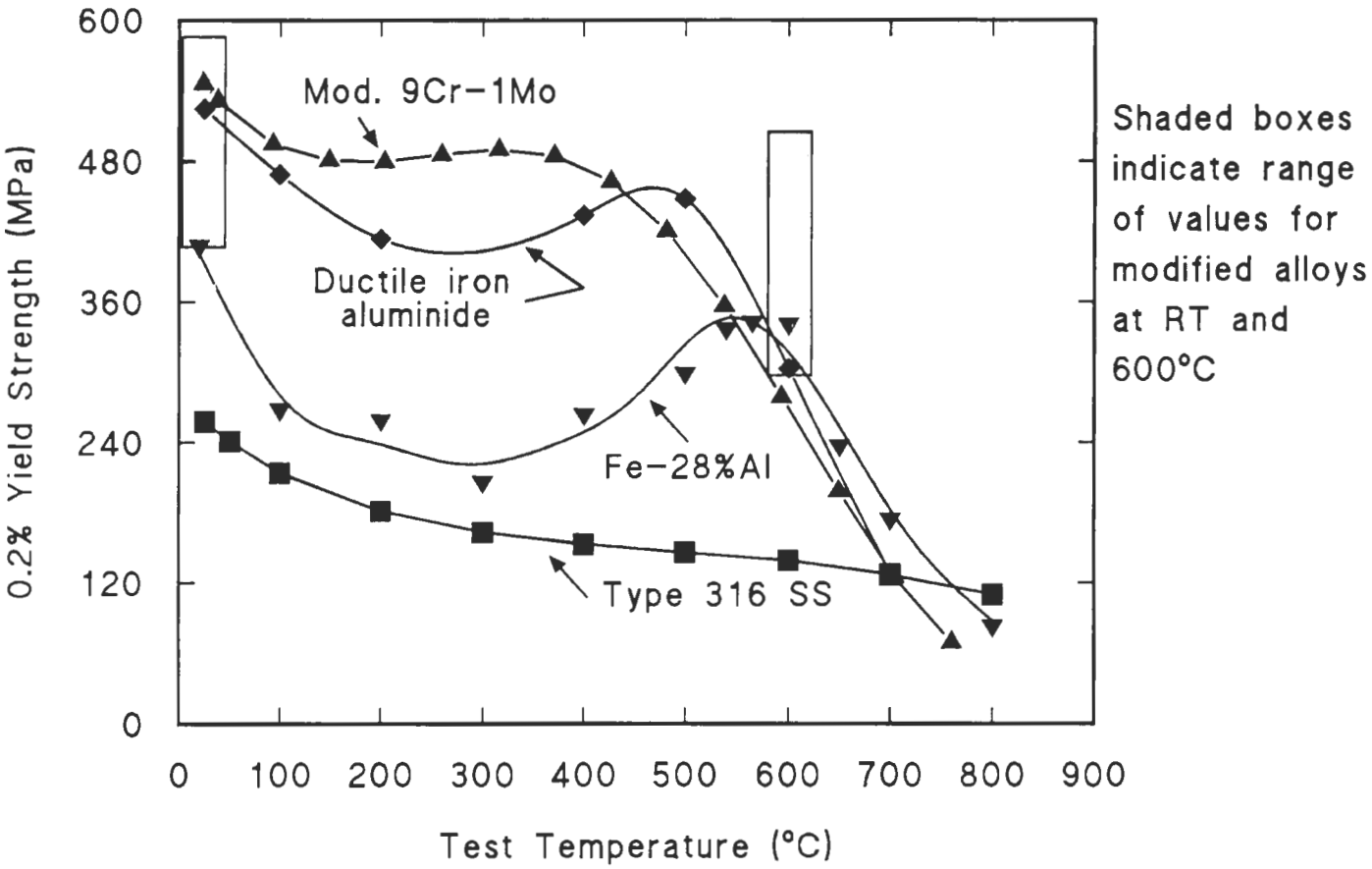
She found that chromium in small amounts (2 to 6 at. %) increases the ductility of the Fe_3Al alloy from <5% to 10%. That is, in the tensile tests, the samples made of $(Fe, Cr)_3Al$ could be stretched to about 10% (rather than merely 5%) of their original length before failing. "That's good enough for the material to be rolled and fabricated into pipes or tubing," says McKamey. She notes that other elements are also added to the alloy to increase room- and high-temperature strength through solid-solution hardening and particle strengthening.

The Office of Technology Applications of Martin Marietta Energy Systems, Inc., has approached several steelmakers to determine if they might be interested in purchasing exclusive rights to this alloy "recipe" through a licensing agreement. Assuming that fabrication procedures are similar to those for most stainless steels, iron aluminide alloys could be less expensive than steels because of the lower cost of iron and aluminum and the limited use of alloying elements. Companies interested in obtaining licenses from Energy Systems to fabricate these iron aluminides alloys include Ametek Specialty Metals; Allegheny Ludlum Steel Corporation; Latrobe Steel Company; The Timken Company; Armco, Inc.; and Cyclops Corporation.

Besides the fossil energy applications, McKamey says these alloys could be useful in the automobile industry. Corrosion resistance is needed in materials used to make exhaust systems for vehicles having catalytic converters. To demonstrate the versatility of the new material, McKamey proudly wields a $(Fe, Cr)_3Al$ table knife made in an M&C Division shop.

Other Efforts

To find the best possible alloy composition, McKamey has been studying the microstructure of various $(Fe, Cr)_3Al$-based samples that have been tested for ductility and strength. In the summer of



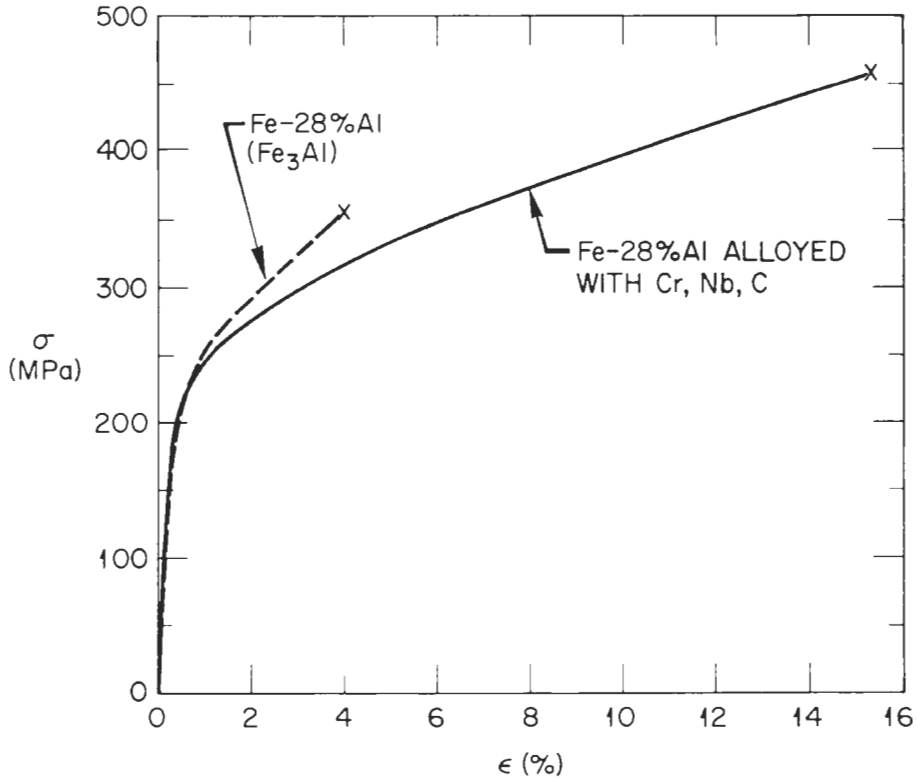
Ductile iron aluminides are stronger than Fe_3Al and have strengths comparable to present commercial alloys, such as a modified steel containing chromium and molybdenum and Type 316 stainless steel. The shaded boxes indicate the range of values for modified iron aluminide alloys at room temperature and 600°C.

1989, she said in an interview that she believes that 20% ductility is possible if the material has an "optimized" microstructure (i.e., optimized grain size, surface composition, degree of order, and control of precipitates), which could be achieved by adding the right types and amounts of minor alloying elements and by subjecting it to the proper level of heat treatment. She also believes that, with alloy additions and control of microstructure, the iron aluminide's strength and resistance to creep (tendency to deform under stress) at 600 to 700°C can be improved. McKamey is collaborating with C. T. Liu, Vinod Sikka, Jack DeVan, and other researchers in the M&C Division in trying to determine the effect of various alloying additions, heat treatments, fabrication procedures, and test environments (air, pure oxygen, or vacuum) on microstructure.

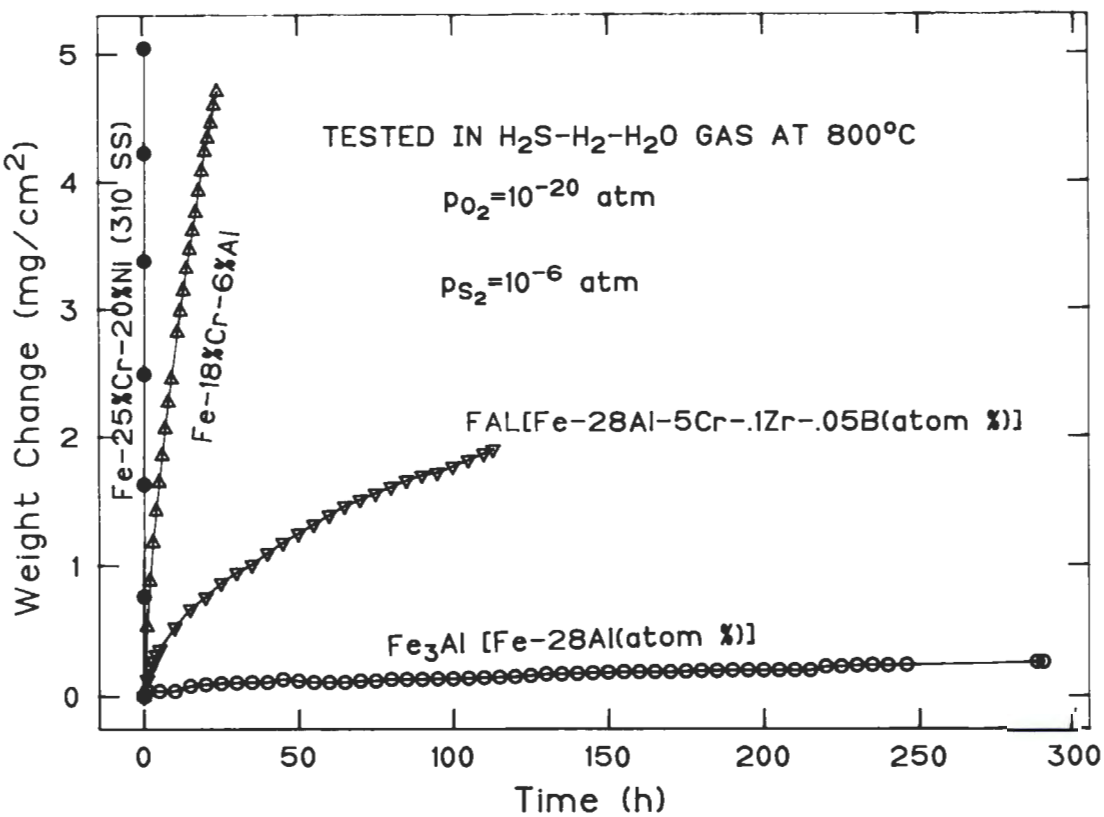
"If we add molybdenum, we get better creep strength, but room-temperature ductility suffers," McKamey says. "It's a tradeoff. But other elements may provide improved creep strength without seriously hurting ductility."

In late 1989, the M&C group achieved 20% ductility on a particular iron aluminide composition using the proper heat treatment.

Recently, the M&C Division has expanded the study and development of iron aluminide alloys into a major effort supported by agencies in the Department of Energy, including the fossil



The tensile properties of Fe_3Al are substantially improved by alloy design—that is, adding the proper amounts of other elements (in this case, chromium, niobium, and carbon) to the iron aluminide.



An ORNL-designed iron aluminide alloy (Fe_3Al) is more resistant to corrosion from exposure to sulfur-bearing gases (sulfidation) than the other alloys tested. The extent of corrosion is determined by measuring the change in each test alloy's weight.

energy, energy conservation, and basic energy sciences programs. Besides Liu and McKamey, other M&C researchers investigating iron aluminides are Vinod Sikka (heat treatment and fabrication techniques), David Alexander (mechanical properties), Joe Horton (electron microscopy), Stan David (welding), and Phil Maziasz (control of precipitates). In addition, Jack DeVan and Pete Tortorelli at ORNL and Ray Buchanan at UTK are doing corrosion studies.

Demand for ORNL Alloy

McKamey is consulting with Liu and his associates on improving the ductility of the extremely brittle FeAl (<2% initial ductility compared with <5% for Fe_3Al), because the superior corrosion resistance of FeAl makes it extremely attractive for some applications.

For example, Air Products and Chemicals, Inc., a fast-growing, medium-size American company in Allentown, Pennsylvania, has developed an efficient process for producing pure gases for industrial uses. This process, called Moltox, extracts pure oxygen from air, using corrosive molten salts. It is expected to use 40% less energy and thus cost less than the traditional cryogenic method for producing pure oxygen. In 1987, Air Products built a pilot plant to demonstrate the feasibility of the new process. The plant had to be shut down within a week of initial operation because severe material corrosion problems developed during testing. Air Products turned to Pete Tortorelli of the corrosion group in the M&C Division at ORNL for help, and this group asked Liu's group to suggest materials that could withstand environments containing corrosive molten salts.

After eight months of consultations, ORNL researchers demonstrated that the FeAl alloy under development at ORNL is the best material for the pipes that contain the molten salts. Convinced that ORNL has a solution to its problem, Air Products terminated its agreement with NKK, a Japanese material company, which was originally contracted to provide pipe material for the pilot plant. Staff members from Air Products have teamed up with ORNL metallurgists to develop an FeAl alloy for the Moltox system. Telling this story during his Lawrence Award acceptance speech, Liu noted that "a blow has been struck on behalf of increased U.S. competitiveness, at least in the area of structural materials."

In their effort to find ways to make FeAl more ductile, Liu, McKamey, and others have sought to understand the process by which embrittlement occurs. They have found that the embrittlement is caused by an extrinsic, not an intrinsic factor—the reaction of moisture in the air with aluminum atoms at crack tips, resulting in the formation of atomic hydrogen that drives into the metal and causes crack propagation and loss in ductility. By controlling the test environments at room temperature, they have increased the tensile ductility for FeAl from 2% to 18%. Now that this embrittlement mechanism is known, FeAl can be designed and treated in such a way to make it a useful structural material for high-temperature environments.

Previously, Liu and his associates have been responsible for nickel aluminide alloy developments that have led to licensing agreements between Energy Systems and five different companies. Now, it appears that the next generation of ORNL alloys that will capture the interest of industry will be iron aluminides, and part of this emerging success can be credited to Claudette McKamey, 1989 Inventor of the Year at Energy Systems. ornl

"A blow has been struck on behalf of increased U.S. competitiveness, at least in the area of structural materials."

Human Behavior in Emergencies

By John H. Sorensen

"Our ultimate goal is to translate research results into practical recommendations that will improve the technical basis for emergency planning."

The Bay Area earthquake struck in October 1989 with no warning, inflicting such damage as this road failure at Moss Landing State Beach. Nevertheless, warnings were important in the immediate aftermath. However, officials could not provide some relevant information such as the locations of buildings in California that were potentially dangerous in the event of a major aftershock.

Thousands of emergencies in the United States each year result from either natural events or technological failures. Over the past several years, for example, about 150 accidental releases of chemicals annually have forced some people to leave their homes to avoid exposure. Studies at ORNL indicate that, in about one-fourth of these cases, people have been exposed to hazardous chemicals. Despite the frequency of such events, fatalities are rare.

However, every year at least one large-scale disaster occurs that is substantially disruptive to society. Major accidents such as the chemical explosion at Bhopal, the nuclear reactor accident at Chernobyl, and the nuclear incident at Three Mile Island command international attention. In the past year, our nation suffered at least two natural catastrophic events. In September 1989, Hurricane Hugo slowly swept along the South Carolina coast, leaving thousands of people homeless and taking the lives of some who did not heed the advance warnings. A month later, the largest earthquake to affect a populated area in northern California since the 1906 San Francisco earthquake struck the Bay Area, causing billions of dollars worth of property damage, injuring 3000 persons, and killing 67.

Social scientists in ORNL's Hazard Management Group, in conjunction with others in the Laboratory's Energy Division and colleagues at the University of Tennessee (UT) and Colorado State University, are studying how to improve preparedness for and response to such events and to reduce the level of damage and loss of life from similar unpreventable disasters. The research focuses on understanding how organizations plan for and manage emergencies and how members of the public behave under emergency conditions. This work draws upon traditional research approaches to disaster and hazard management by the disciplines of sociology and geography.

Our recent research projects and activities include:

- a critical review of social science studies on human response to disasters;

- a survey of people who evacuated following two recent chemical accidents to evaluate the effectiveness of the warning processes used;

- development of a simulation model to predict people's responses to warnings and the effectiveness of alternative protective actions (e.g., staying home, seeking a local shelter, evacuating the area);

- a survey of U.S. communities to determine their level of preparedness for hazardous material accidents;

- an assessment of research to support evacuation planning for both natural and technological hazards;

- an analysis of the evacuation experiences of nursing homes and hospitals;

- an analysis of the variability among organizations in effectiveness of managing an emergency;

- an assessment of the warning system used in a flash flood in Wyoming.

These and other projects have helped us identify several research goals. Our ultimate goal is to translate research results into practical recommendations that will improve the technical basis for emergency planning. From a scientific perspective, however, the goal is to develop better theories about the ways that different levels of society—the individual, the family, the organization, and the

"The goal is to develop better theories about the ways that different levels of society . . . behave in a crisis."

"The public and media often confuse panic behavior with elevated stress."

Evacuation is not always the normal response to an impending emergency. In this example of convergence behavior, people have gathered to witness an expected volcanic eruption of Mt. St. Helens in 1980.

collective—behave in a crisis. Thus, our strategy is to collect empirical evidence that documents emergency behavior and its underlying causes.

Myths

One significant set of findings from social science research on disasters is that the public response to an emergency differs from what is commonly believed. Myths about public behavior in emergencies are largely the result of and perpetuated by disaster movies and media coverage of catastrophic events.

Several of the more common myths about emergency behavior, panic, information overload, and the "cry-wolf" syndrome were identified in a critical review of research on human behavior in emergencies carried out in conjunction with Dennis Mileti of Colorado State University and Barbara Vogt of the University of Tennessee. In designing and implementing an emergency response system, officials and decision makers should not fall prey to these myths.

Myth I: *The public panics when warned that a disaster is imminent.* The public simply does not panic in response to warnings of impending

disasters except in somewhat predictable and rare circumstances. Panic can occur in situations involving a closed physical space, an immediate and clear threat of death, and limited escape routes. The public and media often confuse panic behavior with elevated stress, a psychological response to warnings. The problem caused by this myth is that, afraid to cause panic, officials responsible for warning the public may withhold information and fail to tell the truth.

Myth II: *The public can assimilate only a limited amount of information in an emergency warning.* This myth is often reflected in the terse or glib message protocols designed to guide information dissemination in an emergency. However, the public rarely, if ever, receives more emergency information in a warning than it needs. Because people do not necessarily remember information that they have heard only once, detailed warning messages should be repeated in an emergency. Warnings should not be subject to the Madison Avenue "30-second rule" for marketing consumer products or to the public relations KISS (keep it simple, stupid) principle. People are "information hungry" in a disaster, and they should be given as much up-to-date information as possible. There is no reason why all available information cannot be made part of warning messages.

Myth III: *People ignore repeated false alarms—the cry-wolf syndrome.* The effectiveness of warnings is not always diminished by false alarms. For example, if a warning leads to a public evacuation later deemed unnecessary and if the reasons for the "miss" are told to the public in question and understood by them, the integrity of the system will be preserved. For example, when Hurricane Hugo struck the North Carolina coast, many residents left unnecessarily. However, it is likely that, in a similar situation, they would again follow evacuation recommendations.

In contrast, the repeated activation of an audio alert mechanism may diminish response over time. If false alarms such as the inadvertent sounding of sirens occur through malfunction and no explanation is given, the public will be less likely to respond positively to subsequent warning, particularly if such malfunctions are frequent. False alarms, if explained, can actually enhance public hazard awareness and ability to process risk information in subsequent warning events. As such, false alarms, in many cases, are better viewed as opportunities than as problems. A good emergency plan will have a procedure for explaining false alarms. Decision makers should also be aware that the public prefers that officials err on the side of caution.

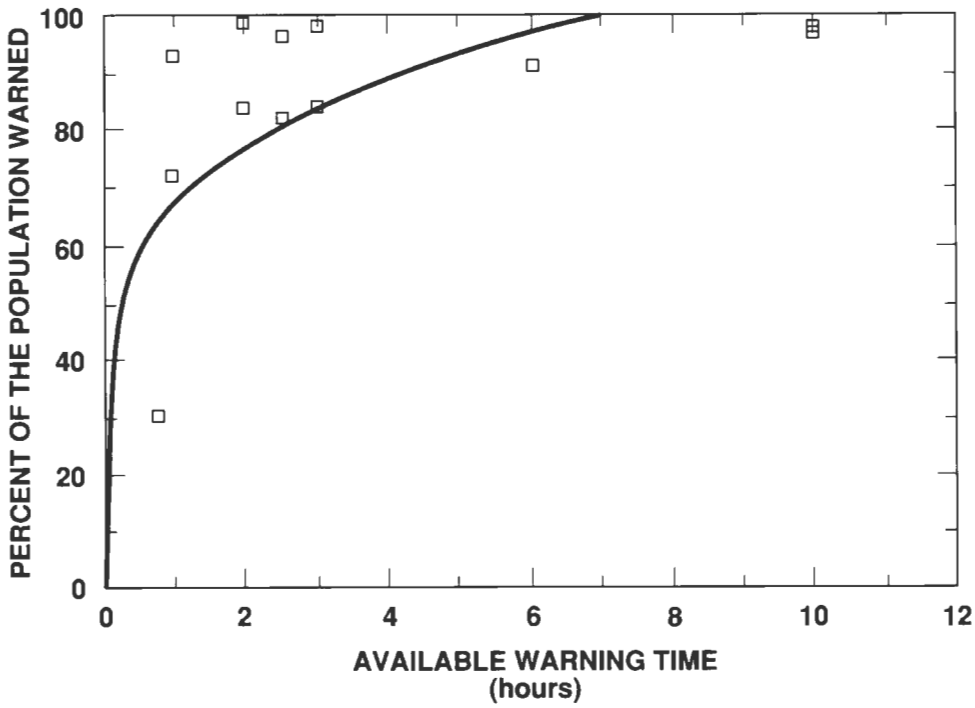
Modeling Human Response

One way of disproving myths is to collect data on people's actual behavior in emergencies and look at the underlying causes of the behavior. Emergency planners may stop worrying about public panic if they have the pertinent information: How long does it take to warn the public? How long after being warned does the public take to respond? How is compliance with protective action recommendations maximized?

To answer these questions, we collected data from a series of surveys conducted by social scientists after a number of large-scale emergencies. We discovered, however, that although none of the surveys had inquired about when warnings were received, we could determine what percentage of the population received a warning and how much time officials had to give the warnings (see plot on p. 34). The data show a logistic relationship: the percentage of individuals warned increases with the amount of available warning time, but the shorter the available time, the more rapid the dissemination.

Building on these findings, George Rogers of the Hazard Management Group developed a mathematical approach to estimate warning diffusion times. A general diffusion equation was used, and the parameters were specified on the basis of available historical data. The most important parameters are *alert* and *contagion*. Alert represents the importance to the system of immediate notification by the initial warning dissemination. Contagion represents the importance of the informal notification process

"False alarms, if explained, can actually enhance public hazard awareness and ability to process risk information in subsequent warning events."



Survey data collected on past emergencies show that the number of people warned increases with available warning time.

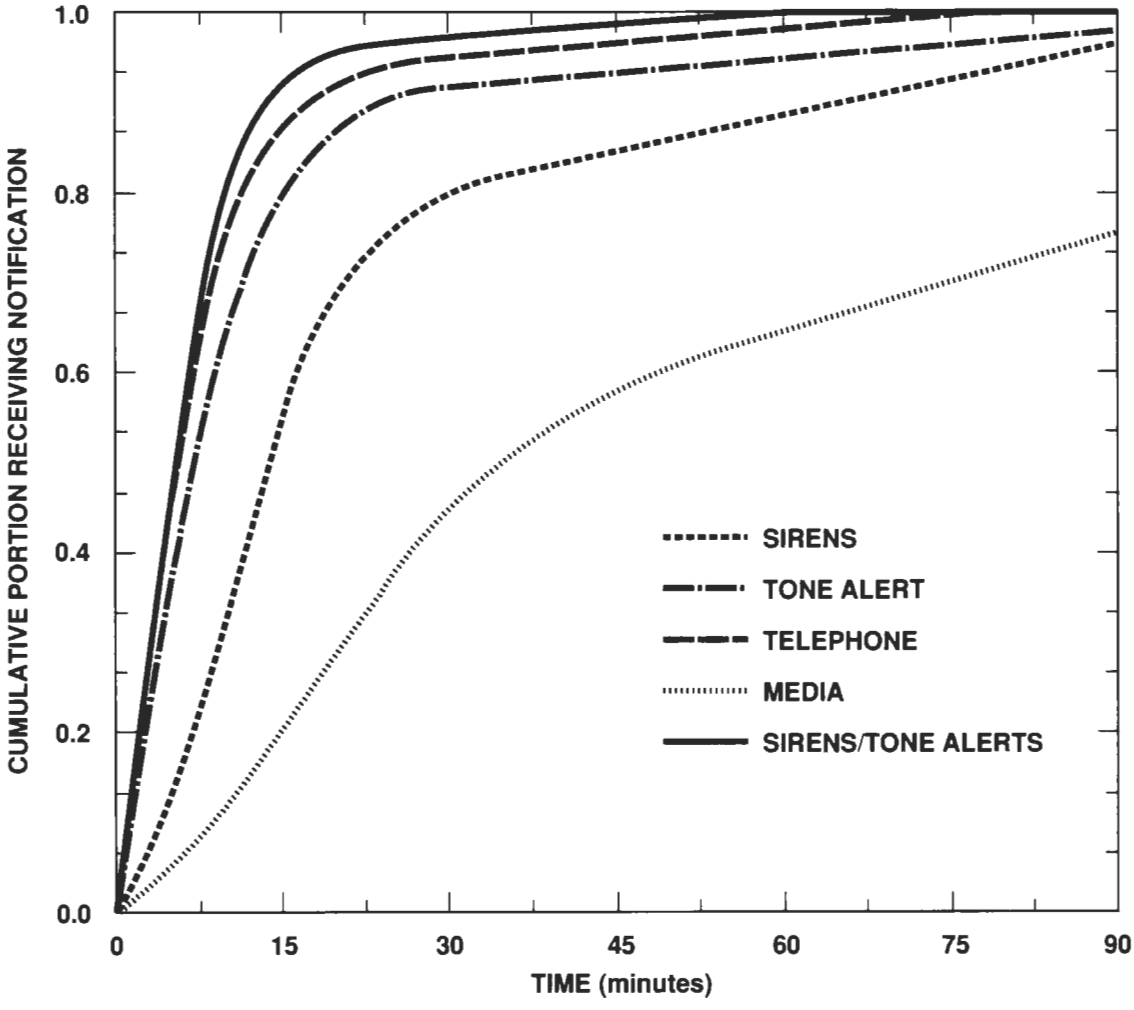
by which people immediately spread the word about the warning to others. Parameters for alternative warning technologies not represented by the historical data were assumed, based on the characteristics of the technologies. Such technologies include tone-alert radios, automated computer-aided telephone dialing systems, electronic sirens, and combinations of these.

• A tone-alert radio is dedicated to receiving an alert and providing notification. Activated from a control station, it sounds an alarm and then broadcasts a recorded or live message.

• An electronic siren, which is usually mounted on a pole, sounds an alert. Some sirens are capable of acting as public address systems.

• An automated telephone system has computer-based dialing equipment to call "banks" of telephones or switching equipment to simultaneously call all numbers in the emergency area.

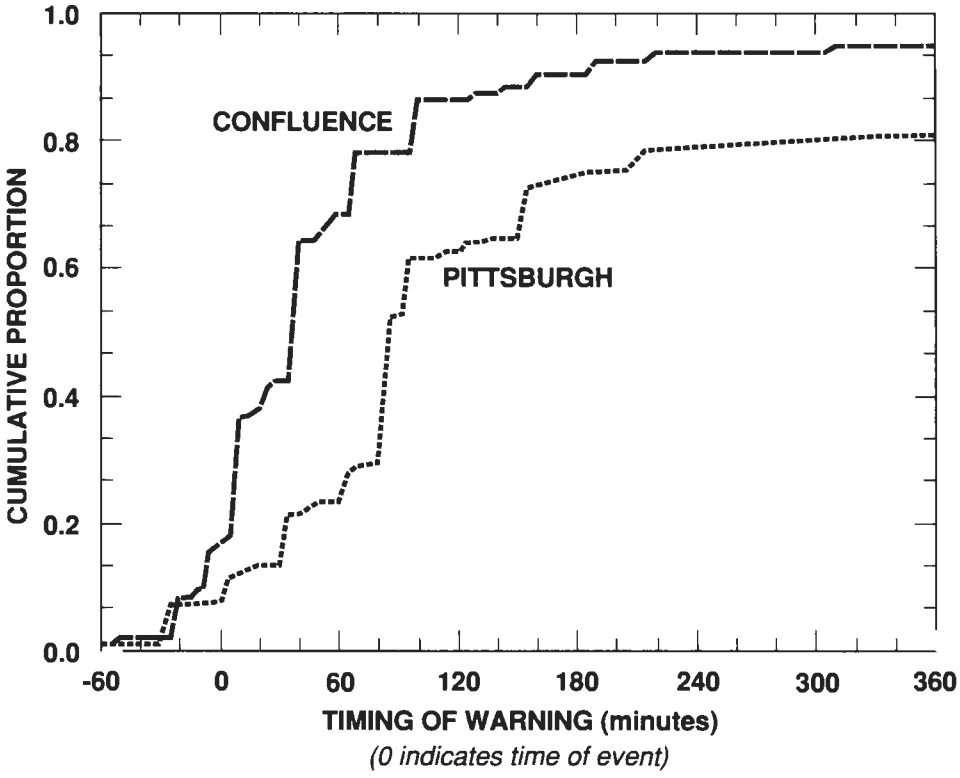
Results of the simulation are shown in the figure on the facing page. The bottom curve represents the simulated dissemination of warnings based on conventional warning technology, usually a combination of broadcasting over electronic media and emergency or law enforcement officials going through neighborhoods. The other curves show the results of the simulations using other warning technologies. These curves suggest varying levels of increased effectiveness using advanced systems.



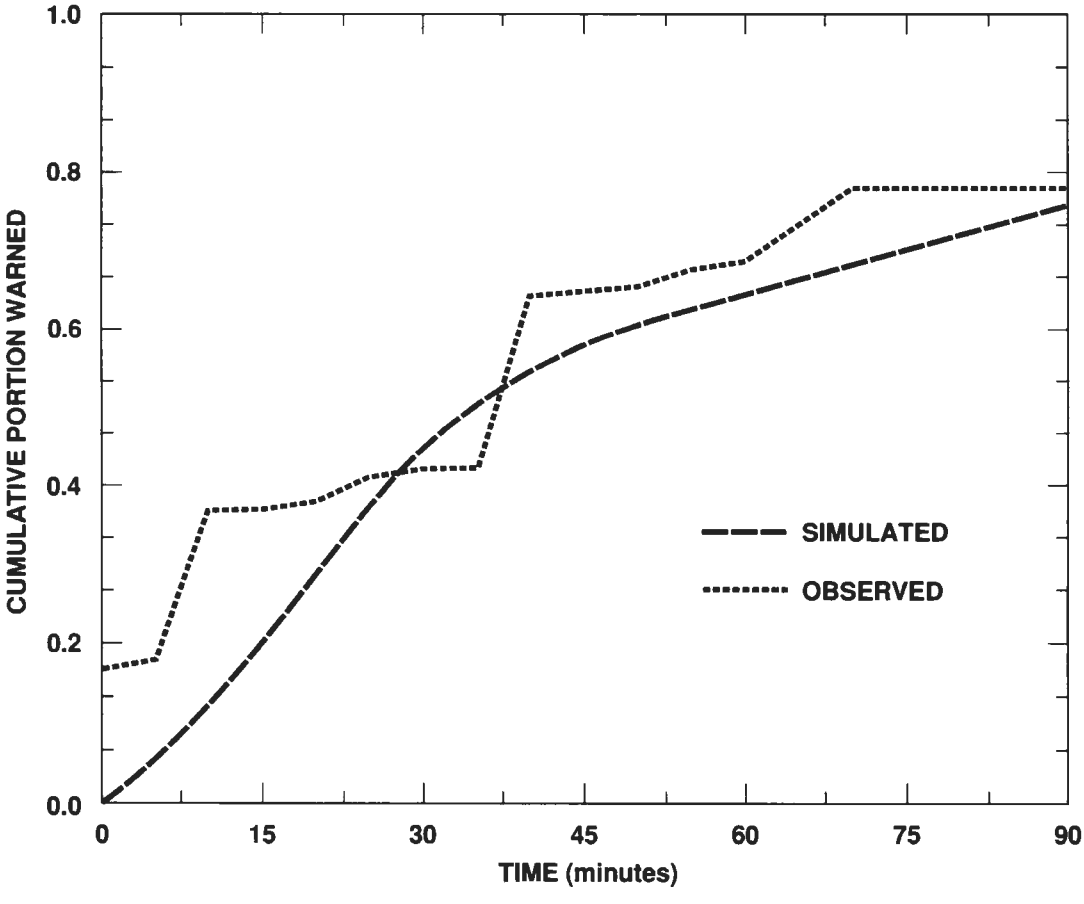
A simulation model is used to estimate the effectiveness of new warning technologies.

More recently, we collected data on warning dissemination and public response following several chemical-release accidents in Pennsylvania caused by train derailments. The surveys asked people when they received a warning, how they received a warning, and how long they took to evacuate after receiving a warning (see results in figure on p. 36). The two warning-dissemination curves are both logistic and reflect slightly different speeds of diffusion. In Confluence, Pennsylvania, about 70% of the residents had received a warning to evacuate within 1 h, whereas the comparable figure for Pittsburgh was 25%. In part, this greater awareness reflects a greater urgency posed by the Confluence accident. The timing of the response was also quite different, with a much slower mobilization in the Pittsburgh event, in which only about 42% of those advised to leave actually did.

Using the data from the survey, we correlated the mathematically derived simulated diffusion curves with the empirically observed diffusion curves (see figure on page 36). The data for the Confluence warning shows a high degree of correlation with the predicted diffusion.



Data collected following two chemical accidents show the time taken by people in the vicinity to evacuate after receiving a warning.



Data collected on how long people took to evacuate Confluence after receiving a warning about the chemical accident are highly correlated with the results of the simulation model.

The implications of this analysis for improving emergency response planning for chemical emergencies are fairly clear. In a rapidly moving chemical emergency such as the Bhopal accident, most existing warning systems not based on advanced technologies will not warn people soon enough to allow them to protect themselves. Technologically advanced systems are needed to protect people in high-risk situations. Recently, our conclusions were used by the state of New York to introduce new legislation that will require all facilities that store hazardous chemicals to perform safety audits with the intent of reducing both the likelihood as well as the consequences of potential accidents.

Community Preparedness for Chemical Emergencies

Our analysis of the warning diffusion process, *Review of Emergency Systems: Final Report*, helped the Federal Emergency Management Agency (FEMA) and the Environmental Protection Agency prepare a report to Congress that was mandated by Section 305b in Title III of the Superfund Amendments and Reauthorization Act of 1986. To obtain additional information on the status of the nation's preparedness capabilities for responding to an accident, a survey was conducted of selected American communities in which hazardous chemical facilities are located. Personnel involved in the effort include ORNL's George Rogers and UT's Bill Clevenger and Deborah Self. A questionnaire was developed and copies were sent to 277 local emergency planning organizations; about 60% were returned.

The results of the survey showed that few communities in the study used state-of-the-art communication equipment or warning system technologies. For example, the most common means for a chemical facility to notify a community official about an emergency is by commercial telephone. Our research on warning system failures has shown that commercial telephone is not a reliable technology in an emergency. Reliable technologies include dedicated phone lines, dedicated radio systems, microwave communication systems, or digital communication systems. Certainly, the experience following the 1989 earthquake in California underscores this point. Clearly, some communities do not need advanced equipment because the risk probably does not justify the expense. In other communities, the use of reliable equipment is more critical because of more severe threats and a larger number of people and institutional facilities at risk. Overall, the ability of the majority of systems to provide a timely alert and notification is questionable, particularly in a rapid-onset event.

With respect to management practices, few communities had well-developed plans and procedures to guide emergency response. Notably lacking were capabilities for making decisions. Both lack of procedures and, more basically, the knowledge needed to make a decision suggest major problems in issuing a timely warning. Also lacking were preplanned warning messages and public information programs.

Based on the findings of this survey, numerous recommendations for improving community preparedness for potential fixed-site chemical accidents were made. These ranged from fairly simple low-cost steps, such as the preparation of standard communication protocols, to the more expensive ones, such as installation of the necessary technologies.

"Technologically advanced systems are needed to protect people in high-risk situations."

Future Directions

In fiscal 1990 and beyond, we plan a number of activities to advance our knowledge of human behavior in emergencies. For example, we will address the debate among chemical hazards emergency planners over whether people are best protected by sheltering or by evacuation. One uncertainty concerns public willingness to comply with official recommendations to seek shelter should such an emergency occur; in the future, we will collect data on how the public at risk responds to a sheltering recommendation. This information

will be used to model differences between people who comply and those who choose to evacuate. Another major data gap concerns public response in an emergency in which one of the advanced warning technologies is used. One of our research priorities is to ascertain the effectiveness of such systems.

In addition to work for FEMA, the group will continue to manage an interdisciplinary program to develop state-of-the-art emergency preparedness capabilities in communities that currently store chemical weapons. This work will facilitate the integration of work by social scientists with that of engineers, computer scientists, meteorologists, and toxicologists including George Rogers, Sam Carnes, and David Feldman, all of the Hazard Management Group; John Reed, Conrad Chester, Robert Miller, and Frank Southworth, all of the Energy Division; Annetta Watson, of the Health and Safety Research Division; and Jerome Dobson of the Computing and Telecommunications Division. The purpose of the research is to gain a better understanding of the effectiveness of alternative means of protecting the public from some of the most toxic chemicals stored in the world. Such an understanding may lead to superior methods for protecting populations from all hazardous chemicals.

Biographical Sketch

John Sorensen, a native of Omaha, Nebraska, received his Ph.D. degree in geography from the University of Colorado at Boulder, where he worked at the Institute of Behavioral Science. He came to ORNL's Energy Division in 1980 after spending three years as an assistant professor at the University of Hawaii. Currently, he is group leader of the Hazard Management Group in the Energy Division. His research at ORNL has focused on public acceptance of technology, the social and psychological effects of hazardous technology, and individual and organizational behavior in disasters. He is the lead author of *The Impacts of Hazardous Technology: The Psychosocial Effects of Restarting TMI-1*, published by the State University of New York Press in 1987. Sorensen is a member of the National Research Council's Subcommittee on Earthquake Research and is a fellow of the Hazard Assessment Laboratory at Colorado State University. In addition, he is a member of the International Research Group on Risk Communications and co-chaired the National Academy of Sciences Post-Disaster Study Team on the 1985 Cheyenne Flood.

The following is based on a National Academy of Sciences Post-Disaster Study of the 1985 flood in Cheyenne, Wyoming, which resulted in 11 deaths. The author took part in this study by assessing the effectiveness of the warning effort for the flood.

The Cheyenne Flood: Were the Warnings Effective?

August 1, 1985, began as a typical summer day in Cheyenne. Residents listening to the weather forecasts for the day heard it would become partly cloudy in the afternoon with widely scattered thunderstorms, possibly with high winds and hail. At 12:50 p.m., the National Weather Service (NWS) issued a "severe thunderstorm watch," which was in effect until 8 p.m. At 6:20 p.m., the watch was upgraded to a "severe thunderstorm warning," indicating that a thunderstorm had occurred. People were advised to seek reinforced shelter and to listen for more information. At 7:20 p.m. a "tornado warning" was issued because of a sighting west of town. Cheyenne area residents were advised to shelter themselves in a basement or interior room and to abandon cars and mobile homes "in the path" of the tornado. At this time the NWS issued the first information to the public about the possibility of "minor flooding." At 7:55 p.m. the civil defense sirens were sounded for almost half an hour to alert the public to the tornado. Tornado warnings were broadcast on cable television, Musak, and Emergency Broadcasting System radio as well as all local radio stations.

At about the same time (7:48 p.m.) the NWS received a report from a weather observer that 3.5 in. of rain and large hailstones had fallen on nearby Western Hills. This was the first indication that the rain was heavy enough to cause severe flooding. Minutes later the NWS received radio reports of flooding on nearby Dry Creek. As a result it issued a "flash flood warning" at 8:00 p.m., reported extensive flash flooding, and described the storm as being extremely dangerous, especially to people in vehicles. The NWS advised people to seek high ground, stay indoors, and avoid driving. The head of the Cheyenne NWS Office broadcast this information directly over one of the local radio stations. Other local radio stations as well as TV stations in nearby Denver announced the warning and read various severe weather statements updating the warning. At 9:00 p.m. the NWS issued another "severe thunderstorm warning" until 10:00 p.m., providing the news that creeks were flooding the area and urging people not to drive.

Without doubt the almost simultaneous development of two hazards—tornado and flood—and issuance of two types of warnings presented an ambiguous situation to the public. Many residents reported being confused about whether to seek shelter in basements to protect themselves from the tornado or to move to higher ground to avoid the dangers of the flood. Some residents in the Dry Creek area apparently received warnings of the flood just before being inundated. Others learned about the flood for the first time when water poured into their basements where they sought shelter after hearing the tornado warning. Many had to flee quickly to avoid the rising waters. Being in basements may have allowed some people to detect flooding earlier than if they had been upstairs. Others at risk in their homes heard no flood warnings and were trapped by rising waters until emergency workers could rescue them. Residents living near Crow Creek had been alerted to the flooding early enough to take protective actions. When the tornado warning was issued, people in trailer parks in the Crow Creek area evacuated to a nearby community college, depopulating some low-lying areas that eventually flooded.

"Some people are more vulnerable than others to disaster."

In the Cheyenne flash flood, water from the creek had briefly covered the bridge, and several cars crossing the bridge ended up in the creek. This photo was taken a day after the event. Trying to cross flowing water is the leading cause of death in floods.

Following the flood, public criticism surfaced regarding the lack of response of some business and commercial organizations to the warning dissemination. People in stores, malls, and movie theaters complained they had not been warned about the tornado, the flood, or both. This lack of warning likely contributed to some fatalities. However, this paucity of action was not universal. One store, for example, reportedly locked its doors until the nature of the flooding was established and customers could be notified.

Eleven persons drowned in the Cheyenne flood. Of these deaths, ten were automobile related. An early rumor suggested that people drowned because of the confusing warnings that first advised people to go to their basements and then to seek high ground. However, only one victim may have died because of basement sheltering. In this case the evidence is inconclusive. The victim was an elderly woman alone at home at the time. Her house was not in a floodplain nor in a minor drainage system. Her basement flooded because of heavy overland sheet flow. It is possible that she went to the basement because of the tornado warning and was trapped by a door that stuck shut, or, alternatively, fell and could not escape. Equally feasible is that she may have gone to the basement to determine if it was flooding and was trapped or had fallen there. Regardless of the cause, this case indicates why some people are more vulnerable than others to disaster. People who are alone at the time of disaster are more vulnerable because they have no one to assist them if they are

Three days after the August 1, 1985, hailstorm and flash flood in Cheyenne, Wyoming, large hailstones 1 m deep still cluttered the yards of some residents.

in danger. In addition, the elderly are often less physically able to respond in rapid-onset or life-threatening circumstances.

As in other flash floods, people died while attempting to traverse the flooding stream. At the time, the seriousness of the flooding was not readily apparent. Unaware of dips in the road over culvert crossings, several victims underestimated the depth of the flood waters by as much as 1.2 m (4 ft). Most fatalities occurred between 10:00 and 11:00 p.m., likely during peak discharge. Six of the victims were under 20 years of age, and, of these, four were under 10. One victim was attempting to rescue people in a van. The other nine victims were in six cars and one truck. In four of these same vehicles, a total of eight adults and teenagers survived by swimming to safety or being pulled out of the water by rescue workers.

From the sketchy evidence available, only people in one of the seven vehicles in which fatalities occurred had likely received a strong warning message. In the remaining vehicles people may have received information over the radio while in their vehicles, but the warning probably was not strong or specific enough to prevent them from trying to cross the creek to reach a safe destination. Because the deaths occurred at least 2 h after the first flash flood announcement, it is unlikely that the tornado warning played a role in causing the flood fatalities. Warning messages regarding the dangers of driving were disseminated as early as 8:30 p.m. Either this information did not reach some drivers who died or was unsuccessful in convincing them not to engage in what proved to be fatal behaviors.

PSYCHOSOCIAL EFFECTS OF RESTARTING A TMI REACTOR

Editor's note—John Sorensen and his colleagues have used some of the same techniques for studying human responses to hazardous technologies that they are using for understanding human behavior in emergencies. Below is the story of how a book was written at ORNL on human responses to the prospect of restarting a reactor at Three Mile Island.

Until March 29, 1979, most people were unaware of two nuclear reactors on a small island southwest of Middletown, Pennsylvania. Then a frightening loss-of-coolant accident occurred at one of the Three Mile Island reactors known as Unit 2, and the news captured world attention.

At the time, Unit 1 was shut down for routine maintenance and refueling. Because of its close proximity to Unit 2, where radiation levels were higher than normal for a short time, and because the designs of the reactors are similar, the Nuclear Regulatory Commission (NRC) ordered the reactor to remain idle until additional reviews were complete.

On September 14, 1979, People Against Nuclear Energy (PANE) requested that, before a decision was made to resume operation of TMI-1, the social and psychological impacts of restart should be considered as matters of public health and safety under the provisions of the Atomic Energy Act and the National Environmental Policy Act (NEPA). PANE and seven other groups petitioned the Atomic Safety Licensing Board (ASLB), an independent committee charged with defining issues appropriate for NRC decision making in restoring the operating license for TMI-1, to consider this request.

On February 22, 1980, the ASLB ruled out considering the issue under the provisions of the Atomic Energy Act. However, the board agreed that NEPA permitted the NRC to consider the fears of community residents and recommended that the Commission take into account psychological and social effects before issuing a decision on restart.

The full Commission twice rejected the contention, so PANE petitioned the U.S. Court of Appeals for the District of Columbia, seeking to gain a court-ordered assessment of the social and psychological impacts of restarting TMI-1. In a decision filed on January 7, 1982, the Court of Appeals voted 2 to 1 in favor of PANE. The NRC was ordered not to allow the restart of TMI-1 until such an assessment had been prepared. The judgment further ordered the NRC to determine whether "significant new circumstances or information have arisen with respect to the potential psychological health effects of operating the TMI-1 facility." If such circumstances or information were determined to exist, the NRC was directed to prepare a supplemental environmental impact

The 1979 accident at the Three Mile Island had a major impact on federal health and safety regulations for nuclear power.

statement considering not only psychological health impacts but also effects on the well-being of communities surrounding TMI.

The NRC requested that a group in ORNL's Energy Division provide assistance in preparing an environmental assessment (EA) to determine significant psychosocial impacts. Our research approach to developing the assessment involved the following tasks:

- Conducting focus-group discussion with pro- and anti-TMI groups
- Reviewing the literature on social and psychological effects of risk and accidents
- Analyzing data collected on impacts of the TMI accident
- Analyzing survey data on attitudes toward the restart
- Analyzing secondary data on community change in the TMI vicinity
- Conducting in-depth interviews with leaders of functional social groups in the area.

However, the EA was never completed. On April 19, 1983, the Supreme Court overturned the Appeals Court decision and exempted the NRC from preparing an environmental assessment. The basis for the ruling was not that psychological health and well-being are not cognizable under NEPA, but rather that the risks of an accident, per se, are not part of the environment. Risk-induced impacts are not, therefore, appropriate for consideration under NEPA, while impacts resulting from changes in the physical environment are legitimate concerns.

Since the analysis for the EA was nearly complete, our ORNL group—Jon Soderstrom, Emily Copenhaver, Sam Carnes, and Robert Bolin—published the findings in an ORNL report. It eventually evolved into a book of which I was the lead author—*Impacts of Hazardous Technology: The Psychosocial Effects of Restarting TMI-1* (published in 1987 by the State University of New York Press in Albany). The book is significant in that it represented the first systematic analysis of the psychosocial effects of risky technologies, integrating concepts and theories from several social science disciplines.

Our analysis concluded that, although the TMI accident had an effect on people in the TMI vicinity, no evidence was found to suggest that restarting the reactor would impose measurable psychosocial effects nor be a significant event in changing the social well-being of communities around the TMI nuclear power plant.—*John Sorensen.* ornl

ENVIRONMENTAL PROTECTION IN CHINA

By Milton Russell

"The root causes of China's environmental predicament are the 'three Ps,'— population, poverty, and (paradoxically) prosperity."

Milton Russell meets with a Tibetan monk. Cultural patterns must be considered in designing ecological protection strategies.

Over the past two years, a number of delegations from the People's Republic of China have visited ORNL, the University of Tennessee at Knoxville, and the Tennessee Valley Authority to study environmental protection and to consult with local experts. Together, these three institutions offer a range of expertise that makes East Tennessee a major resource for solutions to China's environmental problems. In turn, the Chinese experience is potentially of great importance globally. China's population, geographic extent, and storehouse of genetic diversity make protection of the environment there of importance in itself. Further, it shares conditions with most of the developing world; thus, policies and technologies that work in China can prove important for solving problems elsewhere. In addition, some problems are global, such as climate change and loss of the ozone layer, and China's success in finding ways to deal with these challenges is essential for world environmental security. Finally, China can supply test-beds for adapting and evaluating technologies developed at ORNL and elsewhere and a base for spreading them to the Third World. Discussions leading to an ORNL-Chinese program along these lines have been encouraging.

In the summer of 1989, I spent two months in China under the auspices of the United Nations Development Program, the Rockefeller Foundation, and the Chinese National Environmental Protection Agency. The following article, which presents my observations of environmental conditions in China and Chinese attempts to address the problems, is an updated version of an article originally published in the Fall 1989 issue of *Survey of Business*, Center for Business and Economic Research, College of Business Administration, the University of Tennessee at Knoxville.

Environmental conditions in China are dramatically worse than those in the United States, but the Chinese are acting with commendable vigor in attempting to contain and ultimately reverse the damage.

The problems form a familiar litany: the air contains dangerous levels of sulfur oxides, particulates (dust and aerosols), toxic gases, and heavy metals; the surface water is short on oxygen and long on toxics, pesticides, and harmful bacteria; groundwater monitoring indicates rising levels of nitrates, dangerous hydrocarbons, and other chemicals; the soils show growing contamination with heavy metals and pesticides; each year thousands or tens of thousands become ill or die from acute pesticide poisoning in the food supply, and millions are at risk from chronic exposure; no water is really safe to drink without point-of-consumption treatment; and there is no place to put growing amounts of garbage and trash, much less hazardous and radioactive waste.

Besides these pollution hazards, China is experiencing growing deforestation, desertification, soil erosion, destruction of wildlife habitat and wetlands, and depletion of groundwater. Altogether, the outlook is grim.

Population, Poverty, and Prosperity

The root causes of China's environmental predicament are the "three Ps,"—population, poverty, and (paradoxically) prosperity. One of Mao's most enduring legacies is his disastrous promotion of population growth. While the government has been trying vigorously to limit births for more than a decade, the demographic bulge of the 1950s and 1960s that Mao fostered is now beginning to reach a second generation. Population growth will not halt until well into the 21st century, based on even the most optimistic of assumptions about the success of the one-child-per-family policy. The policy itself is cracking around the edges, especially in

"Besides these pollution hazards, China is experiencing growing deforestation, desertification, soil erosion, destruction of wildlife habitat and wetlands, and depletion of groundwater."

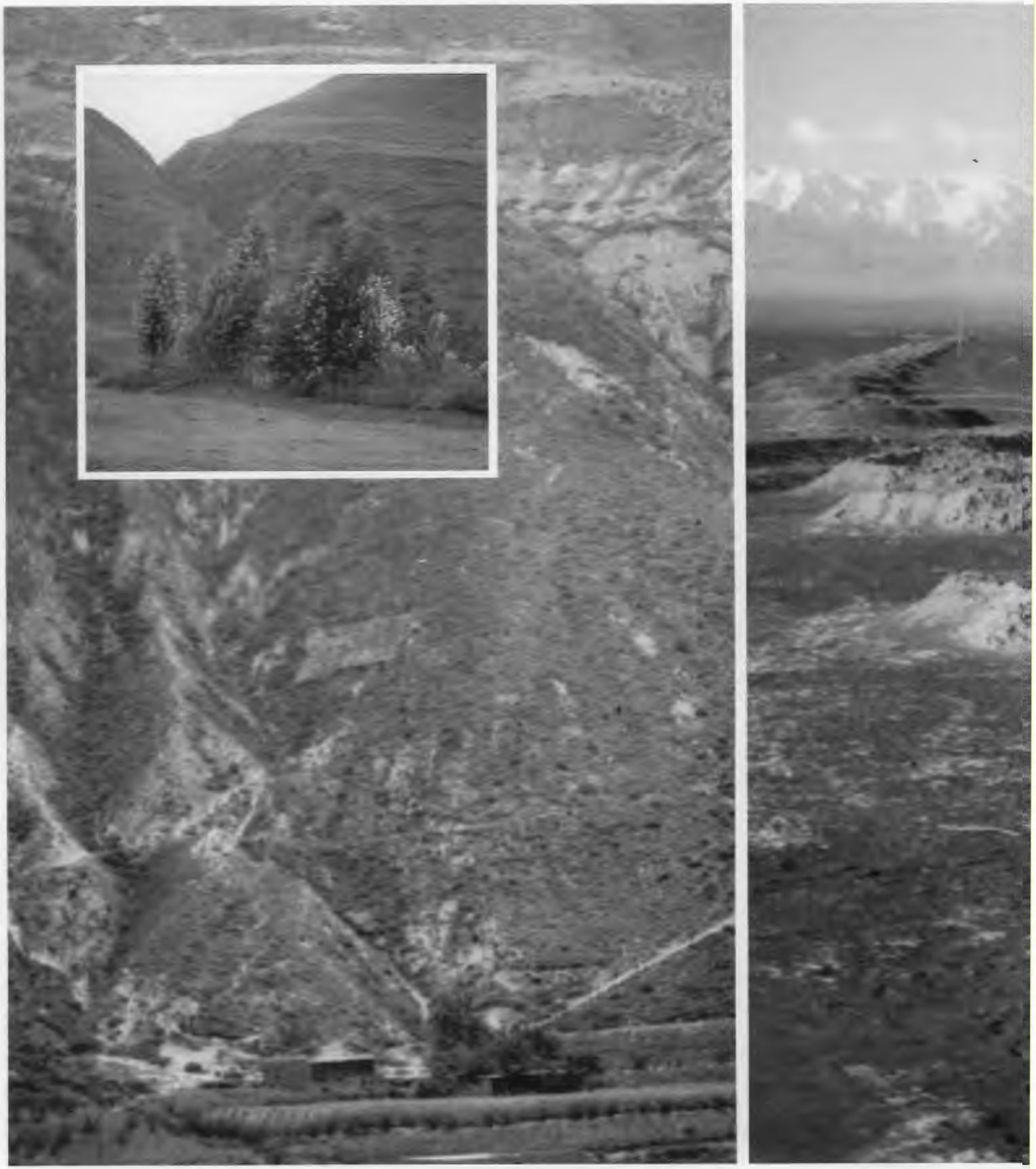
In congested Chinese cities, operators of bicycles, automobiles, and horse-drawn carts fight for space. The most obvious environmental consequence of transportation is the pollution from the growing number of trucks and buses crowding inadequate roads. The number of passenger cars, while still trivial compared with bicycles, is also growing rapidly.

rural areas where reforms have brought prosperity that erodes the economic incentives and penalties for limiting family size. Providing fuel, food, and living space for 1.1 billion individuals places incredible pressure on China's natural resources and its ability to dispose of wastes safely. That pressure will rise as population creeps upward toward 1.3 billion over the next decades, almost double the 750 million that the Chinese calculate would be optimal, given their resource base.

Developed and rich countries can hold environmental degradation at bay by substituting capital and current income for pollution. That is, sulfur oxide in the air can be reduced by flue gas desulfurization (FGD) equipment; increased sewage flows can be mitigated by upgrading treatment facilities; soil erosion can be limited when the government is able to pay farmers to take fragile land out of production and to adopt conservation measures. However, poor and food-short countries such as China realistically have no such options. For example, FGD equipment may add a fifth to the capital cost of an electric power plant and absorb 4% of its power. Up to 20% of Chinese industry is frequently shut down for lack of electricity. It is simply unthinkable that China

"Developed and rich countries can hold environmental degradation at bay by substituting capital and current income for pollution."

Until the 1960s camels were the dominant mode of intercity freight transportation in much of western China. In the background are mud walls from buildings of a city abandoned about 1000 years ago, a possible victim of encroaching desertification.



The people living at the bottom of this steep mountain cleared some of the forest to plant crops (note terraces in center). The result has been soil erosion. Inset: Only a few trees are left after deforestation in this area of China. The forests were destroyed because the wood was needed for fuel.

These mounds of dirt were manually dug out of the ground years ago by Chinese workers to create an underground channel to transport water for use by nearby communities. The source of the water is the snow on the mountains in the background. Periodically, workers go underground to remove sand clogging the channel.

would devote scarce capital to pollution control rather than to building the power plants needed to raise living standards. The story is roughly the same on other fronts as well.

Paradoxically, China's growing prosperity is making these problems worse. While the per capita income is still only around $300/year, total income has been growing at near-double-digit rates since the reforms began in the late 1970s. Capital has been pouring into heavy industry; chemical fertilizers and pesticides have boosted agriculture production; and small factories have sprouted in villages and towns throughout most of the country, absorbing surplus agricultural labor and local raw materials. Draconian policies have dampened the flight to the city that characterizes most developing countries, but many cities have still seen nearly a doubling of population in the last decade.

The environmental consequences were predictable. Added industrial facilities would have resulted in deterioration of the air and water, even if well controlled. And many were not well controlled. Further, added prosperity itself changed behavior in environmentally deleterious ways. For example, richer farmers with access to chemical fertilizers have reduced their use of human and animal waste, burdening the environment with both chemicals and sewage. Moreover, a richer population now enjoys more appliances that use electricity and has more trash to throw away; the current litter problem did not exist a decade ago. Solid waste is growing even while potential disposal sites disappear in favor of housing and land reclamation for agriculture.

Changes in the transportation sector also contribute to this picture. China is creeping toward a national market, whereas, until about the last decade, subregions and even cities were mostly markets to themselves. For example, except for grain in some cases, the area around each city was expected to provide all its food. Fuel was (and is) mostly a local responsibility, and industry was vertically integrated. For that matter, factories were expected to provide housing, schools, and services on-site, limiting the need to move people. Transportation was limited to

Technicians collect rainwater samples in remote, mountainous Southwest China at over 3000 m. A cooperative venture between China and the United States, this is one of five stations in the global network organized to provide baseline data from minimally polluted environments. Technicians living at a base camp climb up daily to take samples, which are analyzed in China and the United States.

distributing or receiving specialized goods. For the most part, residents seldom left their home city.

Demands on transportation have bounded ahead of output and outraced the capacity of the current system. The most obvious environmental consequence is the pollution from the growing number of trucks and buses crowding inadequate roads. (The number of passenger cars, while still trivial compared with bicycles, is also growing rapidly.) The burden of moving people is compounded by China's primitive communication system; simple tasks often performed by telephone or computer linkups in this country must be performed face-to-face in Chinese cities.

In short, powerful stresses on the environment are exerted by a poor country growing richer.

Focus on Management

Faced with this set of conditions, Chinese authorities are trying to hold environmental degradation in check. Although rhetoric admittedly is cheap, environmental consciousness is reflected in frequent pronouncements of the highest government officials, the attention paid to environmental matters in the media, and an

Effluent from a small, reed-based papermill is shown here in the final stage of biological treatment. After initial treatment in lagoons, the wastewater is ultimately directed to a tree plantation, where additional nutrients are removed. This project benefited from ongoing Chinese-U.S. cooperative efforts to develop more effective, lower-cost treatment technologies.

administrative structure for dealing with environmental concerns that extends from the central government to small towns and rural counties in distant provinces. Practice, however, lags far behind.

Paramount in the Chinese approach is rejection of the Western model of "get rich first and then pay attention to the environment," a model still followed in much of the rest of the developing world. Their strategy is grounded on the reality that poverty precludes massive capital investment for end-of-pipe controls. Consequently, their focus is on management—seeking to exploit diverse interventions to limit health damage and environmental degradation at the least possible cost.

The first stage of implementing this strategy was to create an administrative structure that would place advocates for the environment throughout China. That task is virtually complete, and although the quality and training of local and county officials are sometimes poor, a presence has been established. On a parallel track, each ministry (Energy, Heavy Industry, Chemicals, etc.) has an environmental protection structure in place as well, extending to shop floor committees in many cases. The first task of these officials has been to monitor local conditions; it is a common

observation that China collects more data about its pollution than any other country in the world.

The second stage was to create a system of environmental standards and law against which performance could be measured and as a framework for implementing and enforcing controls. Under way for a decade—the first environmental law was passed in 1979—implementation and enforcement of this system is still woefully incomplete, a reflection of the pervasive lack of a "rule of law" that characterizes much of Chinese society.

The third stage was to decide what, in practice, was to be done. Pragmatism dictated that existing pollution sources could neither be controlled nor shut down unless egregious conditions led to acute hazards. Even then, possible remedies were limited; in one instance, for example, the machinery in two facilities was switched so that the one discharging dangerous effluent was located away from shellfish beds and recreational beaches.

"Solutions are easy to articulate but depressingly difficult to implement."

Regarding new facilities, the policy calls for mitigation of potential hazards that have been identified in environmental impact statements. Again, the focus is on lessening risk at the lowest possible cost, which often means controlling location rather than emissions. This realistic, second-best plan seeks to put the most serious pollutants where people are few, lessening the risk to public health. One example: when possible, emitters of harmful air pollution are placed downwind of population centers. Another: because no realistic prospect exists for controlling sulfur emissions, policy calls for installation of very tall stacks to dilute the emissions before they reach the ground. If all else fails, environmental authorities seek to have plants designed so that control retrofits can be added later when the cash flow allows.

Chemicals and Pathogens

Consistent with the pragmatic risk-reducing policy, special attention is paid to persistent and bioaccumulating chemicals; relatively little effort is expended on pathogens, except those discharged to fisheries or water-based recreation areas. Heavy metals and chlorinated hydrocarbons are particular targets for control because they get into the food chain and are not normally eliminated by water treatment. Substantial progress in this area has been made, but pressure on large urban enterprises to control emissions has often led to migration of polluters to rural areas, where emissions remain unchecked. Some of the most dangerous pesticides have been banned or are being phased out; efforts to educate farmers in the judicious use of pesticides are under way.

As for pathogens, domestic sewage is mostly discharged raw into rivers because China is not in an economic position to undertake treatment. However, heavy chlorination and the common practice of boiling all drinking water prevent significant infectious disease outbreaks. The success of this policy is manifest: China has largely eliminated life-threatening waterborne diseases such as cholera and typhoid, which still take a massive toll in many developing countries; life expectancy has risen dramatically; and morbidity rates have been reduced. Indeed, from a public health standpoint, the Chinese story is bright when placed against the backdrop of the limited accomplishments of other developing nations.

Ecological Protection Policies

Space allows only brief mention of ecological protection policies, but it is in this area that problems are perhaps greatest and progress the most difficult. The Chinese have been moderately successful in establishing policies to protect some endangered species. For example, farmers are paid for damage done by tigers and elephants to discourage the killing of these animals; peasants are generously rewarded for actions that protect giant pandas. However, despite massive tree-planting campaigns, forest cover continues to decline because of the demand for wood for cooking fuel; cultivation creeps up erosion-prone hillsides to supply food for a growing population; and overgrazing is turning western grasslands to desert at an alarming rate. Solutions are easy to articulate but depressingly difficult to implement.

In all of these activities, the Chinese are hampered by an economic and political system that

does not price resources and products at their true social value. It also does not provide the long-term assurance of property rights that would give ordinary citizens a financial stake in behavior that would serve the common good. The economic reforms that have been under way are changing incentives toward conservation of natural resources, but unless they are continued and coupled with a full range of environmental laws that are adequately enforced, further degradation will occur.

Road Ahead

The environmental repercussions of the tragic political events of the summer of 1989 are not yet clear. Economically, China has chosen to slow its economy to restrain inflation, foreign investment has decreased, and liberalizing reforms are on hold and in some cases have been reversed. The first two of these changes could provide time to accommodate environmental concerns, but at the same time will result in lower growth and thus fewer resources for investment in pollution control. Environmental policies and trends have not appeared to change so far. A new environmental law was passed in late summer of 1989 to further solidify the institutional basis of protection. A new policy placing more accountability for environmental quality on local and provincial officials has been adopted. The Chinese leadership continues to assert its dedication to environmental progress, and frequent press reports emphasize both successes and work yet to be done.

On the whole, the Chinese have demonstrated that they are serious about holding environ-mental degradation in check. Currently, they are spending about 0.5% of their gross national product directly on pollution control (vs about 2% in the United States) and expect that rate to double in the next few years. The infrastructure to implement pro-environment policies is largely in place. New installations are less hazardous than those built a decade ago; some cities are noticeably cleaner and pollution growth has lagged behind increases in output. Public opinion is aroused and occasionally has led to plant closures and to community rejection of polluting industries. (As an indicator of public interest, the thrice-weekly *China Environment News* has 450,000 paid subscribers.) The problems, however, are enormous, and the resources to confront them are few.

Recognizing that the Western model of throwing money and technology at the problem is impossible, Chinese leaders have emphasized managerial interventions that would limit degradation and cause minimal reduction in economic growth. The key mechanism has been to create economic and political incentives for environmentally responsible behavior. These initiatives have already achieved modest success and have built the foundation for real progress in the future. ornl

Biographical Sketch

Milton Russell is an economist and a collaborative researcher with ORNL and the University of Tennessee at Knoxville (UTK). Author of numerous books, he conducts research in ORNL's Energy Division and is professor of economics and senior fellow at UTK's Energy, Environment, and Resources Center. He has his Ph.D. degree in economics from the University of Oklahoma. He is chairman of the Oversight Review Board of the National Acid Precipitation Assessment Program. Russell's previous positions include economics professor with Southern Illinois University, senior staff economist with the President's Council of Economic Advisors, and senior fellow and director of the Center for Energy Policy Research at Resources for the Future. Before coming to East Tennessee in 1987, Russell was an assistant administrator of the U.S. Environmental Protection Administration. In this capacity, he first visited China in 1984 as part of a delegation that negotiated an environmental protection protocol between China and the United States. He has since been to China on several occasions and spent two months there in the summer of 1989.

Toward a One-Angstrom Electron Microscope

By Stephen J. Pennycook

"A new technique developed at ORNL is revolutionizing electron microscopy."

Steve Pennycook obtains high-resolution images of a high-temperature superconducting material using a scanning transmission electron microscope modified to take advantage of his Z-contrast technique.

A new technique developed at ORNL is revolutionizing electron microscopy. It has demonstrated a resolution improvement of 35% over conventional transmission electron microscopy (TEM), and, equally important, it provides an image that is simple to interpret and reveals a material's atomic composition directly. Based on a scanning transmission electron microscope (STEM), this technique represents a fundamentally new approach to electron microscopy because, for the first time, it provides a direct view of materials on the atomic scale.

The goal of state-of-the-art electron microscopy is to "see," or resolve, features as small as one angstrom (Å), which is one ten-billionth of a meter (10^{-10} m) and about one millionth of the diameter of a human hair. The distances between neighboring atoms are typically 1 to 2 Å in all materials, including semiconductors, superconductors, metals, and ceramics. An instrument that resolves features this small would enable scientists to view directly the structure of these materials on the atomic scale and to locate and identify atoms at defects and interfaces in these materials. This capability would improve the understanding of the origins of bulk materials properties, such as the strength of structural materials, the ability of superconductors to carry electrical current, and the speed of electron transport through candidate materials to be used in compact electronic devices. From such knowledge, we could tailor new materials for improved properties, leading the way to stronger ceramics, faster computers and communications, and other technologies of the future.

ORNL Concept Economical

The principles governing conventional TEM imaging were developed 40 years ago. Since then, significant improvements have been made, particularly in resolution at the atomic level. The 1-million-volt (MV) Atomic Resolution Microscope at DOE's Lawrence Berkeley Laboratory, which can resolve individual atoms that are only 1.6 Å apart, currently has the world's highest resolution. Plans are being made by a Japanese company to achieve 1-Å resolution through technological development. If successful, such a TEM machine would still require a team of trained operators to use and maintain it, and a building in which to house it. The estimated cost for such a microscope, which would probably require 5 years to develop, is $12 million.

ORNL is proposing an alternative method for attaining 1-Å resolution—one that would require only one operator, a normal-size room, and only $1.5 million, practically one-tenth the cost of the conventional approach. The new instrument would be shared with members of the scientific community through the standard policy of collaborative research. By modifying a commercially available 300-kilovolt (kV) STEM, manufactured by VG Microscopes in England, ORNL could achieve a resolution of 1.3 Å—the highest ever obtained. This modification could be accomplished as soon as next year. This is possible because the ORNL approach essentially uses only existing technology; stable 300-kV power supplies already exist for conventional TEMs, obviating the need for extensive technological development.

"ORNL could achieve a resolution of 1.3 Å—the highest ever obtained."

ORNL Concept Simpler

Besides being more economical than the conventional TEM, the ORNL approach is inherently superior because it produces only one image of a material's structure, whereas a conventional TEM image, which is an interference pattern, can take many forms. Like the ORNL technique, a conventional TEM forms a picture of the atomic arrangements inside materials—actually thin sections of bulk materials, penetrated by electrons from the microscope. Scanning tunneling microscopes and scanning electron microscopes provide views only of surfaces.

"In effect, we can use the electron microscope to simply photograph the atomic arrangements inside materials."

How a conventional TEM forms an image is shown in the figure on p. 57. A broad beam of electrons from the TEM illuminates the material. As the electrons pass through the material and bombard atoms, they are scattered in many directions. The images of atoms are obtained by "tracking" the scattered electrons: an electron lens gathers and focuses the scattered electrons onto a screen, giving a magnified interference pattern or image. Although this seems similar to the operation of a camera or optical microscope, there is one crucial difference! The electron beam is different from ordinary light because, like laser light, it is highly coherent. In coherent imaging, two objects can combine either "in phase" or "out of phase," giving a signal that is either brighter or darker than it was before; thus, atoms can look bright or dark, depending on the setting of the lens and the thickness of the sample. An analogy would be making a photograph by changing the focus of a camera so that the sky turns dark and the trees turn bright. Because TEM images of atoms cannot be interpreted simply by eye, a computer-simulated image must be generated and compared with the experimental image.

The ORNL technique uses a fundamentally different approach, shown in the upper right schematic on p. 57. A finely focused electron beam, or "probe," is scanned across the sample. A ring-shaped, or annular, detector picks up those electrons scattered through large angles (like foul balls in a baseball game). These electrons are not coherently scattered, however; the coherently scattered electrons, which are used to form a conventional image, pass through the central hole in the detector (like baseballs "hit up the middle" simultaneously during batting practice). The images produced by the ORNL technique have characteristics typical of an incoherent image such as a photograph—much as the image you see through your camera lens is the same as that you see without it. This new technique makes it possible to view atoms in the same direct way, and we always see atoms as white, never as black. In effect, we can use the electron microscope to simply photograph the atomic arrangements inside materials.

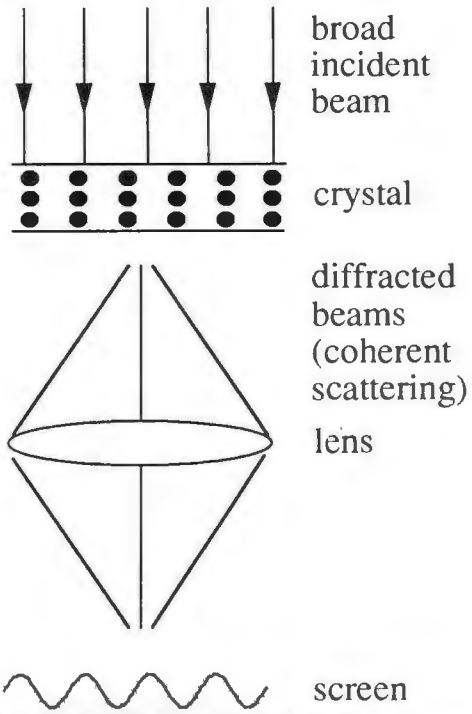
Our technique works even for relatively thick samples in which the scanning probe itself undergoes complex coherent diffraction effects as it passes through the crystal. At first sight, we might expect this interaction to introduce some anomalous characteristics, but detailed theoretical analysis has shown that the image is practically unchanged by these effects. Because calculations are not needed to correct for these effects, computer simulation of images is simpler and images can even be roughly interpreted by eye.

In all optical systems, the ultimate resolution depends on the wavelength of the light or electrons used. Two objects separated by less than a wavelength cannot be resolved as separate objects but will be blurred into one. Because electrons have a much shorter wavelength than light, electron microscopes have a much better resolution than light microscopes. Shorter-wavelength electrons are produced by using a higher accelerating voltage, usually measured in kV. Only in recent years has the resolution of conventional TEM machines exceeded that needed to resolve the atomic separations in most practical materials. However, an incoherent image will always show higher resolution than a coherent image taken under comparable conditions. For this reason, our existing STEM, operating at only 100 kV, provides images having resolution comparable to those taken by conventional microscopes operating at 200 or 300 kV, and a STEM operating at 300 kV would give the world's highest resolution.

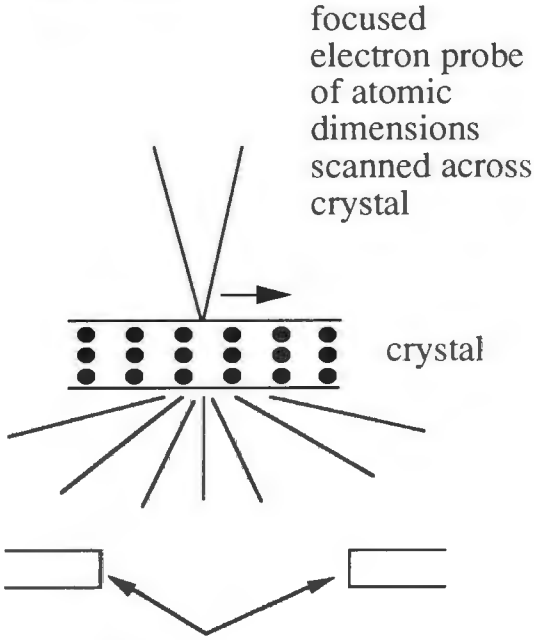
Z-Contrast Technique

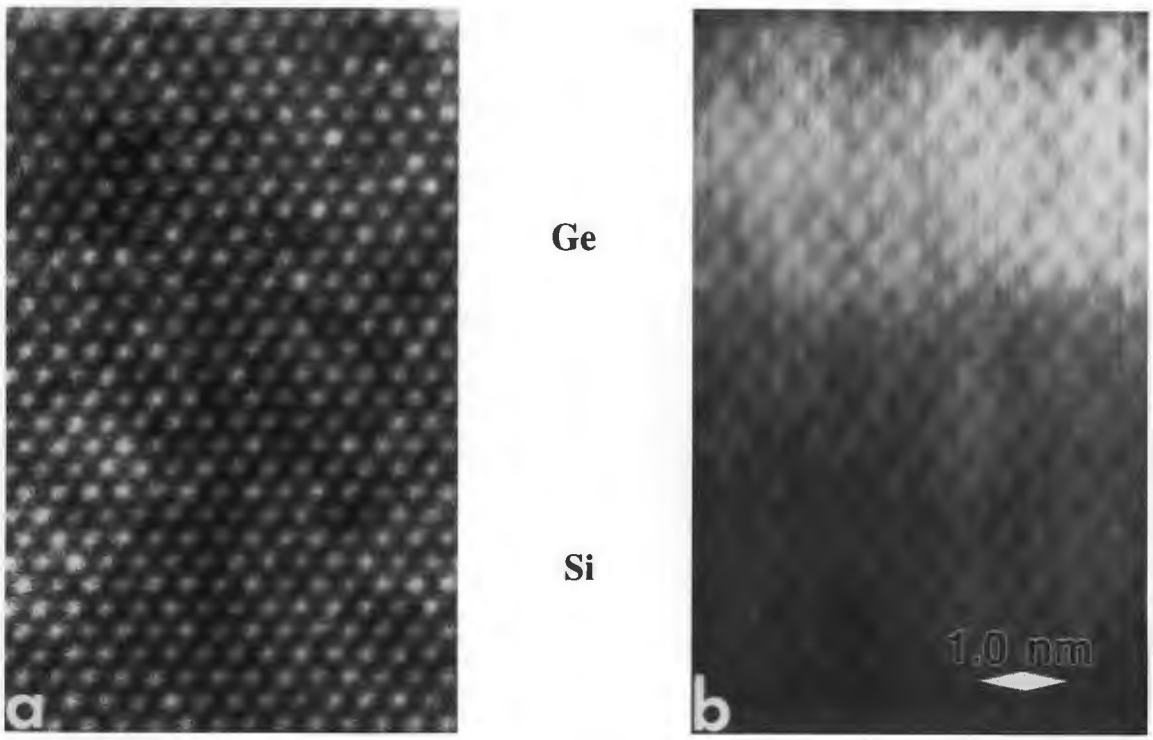
Besides producing superior resolution and an easily interpretable image, the ORNL technique also gives information on the species of atom imaged. For example, it enables scientists to distinguish between silicon (Si) and germanium (Ge) atoms in a material (see figure on p. 57) because the number of electrons scattered by the sample is directly related to the composition. Because atoms of higher atomic number (Z) scatter more electrons, they produce a brighter image. We call this technique Z-contrast imaging because, although atoms are always white in the image, the heavier a species is, the whiter it appears.

Conventional high-resolution imaging



Z-contrast imaging



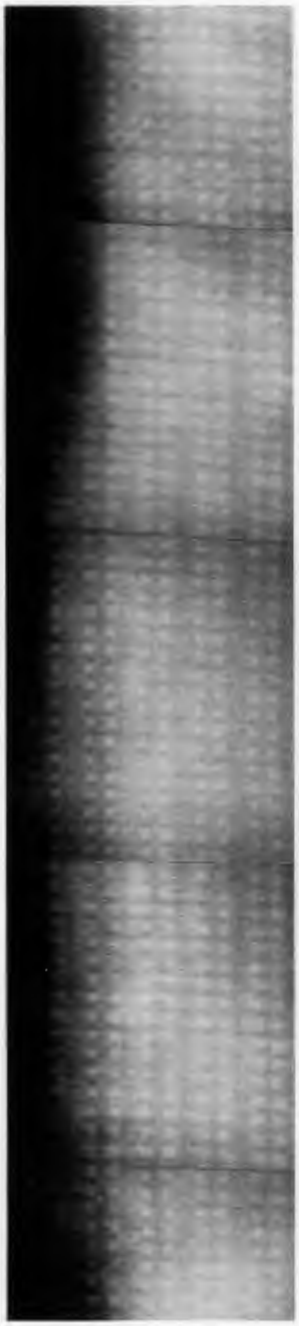


"The images produced by the ORNL technique have characteristics typical of an incoherent image such as a photo-graph."

In a conventional transmission electron microscope, a broad beam of electrons illuminates the sample and the diffracted beams are focused back to form an interference pattern on a screen. This pattern can take many different forms depending on lens focus and sample thickness, making interpretation extremely complex. With a powerful scanning transmission electron microscope using ORNL's Z-contrast imaging, a fine beam of electrons scans the sample and an annular detector collects electrons scattered to high angles, producing a direct, easy-to-interpret, high-resolution image that is simply a map of the scattering power of the sample. Atoms are always seen white, but the heavier the atom, the brighter the image. The image is a direct view of a material's structure and composition.

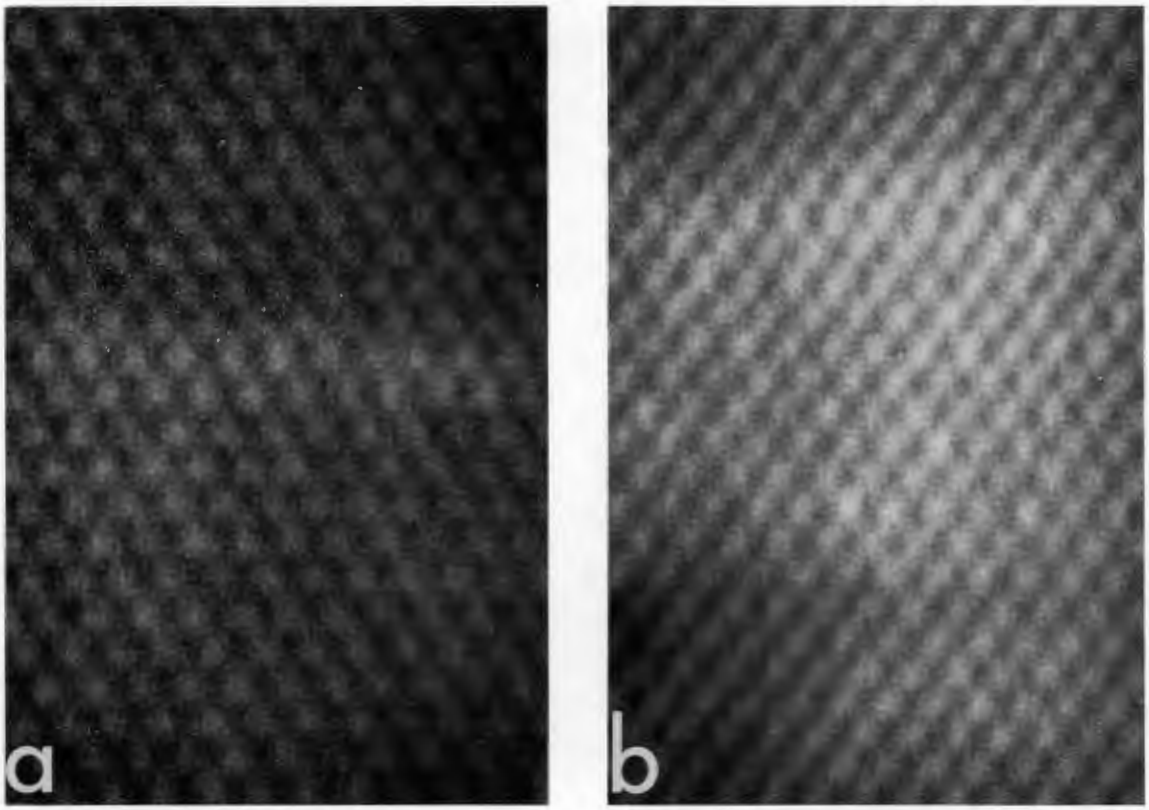
This compositional sensitivity, together with the simple form of the image, enables scientists to locate and study in detail the defects and interfaces of technologically important materials, the regions that ultimately control bulk materials properties. The new Z-contrast image now provides a direct view of the atomic structure and chemistry of these regions. This detailed information could stimulate new theories to explain the microscopic origins of desirable bulk properties, which should lead to the development of new and improved materials.

The photograph on this page shows a cross section of a superconducting thin film of yttrium-barium-copper oxide ($YBa_2Cu_3O_{7-x}$) deposited onto a magnesium oxide (MgO) substrate. Such films are being made and studied because of their potential use in high-speed electronic devices and superconducting motors. The Z-contrast image of the superconducting film is dominated by the orderly rows of bright Ba atoms, with the fainter (lighter)Y atoms barely showing between adjacent Ba rows. The atoms of the substrate are so light in mass that it looks completely dark in the left part of the figure. Undulations, or steps, are clearly present on the surface of the substrate, but the Z-contrast image shows that these do not induce defects in the superconducting film; one or two layers away from the substrate, the current-carrying planes are perfectly continuous. Such information is critical in interpreting the properties of these films. It implies that the current-carrying capacity of these films (1) is not limited in a major way by surface roughness of the substrate and (2) is determined by the boundaries between different grains in the film.



IBM researchers first demonstrated how drastically a grain boundary can affect the current-carrying capacity of a film. They showed that, if two grains are misaligned by only 10°, the current that can be passed from one grain to another drops tenfold. One obvious question arises from this work: because grain boundaries represent an imperfection in the crystal, they are natural sites at which impurities may collect and form a thin insulating layer of some impurity compound. If such a layer exists, then future research should focus on eliminating the impurities. On the other hand, if the current-carrying capacity is reduced by the structural imperfection itself, then the only way to increase capacity is to accurately align all the grains—a very different research direction and a clear case for microscopic examination. Our Z-contrast imaging has demonstrated clearly that low current-carrying capacity is

This cross-sectional view of a superconducting thin film on a magnesium oxide substrate (seen black) shows that continuity of the current-carrying planes is achieved only a few atomic spacings from the substrate surface. (This is a montage of five separate photographs. The horizontal black lines are the joints between photographs, not defects in the film).

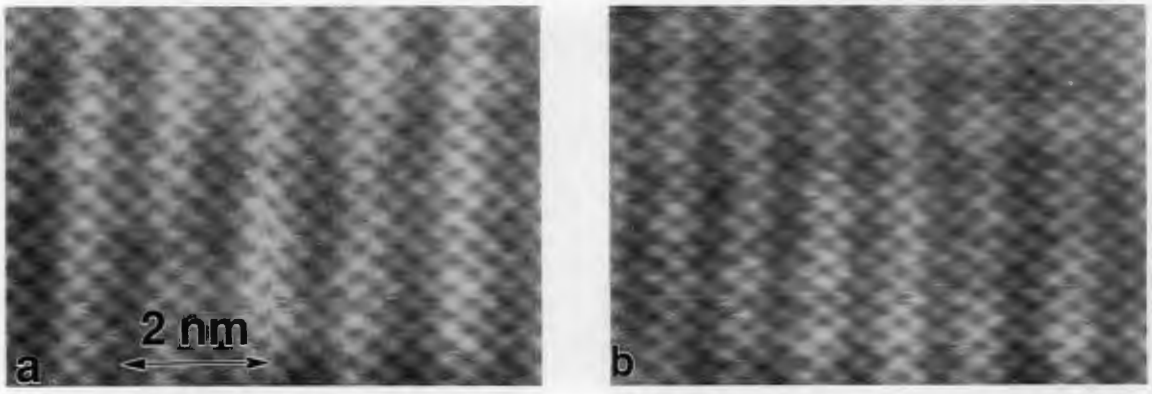


Quantum wells only 2 (left) and 13 (right) atomic layers thick are seen as horizontal bright bands having atomically sharp interfaces. These quantum wells are formed by a gallium arsenide layer sandwiched between layers of indium-gallium-phosphide.

indeed an intrinsic effect of structural imperfection, rather than the presence of impurities. Therefore, we are currently concentrating on methods to accurately align the grains of the film to maximize the current-carrying capacity. This example illustrates how the microscopic view of a material's structure and composition can play a key role in identifying the best approach to improving a material's properties.

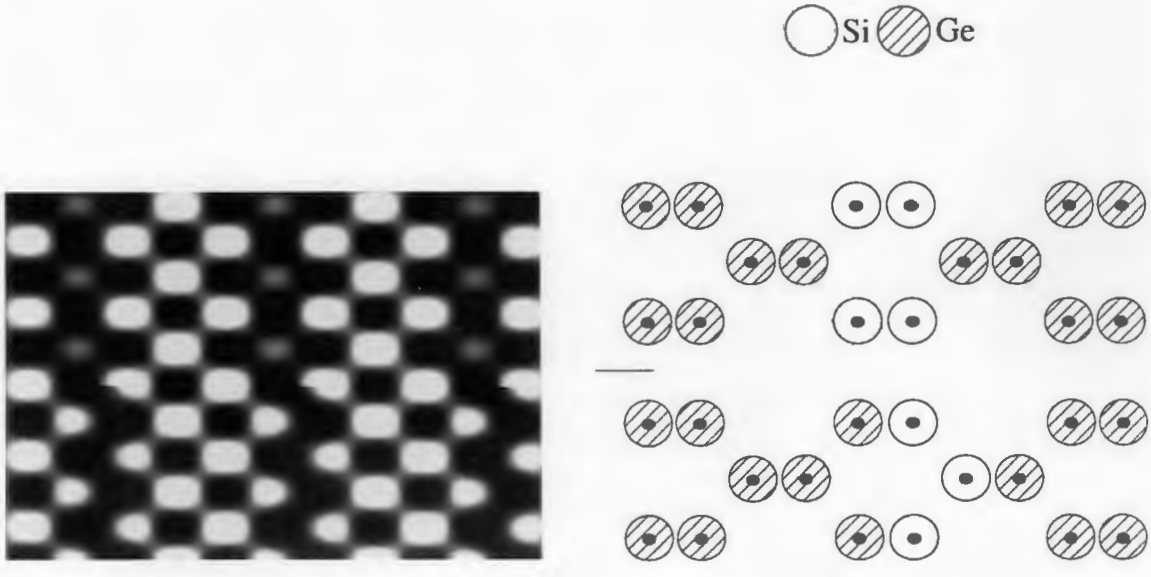
Similar insight can be gained into the behavior of semiconductor materials. A tremendous effort is under way to fabricate artificial structures using techniques such as molecular-beam epitaxy to engineer materials on the atomic scale. For example, a thin layer of one material, perhaps only one or two atomic planes in thickness, can be sandwiched between layers of another to produce a "quantum well" in which electrons behave differently from the way they do in a bulk material. Among their unique properties, quantum wells can be efficient sources of laser light; thus, they are being used in industry to make solid-state lasers for use in fiber-optic communications.

The figure above shows quantum wells of a gallium arsenide layer sandwiched between layers of indium-gallium-phosphide. Such a direct view of the atomic structure and composition is extremely valuable. Suppose that, as is almost always the case in research and development, the prototype device does not perform exactly as predicted. Is this discrepancy because the physics of the device is not sufficiently understood or because the desired structure was not achieved by the complex growth and processing procedures used? The figure at the top of p. 60 shows an example of growth as the problem. In this case, the desired structure was an atomic-scale superlattice—a series of alternating Si and Ge



$(Si_8Ge_2)p$ $(Si_2Ge_6)p$

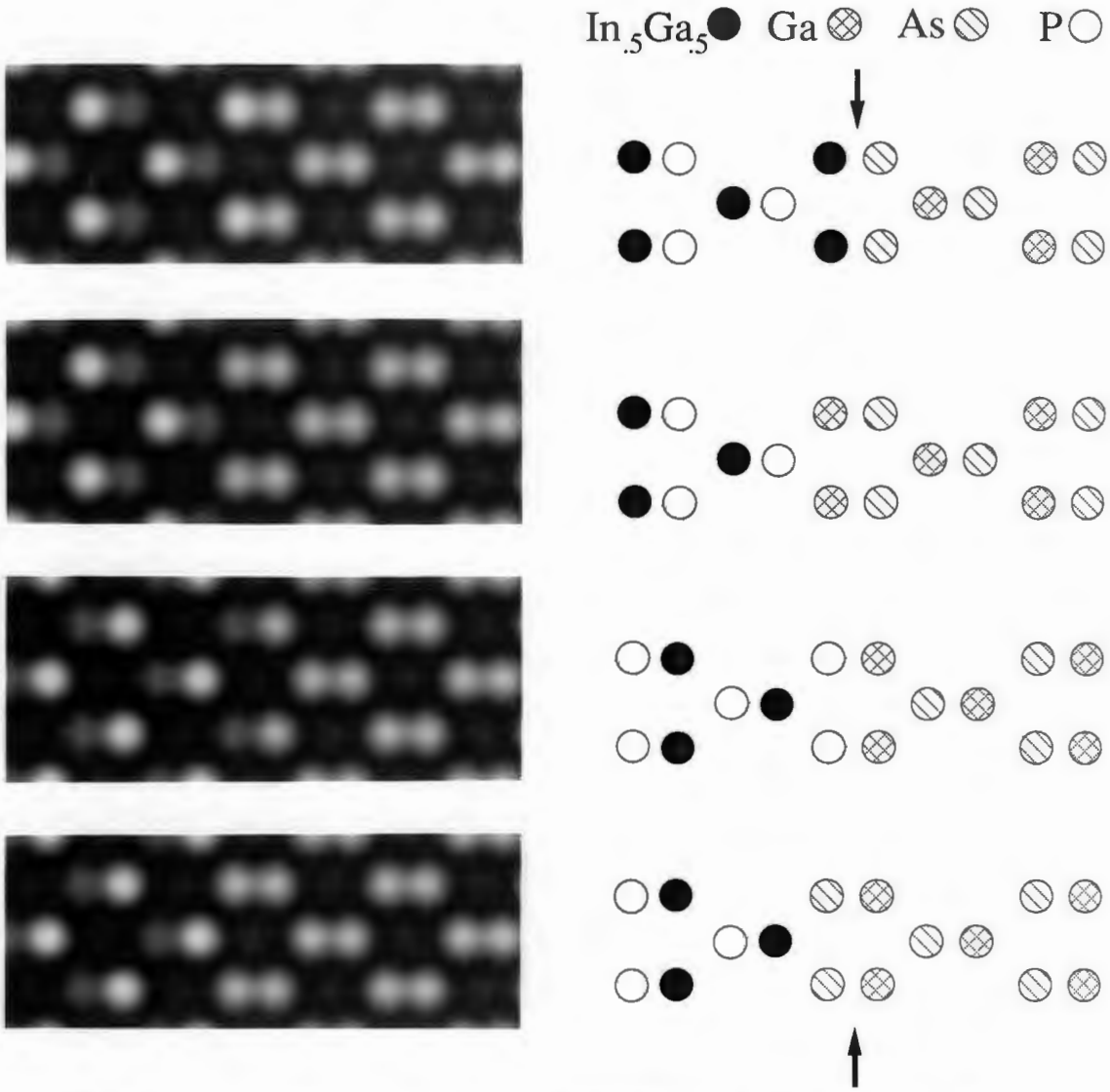
Interdiffusion of atoms is clearly shown in this Z-contrast image of ultrathin silicon-germanium superlattices grown at 400°C using molecular beam epitaxy (left). In the superlattice grown at 350°C (right), the interfaces are more abrupt (indicating less interdiffusion) but irregular because of steps on the growing surface.



Computer simulation of repeating silicon-germanium units (Si_2Ge_6) across a surface step.

layers. Such structures are expected to form the basis for faster transistors and, therefore, faster computers. The critical factor for speeding up electron transport through the material is the "chemical abruptness" of the interface between the Si and Ge—that is, virtually no intermixing of the Si and Ge atoms at the boundaries between Si and Ge layers is desirable. In the left figure, the view of the superlattice shows considerable intermixing; the bright Ge layer was intended to be only a quarter the width of the Si layer. The view of the superlattice on the right shows greatly reduced intermixing because it was grown at a lower temperature than the other superlattice. This image corresponds very closely to the desired structure. The computer simulation in the bottom figure shows that irregularities in the image can arise from surface steps and that surface steps, although too small to be resolved directly, still affect the image in a simply predictable fashion. Features this small would be directly resolvable with the proposed 300-kV STEM, after modification to make use of the Z-contrast technique, because every atomic column would be imaged separately.

The new ORNL capability will be particularly important for imaging quantum wells, which have four possible interface configurations (see the figure on p. 61) because they are fabricated from compound semiconductors. Each structure would have its particular electronic and optical properties. At our current resolution, we cannot distinguish these structures, but at the higher resolution anticipated at 300 kV, each is clearly distinguishable.



Computer-simulated images of quantum wells for a 300-kV high-resolution STEM. Each atomic column can be clearly imaged, and its composition determined. The four possible interface configurations for the quantum wells shown on p. 59 become distinguishable.

ORNL is currently attempting to procure the first high-resolution 300-kV STEM. If successful, we would then have the highest-resolution microscope in the world, perhaps even the first to reach the goal of 1-Å resolution. From a practical standpoint, it is not only the resolution but also the simple nature and compositional sensitivity of Z-contrast imaging that make it such a powerful technique in electron microscopy. The proposed modified STEM will enable us to look inside any material to determine the atomic structure and chemistry in critical areas. This view will provide the fundamental link between a material's growth or processing history and its properties. This capability will have a major impact on materials science and engineering and will improve our nation's competitiveness in these areas. For only a small price, ORNL could offer the key to the understanding of all materials, both natural and artificial.

Biographical Sketch

Steve Pennycook is leader of the Electron Microscopy Group in ORNL's Solid State Division. A native of England, he earned his doctoral degree in solid-state physics at the Cavendish Laboratory of Cambridge University in 1978 and joined the ORNL research staff in 1982. He is a recipient of three Publication Awards (1986, 1988, and 1989) from Martin Marietta Energy Systems, Inc. He received DOE's 1989 Materials Sciences Award for Outstanding Scientific Accomplishment in Solid-State Physics.

Serendipity: Accidental Discoveries in Science

Royston M. Roberts, Wiley Science Editions, John Wiley and Sons, Ltd., New York, 1989 (270 pages), $12.95 (soft cover).
Reviewed by Carlos Bamberger, ORNL's Chemistry Division.

"The book illustrates the importance of luck in some discoveries, yet shows the even greater importance of the discoverer's ability to recognize a new effect, understand the reason for it, and identify its applications."

This interesting, enjoyable, easy-to-read book contains 36 short chapters describing great accidental discoveries ranging from Columbus' New World to the structure of DNA. In the introduction, Royston Roberts gives the etymology of "serendipity," which he defines as a discovery made by accident—a recognition of some new or useful phenomenon that was not sought for. He also coins the term pseudoserendipity, which refers to discoveries made during the search for something else.

The majority of the discoveries described in the book are of a chemical or biological nature, reflecting perhaps the interests of the author, a professor of chemistry who, incidentally, spent time at ORNL learning to use carbon-14 as a tracer. Although a few of the older stories, such as the discovery of quinine for treating malaria, are based on legends, most are well-documented and rely on modern reports.

Whether some discoveries in the book are serendipitous is debatable and a matter of semantics. However, this possible weakness should not detract from the value of the book in informing readers of high-school age and older about the thrills of scientific discovery.

Even a reader who thinks science is boring is likely to be interested in the story behind the discovery of Velcro©: In the 1950s a Swiss hiker was curious about why cockleburs stuck to his coat, so he examined some in a microscope and discovered that they have tiny hooks that latched onto the loops in the fabric of his coat; he later developed the hook and loop tapes known as Velcro© (for *vel*vet and *cro*chet) fasteners. Churchgoers may find it fascinating that the name for Ivory™ soap (the only floating soap) came to Harley Procter while he was in church reading in Psalm 45 about "ivory palaces" and that the idea for Post-it™ notes occurred to a 3M Company employee while he was singing in the church choir, feeling frustrated that the scraps of paper he used to mark his music for two different services sometimes fell out.

Readers who want to know more details about a particular discovery will be delighted by the postscripts that supplement the contents of most chapters. For example, the chapter on Charles Goodyear's pseudoserendipitous discovery of vulcanization—adding sulfur to rubber and heating the mixture to give it desirable properties—is followed up with a brief story on the development of a technique to make synthetic rubber.

As a chemist, I was particularly interested in personal details about chemists and anecdotes about their discoveries. I enjoyed reading about Louis Daguerre's invention of photography, as well as the pseudoserendipitous discovery that led to the development of the birth control pill. The book illustrates the importance of luck in some discoveries, yet shows the even greater importance of the discoverer's ability to recognize a new effect, understand the reason for it, and identify its applications. In other cases, such as the discovery of the drug chlorpromazine, a new idea for a pharmaceutical, rather than luck, led to the discovery of drugs for treating mental disorders.

The discovery of Teflon™ is indirectly the result of a discovery in which luck played a prominent role. Chemists searching for a safe refrigerant used several bottles of antimony fluoride as a reagent in synthesis work. In safety tests, they found that the chlorofluorocarbon refrigerant obtained from the first bottle had no toxic effect on a guinea pig. However, the refrigerant samples prepared from the other bottles of antimony fluoride killed the guinea pigs. The

chemists found that the latter bottles contained the toxic gas phosgene, formed from water-contaminated antimony fluoride. Only the refrigerant made from the water-free bottle was nontoxic. If the water-free bottle had not been used first, chlorofluorocarbon would have been considered toxic, and the development of refrigerants and propellants might have been stalled. However, this line of research continued and, in his attempt to create better refrigerants from tetrafluoroethylene, Roy J. Plunkett found a polymer that led to the development of Teflon™.

Although I strongly recommend this book to the general public and especially to science administrators and science teachers, I have a few observations to make to potential readers. The often quoted thought of Louis Pasteur that "in the fields of observation, chance favors only the prepared mind" is as true now as it was then. However, we also must realize that most of the stories in this book are necessarily condensed and also somewhat romanticized. Readers of these stories may not realize that hard work is usually required to turn a lucky observation into a discovery that is understood and useful. For example, the discovery of safety glass did not occur instantly when in 1903 E. Benedictus dropped a glass flask with an interior thin coating on a hard floor and noticed that, although it shattered, the glass fragments did not fly apart. He conducted experiments over the next 6 years to determine the special properties of this combination and ways to reproduce it. In 1909 he applied for the first patent for safety glass.

The stories in this book can be used to motivate students to be more observant and creative. However, anyone using this book as a teaching tool should emphasize the importance of following up an observation with experiments and of not becoming discouraged by initial negative results (which, if analyzed properly, could lead to the right answer).

One message in the book that deserves more emphasis is Karl Ziegler's guiding principle that "it is not possible to anticipate something that is really new; this can only be discovered by experiment." As a chemist, I subscribe wholeheartedly to this thesis; if you do not perform experiments, you will have nothing to observe!

The book also implies but does not emphasize that freedom to conduct research is important for making new discoveries possible. If a researcher makes an observation but is not given the funding or time to follow through with experiments, a potential discovery may be lost. Managers and teachers should always facilitate, and never obstruct, efforts that could lead to new discoveries. If Roy J. Plunkett had not been given permission to cut open the cylinder that was supposed to contain gaseous fluorocarbon, he would not have found the contents that led to the discovery of Teflon™. If the managers of Sandoz Corporation in Basel, Switzerland, which had originally decided to discontinue work on cyclosporin A®, had not listened to Jean Borel's plea that the drug has great value because it suppresses the activity of the immune system, organ transplants might not be a medical option today. Fortunately, ORNL and the other DOE national laboratories afford their staff members some freedom to pursue their research ideas and to follow up on unusual observations.

One appropriate story that is missing from Roberts' book is the serendipitous discovery of cisplatin, an important drug for treating cancer of several types. The discovery is described in *Biotechnology and Materials Sciences—Chemistry for the Future*, a book edited by M. L. Good and published in 1988 by the American Chemical Society.

If a second edition of *Serendipity* is published, the author could include this story and use it to explain the occurrence of *cis* and *trans* compounds. He also should correct the occasional errors; the one that bothered me the most was the statement that 14-carat gold is 58% gold and 48% other metals. Because of its inspiring stories about new discoveries and its simple explanations of scientific concepts, this book could help attract more students into scientific and technical careers. ornl

"The book also implies but does not emphasize that freedom to conduct research is important for making new discoveries possible."

ORNL's Impact on Radiation Protection Guidance

By Keith F. Eckerman and Alan R. Hawthorne

"ORNL has made major contributions to radiation protection and continues to advance the state of the art through its research programs and participation in the work of the ICRP."

Mark Cristy (left), Lynn Till, and Richard Ward view a computer-processed image of a child's heart and lungs processed from CAT data forwarded to ORNL by Children's Hospital in Washington, D. C. Using software developed for this work station by the Geographic Data Section of the Computing and Telecommunications Division, researchers can examine images of organs of interest to define each one's size, shape, location, and density in the body. Previously such information could be obtained only from autopsies. (See sidebar on "Computerized Anatomical Models of Children" on p. 73.)

The April 1986 accident at the Chernobyl nuclear power plant elevated radiation levels in many parts of the world and heightened the public's concerns about the health consequences of potential accidents at nuclear facilities. Because radiation levels were noticeably elevated throughout Europe, each country there established programs for monitoring the radiation levels and taking protective actions, such as withdrawing contaminated foods from markets, to control the exposures of its citizens. Although each country established its own practices, the approaches of all the European nations were reasonably consistent because they relied on recommendations of the International Commission on Radiological Protection (ICRP).

The ICRP develops recommendations on radiation protection matters based largely on scientific considerations. These recommendations are intended to be tailored by national governments to meet their specific needs. In this capacity, the ICRP addresses a wide range of issues regarding the beneficial uses of medical, environmental, and occupational radiation. Currently, the United States is updating its occupational radiation protection guidance by adopting, with minor modifications, the most recent recommendations of the ICRP.

ORNL has made major contributions to radiation protection and continues to advance the state of the art through its research programs and participation in the work of the ICRP. The Metabolism and Dosimetry Research (MDR) Group of the Health and Safety Research Division (HASRD) has been the focal point of the ORNL-ICRP interactions for the past three decades. Because the Department of Energy and its contractors are rigorously examining their day-to-day radiation protection practices, it is appropriate to reflect on ORNL's role in formulating the principles that guide radiation protection.

History and Principles of the ICRP

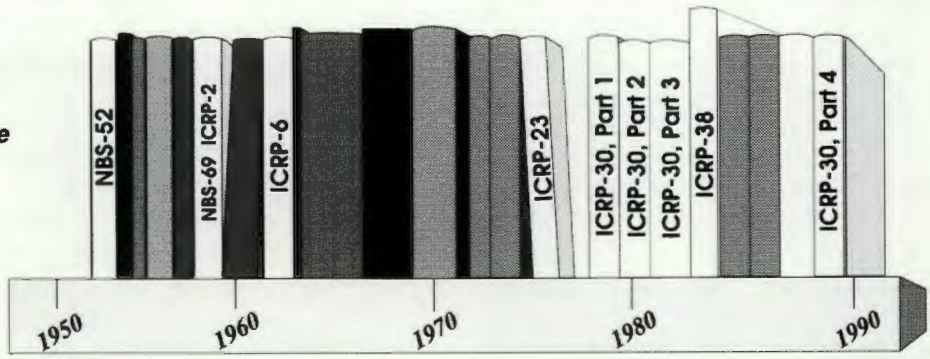
The ICRP was formed in 1928 by the Second International Congress of Radiology to address radiation protection in the medical uses of ionizing radiation. In 1950, the ICRP was reorganized in its current form to address radiation protection in nonmedical, as well as medical, uses of ionizing radiation. The ICRP focuses on the fundamental scientific principles from which it may derive recommendations governing the use of ionizing radiation. The recommendations are used by national regulatory authorities worldwide, thus forming a consistent basis for radiation protection standards within the international community.

In the United States, the scientific advisory body on radiation protection matters is the National Council on Radiation Protection and Measurements (NCRPM). Since 1970, the Environmental Protection Agency (EPA) has had the responsibility of advising the President on radiation protection matters. In 1987, President Reagan approved the EPA Administrator's new recommendations entitled "Radiation Protection Guidance to Federal Agencies for Occupational Exposures." This guidance, which is largely consistent with the current recommendations of the ICRP, is the first extensive revision in radiation protection since 1959. Currently, federal and state regulatory agencies are working on implementing the guidance into law.

Throughout the years, the presentation and application of the radiation protection guidance have changed significantly in emphasis. Initially, compliance with the guidance was considered achieved if the doses received by individuals were below stated numerical limits on dose. Although it has always been considered good practice to keep radiation exposures as low as practicable, efforts to achieve this condition were not part of the

ORNL Contributions to Radiation Protection

The books highlighted on this shelf represent major radiation protection handbooks that ORNL developed throughout the years. Although these volumes are called reports of committees, they are known throughout the world to be ORNL products. ORNL continues to be heavily involved in the development of radiation protection guidance. Drawing by Kim Sneed.



Early in the Manhattan Project, it became evident that efforts to develop the atomic bomb would produce hundreds of radioactive isotopes about which little was known to guide the protection of workers. Because of its unique combination of resources and personnel, ORNL began playing a major role in developing radiation protection guidance for the workplace. Since the 1940s, ORNL has maintained that leadership role.

In 1953, Karl Z. Morgan, then director of the Health Physics Division, led the preparation of the first formal report on permissible levels of radionuclides in the workplace. That report, which contained information on 69 radionuclides, was issued as *National Bureau of Standards (NBS) Handbook 52*. In 1959 it was superseded by *NBS Handbook 69*, which was jointly issued as ICRP's *Publication 2*.

These publications were the source of occupational radiation protection practices until 1975, when the ICRP began a systematic revision of its radiation protection guidance. To accomplish this task, ICRP Committee 2 established the Task Group on Dose Calculations, chaired by Mary R. Ford and composed of members of ORNL's Metabolism and Dosimetry Research Group and its consultants. The ORNL-based Task Group prepared *Publication 30*, a four-part publication with four supplemental volumes providing detailed information. *Publication 30, Part 1*, which was published in 1979, provided guidance for more than 700 radionuclides. The Task Group prepared an additional report, *Publication 38*, on the energies and intensities of the radiations emitted by the various radionuclides. Because of the unique expertise of the Task Group, the ICRP did not disband it following completion of its work, as is the usual fate of task groups, but rather chose to maintain it as a standing task group. Keith F. Eckerman is chairman of the task group.

Over the years, ORNL researchers and managers have been actively involved in the decision making of the ICRP. Morgan was chiefly responsible for bringing about the ORNL-ICRP interaction and fostering the scientific basis of radiation protection. Walter S. Snyder, former leader of the MDR Group, was the chief developer of much of the dosimetric methodology now used worldwide. Efforts continue today to advance these dosimetric methods and to develop information responsive to the dosimetric needs of medical, environmental, and occupational origins in both radiation protection and risk assessments.

Many ORNL researchers have provided technical expertise to various ICRP task groups. ORNL membership on ICRP committees over the years has included Karl Z. Morgan, Walter S. Snyder, Mary R. Ford, Edward G. Struxness, Chester R. Richmond, Keith F. Eckerman, and Michael R. Fry. The last three individuals are current members of ICRP committees.

regulatory framework. Since the 1960s increasing emphasis has been placed on the objective of keeping radiation exposures as low as reasonably achievable (ALARA), taking into account economic and other costs. Efforts to meet the ALARA objective have substantially decreased radiation doses, thus reducing the overall importance of the dose limit in controlling workplace practices. The objective of the dose limits has also changed from the early focus on preventing directly observable injuries (e.g., radiation burns) to its current role of minimizing the risk of radiation-induced cancer and adverse genetic effects in the exposed population.

The objective of radiation protection, as formulated in the most recent ICRP recommendations, is to protect humans from the detrimental effects of radiation and to allow the beneficial uses of radiation (e.g., diagnostic X rays) and radiation-producing activities (e.g., research and power reactors). The radiation protection recommendations of the ICRP are based on three relatively simple principles:

- Justification—No one should be exposed to ionizing radiation unless an overall benefit from the activity causing the exposure is expected;
- Optimization—Radiation exposures should be maintained ALARA, taking into account economic and social factors; and
- Limitation—Radiation doses shall not exceed the limits recommended by the ICRP for the appropriate circumstances.

The ICRP also gives attention to practices that could cause individuals to receive doses in the future. For example, radionuclides ingested

International Radiation Dosimetry Intercomparison

As discussed in the article, radiation dosimetry refers to the measurement of various levels of radiation in an environment. Radiation interacts with an instrument designed to measure radiation levels in much the same way as with tissues of the body. Thus, the observed response of a radiation instrument can be used to estimate the dose that an individual might receive at the location of the measurements.

For many years, ORNL has been involved in developing and calibrating radiation instruments. In recent years, HASRD's Dosimetry Application Research Group, under the leadership of Steve Sims, has conducted national and international intercomparisons of the responses of dosimeters to various levels of radiation. Representatives from more than 40 countries have participated in these studies.

The Health Physics Research Reactor (HPRR), an ORNL user facility that has been shut down for three years, has provided a unique source of radiation fields, especially fast neutrons, for these and other studies. A newly commissioned Radiation Calibration Laboratory (RADCAL), which contains various X-ray and isotope sources for calibrating radiation dosimeters and instruments, will complement the HPRR as a radiation source. RADCAL is currently being certified by the National Institute of Standards and Technology (formerly the National Bureau of Standards) as a national calibrations center.

by a worker may irradiate the individual's body beyond the period of active employment and over the remaining lifetime. The ICRP recommendation limits workplace practices in a year to ensure that no worker will receive a dose in the 50-year period following the exposure or intake that would exceed the numerical limits. Furthermore, it is considered prudent to assume that the risk from radiation exposures is a linear function of dose—that is, the risk of cancer and genetic changes increases proportionally with dose without a threshold. Thus, in radiation protection, no matter how low a radiation dose, some health risk is considered to be associated with the exposure. Because the validity of this assumption is impossible to prove, it has accounted for a significant amount of the scientific effort and debate in the radiation protection community over the past 50 years.

"ORNL scientists have made many contributions to the radiation protection field throughout the years."

Early ORNL Involvement with the ICRP

Since the early days of the Manhattan Project, ORNL staff have been concerned with ensuring the health and safety of employees exposed to radiation during their work. The operation of research reactors, the separation of plutonium and fission products from irradiated uranium, and the disposal of radioactive wastes from these activities presented many new problems to those concerned with health and safety. From these concerns emerged the profession of health physics and the development, both theoretical and operational, of a framework for guiding radiation protection practices.

ORNL scientists have made many contributions to the radiation protection field throughout the years. Karl Z. Morgan, once director of the former Health Physics Division at ORNL and founder of the Health Physics Society, was instrumental in establishing a uniform approach to radiation protection among the national and international organizations responsible for radiation standards. Morgan also recognized the need for a strong research program to develop an understanding of the physical and biological aspects of radiation protection. These needs guided the research programs of the Health Physics Division through the mid-1970s and, subsequently, those of the Health and Safety Research Division. These research efforts have contributed substantially to the scientific basis for radiation protection and have been the origin of much of the radiation dosimetry information used worldwide in nuclear medicine and radiation protection.

Radiation Dosimetry Contributions

Unlike many pollutants to which humans are exposed, radiation can be readily detected and measured. The science of radiation measurements is radiation dosimetry; however, for the discussions here, we broaden the definition to include efforts to define the relationships between the radiation environment and the dose in tissues of the body. The term *dose* was adopted from medicine and initially applied in a pharmacological sense to mean a measure of the amount of medication (radiation) administered to the patient. It was found that the biological response correlated with the amount of energy deposited by the radiation. Radiation dose (or absorbed dose) is a physical quantity defined as the amount of ionizing energy absorbed per unit mass of material; in radiation protection, tissues of the body are the material of concern. However, it has been found necessary, for radiation protection purposes, to introduce the quantity *dose equivalent*, which includes modifiers of absorbed dose to more fully reflect radiobiological considerations associated with the different radiations. Individuals are exposed to ionizing radiations in two ways: from radiation sources external to the body (e.g., a medical X-ray machine) or from internal sources (e.g., radionuclides that have entered the body by being inhaled or swallowed). In either case, the magnitude of the dose to the radiosensitive tissues of the body is of primary concern.

Members of the MDR Group have focused on defining the exposure-dose relationship—that is, the relationship between radiation exposure (either from external or internal sources) and the radiation doses received by the tissues of the body. Although radiation can be readily detected and measured, it is not feasible to measure directly the dose within the organs and tissues of the body. In the case of

inhaled or ingested radionuclides, the relationship is determined by modeling (1) the behavior of radionuclides in the body and (2) the physical processes by which ionizing radiations deposit energy within the radiosensitive tissues. For external radiation fields, only the second model is needed. The exposure-dose relationships are the bases upon which all radiation protection guidelines are established and are critical components of any radiation risk assessment, even the comparative evaluations of alternative diagnostic procedures using radiopharmaceuticals and X-ray machines.

Predicting Organ Doses

Since the mid-1960s, the MDR Group has used a mathematical representation of the body to estimate organ doses. In the early days, complex calculations of organ doses required computing resources available only at national laboratories. The results of these calculations were tabulated and published in a manner that permitted others to make use of these extensive calculations. Much of this information appeared in publications of the ICRP and in publications of the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine. These efforts established the Metabolism and Dosimetry Research Group of ORNL as the major developer of dosimetric data.

In recent years, the emphasis in radiation protection has shifted somewhat from occupational exposures to exposures of the general public. In addition, the need for improved estimates of organ and tissue doses arises from the varied arenas in which such information is applied—radiation risk assessments, epidemiological studies, and development of radiopharmaceuticals. For example, we found it necessary to modify the mathematical representation of the body to extend the anatomical model to children of various ages (see sidebar on p. 73), to Western adult females, and to adult Japanese males and females.

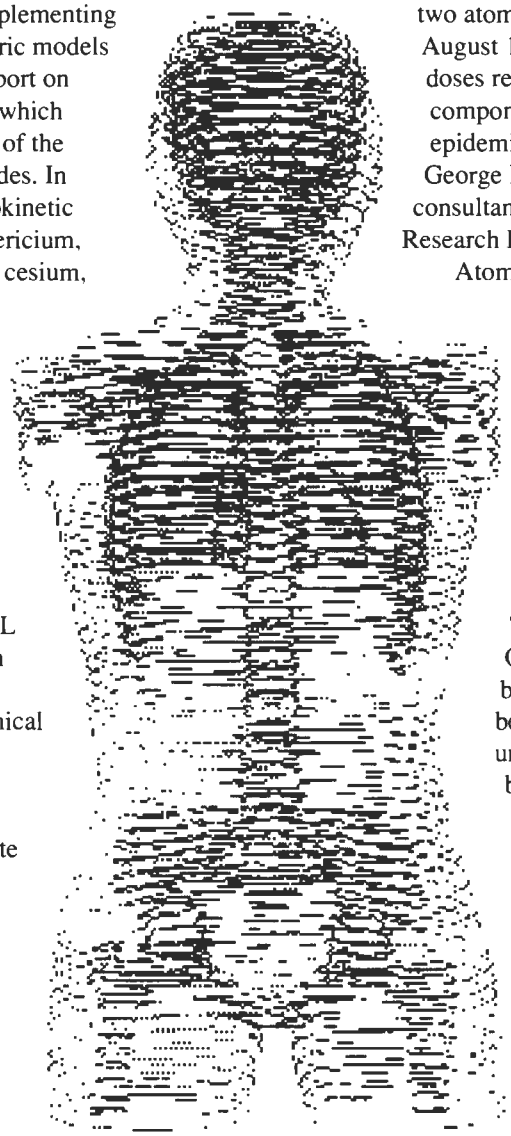
Estimating the dose to organs and tissues from an ingested radionuclide is a difficult problem because of the need to describe the behavior of the radionuclide in the body; for example, a radionuclide may be metabolized in the body into other chemical substances or it may be changed into other substances through radioactive decay.

Biokinetic models developed in the past to describe the behavior of radioactive elements in a reference adult generally have been derived on a strictly empirical basis—that is, by fitting simple mathematical expressions to available element-specific retention data for adult humans and laboratory animals. Such mathematical expressions provide some basis for calculating integrated doses from radionuclides but, in general, have no discernible correspondence to the physiological processes actually controlling behavior of the radioactive elements in the body. Development of models describing the biokinetics in persons other than a hypothetical young adult male has required a substantial departure from this approach because of the scarcity of element-specific data for special populations (for example, young children). R. W. Leggett of the MDR Group has led the development of a new approach.

As far as practical, the models currently being developed at ORNL explicitly depict the tissues and physiological processes controlling the movement or retention of radionuclides in the body. The advantages of a physiologically realistic approach are that it allows (1) incorporation of basic physiological information into the model, (2) realistic treatment of decay products formed in the body, (3) meaningful extrapolation of data from laboratory animals to humans, (4) meaningful analogies to be drawn between an element of interest and physiologically similar elements, and (5) a linkage between excretion of a radioactive element and its movement between body tissues and blood. With this approach, construction of a biokinetic model might take into account, for example, the blood flow rate to organs, the rate at which different parts of the skeleton are modeled and remodeled during life, and the changing essential elemental content of organs during life. The level of detail that might be used for a short-lived radionuclide such as rubidium-82, which is important in nuclear medicine, is illustrated in the figure on p. 71.

"In 1989 the MDR Group played a dominant role in formulating and implementing the biokinetic and dosimetric models used in the ICRP's first report on age-dependent dosimetry."

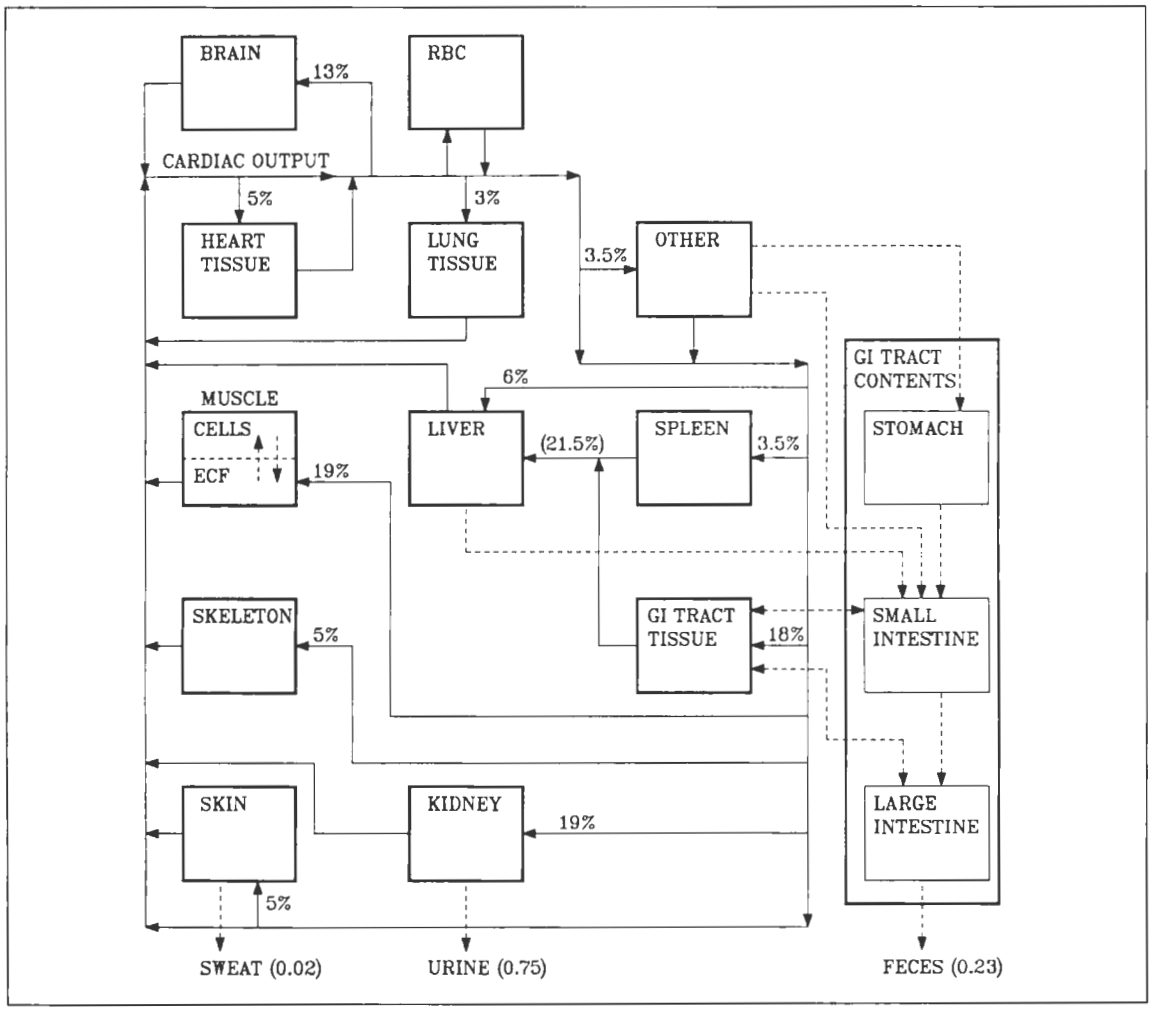
Largely as a result of the Chernobyl accident and the subsequent increased concern over radiation doses to young children, the ICRP has made a major effort to develop exposure-dose relationships for persons of all ages. In 1989 the MDR Group played a dominant role in formulating and implementing the biokinetic and dosimetric models used in the ICRP's first report on age-dependent dosimetry, which deals with a small number of the more important radionuclides. In particular, age-specific biokinetic models for plutonium, americium, neptunium, strontium, and cesium, which were developed by Leggett, were adopted for use in that report. The ICRP's second report on age-dependent dosimetry, now in preparation, also will include several of Leggett's age-specific biokinetic models.



In a related effort, ORNL researchers are involved in an ICRP task to revise Reference Man, an anatomical and physiological representation of the body used by the ICRP. Chet Richmond, former associate director for Biomedical and Environmental Sciences, is the chairman and Mark Cristy of HASRD is the vice chairman of the ICRP Committee 2 Task Group charged with revising the Reference Man publication. The revision will give greater emphasis than the original publication to the normal variations in anatomical and physiological characteristics with age and gender as well as the differences among persons of the same age and sex.

ORNL staff members were primarily responsible for developing the original Reference Man report.

ORNL has made numerous contributions to the understanding of the body's response to radiation exposure. The major source of such information is the medical studies of the survivors of the two atomic bombs dropped on Japan in August 1945. Estimates of radiation doses received by these subjects are components of the continued epidemiological studies. Since 1975, George D. Kerr of HASRD has been a consultant to the Radiation Effects Research Foundation, formerly the Atomic Bomb Casualty Commission, on dosimetry. Recently, a reevaluation of the gamma, X-ray, and neutron doses received by the Japanese A-bomb survivors was completed. Kerr was involved in this binational effort to improve the dose estimates for the survivors. The need to update the earlier ORNL estimates of dose became increasingly apparent because of newly identified uncertainties in the Hiroshima bomb's yield and the relative intensities of gamma and neutron radiations. Because of important modifications to the earlier dose estimates and the use of a new model for estimating risk, the estimates of radiation risk to humans have been updated. The National Academy of Sciences' fifth report on the biological effects of ionizing radiation (*BEIR V Report*), entitled "Health Effects of Exposure to Low Levels of Ionizing Radiation," states that low doses of gamma radiation and X rays pose a human cancer risk 3 to 4 times higher than previously estimated. This report is now being



This schematic illustrates the direction of flow of rubidium among tissues and organs for a reference adult male. Full arrows indicate blood plasma flow and broken arrows indicate flow not involving plasma. Numbers next to the compartments refer to relative percentages of rubidium passing through the compartments in blood plasma. The numbers to the right of the sweat, urine, and feces are typical relative fractions of rubidium excreted along these routes.

"ORNL researchers are involved in an ICRP task to revise Reference Man."

reviewed by a DOE technical committee, which includes Kerr.

To improve the understanding of the factors influencing the effects of radiation on biological systems, we must consider not only the average energy deposited per unit mass of the organ (the absorbed dose) but also the spatial distribution of dose, at least at the cellular level. Application of human experience with radiation in one exposure situation (e.g., the A-bomb survivors) to other situations encountered (e.g., radionuclides within the body) requires detailed consideration of the physical and biological variables characterizing each situation. In this regard, the MDR Group has devoted much work to improving estimates of dose in the heterogeneously distributed cells within the skeleton thought to be at risk for induction of leukemia and bone cancer.

Commentary

We believe that ORNL's long history in providing sound scientific contributions to radiation protection provides an opportunity for Energy Systems and DOE to more effectively implement state-of-the-art radiation protection practices. The delay—from acceptance of new information by the ICRP (which itself may take many years) through national adoption and implementation, issuance of the federal guidance, and finally to adoption in local practices—is often much longer than necessary. This process may take a decade or more to accomplish, given the inevitable real-world delays. We should look for opportunities to benefit from ORNL's close interaction with the ICRP and our scientific leadership in this area to provide a model of radiation protection for the DOE system. ornl

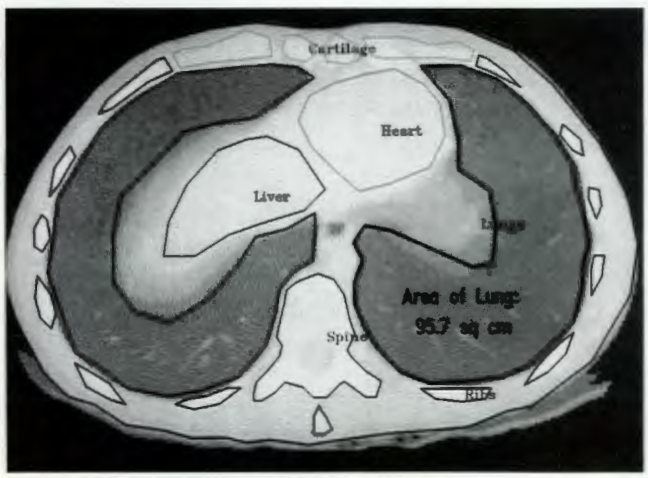
Biographical Sketches

Keith Eckerman is leader of the Metabolism and Dosimetry Group in the Health Studies Section of ORNL's Health and Safety Research Division. In this capacity, he is reponsible for directing research efforts to develop dosimetric and metabolic models for estimating radiation doses to human organs. Before coming to ORNL in 1979, he was a senior radiological physicist for the Nuclear Regulatory Commission and an environmental scientist at Argonne National Laboratory. He has a Ph.D. degree in radiological health from Northwestern University.

Alan Hawthorne is head of the Health Studies Section of ORNL's Health and Safety Research Division. From 1982 through 1987, he was leader of the Measurement Applications Group. Since coming to ORNL in 1976, he has pursued several interests, including measurments of radon in houses. He has a Ph.D. degree in nuclear engineering from North Carolina State University.

Alan Hawthorne (left) and Keith Eckerman prepare to assemble a phantom, which has been irradiated in a reactor for measuring radiation doses to organs. Inset: The assembled phantom.

Computerized Anatomical Models of Children



This image of a child's heart, liver, and lungs, constructed on a computer at ORNL based on data from CAT scans of patients at Children's Hospital in Washington, D. C., allows researchers to calculate the size and determine the location of each organ. Such information improves estimates of the radiation doses to specific organs for various radiation exposures.

The lack of detailed information on the locations, sizes, shapes, densities, and compositions of organs in children became apparent in efforts to construct mathematical models for use in calculating radiation doses to children's organs for various levels of exposure. Recent advances in medical diagnostic imaging, such as computerized axial tomography (CAT) and nuclear magnetic resonance imaging, suggested that this deficiency in anatomical information could be corrected. Thus, about four years ago, Keith Eckerman and his Energy Systems colleagues began a collaborative investigation with Children's Hospital in Washington, D.C.

Since that time, ORNL has been receiving from Children's Hospital numerous CAT images on magnetic tape that were obtained in normal diagnostic procedures. Staff members in the Computing and Telecommunications Division (C&TD) developed the hardware and software needed to extract from the digitized images the anatomical information of interest. This information is used to create realistic geometric representations of the body for use in calculating radiation doses to various organs—brain, lungs, liver, and kidneys, for example—for various levels of exposure from internal or external radiation sources.

Colorful computer images of the body, such as those appearing on the front and back cover of the *Review*, have depended heavily on the expertise of a number of individuals within C&TD, including S. M. Margle, E. P. Tinnel, Lynn E. Till, and R. C. Durfee of the Geographic Data Section and Richard C. Ward of Applied Physics. In addition, J. C. Ryman of C&TD developed for ORNL's Metabolism and Dosimetry Research Group a computer code, based on Monte Carlo methods, to calculate the radiation transport in a geometry represented by a stack of CAT cross-sectional images.

CAT scans have provided a means of obtaining age-specific anatomical data that have reduced uncertainties in the estimates of radiation doses to children, a critical segment of the population.

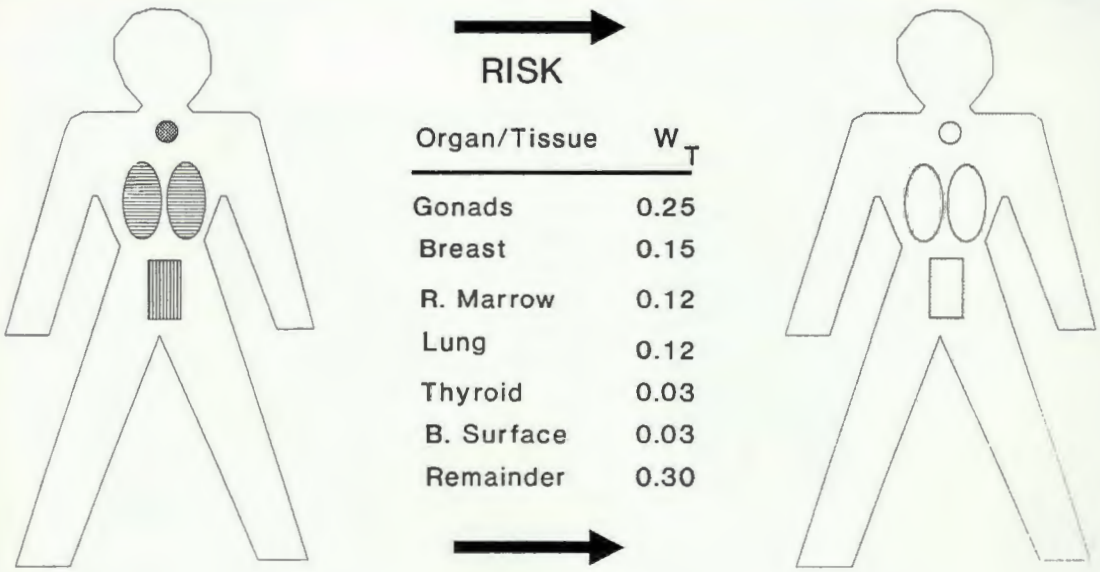
Improvements in the estimates of organ doses are important for (1) epidemiological studies to determine the health risk per unit exposure and (2) determination of compliance with regulatory guidance. Both the NCRP and the ICRP are concerned with improving estimates of radiation doses and determining uncertainties in the estimates for children.

A Look at Natural Background Radiation

For radiation protection, it is considered prudent to associate an element of risk with each radiation exposure. In other words, for a given radiation exposure, it is desirable to know the probability that an adverse health effect, such as a mutation or cancer, might result. The magnitude of the risk is assumed to depend principally on two factors: (1) the distribution of the radiation dose among the tissues of the body and (2) the dose-risk relationships for the irradiated tissues. In its most recent recommendations, the ICRP introduced a new dosimetric quantity, the effective dose equivalent, that considers both factors. The effective dose equivalent (H_E) is the weighted sum of the dose equivalent in the organs of the body at risk; the weights represent the fractional contribution of the organs to the total risk when the body is uniformly irradiated.

The annual effective dose equivalent to an individual from all radiation sources in the United States is about 3.6 mSv (360 mrem). Natural radiation sources are estimated to contribute about 3 mSv (300 mrem) to the annual effective dose equivalent. In other words, about 83% of the radiation received by an average individual comes from natural sources.

Natural background sources are chiefly the naturally



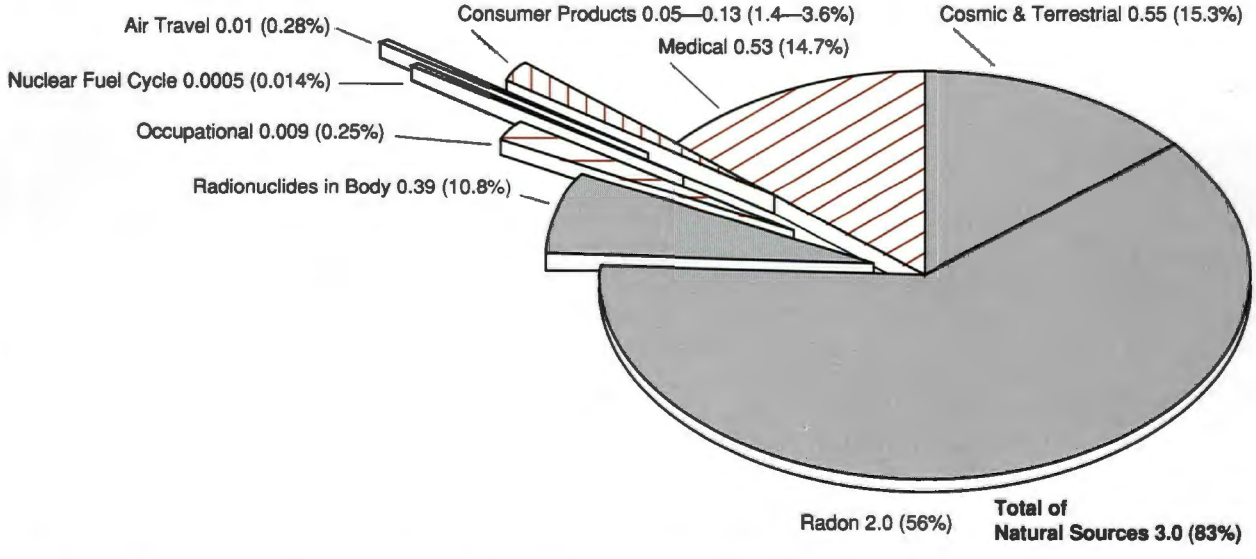
Organ/Tissue	W_T
Gonads	0.25
Breast	0.15
R. Marrow	0.12
Lung	0.12
Thyroid	0.03
B. Surface	0.03
Remainder	0.30

$$H_E = \sum W_T H_T$$

The effective dose equivalent is used as a health risk–based measure of nonuniform radiation exposures. The magnitude of the weighting factors, W_T, depends on the health risk associated with irradiation of the particular organ. These numerical values might be modified by the continued medical follow-up in the epidemiological studies recently reviewed by the BEIR V Committee.

occurring radionuclides associated with the formation of the Earth itself (primordial), those produced by interactions of cosmic rays with Earth's atmosphere (cosmogenic), and the cosmic rays bombarding Earth. The three primordial radionuclides of importance are uranium-235, uranium-238, and thorium-232. The primordial radionuclides are principally the isotopes of three series of radioactive isotopes—those initiating from uranium-238, thorium-232, and uranium-235. Two other primordial radionuclides of biological importance are potassium-40 and rubidium-87. Although small contributors to radiation doses, three of the cosmogenic nuclides—tritium, carbon-14, and sodium-22—are of interest because they are radioisotopes of elements that are the basic units of living matter. The major natural source of radioactivity is radon, which comes from soil and rocks. Inhalation of radon, a member of the uranium-238 series, contributes 2 mSv (200 mrem) to the annual effective dose equivalent. In other words, 56% of the radiation received by an average individual comes from breathing radon.

Radiation used for medical diagnosis and treatment is the principal human source of radiation exposure. Medical exposure contributes 0.53 mSv, or 53 mrem to the annual effective dose equivalent (15% of the radiation received by the average individual). Other human sources of radiation—consumer products, air travel, occupational activities, and nuclear power plant operations—contribute less than 0.1 mSv (10 mrem, or 3% of the radiation received by the average individual) to the annual effective dose equivalent in the United States.



The annual effective dose equivalent in the United States is about 3.6 mSv, or 360 mrem. Natural sources (83%), shaded area, and medical exposures (15%) are the major contributors to the dose. Note that radon is considered to be responsible for over half the total dose.

RE: Awards & Appointments

Murray Rosenthal

Bob Van Hook

Louise Dunlap

Jim Ball

Murray Rosenthal has been elected to the National Academy of Engineering.

Alvin W. Trivelpiece has been appointed chairman of the Mathematical Sciences Education Board by the National Academy of Sciences.

Fred Mynatt, formerly ORNL's first associate director for Environmental, Health, and Chemical Protection, has been named Energy Systems vice president for Compliance, Evaluations, and Policy.

Thomas H. Row has been appointed to the new position of director of Environmental, Safety, and Health Compliance.

David E. Reichle has been named associate director for Biomedical and Environmental Sciences, replacing **Chester R. Richmond,** who served in this capacity for 15 years. Richmond has been appointed ORNL Director of Science Education Programs and External Relations. **Robert I. Van Hook** has been named director of the Environmental Sciences Division, replacing Reichle.

Michael P. Farrell and **Steve Rayner** have been named acting director and deputy director, respectively, of the ORNL Center for Global Environmental Studies.

Sterling A. (Sam) Meacham has been named director of ORNL's Fuel Recycle Division, replacing **William Burch,** who is heading ORNL's effort to help DOE develop plans for its new initiative on actinide burning.

Robert B. Shelton has been appointed director and **Michael A. Kuliasha** is associate director of ORNL's Energy Division.

Louise B. Dunlap has been named director of the Office of Guest and User Interactions at ORNL.

Frank C. Kornegay has been named environmental coordinator for ORNL.

Sheldon Datz has been awarded the Tage Erlander National Science Professorship, created by the Swedish Parliament to honor the former Swedish Prime Minister. He will conduct research in Sweden for a year, starting in September 1990.

James B. Roberto has been elected first vice president and president-elect of the Materials Research Society.

James B. Ball has been elected vice chairman of the Division of Nuclear Physics of the American Physical Society.

Robert N. Compton has been elected to the Panel of Public Affairs of the American Physical Society.

Charles T. Garten has received the Scientific Achievement Award from the Environmental Sciences Division "for his outstanding research on the application of isotopic methods to understanding mechanisms and pathways of element cycling in forest systems."

Michael A. Huston has been elected a member of the American Society of Naturalists.

Larry W. Barnthouse has been appointed to the Board on Environmental Studies and Toxicology, Commission on Life Sciences, of the National Research Council.

Barbara T. Walton has been elected to the board of directors of the American Board of Toxicology.

Steve Lindberg has been appointed to the Panel of International Experts (to review mercury in the Swedish environment), Advisory Panel for the Air/Deposition Group of the Environmental Monitoring and Assessment Program of the U.S. Environmental Protection Agency, the Steering Committee for the Fifth International Conference on Atmosphere-Surface Exchange Processes, and the Program Committee of the International Conference on Metals in Soils, Waters, Plants, and Animals.

Warren C. Oliver was the co-recipient of the American Ceramic Society's 1989 Ross Coffin Purdy Award for his outstanding contribution to the ceramic research literature in 1987. The award reflects his co-invention of a mechanical properties microprobe used to characterize interfaces in ceramic composites.

Milton Russell, UT/ORNL Collaborating Scientist in the Energy Division, was appointed chairman of the Oversight Review Board of the National Acid Precipitation Assessment Program.

Walderico M. Generoso has been appointed to the Committee on Toxicology of

Chuck Garten

Steve Lindberg

Barbara Ashdown

Michelle Buchanan

the National Academy of Sciences/National Research Council.

David E. Reichle has been elected to the plenary advisory Council of Affiliate Societies of the American Institute of Biological Sciences.

Stanley I. Auerbach has been appointed a member of the Environmental Advisory Board of the U.S. Army Corps of Engineers.

Curtis C. Travis has been named a member of the editorial advisory board of the international journal, *Toxicology and Environmental Chemistry*. He also has been appointed to a Technical Advisory Committee to the New York City Sludge Management Plan.

Barbara Ashdown has been named director of the Information Services Division, replacing **Nancy Norton,** who has been appointed coordinator for the Personnel Management Improvement Committee.

Tommy Wright has been elected a member of the International Statistical Institute.

Michelle Buchanan has been named associate editor of the international journal *Biomedical & Environmental Mass Spectroscopy*.

Elizabeth L. Dagley has been elected regional director of Region 11 of the American Society for Quality Control.

C. Stephen Sims has been named associate editor of the journal *Health Physics*.

George D. Kerr has been named to a DOE technical committee to review the new National Academy of Sciences BEIR V Report, "Health Effects of Exposure to Low Levels of Ionizing Radiation."

Steven R. McNeany has been named manager of the Capital Assets Planning Group in ORNL's Office of Planning and Management.

Cliff H. Brown, Jr., has been named head of the Engineering Development Section of ORNL's Chemical Technology Division.

Archibald C. Buchanan, Philip F. Britt, and **Cheryl Biggs** have received the American Chemical Society's R. A. Glenn Award for "best paper." Their paper describes the design of a model to understand the thermal reactivity of coal.

H. Richard Hicks and **Mona Heath** have joined the new Office of Laboratory Computing at ORNL.

Steven Bartell has been appointed to the editorial advisory board for *The Handbook of Environmental Chemistry* and to the participating board of editors for the ecotoxicology section of the technical journal *Chemosphere*.

Webb Van Winkle has been elected a Fellow of the American Institute of Fishery Research Biologists.

Robert D. Hatcher has been named to the Earth Sciences Advisory Committee for the Savannah River Plant.

Karen L. Von Damm has been appointed by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) Planning Committee to the East Pacific Rise Detailed Planning Group.

Sixteen ORNL employees recently received monetary awards because they have contributed important technical support to an invention licensed to industry or they are named on a patent for an invention in the category of "unlicensable or government-use." Some of the $19,000 in royalty income distributed to 30 Energy Systems employees went to these ORNL employees in the form of Technical Support Awards: **Ronald L. Beatty, Vinod Sikka, Claudia A. Walls, Richard A. Strehlow, Albert C. Young, H. Stanley Roach, Norman Lee, Michael A. Kuliasha,** and **Phillip D. Fairchild**.

ORNL employees recently receiving monetary awards for unlicensable and government-use inventions were **H. Wayland Blake,** for the ring compression fixture; **Stephen W. Allison** and **Robert G. Rudness,** for a laser paint stripper; **Jeffrey D. Muhs,** for a weight/velocity sensor; **Stephen W. Allison, Michael R. Cates,** and **Mark L. Simpson,** for a cancer probe; and **Harold Kimrey** (with Cressie Holcombe and Andrew Gorin of the Oak Ridge Y-12 Plant), for a silicon nitride material.

Steve Pennycook has received DOE's 1989 Materials Science Award for Outstanding Scientific Accomplishments in Solid-State Physics. ornl

Martin Marietta, DOE, State Pledge $3 Million for Science and Math Initiatives

"Improving science and mathematics education as a cornerstone to this country's future."

Secretary of Energy James Watkins (second from left) visited the control room of ORNL's High Flux Isotope Reactor (HFIR) on November 3, 1989, after he announced his educational initiatives. With him are, from left, Sam Hurt, HFIR plant manager; Howard Baker, former U.S. senator from Tennessee; Leo Duffy, special assistant for coordination of DOE Defense Waste Management; and Jackson Richard, ORNL director of Reactor Operations.

During his February 2, 1990, visit to the University of Tennessee at Knoxville (UTK), President Bush renewed his strong commitment to improved science and mathematics education as a conerstone to this country's future. The President met with area researchers, including UT/ORNL Distinguished Scientist David White, Science Alliance Coordinator Lee Reidinger, and outstanding high school students, to learn firsthand about initiatives in both frontier areas of research (biotechnology and nuclear physics) and in science education. Accompanying the President to Knoxville were Energy Secretary James Watkins, Education Secretary Lauro Cavazos, and four members of the Tennessee Congressional delegation.

Tennessee Governor Ned McWherter and Martin Marietta Corporation Chairman Norman Augustine joined Lamar Alexander, UT President and former Tennessee governor, in announcing plans for a new $3 million initiative, the Summer School of the South for Science and Mathematics for precollege students, and an Academy for Teachers of Science and Mathematics, an advanced training ground for 200 of the region's most outstanding teachers. Alexander said the Summer School would join the resources of UT and its "sister campus," ORNL, in a partnership that could serve as a model for the nation. Teachers participating in the 4-week summer institute would be distinguished Martin Marietta Fellows.

Pledging $1 million each were the Department of Energy, Martin Marietta Corporation, and the state of Tennessee. The initiative will significantly expand existing Science Alliance and Governor's School Programs.

On November 3, 1989, during his first visit to ORNL as DOE Secretary, Admiral James Watkins announced three major educational initiatives in partnership with UT. The purpose of the initiatives is to help the nation address a crisis in mathematics and science education, which has resulted in a shortage of Americans trained for available and anticipated scientific and technological positions in the United States.

Addressing ORNL employees, superintendents of schools from three local counties, principals from seven school districts, and a host of dignitaries (including UT President Lamar Alexander, U.S. Rep. Marilyn Lloyd, Martin Marietta President Caleb Hurtt, and former White House Chief of Staff and U.S. Senator, Howard Baker), Watkins called for

- the creation of an adjunct teaching core through alternative certification of two groups—retirees and scientists and engineers desiring to change careers, who can bring their experience to the classroom;
- a 5-year B.S./M.S. program that would offer summer experiences at ORNL and other DOE laboratories to college students interested in teaching math and science; and
- the adoption of two schools in the region by ORNL, through its director, Alvin Trivelpiece, to allow their teachers and students to work with ORNL researchers to get "something special in math and science."

Under a new program called SMART (Science/Math Action for Revitalized Teachers), carried out jointly with Oak Ridge Associated Universities, ORNL already is working with teams of teachers (K–12) from Roane County and Chattanooga city schools. In addition, the program is preparing to expand its Partnerships at the Laboratory in Science (PALS) "adopt a school" initiative (begun in 1988 with Oak Ridge Schools) in which current and retired ORNL scientists volunteer to be resource persons for schools or individual teachers.

Science Education Center Planned

A new position—ORNL Director of Science Education Programs and External Relations—has been created at ORNL, and one of its missions is to develop a Science Education Center to promote interest in science, engineering, and mathematics among precollege students. Chester Richmond, former ORNL associate director for Biomedical and Environmental Sciences, has been appointed to this new role. His responsibilities include providing managerial oversight for the ORNL Office of University and Educational Programs and for ORNL's liaison with Oak Ridge Associated Universities, the Southeastern Universities Research Association, the University of Tennessee, the Tennessee Valley Authority, and the Tennessee Department of Education.

Richmond and his staff are responsible for developing science education programs through which ORNL can help community school systems in Tennessee and for expanding working agreements with research and development institutions in the United States and abroad.

ORNL's Science Education Center incorporates learning experiences at all levels—from early elementary through graduate and postdoctoral study. The aim of the program is to provide opportunities for science students and teachers to acquire firsthand experience with and understanding of the scientific process and natural phenomena. The "hands on" approach not only develops skills in observation, obtaining measurements, and performing analysis but also builds an appreciation of science as both a discipline and an adventure.

This expanded program, managed through the Laboratory's Office of University and Eductional

"The aim of the program is to provide opportunities for science students and teachers to acquire firsthand experience with and understanding of the scientific process and natural phenomena."

Programs, includes the precollege Ecological and Physical Sciences Study Center, summer teacher appointments, honors workshops and individual study for secondary students, undergraduate "science semesters," and summer research opportunities, as well as the more traditional opportunities for research participation for graduate and postgraduate students.

Designation as a Science Education Center reflects DOE's directive that ORNL and the other national laboratories consider education a primary mission.

"Our real challenge is to make a compelling case for fundamental changes in the way we learn, teach, create, and use mathematics."

New Postdoctoral Fellowship for Advanced Computer Training

ORNL has created a new postdoctoral fellowship to advance the training of new computer scientists. The first Alston S. Householder Fellowship in Scientific Computing has been established by the Mathematical Sciences Section of the Engineering Physics and Mathematics Division.

The fellowship recognizes the contributions of Alston S. Householder, organizer and founding director of ORNL's former Mathematics Division, for contributions to numerical analysis and scientific computing. The 1-year fellowship's purposes are "to promote innovative research in scientific computing on advanced computer architectures and to facilitate technology transfer from the laboratory research environment to industry and academia through advanced training of new computational scientists."

The ORNL fellowship has been awarded to Elizabeth R. Jessup, an assistant professor of computer science at the University of Colorado in Boulder. She received her doctorate degree in computer science in 1989 from Yale University. She will be collaborating with researchers at ORNL on solving scientific problems using parallel computing.

Alvin Trivelpiece Appointed to NAS Math Science Board

ORNL Director Alvin W. Trivelpiece, selected for his "distinguished scientific performance and proven leadership ability at the national level," has been appointed to a 3-year term as chairman of the Mathematical Sciences Education Board by the National Academy of Sciences in Washington, D.C.

The 34-member board, which oversees the quality of mathematics education in the United States, will help lay the groundwork for a new mathematics curriculum for U.S. education in the 21st century. Board members will agree on professional teaching standards and develop a national strategy to ensure that minorities are adequately represented in the field of mathematics.

"Our real challenge is to make a compelling case for fundamental changes in the way we learn, teach, create, and use mathematics," says Trivelpiece, "but our efforts will be successful only if parents, business, industry, and government are active participants in developing educational policies.

"U.S. schools are not meeting employers' needs for graduates skilled in quantitative thinking and problem solving. This failure leaves the United States at a disadvantage in the world marketplace."

High-Performance Parallel Computer Being Tested at ORNL

The first manufactured version of one of the world's most powerful computers—the Intel Touchstone Gamma Prototype parallel computer, or Intel RX—is being tested at ORNL. This high-performance machine was delivered in January 1990, to ORNL's Engineering Physics and Mathematics Division.

The Intel RX computer will be used to solve complex mathematical problems to better meet the needs of scientific research groups at ORNL, the University of Tennessee at Knoxville, and Vanderbilt University. The three institutions jointly procured the computer.

Mike Heath tries out the new Intel RX parallel computer as fellow computer scientist Tom Dunigan looks on.

"The Intel RX computer will be used to solve complex mathematical problems to better meet the needs of scientific research groups."

It will be employed to meet the massive computational requirements of tough scientific research problems related to global warming, the structure of high-temperature superconductors, understanding the early universe, the modeling of fusion and environmental processes (such as underground contaminant transport), image analyses, and human genome sequencing.

The new computer has 128 processors, which could be operated simultaneously to solve all the "pieces" of a large, complicated problem more efficiently than can be done by other computers. By comparison, the other parallel computers in the division's Mathematical Sciences Section have a maximum of 64 processors, or nodes. The new computer also has much greater computational speed and more memory to store the information needed to solve large-scale, complex problems.

According to Bob Ward, head of the Mathematical Sciences Section, "The Intel RX parallel computer, which has a peak computational speed of 5 gigaflops when all 128 processors are operating simultaneously, compares well with today's fastest traditional supercomputer, the 8-processor Cray Y-MP, which has a peak speed of 2.7 gigaflops, and with the fastest parallel computer, Thinking Machines Corporation's CM-2, which has a peak speed of 5 gigaflops. The Intel RX is more flexible than the CM-2 because its processors operate independently, each with its own set of instructions and data."

A gigaflop is a billion floating-point operations per second. A floating-point operation is a mathematical operation, such as addition or multiplication, on a high-precision number expressed in scientific notation.

Each of the Intel RX's 128 processors has 8 million bytes of memory, and the total amount of memory for the parallel computer is 1 billion

bytes (a byte is a set of eight bits, or basic pieces of information). The Cray Y-MP has only a quarter as much memory, and the CM-2 has only half as much.

In addition, the 128 processors are connected by hardware that effectively emulates a fully connected system to permit extremely efficient routing of messages, a feature that should help scientists solve problems more efficiently.

ORNL was the first facility selected by the Intel Corporation as a test site for the new $3-million computer because of the special expertise of the Mathematical Sciences Section in using parallel computers to improve problem-solving efficiency. (A parallel computer is 100% efficient in solving a problem if, for example, 8 processors can solve the problem in 1/8 the time required by one processor. However, if 8 processors reduce the time by only a factor of 6, then its efficiency in solving that problem is 75%.)

"ORNL is expected to play a significant role as a base location for the design and construction of the Lone Star detector."

Detector Center for SSC Set Up at ORNL

Large components of an instrument that can detect quarks and other basic constituents of matter may be designed and partly constructed at ORNL in support of a $5.9-billion high-energy physics project. This detector, which will be eight stories high and weigh 50,000 tons if its development is funded, may be part of the national Superconducting Super Collider (SSC) to be built by 1998 in Waxahatchie, Texas.

The local work will be coordinated through ORNL's recently established Oak Ridge Detector Center. The SSC project offers ORNL the opportunity to become involved in high-energy physics research as well as to expand its capabilities in the engineering and construction of large-scale systems.

"The purpose of the center," says Bill Appleton, ORNL's associate director for Physical Sciences and Advanced Materials, "is to provide an organization to interact with outside collaborators in detector research and development. Our organization, in particular, will support the efforts of DOE, a number of universities, private industry, and other laboratories to design and build detector systems for the SSC."

The director of the Detector Center is Tony Gabriel of the Engineering Physics and Mathematics Division and the deputy director is Hugh Brashear of the Instrumentation and Controls Division. These two men, along with Frank Plasil of the Physics Division, form a task force to advise Appleton on ORNL involvement in high-energy physics. Design support for detector development will be provided by Mark Rennich of the Engineering Organization of Energy Systems.

A number of southern universities have formed the Southern Association for High Energy Physics (SAHEP) with the intent of becoming involved in the design and construction of one or more major detector systems for the SSC. Professor J. Reidy of the University of Mississippi is chairman of SAHEP.

On January 26 through 28 and April 26 through 28, 1990, representatives from the Oak Ridge Detector Center and from many universities and laboratories all over the world met in Oak Ridge for a series of workshops to discuss the design of the SSC's Lone Star detector. The proposal effort for the Lone Star detector is led by Samuel Ting, a professor at the Massachusetts Institute of Technology, recipient of the Nobel Prize in Physics in 1976, and detector designer.

"ORNL is expected to play a significant role as a base location for the design and construction of the Lone Star detector," Appleton says. "In addition, ORNL will be involved in innovative R&D on new detector concepts for high-energy physics and other areas important to ORNL programs. We will also work jointly with UTK to enhance our high-energy physics programs in order to participate in research on the SSC once it is completed."

The Oak Ridge Detector Center will also provide a focus for research related to the development of SSC detectors by participants from several ORNL and Energy Systems divisions. These include the Engineering Physics

and Mathematics, Fusion Energy, Instrumentation and Controls, Health and Safety Research, and Physics divisions and the Engineering Organization.

The SSC will accelerate protons to an energy of 20 trillion electron volts in both directions around a 53-mile ring. Studies of the proton collisions should reveal if quarks—constituents of protons and other hadrons believed to be the most basic particles of matter—are indeed indivisible or made up of smaller particles. SSC experiments should also determine whether the "top" quark—the only one of six hypothesized quarks that has not been detected experimentally—really exists.

The SSC accelerator will be technically advanced because it will require improvements in colliders, active optics, superconducting magnets, cryostats to hold the magnets, and the current-carrying capacity of superconducting cable. These advances could have technology transfer possibilities in magnet construction, electronic controls, and radiation damage studies, and in software and materials development.

In addition to the proton-proton collider and two rings of 6.6-tesla dipole magnets, the SSC will have several gigantic detectors to detect the basic constituents of matter (e.g., the Higgs boson, if it exists). Each detector will include a calorimeter, which detects signals proportional to the energy deposited in a large bulk of matter by showers of particles emerging from proton-proton collisions.

The expertise and experience of ORNL scientists in calorimeter development should be invaluable in SSC detector development. In the late 1980s, ORNL physicists led by Plasil designed and built two major portions of calorimeters for the WA-80 "quark-gluon plasma" experiment at the CERN accelerator in Geneva, Switzerland. This plasma of free quarks and gluons, which theoretically was created in the Big Bang, is believed to have condensed into the particles that form atoms, such as protons and neutrons.

ORNL experts in radiation damage also can guide the detector design to minimize damage from neutrons produced from nuclear collisions in detector components, especially the calorimeter.

ORNL Leads in Meeting Nuclear Data Needs

Research results at ORNL's Oak Ridge Electron Linear Accelerator (ORELA) have contributed to the bulk of new nuclear data used in the updated Evaluated Nuclear Data File, called ENDF/B-VI.

Originally obtained and evaluated for reactor design, nuclear data have many other uses today. These include designing detectors for airport security, formulating cancer treatment, developing medical diagnostic techniques, advancing radiation damage and acid rain research, and improving weapons production.

Nuclear data are also essential in designing fusion reactors. For example, ENDF/B-VI provides information about neutron activation of candidate structural materials for fusion devices.

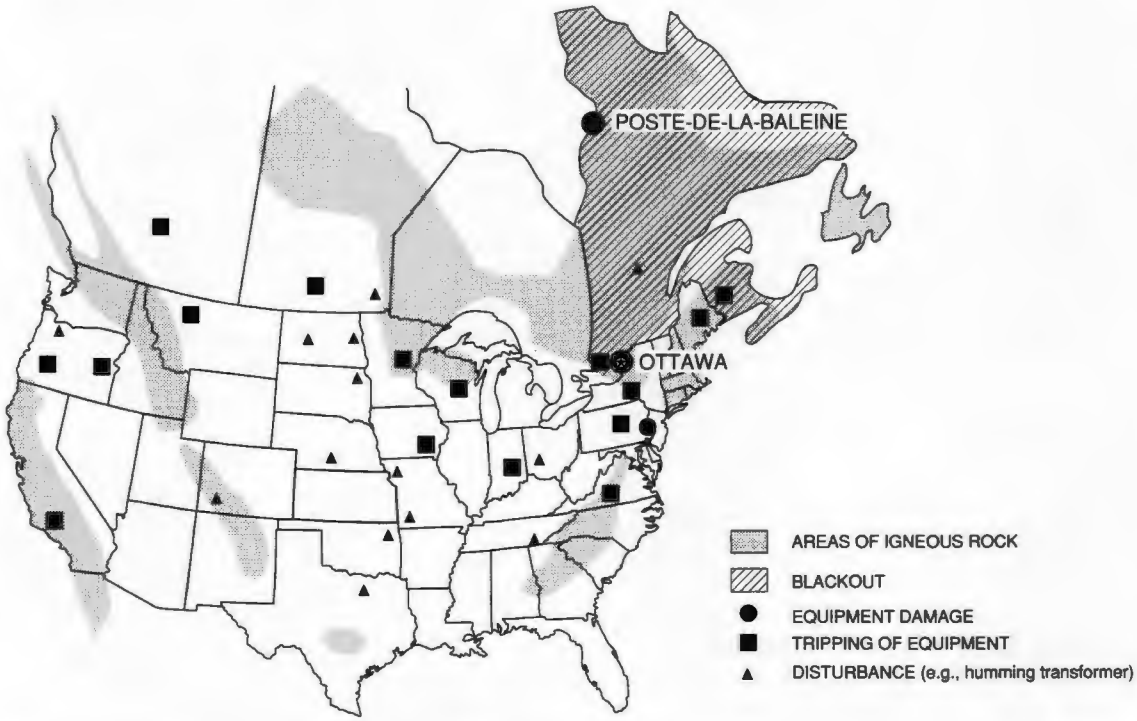
At a recent International Atomic Energy Agency conference, representatives from Europe, Japan, the Soviet Union, and the United States (including ORNL) compared their individual nuclear data libraries for possible use in the design of the new international fusion device, the International Thermonuclear Experimental Reactor. After extensive study of the competing nuclear data evaluations, the conferees decided to use only a few results from each of the non-American representatives but to use 35 U.S. results. Of these, 20 were provided by ORELA, which is operated by ORNL's Engineering Physics and Mathematics Division.

ORNL Studies Effects of Solar Storms on Power Systems

In March 1989, the entire Hydro Quebec Power System in eastern Canada experienced a blackout. About the same time, large power transformers were damaged in Pennsylvania and New Jersey, and protective devices were activated as far south as the border between Virginia and North Carolina. The cause of these widespread phenomena was a "solar storm."

A solar storm, or solar flare, is a giant explosion on the sun's surface. The frequency and intensity of solar storms is related to the sunspot cycle.

"The expertise and experience of ORNL scientists in calorimeter development should be invaluable in SSC detector development."



Power blackouts triggered by solar storms are more likely in areas of igneous rock because the relatively high resistance of the Earth in these regions causes large geomagnetically induced currents to flow in high-voltage transmission lines. On March 13, 1989, a major blackout occurred in the Canadian province of Quebec. Other effects of solar storms observed in the United States in 1989 include equipment damage, trips of equipment and power lines, and disturbances such as humming transformers. Because of its geology and the use of long, heavily loaded lines to import power, the Northeast is considered potentially vulnerable to blackouts during intense solar activity.

Sunspots are dark areas on the sun's surface that vary in number and size over the 11-year solar sunspot cycle. In the current cycle, the number of sunspots is expected to reach a maximum in 1991, and magnetic storms on Earth resulting from intensive solar activity are expected to peak around 1992.

Solar storms increase the intensity of the solar cosmic rays bombarding Earth; as a result, the interaction between solar radiation and Earth's magnetic field is stronger. This interaction, one manifestation of which can be seen as a brighter and more widely spread display of the northern lights, can disrupt electric power systems, navigation, and communication systems, such as radio, telephone, and television.

ORNL researchers Randy Barnes and Ben McConnell are studying the effects of solar storms and other solar activity on electric power systems in the United States. Their research is being jointly sponsored by the Department of Energy and the Defense Nuclear Agency. Parallel efforts will be conducted at the Electric Power Research Institute and key utilities. The ABB Corporation (Westinghouse Electric) will be involved in the analysis of the dynamic response of power systems to these phenomena.

In recent years, the ORNL researchers have studied the effects on power systems of the electromagnetic pulse (EMP), which results from the explosion of a nuclear bomb above Earth's atmosphere. Interestingly, the increased radiation from solar storms interacts with Earth's magnetic field in a manner similar to a nuclear-induced EMP. ornl

ORNL Concept Would Greatly Increase Optical Data Storage

Every word in every book in these shelves could fit on one 12-in. optical storage disk, similar to the one held by Tuan Vo-Dinh, and enough space would remain for the rest of the library, too. Surface-enhanced Raman optical data storage (SERODS), a new technology developed by Vo-Dinh, when developed to its full potential, could produce a compact disk having a data storage capacity of 1000 billion bytes. Such a disk would hold more than a million 300-page novels.

ORNL researchers have developed a technique, surface-enhanced Raman optical data storage (SERODS), which uses the light-emitting properties of molecules to pack considerably more information in compact disks. This new technology, for which a patent application has been filed, has the potential to store 10 days of music—instead of just 90 minutes—on a single disk.

A 12-in. disk using SERODS could hold more than 100-1000 times more information than a conventional 12-in. compact disk and 1.5 million times more data than a 5-1/4 in. floppy disk for a personal computer. For example, it could store 18,000 sets of the *Encylopaedia Britannica* (450 million pages of text), the name of every taxpayer listed with the Internal Revenue Service, all the records on a U.S. Navy ship, or all the information on a NASA satellite used in future global environmental monitoring projects.

The ORNL technology, developed by Tuan Vo-Dinh, a group leader in the Health and Safety Research Division, offers the potential of virtually unlimited data storage and improved protection of secret, sensitive, and private information. Vo-Dinh realized that Raman scattering (discovered by Indian physicist C. V. Raman in the 1920s) held potential for an innovative optical data storage technology when he worked on new soil analysis systems for environmental monitoring and health protection applications.

Today's compact disks using Compact Disk–Read Only Memory (CD-ROM) technology store data in the form of bits—ones and zeros—in microscopic pits burned by lasers on reflective aluminum disk surfaces and in the surface areas between the pits. A photodiode reads each bit on the disk by distinguishing between the laser light scattered by the contrasting surface areas.

A CD-ROM disk has a capacity of up to 600 million bytes (megabytes) and offers the equivalent in storage capacity of 270,000 typewritten pages of text, 28 20-megabyte hard disks, and 1500 double-sided, double-density 5-1/4-inch floppy disks. The latter two media are examples of magnetic storage in which the binary

"The ORNL technology offers the potential of virtually unlimited data storage and improved protection of secret, sensitive, and private information."

(bit) information is based on the direction of a magnetic field. A 12-in. compact disk using the ORNL technology could have a capacity of one trillion bytes, or 1 terabyte.

The SERODS technology is based on the principle that the enhanced light-emitting properties of certain molecules embedded in an optical medium can be altered at the molecular level to store information. When they are close to a rough metal surface, certain molecules emit a strongly enhanced light, called Raman light, which is characteristic of their vibrations (all molecules vibrate, and each type vibrates at characteristic frequencies related to its structure). This enhanced emission is due to the surface-enhanced Raman scattering (SERS) effect.

The SERODS technology requires two lasers, a signal detector, and a compact disk master, or some other optical storage medium such as a three-dimensional optical block. A compact disk master could be a polymer or glass plate coated with silver-covered microparticles, the substrate. A laser is used to "write on" the optical disk—encode bit information—by altering the light-emitting properties of specific clusters of molecules on the disk while leaving other microregions intact. The "read" laser then excites all the molecules in the optical layer, inducing specific microregions of the disk to produce altered SERS light signals and unaltered signals that correspond with "one" bits and "zero" bits, respectively. The signal detector "sees" the encoded information.

With current SERODS technology, each information bit can be carried by about 1000 molecules—about 100 times greater storage capacity than current compact disk technology. Theoretically, the SERODS storage technology could be improved so that several hundred molecules would represent individual bits—about 1000 times more storage capacity than current compact disks.

To greatly increase data storage capacity, molecules could be embedded in multiple optical layers or in a three-dimensional block transparent to laser light. Thus, three-dimensional blocks could replace two-dimensional disk surfaces as storage media.

Top-secret, sensitive, or private information could be protected because information can be accessed only if the frequency of the vibrating molecules used for the optical layer is known. The detector can read the disk only if it is tuned to the exact frequencies of the Raman emission.

So far 90 companies and government agencies have expressed interest in the new technology. According to Guven Yalcintas of the Office of Technology Applications, Energy Systems is trying to find three companies—each specializing in substrates, engineering, or software development—that are willing to locate in Oak Ridge to collaborate on the development of SERODS. The long-term development work is projected to cost $5 million.

ORNL Clones Human Repair Gene Segments

ORNL researchers have cloned essential segments of a human gene responsible for the repair of a critical type of damage to DNA, the so-called blueprint for life. The work could lead to a more effective use of certain drugs to treat cancer patients as well as a better understanding of why certain tumors arise more frequently in some tissues than others following exposure to environmental carcinogens.

The gene provides instructions for the manufacture of a human repair protein, which removes harmful O^6-alkylguanine from DNA. This lesion, produced in DNA by many environmental mutagens (e.g., ethylene oxide, an industrial chemical, and nitrosamines, which are generated from food), leads to mutation and possibly cancer if not removed promptly. Interestingly, certain anticancer drugs destroy tumor cells by inducing similar damage.

The ORNL group is the first to (1) clone a repair gene whose role in mutation and tumor induction is well understood and (2) use the mass-produced gene segments to produce large amounts of the repair protein, which can be used for making antibodies to evaluate anticancer drugs.

Many tumors are resistant to chemotherapy with alkylating drugs because of the presence of this repair protein. However, for some tumors having a

very low level of repair protein, this type of chemotherapy can be effective.

Antibodies can be used to screen tumor tissue for the presence of repair protein. The information can help physicians determine whether certain anticancer drugs would be effective or should be avoided, so that a patient is not exposed unnecessarily to toxic drugs.

A report on this breakthrough was published in the January 1990 (Vol. 87, pp. 686–690) issue of the *Proceedings of the National Academy of Sciences*. The authors of the article are members of the Nucleic Acid–Protein Transaction Group in ORNL's Biology Division, led by Sankar Mitra.

Keizo Tano, Japanese postdoctoral fellow in ORNL's Biology Division, recently cloned essential parts of an important human repair gene. The gene provides instructions for the manufacture of a protein that repairs damage inflicted on DNA by toxic chemicals. Tano and his ORNL colleagues, led by Sankar Mitra, have shown that the gene can make enough protein to produce antibodies. These could be used to determine whether certain anticancer drugs, which are themselves toxic, would be effective on individual patients.

"ORNL researchers have cloned essential segments of a human gene responsible for the repair of a critical type of damage to DNA."

In April 1989, Keizo Tano in Mitra's group first cloned human gene segments (cDNA) that code for the repair protein, which is called O^6-methylguanine-DNA methyltransferase. This protein repairs DNA by removing O^6-alkylguanine. It is unusual in that the repairing reaction inactivates it.

In the 1970s researchers found that rats exposed to nitrosamines had a high incidence of tumors in their brains, an intermediate incidence in their kidneys, and a low incidence in their livers. Later studies showed that rat livers had a high level of the methyltransferase, kidneys had an intermediate level of repair protein, and brains had a low level. These findings suggested that repair genes in the rat brain are relatively inactive and that those in the liver are more active.

"If we understood how to turn on repair genes in the brains of these experimental rats," says Mitra, "we might be able to lower the tumor induction rate in the brains of rats exposed to carcinogens. Improved understanding could also lead to better human cancer therapies."

The cloning of the repair gene was elusive for several years in spite of efforts by a number of laboratories.

After failing with the commonly used techniques, Tano, along with Susumu Shiota, Julia Collier, and Robert S. Foote in Mitra's group, succeeded in cloning the gene segments by allowing the human repair protein to be produced in *Esterichia coli*, bacteria commonly found in the human digestive tract. However, the strain of bacteria selected for the cloning research was deficient in its own methyltransferase.

The researchers then exposed some 10 million bacterial cells, carrying different cDNAs derived from human messenger RNA, to an anticancer drug. Most cells died except for a few able to produce enough human repair protein to reverse drug-induced damage. From these surviving cells, using standard DNA recombinant techniques, Mitra's group then isolated the pieces of recombinant DNA responsible for producing the repair protein.

Mitra thinks the ORNL technique would be especially useful for cloning many of the 10 or 12 human repair genes whose functions are known. A few hundred DNA repair genes may be present in humans and other mammals. Only three other human repair genes have been cloned until now, but the function is known for only one of them.

"The new centrifuge pellet injector developed and built at ORNL provides fuel to the Tore Supra tokamak."

ORNL Developments Support French Fusion Device

Two devices developed by ORNL are incorporated into a French project directed toward developing fusion energy as a power source for the future. ORNL is also managing an experimental program for the project.

An ORNL pellet injector has been fueling the Tore Supra tokamak—a new doughnut-shaped superconducting magnetic fusion device in Cadarache, France—since January 25, 1990. A radiofrequency (rf) antenna built at ORNL will use high-power radio waves to help heat the atomic particles confined in the French tokamak.

In exchange, ORNL researchers in the Fusion Energy Division will carry out experiments on the French machine in accordance with an agreement between DOE and the French Commissariat l'Energie Atomique (CEA).

The Tore Supra is one of several large tokamaks built to show that superhot plasmas—ionized hydrogen gases heated to millions of degrees—confined by magnetic fields could give rise to heat-producing fusion reactions. The goal is to design fusion machines that can be an economic source of electricity.

The Tore Supra differs from other tokamaks in that it is designed to create and sustain hot plasmas for longer times (e.g., 30-s pulses). To achieve this mission, several key technologies—including superconducting magnets to confine the plasma and ORNL-developed steady-state fueling and plasma heating techniques—are required.

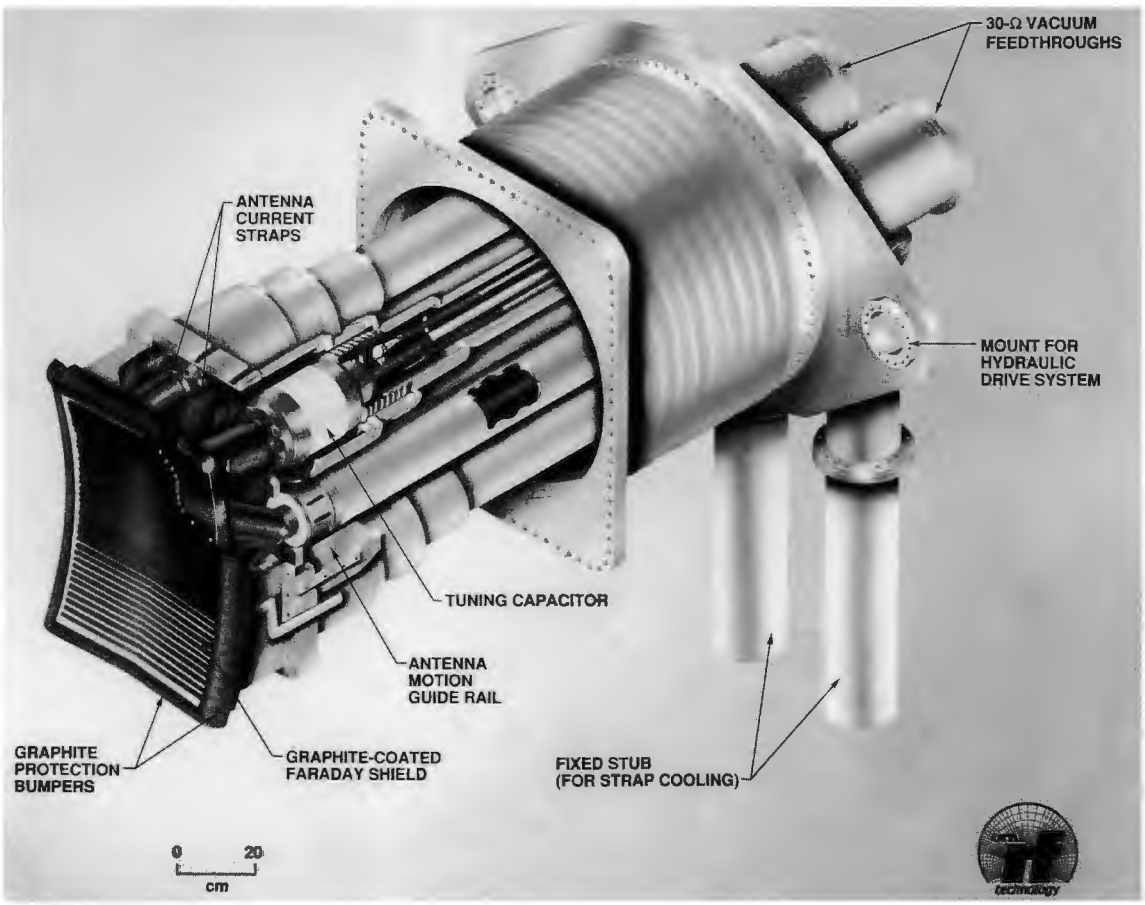
The new centrifuge pellet injector developed and built at ORNL provides fuel to the Tore Supra tokamak by propelling frozen pellets of heavy hydrogen (deuterium) into the core of the plasma, which consists of electrons and positively charged ions (hydrogen nuclei). The hydrogen ions, which normally repel each other, release large amounts of energy when high temperatures and magnetic fields force enough of them to collide and combine, or fuse.

The new ORNL injector was installed in September and tested in October 1989. It injects up to 100 pellets per second at a rate of 600 to 900 m/s into the Tore Supra plasma.

This is the second ORNL injector to be installed on a foreign fusion machine. In 1988, a pneumatic pellet injector that "shoots" pellets into the plasma was installed on the Joint European Torus (JET) in England. It has been a key factor in the achievement of record plasma parameters on JET.

The centrifuge injector on the Tore Supra is based on a concept developed by Chris Foster of the Fusion Energy Division. Like a rotary lawn sprinkler, the whirling injector uses centrifugal forces to accelerate the frozen pellets before they are injected into the plasma.

A second ORNL development for the Tore Supra is an rf antenna that transmits energy to the ions of the fusion plasma at frequencies close



The unlabeled version of this Energy Systems drawing, *Compact Loop Antenna for the Tore Supra*, received the Best-of-Show-in-Art Award of the 1990 Technical Publications and Art Competition sponsored by the East Tennessee Chapter of the Society for Technical Communication. The drawing is the work of Judy C. Neeley, D. J. Taylor, and D. J. Hoffman.

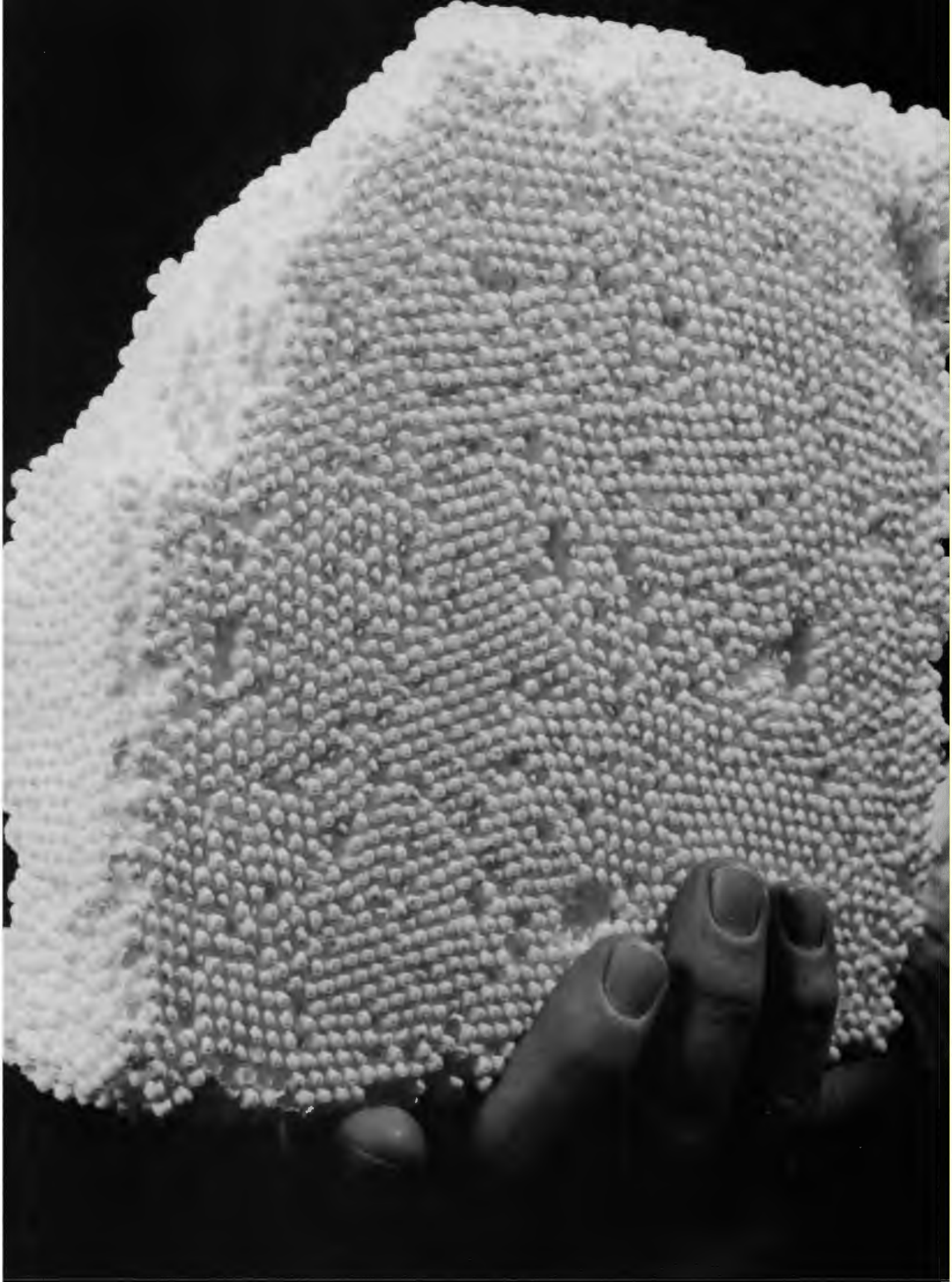
"A radio-frequency (rf) antenna built at ORNL will use high-power radio waves to help heat the atomic particles confined in the French tokamak."

to those used for radio and television but at much greater power (4 MW). This auxiliary heating device is being tested on the tokamak.

ORNL researchers led by Dan Hoffman developed, built, and tested the antenna, which consists of two current straps mounted in a single large opening on the tokamak vessel. A Faraday shield covers the front of the antenna. The patented, water-cooled structure was designed to meet the difficult requirements imposed by the 30-s duration of the Tore Supra's plasma pulses.

Fabrication of the rf antenna required the development of water-cooled "bumper" tiles, made of a graphite-molybdenum composite, and graphite-coated Inconel tubes for the Faraday shield on the antenna to protect its interior from plasma particles. Two radiating straps and their high-current, high-voltage (50-MVA) capacitors are located behind the Faraday shield and serve as the antenna's "heating elements."

Under the direction of Peter Mioduszewski of the Fusion Energy Division, an ORNL group is leading a program of research in plasma edge physics and particle control at the Tore Supra using a pump limiter developed by Sandia National Laboratories. The goal is to remove



Hollow spheres bonded into lightweight boards show increased compressive strength. Such boards could be used for high-temperature insulation, according to ORNL studies.

undesirable particles (helium ash) from the plasma edge and to control the plasma density so that the tokamak can produce useful energy.

ORNL Finds Spheres Could Make a Good Insulation

Hollow spheres—ceramic bubbles blown from a mixture of powder and liquid—may be the most acceptable of the high-temperature insulations of the future. These bead-size, thin-walled "aerospheres" are light, durable, and pose no known environmental hazard. Alumina spheres can withstand temperatures as high as 3200°F without shrinking or cracking. The sponsor of the research, the U.S. Department of Energy's Energy Conversion and Utilization Technologies (DOE-ECUT) Materials Program, sees hollow spheres as a possible improved high-temperature insulation.

Hollow spheres of ceramic materials are being produced using a patented technique originally used for making glass spheres. The technique was successfully applied by Joe Cochran and Ted Chapman of the Georgia Institute of Technology to a liquid slurry of ceramic powder as the starting material. Today hollow spheres are made by Ceramic Fillers, Inc., a company sponsored by Georgia Tech's Advanced Technology Development Center. The company has made spheres of a variety of ceramic powders ranging from alumina to zirconia.

Although the spheres' thermal conductivity is slightly higher than that of fibrous insulating materials, evidence obtained by David McElroy of ORNL's Metals and Ceramics Division indicates that changes in sintering could increase the porosity of the thin walls of the spheres enough to significantly improve their resistance to heat flow. Pores of the right size and number could theoretically scatter thermal radiation, reducing apparent thermal conductivity and improving insulating effectiveness.

Tests have shown that hollow spheres have a higher compressive strength than fibers used in insulation; hence, they will stay in place and not require supplements of loose fill material to maintain the desired insulating value. In addition, these spheres can be bonded into boards that have enhanced compressive strength and are lightweight (have low bulk density), making them more durable and easy to install. Unlike some materials used in today's insulations, these spheres are nontoxic and cannot be burned, made airborne, or inhaled. Thus, they may also be preferred for health, safety, and environmental reasons.

Hollow spheres can be bonded together into thick boards resembling closed-cell honeycombs to provide the structural strength needed for the refractory insulations used in industrial furnaces and other high-temperature environments such as steel mills and petrochemical plants. Loose spheres can also be blown into confined spaces to increase R-value. Spheres also could be added to refractory fibers and other materials in a matrix to make "designer" insulations to meet special needs, especially for high-temperature applications. They could have other applications as auto exhaust insulation and fire-protection products and as beds for catalysts.

Measurements at ORNL showed that the thermal conductivity of aerospheres of alumina, mullite, and silica was slightly higher than that of space shuttle tiles and kaolin fiber. The measured thermal conductivities of alumina aerospheres with varying densities showed that the lowest-density sphere had the lowest thermal conductivity.

This finding led to the conclusion that altering the sintering process to make slightly porous spheres might lower the thermal conductivity, making hollow spheres more suitable as insulation. Wall pores are important because they scatter thermal radiation.

In insulation, heat moves through the material mostly by conduction and thermal radiation. If a material is altered so that it scatters thermal radiation rather than allowing it to move in straight paths, the material's thermal conductivity should be lower (and its resistance to heat flow and its insulating value should be higher). In conventional insulations, voids and other "opacifiers" are intentionally included to scatter radiation. McElroy, Chapman, and Cochran

"DOE . . . sees hollow spheres as a possible improved high-temperature insulation."

believe that wall pores will act as opacifiers to improve the insulating value of hollow spheres.

Three features of the sphere-production process make it a candidate for large-scale use in the U.S. ceramic industry:

- It is so flexible that it should be able to make spheres from virtually any material, including cheap raw materials such as clay and feldspar.
- It allows "tailoring" of the wall microstructure, such as changing wall porosity to achieve desired properties, such as radiation scattering.
- The sphere-making process uses conventional ceramic manufacturing methods—handling ceramic powder slurries and sintering.

Thus, should there be rising demand for hollow spheres for insulation or other applications in the future, it could be easily met by the ceramic industry once the technology—now covered by more than 20 patents—is transferred.

Microorganisms May Play Role in Waste Management

ORNL researchers are studying microorganisms that remove metals from water for possible use in managing radioactive and hazardous wastes in Oak Ridge and elsewhere. These organisms, including bacteria, fungi, and algae, selectively absorb metals from water. Thus, in high concentrations, they could be used to treat wastewater containing radioactive or toxic metals.

According to Chuck Scott, a senior corporate fellow in ORNL's Chemical Technology Division, a column of gelatin beads containing trillions of these microorganisms could make an efficient system for removing radioactive and toxic heavy metals from wastewater. The organism-bearing gelatin beads are called biobeads.

Certain microorganisms have long been known to absorb metals if the organisms are present at a concentration 10,000 times greater than their normal concentration in water. However, only within the past few years have researchers tried to apply that knowledge to waste management (John Napier and others have used microorganisms at the Oak Ridge Y-12 Plant to remove mercury contamination from ponds).

Some microorganisms have an affinity for many types of metals, but others absorb metals of specific types. The organisms don't have to be alive because absorption generally is accomplished chemically rather than metabolically. A column containing large numbers of the organisms could remove enough heavy metal from a tank of liquid waste to allow safe discharge to the environment.

Biobead technology offers two advantages over other techniques. First, the isolated waste product—the biobeads and absorbed metals—has 10,000 times less volume than the tanks of liquid waste. Such volume reduction makes ultimate disposal of the actual wastes much easier and less expensive. Second, biobead technology has the potential of selectively removing any contaminant for special handling required by regulations.

The microorganisms, says Scott, perform their task most effectively when sealed into gelatin beads. Each bead, about the size of a pinhead, contains millions of these organisms.

An ORNL group in the Bioprocessing Research Program of the Energy Research Section of the Chemical Technology Division is conducting research to determine the best type of gel material for various applications. The gels come from natural sources, such as seaweed.

The beads may be tailored to the type of metal present in the liquid. Strontium and cesium, for example, are commonly present in radioactive wastewater. Beads containing two types of organisms, one with an affinity for strontium, the other an absorber of cesium, could be produced to remove the metals.

In a column less than 0.5 m (1 ft) in diam and just under 2 m (5 ft) high, containing 3785 L (1000 gal) of water, about 100 L (30 gal) of biobeads could process 3785 L (1000 gal) of water per day and reduce the metals concentration 1000-fold—from 50 parts per million to about 50 parts per billion—in one day.

After absorbing the metal from the wastewater, the biobeads could continue to be used until the organisms absorb their limit. The next step would be either to force the organisms, by altering their chemical environment, to release the metal for retrieval for possible reuse or to discard the beads and replace them with new ones. In most cases, replacement would be more economical.

The research is focused on naturally occurring microorganisms that do not cause disease. They are grown in a tank of nutrients, such as sugar and water, and can be harvested by a centrifuge or filtered. There are no plans to genetically alter these organisms in the foreseeable future.

The ORNL group can produce about a liter of the biobeads in an hour using only laboratory equipment. Research has been limited to the laboratory scale, but Scott says that the initial results look favorable for using biobead technology for actual waste management operations at ORNL.

Chuck Scott examines a column of gelatin beads containing microorganisms that remove radioactive and toxic metals from wastewater.

ORNL has been studying alternatives for managing radioactive waste. It is possible that microorganisms could play an important role in ORNL's waste management program once they are shown capable of efficiently and economically reducing the volume of waste requiring storage or disposal. ornl

SEMATECH, Energy Systems To Collaborate on Advanced Semiconductor Technology

Robert Noyce (right), co-inventor of the microchip and SEMATECH chief executive officer, gives Sen. Gore one of the first silicon wafers produced by SEMATECH, which recently signed a research agreement with Energy Systems on developing an advanced etching technology for semiconductor production.

ORNL will conduct research aimed at developing an advanced etching technology for the production of improved semiconductors for SEMATECH, an industrial consortium formed to regain U.S. leadership in semiconductor manufacturing.

On December 20, 1989, in Oak Ridge, Sen. Albert Gore of Tennessee announced the new research agreement between Energy Systems and SEMATECH. During the ceremony attended by ORNL, DOE, and SEMATECH officials (including consortium president and chief executive officer, Robert N. Noyce), Sen. Gore said, "SEMATECH represents a key national asset in the struggle to stop the rapid decline of America's position in electronics manufacturing and to ensure that our country stays at the forefront of this essential technology as we enter

the 21st century. The match of SEMATECH and ORNL is ideal, marrying the strengths of ORNL to the ambitious goals of SEMATECH. I look forward to an immense success."

SEMATECH, an organization of 14 semiconductor manufacturers, seeks to develop the technology to produce semiconductor chips having circuit paths more than 40% narrower than those in existing chips. This size reduction would allow production of smaller, more powerful computers and consumer electronic products having American-made parts.

Wayne Morrison operates a computer protected by the new security system he helped to develop.

In this Work-for-Others project, ORNL's Solid State and Fusion Energy divisions will develop and evaluate several experimental etching concepts for fabricating high-density semiconductor chips. Precision etching is a critical step in producing a circuit in which 1 million transistors are located on one side of a 0.25-in. chip. The technology would be transferred to a U.S. tool manufacturer, which would design and produce the etching tools required for commercial use.

The ORNL effort is part of SEMATECH's University and National Laboratory Program, in which scientists and educators cooperate under research grants. ORNL is the second national laboratory to enter an agreement with SEMATECH.

SEMATECH's annual budget is $200 million, of which half is contributed by member industrial firms. The other half is provided by the U.S. Defense Advanced Research Projects Agency.

Computer Security Technology Licensed to Start-up Company

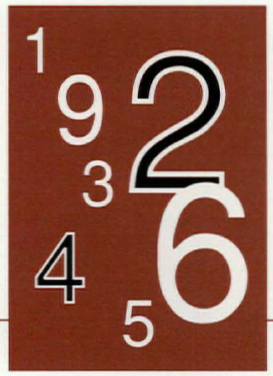
Energy Systems has licensed a microcomputer security technology developed at the Oak Ridge Y-12 Plant to Micro Safe-T Systems, Inc., a start-up company in Knoxville. This is the first license granted for a technology developed at the Y-12 Plant.

The new technology prevents the deletion or alteration of data stored on a hard disk of a microcomputer. This device, which will be marketed this year under the brand name Diskloc, is the only hardware available that ensures that users reading stored information on a fixed disk cannot erase or write on it. It was originally developed to protect classified information stored on a microcomputer.

The protective device, which can be installed by users, involves replacing two cables with one cable. A switch assembly for turning the security device on and off can be placed beside the computer.

The technology, which Micro Safe-T Systems plans to market this year, was developed by G. Wayne Morrison, Trygve C. Myhre, and other members of the Operations Research Department of the Y-12 Plant's Program Management Division. Morrison has been named vice president of Micro Safe-T Systems. The president of the company is Hannah Van Horn, currently vice president of a Knoxville advertising agency. ornl

Take a Number



By V. R. R. Uppuluri

Divisibility

Using the first nine natural numbers 1, 2, 3, 4, 5, 6, 7, 8, and 9, it is possible to form 362,880 (9!) different nine-digit numbers. One of these numbers, 381,654,729, has a particularly interesting property.

The number formed by the first two digits, 38, is divisible by 2; the number formed by the first three digits, 381, is divisible by 3; the number formed by the first four digits, 3816, is divisible by 4; the number formed by the first five digits, 38,165, is divisible by 5, and so on. Of course, 381,654,729 is divisible by 9. No other nine-digit number of this class has this property.

Interesting Square Numbers

There are several ways of generating perfect squares. One way is by inserting certain two-digit numbers within some squares to produce square numbers. Consider the following squares:

$$49 = 7^2$$
$$4\mathbf{48}9 = 67^2$$
$$44\mathbf{4},\mathbf{8}89 = 667^2$$
$$44,4\mathbf{48},889 = 6667^2$$

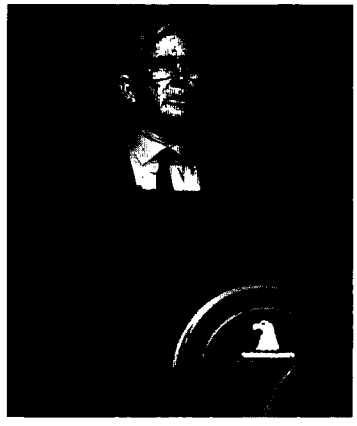
By inserting 48 in the middle of the square 49, we obtain 4489, which is a perfect square (67^2). Now, insert 48 in the middle of this number to get 444,889, another square (667^2). Insert 48 in the middle of this number to obtain 44,448,889, which is the square of 6667. Continuing this process will produce the same results.

For another example, consider the following:

$$16 = 4^2$$
$$1\mathbf{15}6 = 34^2$$
$$11\mathbf{1},556 = 334^2$$
$$11,1\mathbf{15},556 = 3334^2$$

By inserting 15 in the middle of the square 16, we obtain 1156, which is a perfect square. By inserting 15 in the middle again, we obtain 111,556, also a square. Another square is obtained by inserting 15 in the middle of this six-digit number. Even larger squares can be produced by continuing this process.

Are there any other examples like these?



NEXT ISSUE

ORNL Director Alvin Trivelpiece's first "State of the Laboratory" address will be featured.

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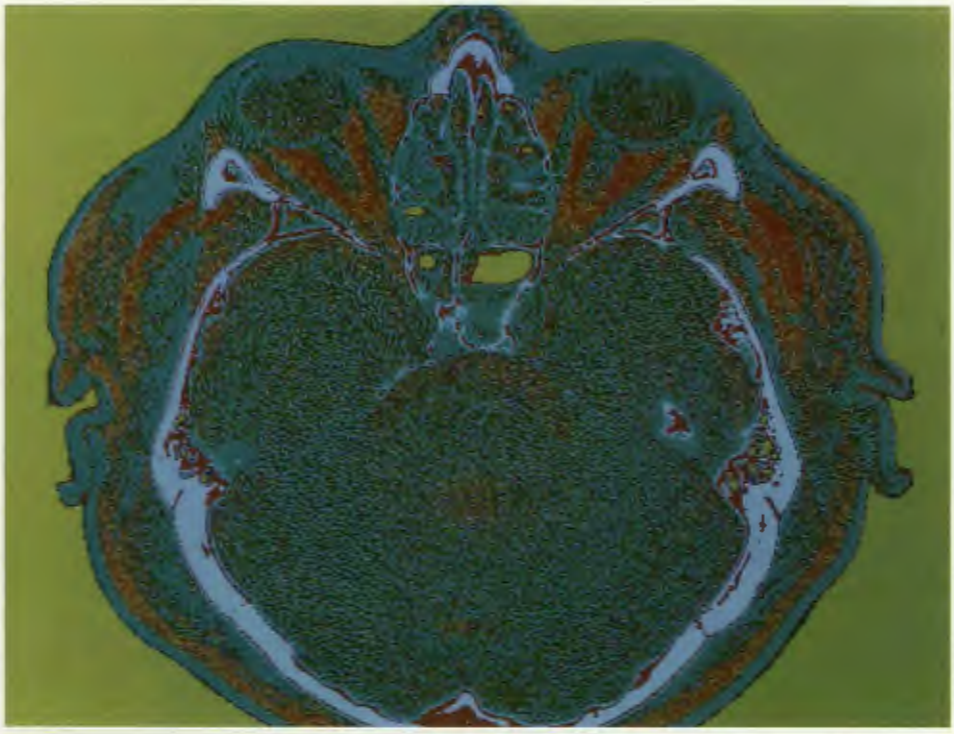
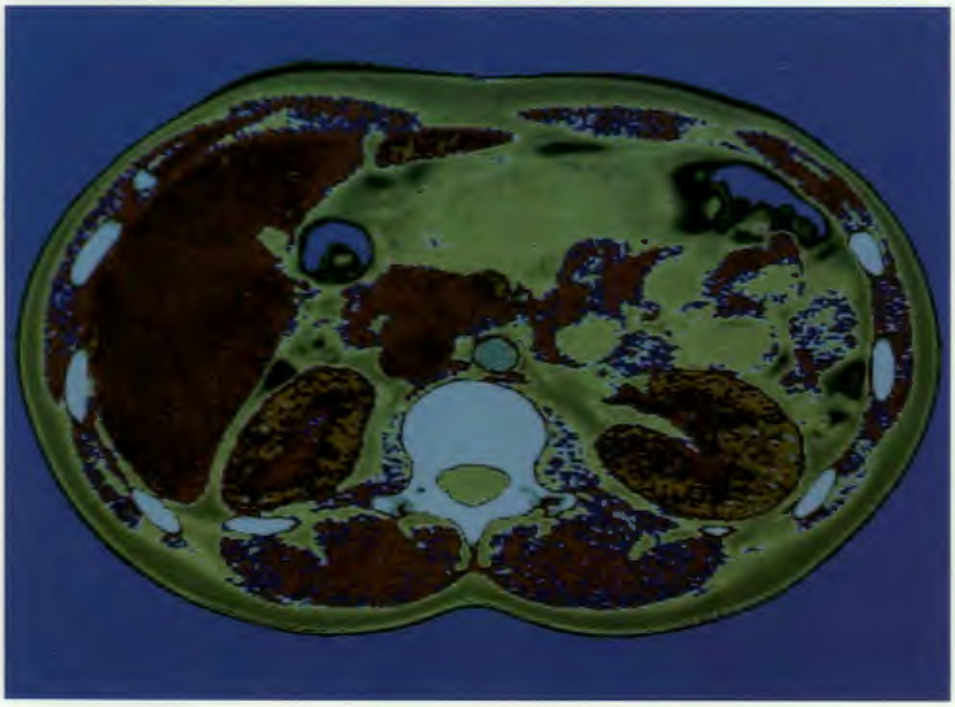


In this ORNL computer graphic constructed from CAT images of children's organs, the cranium, brain, and eyes are readily identified. Note the outline of the muscles (orange) that control each eye (at top) and the individual lenses (blue). Details in the nasal region are also visible.



This view through the upper trunk shows a portion of the liver (colored red on the left) and the kidneys on either side of the vertebra body, the white object in the lower center region. The blue regions in the trunk are actually pockets of air within the gastrointestinal tract. See "Computerized Anatomical Models of Children" on p. 73.

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