Number Four 1985

Oak Ridge National Laboratory review

Jack Davidson with his EIDEC Camera

Technology Transfer and ORNL: *The Changing Picture*

THE COVER: Jack Davidson adjusts the latest version of his electronic image detector for electrophoresis and chromatography (EIDEC), a TV camera and image intensifier with biomedical uses. Efforts have intensified to move ORNL innovations like this into the marketplace. For a report on the changing picture of technology transfer at ORNL, see the article on page 19.

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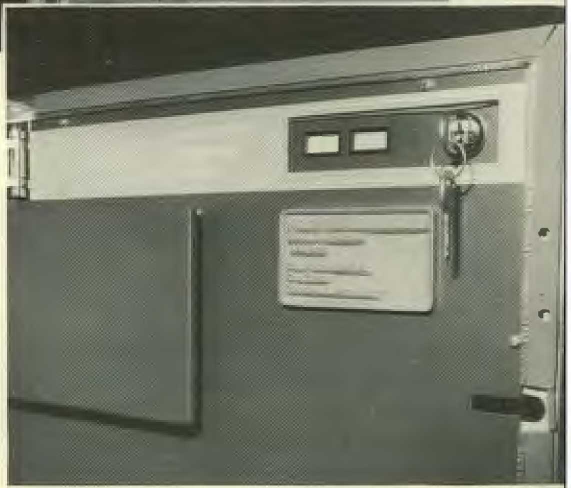


Parallel Computing at ORNL

Are 64 heads better than 1?

By MICHAEL T. HEATH

Parallel computing, sharing work among many processors, potentially allows computational problems to be solved far more quickly than with single processors. Parallel computing is the focus of several new research initiatives at Oak Ridge National Laboratory including large-scale matrix computations and the intelligent control of robots.

What is the motivation for the current interest in parallel computing? What is its potential? What are some challenges that parallel computing presents?

The inexorable advance of technology has become a commonplace facet of modern life. Nowhere has the impact of technological innovation been more spectacular than in computing. The prodigious speed and capacity of today's digital computers for processing and storing information touch almost every aspect of our

ORNL Director Herman Postma (left) and ORNL Executive Director Ray Wiltshire admire the Intel hypercube that Mike Heath has been programming. Inset: Part of the Intel hypercube for parallel computing. Parallel computers are needed to provide the greater computational speed and capacity required in climate modeling, fluid dynamics, and control of complex systems such as space vehicles and robots.

Computer scientists are learning how to use new parallel processing machines to meet ORNL's research needs. New parallel algorithms for solving large systems of equations have been developed at ORNL.

daily lives. Moreover, with every passing year, computers become faster and cheaper and shrink in physical size, even as their logical capacity grows.

Based on the rate of progress over the past 30 years, one might expect these trends to continue indefinitely. But closer examination reveals that such gains are becoming increasingly difficult to attain and that the pace at which new performance levels are reached is slowing perceptibly. In short, computer designers are becoming victims of their own success because their designs are approaching fundamental physical limitations that bar significant further improvement. At least this is the case within the standard architectural paradigm, developed by Hungarian-American mathematician John von Neumann, that has served so well for the past 40 years.

Von Neumann Concept

What is the von Neumann concept of computation, and what are the limitations on its potential speed? The fundamental elements of a von Neumann computer are a central processing unit (CPU) and a memory (Fig. 1). The CPU executes instructions that manipulate data. Both instructions and data are stored in memory, and usually the results of operations are also transmitted back to memory for storage. Input/output channels are used for communication with the outside world, such as reading programs and data into the computer and sending results to output devices.

The two primary factors determining the speed of such a computer are how fast instructions can be executed and how fast instructions, operands, and results can be fetched from and returned to memory. This critical dependence on memory access is often referred to as the "von Neumann bottleneck." A number of architectural improvements have been devised to alleviate this memory bottleneck, including multiple paths to memory, multiple memory banks with interleaved storage, pre-fetching of instructions and operands before they are needed, and hierarchical memory (registers, cache, conventional random access memory, and mass storage devices). At the hardware chip level, the technological considerations in making memory access faster are similar to those in making processors faster, so I will discuss only the latter in detail.

The timing of the basic logical operations in a processor is governed by a regular pulse generated by a clock. Thus, the speed at which the processor runs is determined by the rate at which its clock "ticks." Can this clock be set to run arbitrarily fast? The answer is "no" for several reasons:

Speed of light. The speed at which electric current travels is limited by the speed of light. In the new Cray-2 supercomputer, for example, the clock cycle time is 4.5 ns, in which time light travels a distance of only about 1.35 m. The actual propagation speed of electronic signals depends on the physical properties of the conductor, but in any case, this speed is bounded by that of light in a vacuum. Thus, if the length of any wire in the computer exceeds about 1.35 m, signals cannot travel over it in a single clock cycle, and the computation is slowed down. This is why faster computers must also be more compact and why the day of the room-sized supercomputer is past.

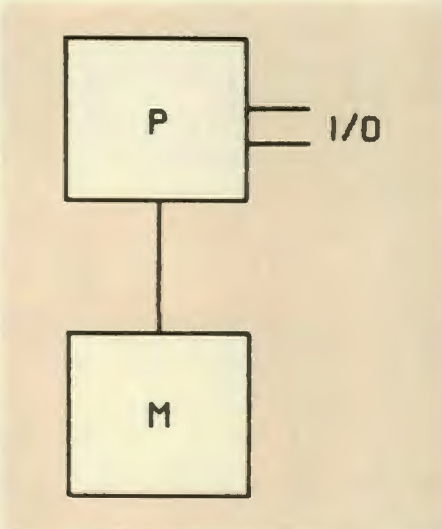


Fig. 1. The fundamental elements of a von Neumann computer are a central processing unit (CPU) and a memory. The CPU executes instructions that manipulate data. Both instructions and data are stored in memory, and usually the results of the operations are also transmitted back to memory for storage. Input/output (I/O) channels are used for communication with the outside world, such as reading programs and data into the computer and sending results to output devices.

Gate delays. The speed with which a logic gate (a switching circuit that performs one of the elementary operations out of which more complex operations, such as arithmetic, are built) can operate is determined by the physical properties (electron mobility, etc.) of the semiconductor material of which it is made. The current standard material, silicon, will probably not support significant further advances in speed. Consequently, more exotic semiconductors, such as gallium arsenide and Josephson junctions, are now under investigation, but further improvement in switching

Michael T. Heath is leader of the Computer Science Group of the Mathematical Sciences Section of ORNL's Engineering Physics and Mathematics Division. After receiving his Ph.D. degree in computer science from Stanford University in 1978, he came to ORNL as a Eugene P. Wigner Postdoctoral Fellow. In addition to parallel computing, his research interests center on the development of numerical algorithms for solving large-scale scientific problems, particularly sparse matrix computations. Here, Tom Dunigan watches as Heath programs the new Intel hypercube.

speed is still expected to be only another order of magnitude or so.

Clock skew. Because of differing wire lengths, etc., two signals headed for a logic gate will not necessarily arrive at the same time. Thus, a brief time may elapse during which the output of the gate is indeterminate before the gate settles into its ultimate state. Obviously the clock-cycle time must not be less than this settling time, or havoc will result.

These limitations on ultimate processor speed, especially when combined with the memory access bottleneck, account for the rapidly approaching point of diminishing returns that haunts designers of traditional von Neumann–design computers. Meanwhile, the need for ever greater computational speed and capacity grows unabated in such areas as numerical weather prediction and the real-time estimation and control of complex systems such as space vehicles and robots.

It is now generally recognized that the best way out of this conundrum is to exploit parallelism. Now under development are computers having not one CPU and memory but tens, hundreds, or even thousands of processors and memories that can work together in solving a given problem. Although each individual processor is still subject to the limitations I have discussed, the ensemble as a whole is not, at least for many applications. On the other hand, the effective use of multiple processors involves new sets of difficulties, both in hardware design and algorithm design. I will discuss these in turn.

Multiprocessor Architectures

There are basically two ways of connecting multiple processors and memories to form a multiprocessor network. In a *shared-memory* (or global-memory) arrangement, a switching network connects the processors to the memories so that every processor has access to every memory (Fig. 2). In a *local-memory* (or distributed-memory) arrangement, the network connects the processors to each other, with each processor having access only to its own memory (Fig. 3). Among the multiprocessor architectures within each of these two broad classes, perhaps the most important distinguishing feature is the topological structure of the interconnection network.

The main advantage of the shared-memory approach is ease of programming: because a single copy of a whole problem can be stored in the common memory, where it is accessible by all processors, the programmer need not worry about how to split up the problem to distribute it over multiple memories, as in the local-memory model. On the other hand, because it must provide complete interconnections, the switching network for a global-memory model is relatively expensive and may not scale up well to very large numbers of processors.

In a local-memory system, a simpler network with relatively few interconnections (therefore, a less expensive network that is more readily scalable to large numbers of processors) can nevertheless provide excellent performance. A distributed-memory multiprocessor may seem at first glance to be more difficult to use than shared memory, but this difference is often more apparent than real. In particular, for global-memory systems, the programmer must carefully manage access to shared memory by the processors, or memory contention will become a serious bottleneck inhibiting performance; moreover, this effect becomes worse as the number of processors grows. I will return later to a discussion of programming techniques and algorithm design for multiprocessors.

The Hypercube

Many multiprocessor designs have been proposed, and several experimental prototypes have been built at universities, national laboratories, and private companies. Most of the multiprocessors that have reached the commercial marketplace have relatively few processors (2 to 20) and are based on a shared-memory model. The first generation of more massively parallel multiprocessors (with 64 or more processors) is just now emerging. These machines are based on the local-memory model. The individual processors are coordinated by passing messages between them. One of the most successful designs is the hypercube developed at the California Institute of Technology. It has been transformed into a commercial product by three different companies. ORNL has acquired hypercubes from two of these, Intel and NCUBE. Both hypercubes at ORNL have 64 processors.

ORNL selected the hypercube primarily because of its flexibility and cost-effectiveness. Many other processor interconnection topologies (rings, meshes, trees, etc.) can be embedded within a hypercube topology, so that the hardware can

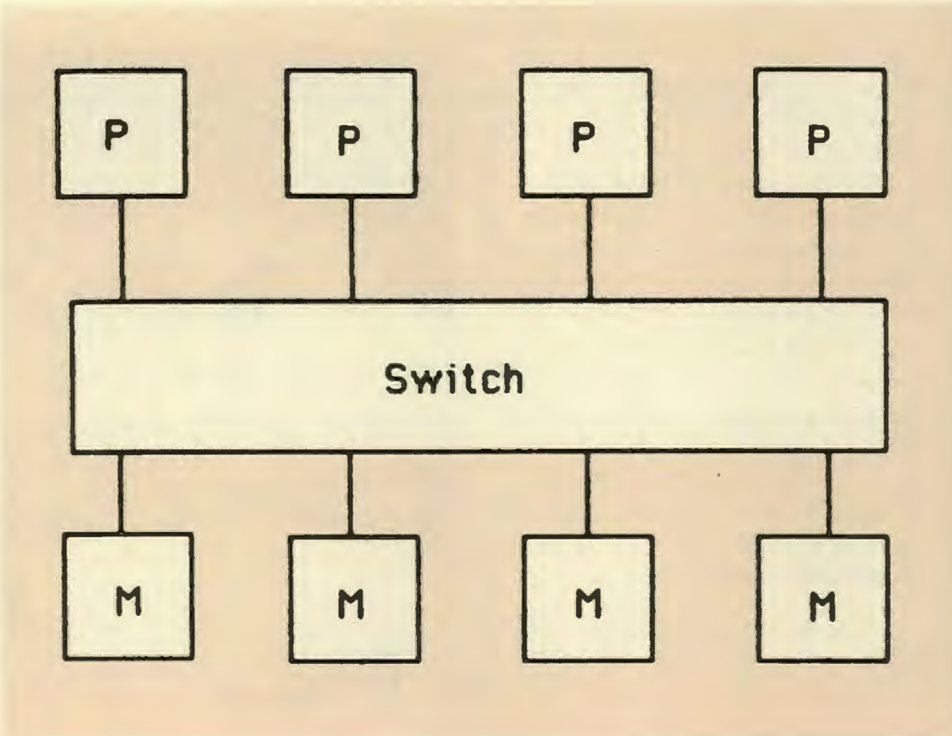


Fig. 2. In a shared-memory (or global-memory) arrangement, a switching network connects the processors to the memories so that every processor has access to every memory.

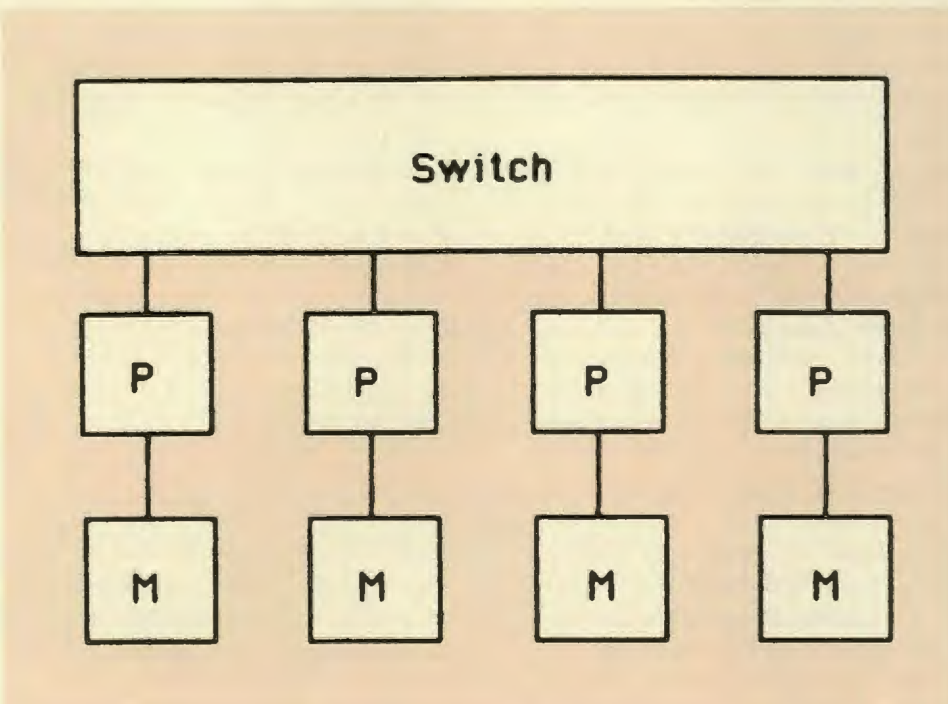


Fig. 3. In a local-memory (or distributed-memory) arrangement, the network connects the processors to each other, with each processor having access only to its own memory. Among the multiprocessor architectures within each of these two broad classes, perhaps the most important distinguishing feature is the topological structure of the interconnection network.

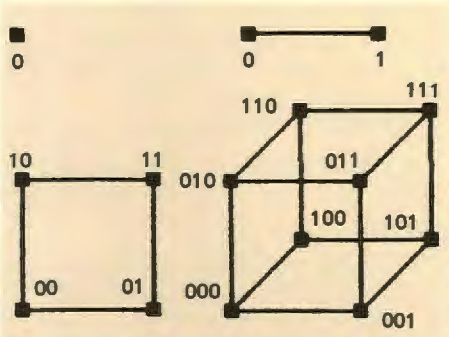


Fig. 4. In a hypercube, each processor is connected to all other processors whose binary tags differ from its own by exactly one bit. Topologically, this arrangement places the processors at the vertices (corners) of an N*-dimensional cube; hence the name hypercube. In practice, the actual physical layout of the processors is a linear arrangement in a card cage or a planar arrangement on a printed circuit board; the cube connections are made by wires, conducting layers, or a backplane.*

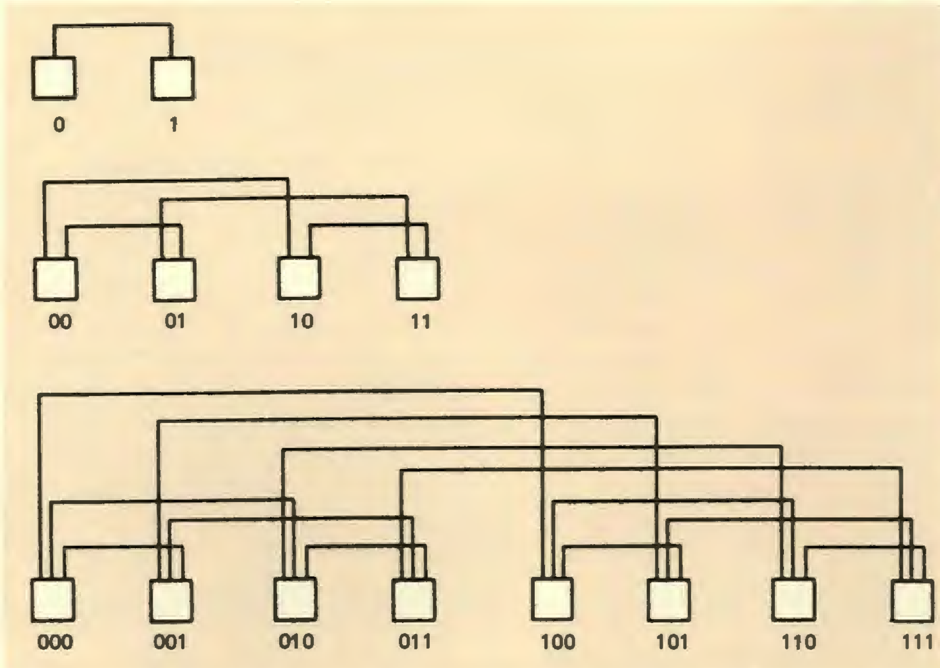


Fig. 5. Hypercubes of arbitrary dimension can be made by using a linear arrangement with connecting wires. The cube of each dimension is obtained by replicating the one of next lower dimension and then by connecting corresponding nodes. One advantage of the hypercube network is that, as the number of processors increases, the number of connecting wires per processor grows only logarithmically so that very large numbers of processors become feasible.

efficiently execute algorithms intended for a variety of architectures. The hypercube is also the first commercially available architecture with enough processors to support our research and development efforts in parallel algorithms.

In a hypercube (also variously called the binary N-cube, cosmic cube, homogeneous ensemble machine, etc.), 2^N processors are consecutively numbered (or tagged) by binary integers (i.e., bit strings of length N) from 0 through 2^N-1. Each processor is connected to all other processors whose binary tags differ from its own by exactly one bit. Topologically, this arrangement places the processors at the vertices (corners) of an N-dimensional cube (Fig. 4), hence, the name hypercube. In practice, the actual physical layout of the processors is a linear arrangement in a card cage or a planar arrangement on a printed circuit board; the cube connections are made by wires, conducting layers, or a backplane.

Hypercubes of arbitrary dimension can be made by using a linear arrangement with connecting wires (Fig. 5). The cube of each dimension is obtained by replicating the one of next lower dimension and then by connecting corresponding nodes. Thus, one of the advantages of the hypercube network is that, as the number of processors increases, the number of connecting wires per processor grows only logarithmically so that very large numbers of processors become feasible.

Another attractive feature of the hypercube is its homogeneity, and for this reason all of the processors are usually identical. Nevertheless, with any distributed system it is convenient to have a separate processor that acts as master controller or manager of the remaining ensemble of processors. This special processor, usually called the *host*, is not itself part of the hypercube network, whose processors are called *node* processors or simply *nodes*. The host initiates a computation, collects results upon completion, and serves as the link to the outside world. It is desirable for the host to be connected to all of the nodes, perhaps by a global bus that is used only for host-node (not node-node) communications.

In the hypercube, if a message needs to be sent between two nodes that are not adjacent (i.e., directly connected), a simple and efficient algorithm exists for routing the message through intermediate nodes until it reaches its ultimate destination. The path length for sending a message between any two nodes is precisely the number of bit positions in which their binary tags differ, which is, of course, a maximum of N. One interpretation of this routing scheme is that the message moves into subcubes of successively smaller dimensions in which the destination node resides, ultimately reaching the 0-cube (i.e., the destination node itself). Numerous possible paths connecting any two nodes exist, and this redundancy can be exploited to enhance communication bandwidth and fault tolerance of the hypercube network.

Because it has only local memory, the hypercube necessarily employs a distributed operating system. An operating system kernel resides in each node processor to supervise user processes running on the node and to send, receive, and queue messages. In particular, the kernel in a given node sends and receives messages for processes running on its node and passes along messages intended for processes running on other nodes. Some designs have a separate communication coprocessor to handle these chores, thus freeing the main node processor of most communication overhead. The host compiles user programs and loads the resulting object code onto the node processors. Once the host has initiated a computation, the host and nodes all proceed asynchronously, coordinated only by transmitting and awaiting messages that contain problem data or control information.

Parallel Algorithms

The use of a multiprocessor places new demands on the programmer and algorithm designer. Having more processors available does not in itself guarantee that a problem can be solved more quickly. If one person can dig a post hole in 1 h, it does not follow that 60 people can dig a post hole in 1 min. The difficulty here, of course, is that the post hole is a shared resource, and contention for the resource is devastating to the performance of this particular algorithm. Other important problems in designing parallel algorithms include balancing the workload among processors, minimizing communication or synchronization overhead, and determining an appropriate size (granularity) of subtasks. The main point of these issues is to speed up the computation as much as possible so it will be faster than the fastest serial algorithm for solving the same problem. In addition, new software engineering problems abound, such as the much greater difficulty of debugging in a parallel computing environment.

Although parallelism is common in many aspects of everyday life, its use in computing has been largely restricted to such areas as computer operating systems. The word "algorithm" is sometimes defined as a recipe for carrying out a given computation, but the algorithms embodied in traditional programming languages specify a strictly sequential series of steps. Recipes used in the kitchen, however, often involve parallel activities, as when both cake and icing are prepared simultaneously. Even in this domain, contention for resources (oven, mixer, etc.) can be troublesome, as any cooking couple can attest.

Parallelism is fundamental to any large construction project, such as building a skyscraper. Critical path scheduling and similar techniques are essentially methods for determining and specifying the time dependence of parallel, but related, activities. The 50th floor cannot be constructed before the 49th, but once both are framed in, interior work on both can proceed simultaneously. Most plumbing and electrical work can be done independently, but occasionally a pump or gauge will require wiring. Similarly, the solution of problems in mathematics and science usually involves some steps that must honor a certain sequential order and others that can take place more or less independently. We now examine these varieties of parallelism more closely.

For a given set of tasks, numerous types and degrees of possible parallelism may exist. In the worst (and most uninteresting) case, all of the tasks must be done in some purely sequential order. The opposite extreme, total independence of the tasks, seems ideal for parallel computation but may still present a challenge for a specific multiprocessor. For example, if the tasks outnumber the processors, how can we best balance the workload? Can a well-balanced schedule be determined in advance, or must it be determined dynamically as computations proceed? On the other hand, if the processors outnumber the tasks, can we profitably subdivide some of the tasks to make use of all the processors?

The problems of determining a good load balance and appropriate granularity of subtasks are further complicated if the tasks are not independent, that is, if some of the tasks depend on results produced by other tasks. In this case, we also wish to schedule the tasks to minimize the time that processors are idle while awaiting data they need to continue.

One powerful way of dealing with sets of tasks that are partially sequential and partially independent is *pipelining*. With pipelining, execution of tasks is largely overlapped, but the necessary sequential ordering is still honored. Consider the analogy of a manufacturing assembly line. Suppose that 100 steps are required to assemble an automobile and that each is performed at a successive station along the line. For any one car, the steps are carried out in strictly sequential order. Indeed, for building a single car, an assembly line offers no advantage. But if 100 or more cars are to be assembled, then as soon as the first car goes to step 2, another car is begun at step 1, and so on. By the time the first car reaches the final step, 100 cars are under construction simultaneously, in varying degrees of completion. Thus, 100 steps are required for the "pipeline" to become full, but thereafter, another car is completed with each additional step.

In the automobile assembly line, the first station will become idle after 100 steps unless more than 100 cars are to be built. This is an example of another important principle: the set of tasks needs to be substantially larger than the number of processors if pipelining is to maintain high processor utilization. Pipelining is applicable to many of the most basic numerical computations, such as processing successive components of vectors or successive rows or columns of matrices.

ORNL Develops Algorithms

Initial research and development work on parallel algorithms in the Engineering Physics and Mathematics Division of ORNL has been concentrated in two areas: matrix computations and robot dynamics. Matrix computations are a fundamental building block upon which many more complex scientific and engineering computations, such as network analysis, structural analysis, and solving of partial differential equations, are based. Principal investigators for work in this area at ORNL are Esmond Ng, Al Geist, and I. We have developed efficient, new parallel algorithms for solving systems of linear equations, least squares problems, and eigenvalue problems. Our algorithms for various matrix factorizations used in solving linear systems of equations make extensive use of pipelining techniques to attain very high processor utilization for sufficiently large problems. We have studied the effects on processor utilization, load balancing, communication volume, etc., for various ways of mapping matrices onto processors. The development of these algorithms and the analysis of their performance have been facilitated by a hypercube simulator developed by Tom Dunigan.

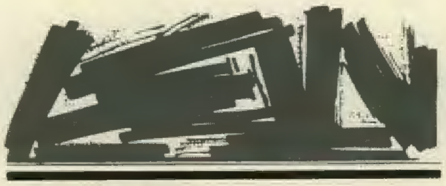
Intelligent control of robots requires the solution in parallel of many separate but interrelated tasks. For example, a robot has to locate an object that it must grasp or avoid, so vision and movement must be concurrent. Principal investigators for work in this area at ORNL are Jacob Barhen, Ralph Einstein, and Matthew Hall. They have focused on the problem of scheduling a set of tasks for efficient execution on an ensemble of processors, such as a hypercube. An ideal solution would be to find an assignment of tasks to processors that provides maximum overall efficiency given the topology of the multiprocessor network and any priorities among tasks that must be satisfied. Such an exact solution would require examination of an immense number of possible combinations, however, so that in practice heuristic techniques (rules of thumb) are used to attain good efficiency and to balance the work load among processors.

During the coming year, additional efforts will begin to spread this new expertise in designing parallel algorithms to other ORNL divisions. Several projects have been selected for prototype applications development on the hypercube, including pollutant transport modeling, displacement cascade simulation, finite element fracture analysis, computer vision, density functional theory, molecular dynamics of polymers, and three-dimensional resistive magnetohydrodynamics. This broad spectrum of applications should give us further insight into the general principles of parallel computation and establish the viability of multiprocessor technology in general scientific computation.

Heath and Tom Dunigan proudly display the Intel hypercube for parallel processing. The computer has 64 processors.

In August 1985, ORNL sponsored a conference in Knoxville, Tennessee, on hypercube multiprocessors. The conference brought about 150 researchers from universities, industry, and national laboratories who have a common interest in hypercube architectures to share ideas and plans for using this emerging class of multiprocessors. Topics included programming languages, data structures, operating systems, architecture, algorithms, and applications.

In summary, the use of parallelism in multiprocessors offers a potential solution to the fundamental limitations on processor speed, but it also creates new challenges to hardware designers, algorithm developers, and programmers. Parallelism adds many new degrees of freedom to all of these design choices. We have just begun learning how to exploit this freedom effectively. The availability of massively parallel multiprocessors is ushering in an interesting and exciting new era in computing. ornl



BOOKS

***Chancing It: Why We Take Risks**, Ralph Keyes, Little, Brown & Co., Boston, 1984. Reviewed by W. S. Lyon, consultant to ORNL's Analytical Chemistry Division.*

Skydivers and high-wire walkers don't take risks, at least not from their point of view. Ralph Keyes interviewed and studied practitioners of what most of us would call high-risk occupations, and all of them considered their "jobs" quite safe. To them, getting married, trying to settle down to a steady job, or assuming a long-term mortgage is *really* taking a risk.

Are the rest of us risk takers, or are these daredevils crazy? The answer, according to Keyes, is neither of the above. Risk, he maintains, manifests itself in lack of control over a situation. Despite the high death rate among skydivers, most believe that they can control their fate by careful planning and conservative action.

"Familiarity breeds content" is a variant of an old saying, but it seems applicable here because little fear is experienced by persons who know all the parameters of a job or situation and are completely at ease with them. Those who work routinely with levels of radioactivity thousands of times greater than the levels that make the Ernest Sternglasses of the world shudder can appreciate this point of view. It also may help explain why so few drivers use automobile seatbelts but stay buckled up during an airplane flight. Drivers feel more in control on the road than when they are passengers in the air and seem oblivious to statistics that indicate it is safer to fly than to ride on the highway. The tendency for people to be less comfortable in situations where they have little control (even though the probability is low that an accident could occur) may help supporters of nuclear power better understand why it is so unacceptable to others.

The book contains a series of vignettes about people who take (or have taken) what most would call risks but who themselves see nothing unusual in their deeds. At first glance these ventures seem to have little in common: opening a dress shop, running marijuana into coastal waters from a small boat, and working as a stand-up comic. All three are perceived by most people as having varying degrees of riskiness, but to those involved, the risk lies in not trying.

Just as the medical profession has classified people according to personality types—the more aggressive Type A and the much more relaxed Type B—to better estimate their relative risks of having a heart attack, Keyes divides the world into two classes of risk takers—level I and level II. Practically everyone I know (including myself) falls into level II. We're the people who get married, raise children, and shun death-defying acrobatics.

Keyes outlines which actions are considered risks within each group and suggests mild "broadening" activities that involve risks worth taking. Taking risks, Keyes believes, adds a bit of zest to life. Sample level I risks for level II people include running for office, taking a trip without reservations, buying a used car, or making love in a phone booth. Level II risks for level I people might be joining a religious order, not changing jobs, complimenting someone, or reading Proust. The vignettes that Keyes details grow a bit wearying after a while, so unless readers are interested in arguments that reinforce their own beliefs or in the intimate details of the lives of selected adventurers, most of the middle section can be rapidly scanned with no great loss.

The last two chapters, "The American Way of Risk" and "Genuine Risk," are more provocative. In the former, Keyes maintains that we 20th-century Americans are but pale imitators of our red-blooded forebears who carved a nation out of the wilderness. We relish the appearance of risk without the danger. For us, scary rides at Disney World, staged gunfights at Silver Dollar City, and television programs such as "That's Incredible" are entertaining. This argument that risk can be appealing is amusing and rather convincing.

In the last chapter, Keyes discusses too briefly the need for genuine risk in our lives. Have we missed something by this sanitizing of our culture? Have we become a nation of Miniver Cheevys? Miniver Cheevy is Edward Arlington Robinson's poetic creation who longed for "days of old when swords were bright and steeds were prancing." For those who relish risk and adventure reminiscent of medieval times, there are still some choices: strolling in an inner city, joining the U.S. Marines, or vacationing in the Middle East. ornl

Guy D. Griffin is a member of the Advanced Monitoring Development (AMD) group in ORNL's Health and Safety Research Division (HASRD). A native of Omaha, Nebraska, he earned his Ph.D. degree in biochemistry from the University of Nebraska Medical Center in 1971. In 1972 he came to ORNL's Biology Division under an American Cancer Society postdoctoral fellowship to investigate RNA metabolism in human lymphocytes, under the direction of G. David Novelli. He subsequently received a National Cancer Institute (U.S. Public Health Service) postdoctoral fellowship to continue biochemical studies of lymphocyte function and in 1976 became a staff member of the Biology Division. In 1978, he joined the newly formed HASRD. His research interests at HASRD have included assessment of human health effects produced by exposure to environmental chemicals, development of biological markers useful for estimating human exposure to chemicals, and integration of biochemical and basic physical techniques, such as spectroscopy, to develop biosensors useful for detecting pollutant chemicals in human fluids or tissues. He is a member of the American Society of Biological Chemists. In 1984 he served on the Biological Monitoring Committee, which was part of a Workshop on Monitoring and Dosimetry in an Occupational Health Research Program for Synfuel Technologies, convened by the Office of Health and Environmental Research of the U.S. Department of Energy. Here, Griffin (top right), Tuan Vo-Dinh (middle) and Mayo Uziel (seated) are preparing to separate chemical products from human urine samples using the high-performance liquid chromatograph. Injecting the sample is Gordon Miller.

Protecting Human Health:

The Chemical Challenge

By GUY D. GRIFFIN

The emergence of today's complex, postindustrial "hi-tech" society from a simple agrarian society has resulted in vast changes in the American way of life. Included among these changes is our exposure to a much more varied and complex array of chemicals than our ancestors experienced. In the workplace and off the job, we are exposed to chemicals released from fossil fuel combustion and manufacture of metals and metal alloys or to chemicals in solvents, plasticizers, pesticides, food, etc.—the list is virtually endless.

The impact of the modern chemical environment on human health is largely unknown, but conventional wisdom, bolstered by results from animal experiments, suggests that chemical exposures should be minimized to the extent possible and practical. How much of each kind of chemical or chemical mixture affects human health? What duration of exposure is required before an effect is detected? These questions need answers in the chemical culture of the 1980s. Answering these questions, particularly with regard to energy-related pollutant chemicals, is one of the goals of the Health and Safety Research Division (HASRD) of Oak Ridge National Laboratory. Within the Health Studies Section of HASRD, the Advanced Monitoring Development (AMD) Group is particularly concerned with ways of detecting human exposure and response to chemicals.

Measuring Human Exposure to Environmental Chemicals

Several approaches can be taken to estimating and quantifying human exposure to chemicals. These approaches form a basis for chemical pollutant monitoring:

• Ambient monitoring—measurement of the chemical concentration in the whole environment (for example, air monitors) or in the microenvironment around an individual (personal exposure monitors)
• Internal dose monitoring—measurement of the concentration of a chemical in body fluids or within body tissues
• Bioeffects monitoring—measurement of biological effects or changes that occur as a result of chemical exposure.

Bruce Tromberg (left), a University of Tennessee (UT) graduate student, Vo-Dinh, and Michael Sepaniak, UT assistant professor, measure fluorescent products in a solution using the fluoroimmunosensor (FIS).

Ambient monitoring is an important first step because it can establish whether an environment is heavily or lightly polluted by chemicals and which chemicals are the major offenders. The usefulness of ambient monitoring, however, is limited. In a complex chemical environment, many different chemicals may require monitoring; furthermore, ambient monitoring cannot quantify the extent of individual uptake of pollutant chemicals.

The problem of monitoring individual exposure and subsequent uptake can be solved by determining the internal chemical dose—that is, the amount of a given chemical that a human actually absorbs, whether by inhalation, skin absorption, or some other route. Internal chemical dose can be estimated by measuring the concentration of a chemical or its biotransformation products (chemical products changed structurally from the original chemical species as a result of body metabolism) in body fluids or tissue samples. Such measurements have some limitations. For example, (1) in the case of individuals exposed to a complex chemical environment, it may be necessary to measure the concentrations of many different chemicals, and (2) the metabolic conversions and transformations of some chemicals are exceedingly complex and not well understood, thus making it difficult to estimate total internal dose based on chemical concentrations in a body fluid or specific tissue.

Bioeffects monitoring measures a change in biological function in humans that results from chemical exposure; this biological response can serve as an indirect indicator of

Following chemical exposure, fluid samples can be withdrawn and analyzed.

Scientists at ORNL have developed several methods of detecting human responses to hazardous energy-related chemicals. They are using interferon as a bioeffects marker and are developing the "fluoroimmunosensor," which detects minute amounts of polynuclear aromatic hydrocarbons in body fluids and tissues.

chemical exposure. For example, if the body is exposed to a certain chemical, it may produce a new chemical (such as an enzyme) to neutralize the effect of the chemical exposure; this new body chemical could serve as a red flag to indicate exposure to the environmental chemical. The change in biological function can be, but does not necessarily have to be, associated with some disease process caused by the chemical. All that is really necessary for a useful estimate of chemical dose is a detectable, reproducible biological change in response to a chemical exposure. Ideally, the magnitude of this response would be related to the dose of chemical received; lack of such a dose-response relationship is often a hampering factor in applying bioeffects markers to monitoring needs.

Although relating some biological response to a dose of chemical received by an individual may be very difficult, bioeffects markers do have unique advantages in chemical monitoring. A bioeffect produced by chemical exposure may be an integrative response to a whole class of chemicals (or even the total chemical mixture): thus the bioeffect marker may provide a general indication of *total* chemical exposure. Furthermore, bioeffects markers can indicate individual human sensitivity to chemical exposure.

The primary goal of the AMD Group is to develop a research program that addresses all three aspects of chemical pollutant monitoring by integrating HASRD's resources and expertise in molecular spectroscopy, instrumentation, biology, and biochemistry. While advanced monitoring techniques, such as room-temperature phosphorescence, synchronous luminescence, and surface-enhanced Raman spectroscopies, are being developed to detect ultratrace levels of chemicals in the ambient environment, a new generation of monitors is being investigated for use as practical tools for assessing internal dose and related bioeffects of chemicals. This article will focus on ORNL research on bioeffect monitors (such as interferon) and internal dose monitors.

Interferon Production: Indicator of Human Response to Chemicals?

Interferon, a protein product of the immune system as well as other body cell types, performs several functions that make it extremely interesting to biologists. It can slow or stop the growth of various viruses (it is one of the body's chief defenses against viral invasion), it helps regulate cellular growth, and at least in some cases it can inhibit growth of cancer cells. Because of these properties and their obvious importance to human health, interferon has received a great deal of publicity in recent years and has been hailed as one of the "magic bullets" in modern medicine's armamentarium.

Interestingly, the idea of using interferon as a biomarker for chemical exposure evolved from my discussion with Eugenia Calle (currently at the Centers for Disease Control in Atlanta) after we had each watched the same science information program on public television. The program dealt with new discoveries about interferon and its uses. Our interest grew as we read the available literature and communicated with various experts. We became convinced that our idea was worth pursuing. We eventually found a receptive ear in David Smith of the U.S. Department of Energy's (DOE's) Office of Health and Environmental Research and received funding to carry out a pilot study using mice as a model system to demonstrate the feasibility of future human studies.

The experimental evidence that encouraged us to investigate the interferon system came from cell culture studies. In these studies, if certain cells growing in test tubes are treated with an appropriate inducing substance (such as a viral preparation), they will begin to produce interferon, which can be detected in the cell-culture fluid. If these same cultured cells are treated with certain carcinogenic (cancer-causing) chemicals before

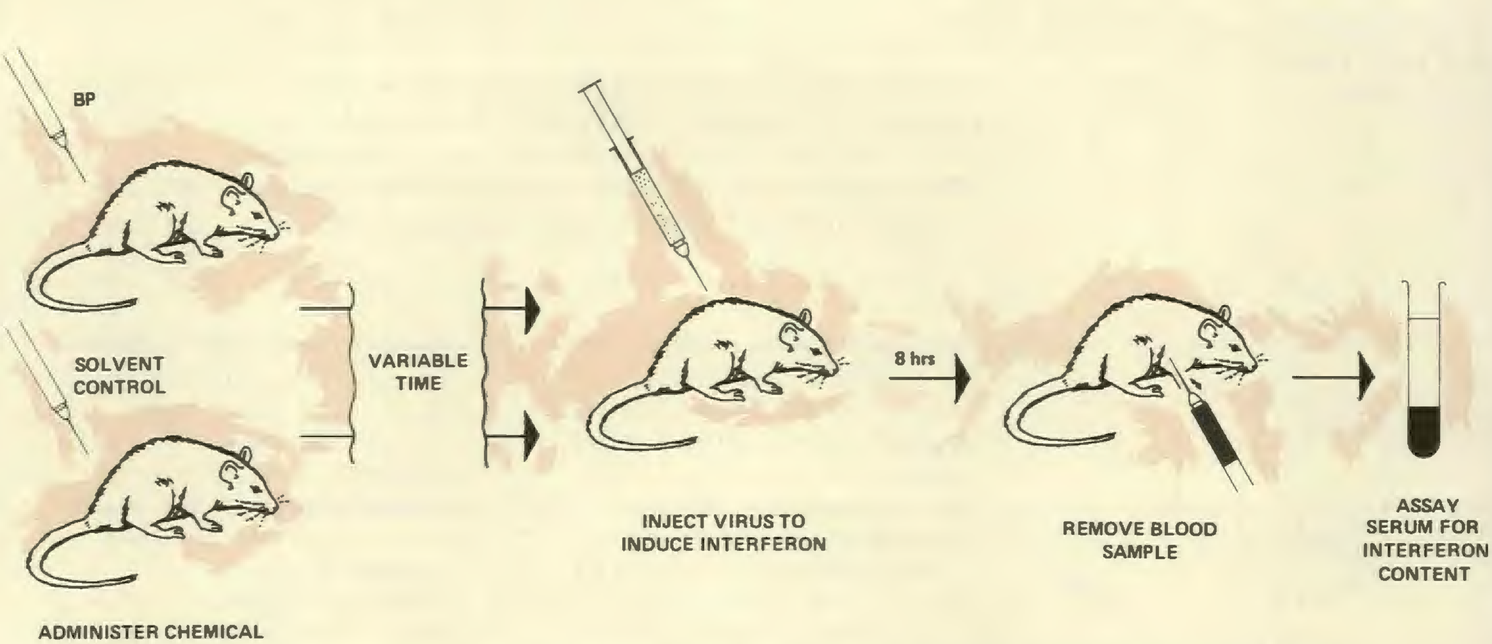


Fig. 1. Experimental protocol used to test the effect of benzo(a)pyrene (BP) administration on induced interferon production in mice.

being induced for interferon production, the interferon response is strongly suppressed. Pretreatment with chemicals not active as carcinogens but with structures similar to the chemical carcinogens has no effect on interferon production. For example, benzo(*a*)pyrene (BP), a carcinogen found in the products of fossil fuel combustion and conversion, was shown to suppress interferon production, but benzo(*e*)pyrene, a noncarcinogenic analog, had no effect.

Almost all of the studies that demonstrated an effect of chemicals on the interferon response have involved cell-culture systems. We thought it important to extend these results to a whole-animal model to answer this question: Would treatment of an animal with a toxic, cancer-causing chemical affect interferon production in response to an appropriate stimulus?

In collaboration with William Mitchell of Vanderbilt University, in whose laboratory the interferon assays were done, we treated mice with intraperitoneal (within the abdominal cavity) injections of BP of varying doses. At various time intervals after chemical injection, mice (Fig. 1) received a further injection of viral preparation that induced a systemic interferon response. After 8 h (when the interferon response to viral induction was optimal), blood was withdrawn from the mice, and interferon levels in serum were determined. The interferon measurements involved a biological assay in which the activity of interferon-containing samples was quantified by the extent of protection afforded to cells in culture. In this assay, cells were treated with interferon samples, and then a virus was added that destroyed those cells not protected by interferon (Fig. 2).

We found that BP treatment depressed interferon production in mice in a dose-dependent fashion when interferon production was induced by viral treatment 48 h after BP injection. At the highest dose of BP used (Fig. 3), interferon production in treated animals was less than 10% that of control animals. In further experiments, we demonstrated that the interferon response was suppressed as early as 12 h after BP treatment and that the effect persisted for as long as 5 days after the BP injection.

Although the highest dose of BP we used is certainly very large (particularly for a single exposure) when scaled to a "reference" human (an individual weighing 70 kg, or 154 lb), we know nothing of the differences in species sensitivity with respect to the interferon response to chemicals. The human interferon response may be sensitive to quite different doses of toxic chemicals than is the case with mice. Whether the BP effect on interferon production has some relationship to the carcinogenic activity of BP is unclear. Altered interferon can still be a useful biomarker for chemical exposure, even though basic biological mechanisms have not been elucidated.

At this stage, it is logical to extend our studies to actual human subjects. We can exploit the ability of certain cell types in the circulating blood (lymphocytes) to

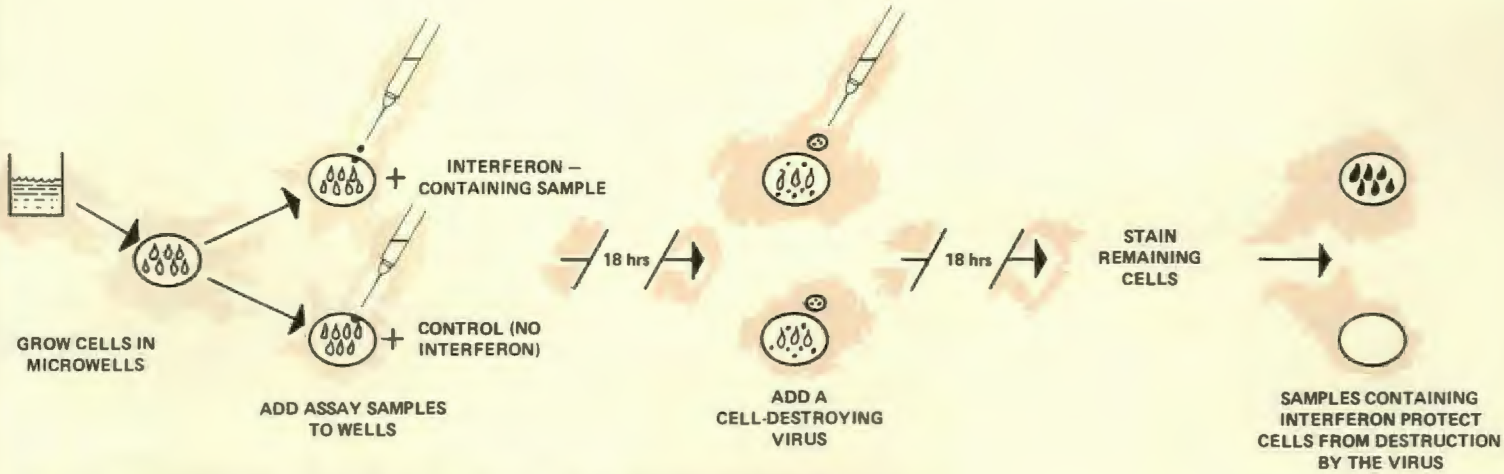


Fig. 2. Assay protocol for detecting interferon activity in samples of biological fluids.

produce interferon either inside or outside the body. We could withdraw small blood samples from individuals, separate the lymphocytes, induce them in cell culture to produce interferon by adding a viral preparation, and assay the fluids from the culture system for interferon content. It would be interesting to compare the interferon responses of smokers and nonsmokers and of individuals working in a chemically polluted environment for different time periods. This method would also be useful for conducting sequential studies of individuals before and after occupational exposure. The potential practicality of the interferon response as a bioeffects marker in humans now awaits exploration.

Other Bioeffects Markers

Besides the interferon work, ORNL researchers are examining other potential bioeffects markers. Mayo Uziel, also a member of the AMD Group of HASRD, is investigating whether certain unique chemical compounds produced by tissue breakdown could serve as markers of cellular damage induced by toxic chemicals. These substances are unique because, unlike other cellular degradation products, they are not directly derived from the diet, and often they are not changed by the body (metabolized) to other compounds. Examples of such substances are certain chemicals derived from the breakdown of cellular nucleic acid. These breakdown products may be produced after cellular damage from toxic chemical exposure; they are not reused to make new cellular material, so they are excreted. Measuring the concentration of such products in the urine of exposed individuals might therefore indicate the extent of tissue damage.

In another project, I am collaborating with Carl Burtis, Zane Egan, and Norman Lee of ORNL's Chemical Technology Division in studying the potential usefulness of a particular enzyme as a biomarker of human exposure to polynuclear aromatic hydrocarbons (PNAs). PNAs are produced by incomplete combustion of fossil fuels and in processes that convert coal and oil shale to synthetic fuels. These hydrocarbons include compounds of a highly toxic nature, such as BP. The particular enzyme (cytochrome P_{448}, a mixed-function oxidase) involved is interesting because PNA exposure can cause large increases, at least in certain cell types, in the enzyme's concentrations. Thus, by comparing measurements of this enzyme's level in appropriate cells from individuals exposed to PNAs with the enzyme level measured in the unexposed state, we might be able to estimate the degree of exposure. We are currently investigating the activity of this

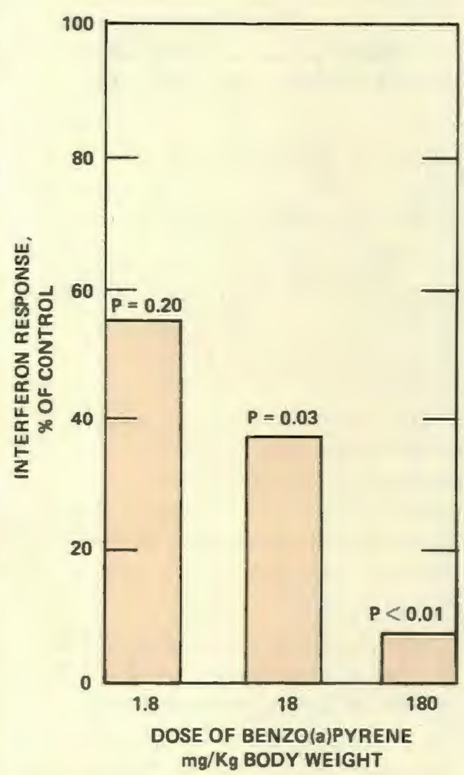
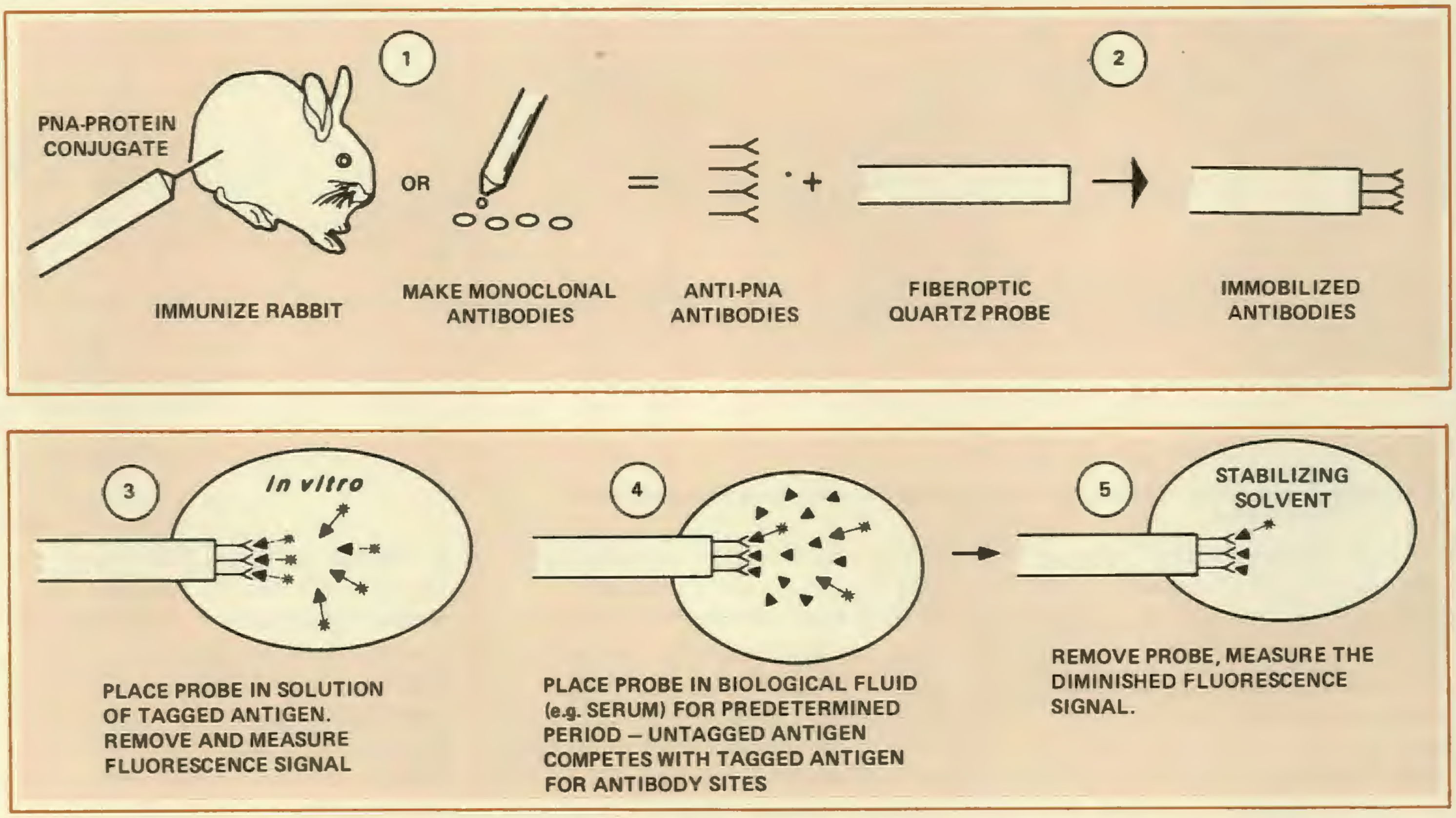


Fig. 3. Depression of interferon response in mice 48 h after BP treatment.



Figs. 4 and 5. Generalized schematic for development of a fluoroimmunosensor. Either immune animal sera or monoclonal antibodies (homogeneous antibodies produced by clones of specially formed cells that have high specificity and affinity for a single antigen) may be the source of chemical-specific antibodies. In the case of chemicals having strong fluorescence of their own (like certain PNAs) [step 3] may not be necessary; that is, their presence in biological fluids [step 4] can be determined directly, rather than indirectly. The schematic presents the technique of most general application to a wide range of chemicals, whether fluorescent or not.

enzyme in human blood lymphocytes and hair follicles, with a view toward using tissue samples that can be easily obtained from workers in the fossil fuel industry.

Internal Dose Monitors

Another aspect of pollutant monitoring research at ORNL involves devising ways to measure internal chemical concentrations in humans. In particular, I will describe our current efforts to develop a device called a fluoroimmunosensor (FIS), which can detect minute amounts of PNAs in body tissues and fluids. This work is a collaborative effort between ORNL and the University of Tennessee (UT) at Knoxville; Tuan Vo-Dinh, Kathleen Ambrose, and I at ORNL are working with Michael Sepaniak and Bruce Tromberg at UT. We have also had valuable assistance from students (Chris Murchison and Melissa McManus) and from Allen White and Gordon Miller in our group. This project is supported by DOE and the National Institutes of Health.

The FIS device combines concepts from two quite different scientific disciplines (biology and spectroscopy) into an integral detector of potentially great utility. The biological contribution comes in the development of chemical-specific antibodies. Antibodies are protein molecules made by certain cells of the immune system; they are produced in response to antigens, chemicals that are foreign to the system. To protect the body from these foreign chemicals, antibodies bind to the antigens in a lock-and-key fashion to render them harmless. The unique feature of antibodies that we exploit is the "hand tailoring" of a particular molecular site on the antibody so that it will fit and bind, with exquisite specificity and high affinity, the antigen molecule against which the antibody has been synthesized. Thus, if we can make antibodies using chemicals of interest as antigens, we will have an extremely specific probe to look for those chemicals, even in samples containing many other similar chemicals.

To produce a device that can use these chemical-specific antibodies as a detector (Figs. 4 and 5), the

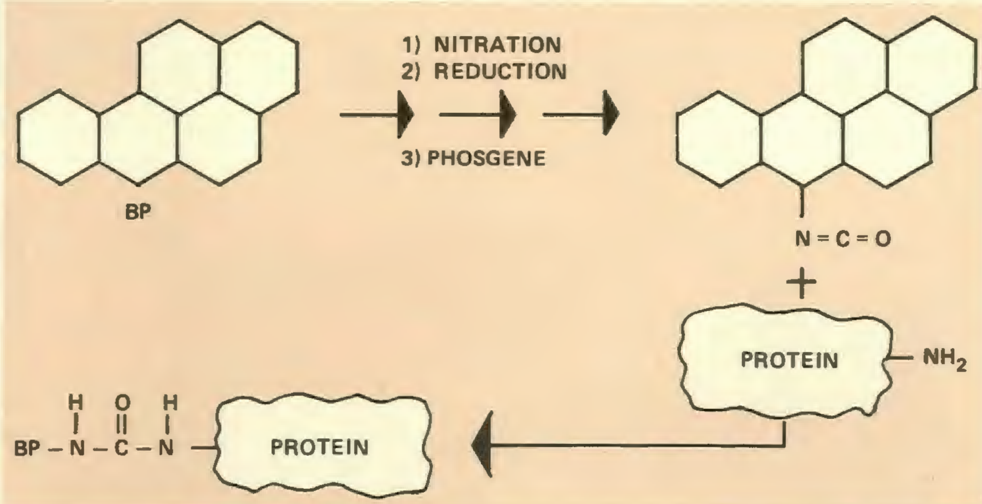


Fig. 6. Chemical synthesis of a BP-protein conjugate used to produce antibodies against BP.

antibody must be chemically bound, or immobilized, onto the tip of a quartz optical fiber, or light pipe. This arrangement provides a mechanism for directing a very intense and tightly focused light beam from a laser onto the antibody-coated tip. The fiber-optic probe can then be immersed into a standard solution that contains the antigen, which is tagged with a chemical that fluoresces when excited by light of the appropriate wavelength. The actual analytical technique employed is detection of the fluorescence of this "tag." After saturating binding sites on the immobilized antibody with the fluorescent antigen, laser light of an appropriate wavelength can be passed down the fiber to excite the fluorescent tag, and the resulting fluorescent light can be collected and quantified by the same fiber.

If the probe is now placed in a body fluid sample (an in vivo or living source, such as blood or saliva) from an individual who has received an internal dose of the chemical of interest, molecules of chemical (the antigen) in the body fluid can compete for and remove some of the fluorescently tagged chemical molecules bound to the immobilized antibody. (Because the antigen-antibody reaction is reversible, it is governed by the principles of reversible reactions.) The decrease in the fluorescence signal, then, will be proportional to the concentration of chemical in the body fluid. Laser light sources and sophisticated electronics can be used to obtain high resolution and sensitivity. In this way, the amount of a target chemical can be inferred.

In developing the FIS detector system, we have chosen BP as a model PNA; our eventual goal is to develop FIS detectors that can monitor other PNAs of particular interest because of their environmental abundance or toxicity. Our first task was to induce rabbits to make antibodies to BP. To accomplish this, we had to resort to a trick because small molecular structures like BP are not very antigenic. Because the immune system seems to produce more antibody in response to large molecules like proteins, we decided to introduce BP to the immune system as part of a larger molecule. Aided by chemists from HASRD's Nuclear Medicine Group, we used a chemical synthesis to couple a BP derivative to free amine groups of a protein molecule (Fig. 6). Many more than one BP residue is actually coupled to a given protein molecule. This BP-protein conjugate was injected into rabbits, and we depended on the rabbits' immune systems to do the rest. Of course, the immune system would recognize the protein molecules and develop antibodies against it, but, because development of antibodies that recognize *unique* structural sites on a large antigenic molecule is quite common, we hoped that antibodies specific against the BP molecular structure would also be developed.

To determine whether the rabbits were producing BP-specific antibodies, we needed a method to test for this activity. Although we used two independent assays, I will describe only one, the Enzyme-Linked Immunoabsorbent Assay (ELISA). For this highly sensitive, easy-to-use assay (Fig. 3), we first add BP-protein conjugate to microwells of "sticky" polystyrene. The BP-protein molecules attach to the plastic and are immobilized, thus preventing removal by washing. Next we add serum samples from rabbits to test their anti-BP activity. If anti-BP antibodies are present, they will recognize and bind to BP antigen immobilized in the well.

After washing the plastic microwells to remove nonspecifically bound antibody, we add a second, or detecting, antibody to the wells. This antibody, made in a goat or other animal species, recognizes and attaches to any rabbit antibody already immobilized in the wells, forming a chemical "sandwich." This second antibody has a unique feature on which the assay depends; an enzyme molecule is chemically attached to it. If this second antibody is immobilized in a well, so is the attached enzyme. When a chemical called the enzyme substrate is added to the wells, the enzyme converts this substance into a colored (or fluorescent) product, which can be detected by spectroscopy. Because a single enzyme molecule can convert thousands of substrate molecules into a colored product, the intensity of color in the wells can be multipled manyfold beyond the actual amount of enzyme in the wells. The enzyme activity in essence, therefore, produces a chemical amplification of the previous specific antibody binding that has taken place in the well. The production of color in the microwells thus provides a very specific and sensitive means of assaying for the presence of antigen-specific antibodies. We have recently used the luminoscope, a fiber-optic-based device developed in the AMD Group, to successfully detect less than 100 picograms of anti-BP antibody (Fig. 7).

By using this assay system to monitor the immunization of rabbits with BP-protein conjugates, we detected some highly immune animals. In fact, in one case, a dilution of one part of immune serum to 2×10^6 parts of buffer was still active in our ELISA system. We also found that our antibody preparations recognized free BP in solution (not covalently bound to protein as in the BP-protein conjugate). We established this by using a radioimmunoassay in which we added radioactively labeled BP to our antibody preparation and then separated the free BP from antibody-bound BP. The antibody-bound BP fraction was quantified by radioactive counting. The antibody recognition of free BP was good news because it indicated that at least some antibody molecules respond to the BP molecular structure alone; thus, presentation of the BP antigen in conjunction with a large protein molecule is not necessary for antibody recognition.

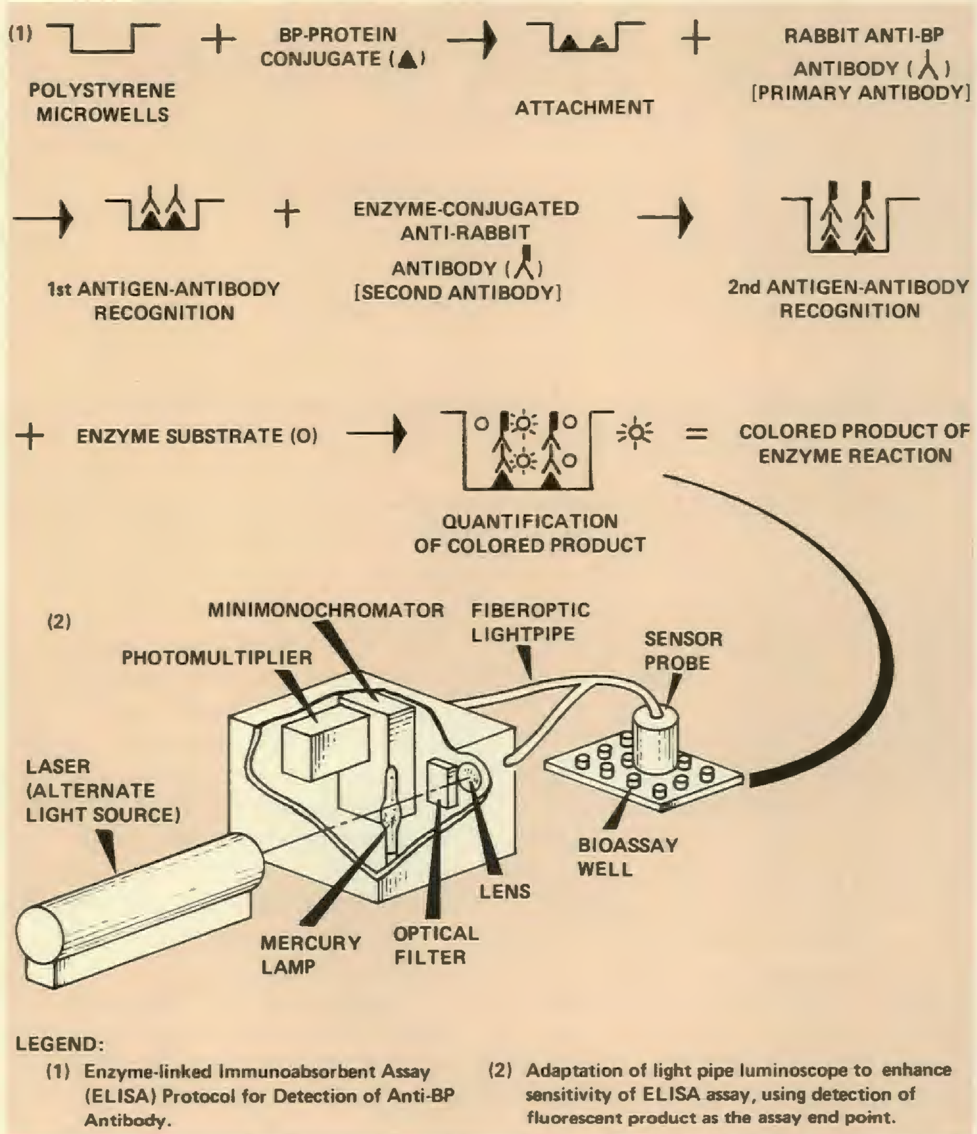
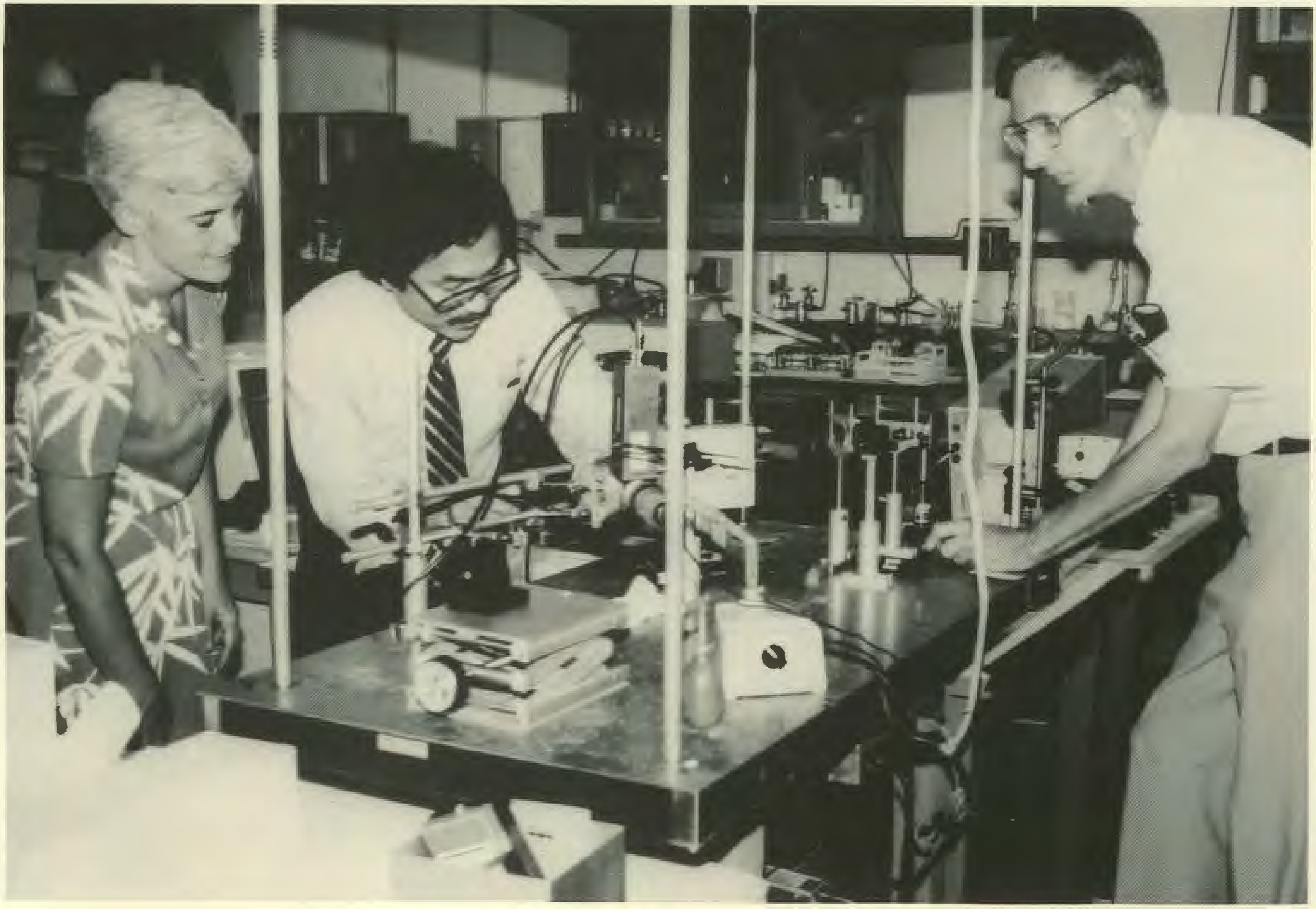


Fig. 7. (1) Enzyme-Linked Immunoabsorbent Assay (ELISA) protocol for detection of anti-BP antibody. (2) Adaptation of light pipe luminoscope to increase the sensitivity of the ELISA assay, using detection of the fluorescent product as the assay endpoint.

Future Directions

We are currently purifying our anti-BP antibody from other serum proteins; the next step will be to immobilize it on the optical fibers. Several questions remain. Will any loss of antibody activity occur upon attachment to the fiber? Will other PNAs react with the antibody and possibly interfere with detection of BP? Will the antibody recognize certain conversion products of BP that might be produced by body metabolism? What is the detection sensitivity of the device? Despite these questions, we are very optimistic about the future of FIS instruments.

The application of such devices could obviously extend beyond biomonitoring into numerous areas of medicine. With appropriate antibodies, sensors could be made to detect levels of therapeutic drugs in fluids of patients receiving these drugs. For example, an FIS device might be used to monitor heart



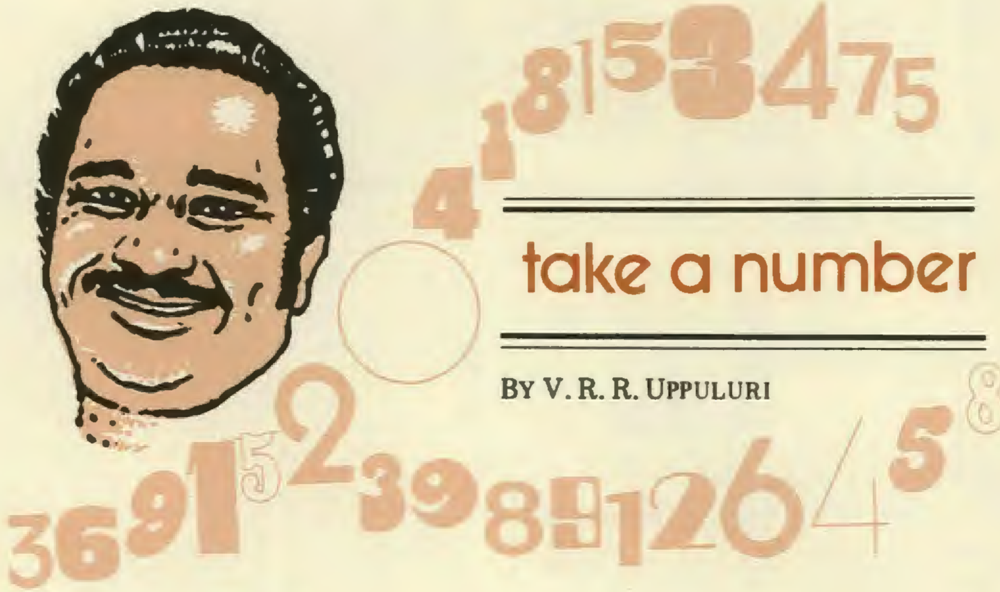
patients taking digitoxin, a drug that is toxic if an accumulated overdose results. Sensors could also be used as diagnostic tools to detect levels of hormones, enzymes, and other cellular products in very small samples of human blood, urine, or other fluids.

New advances in biotechnology may also contribute substantially to development of the FIS concept. Although so far we have used antibodies from rabbits in our work, it is also technically feasible to use monoclonal antibodies (antibodies produced from clones of cells formed by fusing endlessly growing cancer cells with antibody-producing spleen cells from mice). Monoclonal antibodies are superior to conventional antisera preparations because they are pure, can have an extreme specificity and high affinity for antigenic structures, and are readily obtainable in large amounts. Because of their high specificity and avidity for a particular antigenic structure, monoclonals would provide a much better antibody for the FIS device than would the usual rabbit polyclonal antisera.

Finally, we can see applications of FIS devices to other aspects of our own research. One intriguing idea is to develop an FIS device that could measure interferon concentrations in various biological samples. Such a device would eliminate the need for the lengthy, variable-laden biological assay now in use, thus making interferon measurements much more practical as a screening tool for chemical exposure.

Kathleen Ambrose, Vo-Dinh, and Griffin align the laser with the fiber-optic probe before making FIS measurements in solution. When applied to human body fluids such measurements could determine internal chemical dose.

Development of techniques and devices to detect and quantify human exposure to chemicals, either by measuring directly the internal concentration of a chemical or by using bioeffects markers, remains an important mission as new energy technologies, with their attendent chemicals, are developed. For us, protecting human health from this chemical threat is an exciting and worthwhile challenge. ornl



take a number

BY V. R. R. UPPULURI

Prime Numbers and Benford's Law

In 1938 Frank Benford empirically observed that among the first digits of physical constants observed in nature, the number 1 appears more often than 2, and the number 2 appears more often than 3, and so on. Examples of physical constants are the index of refraction of light in water (1.3) and the atomic weight of hydrogen (1.0080). Astonishingly, Benford predicted correctly the proportion of times that the digit d appears as the initial digit. This proportion is equal to $log_{10}[1 + (1/d)]$ for $d = 1, 2, \ldots, 9$. Benford's Law may be summarized this way: 1 appears as the initial digit in 30.1% of the physical constants, 2 appears as the initial digit in 17.6%, and 9 appears as the initial digit in only 4.6%.

Prime numbers—natural numbers with only two factors (1 and the number itself)—have attracted attention for centuries because of the lack of patterns. For example, the first few prime numbers (2, 3, 5, 7, 11, 13, 17, 19, 23, and 29) show no relationship, thus making it difficult to predict which of the subsequent numbers are primes.

In an article published in an issue of the *American Mathematical Monthly* in 1972, R. E. Whitney proved that the relative logarithmic density of prime numbers with initial digit d among the class of primes is equal to $log_{10}[1 + (1/d)]$. From this relationship, it can be concluded that the initial digits of prime numbers follow Benford's Law. In other words, a higher percentage of prime numbers starts with the number 1 than with 2, and a higher percentage of prime numbers begins with 2 than with 3, and so on.

Vinod Sikka (left), Tony Schaffhauser, and Jon Soderstrom examine extrusion billets of the modified nickel aluminide alloy developed at ORNL. The extrusion billets in the photograph were produced by Armco Steel, and the centrifugally cast pipe was made by Combustion Engineering. The two companies performed this work for Martin Marietta Energy Systems, Inc., under a cooperative cost-sharing agreement. In the background is ORNL's extrusion press. Sikka and Schaffhauser are working on transferring to industry the technology of making modified nickel aluminide alloys, and Soderstrom is ORNL's director of technology applications.

THE TECHNOLOGY TRANSFER FUND:

A Status Report on the ORNL Projects

By CAROLYN KRAUSE

For many years, employees at Oak Ridge National Laboratory talked about technology transfer but little was done to make it happen. In fact, only in the past several years have employees been encouraged to start their own firms or to consult with established companies to move new developments with practical uses from the laboratory bench to the marketplace. Since then, a number of developments have begun to stimulate technology transfer, culminating in the December 1985 announcement of the first commercial licensing by the Laboratory's operating contractor of a patented, ORNL-developed technology.

In 1984 ORNL for the first time committed money to hasten the process of transferring information to companies that might be interested in manufacturing and marketing products based on Laboratory prototypes. This commitment was part of a new industrial technology initiative, whose goal is to increase both the rate of innovation at ORNL and the frequency of effective commercialization of ORNL processes and products.

To increase the rate of innovation, Martin Marietta Energy Systems, Inc., the Laboratory contractor, pays ORNL inventors royalties of $100 to $1000 for work-related innovations after they have filed a patent application with the U.S. Patent Office. In the past, ORNL employees receiving patents were given only a framed one-dollar bill. The first cash awards were

ORNL, DOE, and the Office of Technology Applications of Martin Marietta Energy Systems, Inc., have committed funds to stimulate innovation and bring ORNL technologies to the stage where their commercial potential can be judged. The status of five technology-transfer projects is described.

given by Energy Systems in June 1985. Of the 42 Energy Systems employees receiving the awards, 31 work or used to work at ORNL (for names of the ORNL employees, see page 41 of "Awards and Appointments").

William W. Carpenter, Energy Systems vice-president for technology applications, is enthusiastic about the inventor awards. "These awards help to recognize the creativity and hard work of our many employee inventors, more than 500 of whom already are holders of one or more U.S. patents," says Carpenter. "Our new program is designed both to recognize these important contributions and to create an incentive for even greater innovation and productivity in the future."

To increase the rate of commercialization of ORNL developments, Martin Marietta has taken several approaches. It has helped set up the Tennessee Innovation Center to nurture start-up businesses including those marketing ORNL technologies. In 1985 the Innovation Center invested in several new companies, among them ORNL spin-offs; it is now building permanent quarters for itself and companies it is assisting. In addition, Energy Systems has proposed to the Department of Energy a plan for owning and licensing patent rights to ORNL-developed technologies to expedite commercialization. Finally, the company has worked with the Laboratory management in selecting a few commercially promising technologies developed at ORNL and bringing them to the stage where industry can judge their commercial potential.

In 1984 ORNL contributed $100,000 to a new Technology Transfer Fund, now administered Energy Systems' Office of Technology Applications, and DOE agreed to match this investment. Then a committee selected 5 of 24 ideas submitted by the staff for support by the $200,000 fund.

The projects selected for support were modified nickel aluminide alloys, multicomponent separations by continuous chromatography, remote analytical instrumentation, an electronic image detector for electrophoresis and chromatography (EIDEC), and a pulsed-helium ionization detector for gas chromatography. (As an indication of the Laboratory's good judgment in identifying commercially promising developments, the latter two received 1985 I•R 100 awards from *Research & Development* magazine.) In 1985 additional support from the Technology Transfer Fund was given to the nickel aluminide alloy project and the pulsed-helium ionization detector development.

New projects that received support from the 1985 Technology Transfer Fund (nearly $200,000) were

• **Fabrication of ceramic composites by chemical vapor infiltration.** Tough composites are formed by depositing a ceramic matrix around a fibrous preform. Numerous companies have requested samples of these composites for testing and evaluation. Currently, sample production is limited by the amount of time required to produce each sample (20 h) and the availability of only a single furnace. Technology transfer funding will be used to modify another furnace for sample production, to purchase higher-strength, three-dimensional woven preforms for infiltration, and to buy better flow meters and controllers needed for further development of ceramic composite coatings.

• **Biocatalyst beads for advanced fermentation systems.** Bioreactors such as fermentation systems use microorganisms to catalyze chemical reactions. Bioreactors can be made more efficient by fixing high concentrations of microorganisms into or onto a solid material to prevent the organisms from being washed out of the reactor even at high flow rates. A particularly attractive approach for fermentation systems is to encapsulate densely packed microorganisms into a gel matrix in the form of beads. Such biocatalyst beads may be 10 times more effective than the conventional technique of suspending the microorganisms within a culture medium in the bioreactor. Support from the Technology Transfer Fund will allow production of a series of biobead samples that can be supplied to interested companies for evaluation.

• **Whole-blood processing rotor.** This ORNL-developed analytical device is capable of accepting a specimen of whole blood and automatically processing it into separate microliter samples of serum, which can then be individually analyzed. The device is expected to be useful for physicians' offices, hospital emergency rooms and special care units, and even bedside monitoring. Technology transfer funding will allow fabrication and evaluation of a modified prototype of the device.

The most successful of the projects initially funded in 1984 has been the nickel aluminide alloys developed under the leadership of C. T. Liu of the Metals and Ceramics (M&C) Division. These alloys, modified at ORNL, are of particular interest to the commercial world because of their strength at high temperatures (1000°C), resistance to corrosion, and ductility—ability to be deformed or shaped without breaking. These alloys also use feed materials that are less expensive and lighter than those in conventional high-temperature alloys.

The long-range ordering of nickel aluminide increases the alloy's strength with rising temperatures; the aluminum in the alloy contributes to the light weight and to corrosion resistance because aluminum forms protective oxide scales; and small additions of boron make the alloy ductile. Such modified alloys are in demand for valves and other components of energy-efficient engines operated at high temperatures, as well as high performance jet engines, gas turbines, vessels for coal gasification and liquefaction systems, and heat exchangers in nuclear and coal-fired steam plants.

ORNL Technology Licensed

In December 1985, Energy Systems and Cummins Engine Company signed an exclusive license agreement for joint research, development, and commercial application of nickel and nickel-iron aluminide alloys. Cummins, the world's largest manufacturer of heavy-duty diesel engines, will carry out research on the ORNL alloys, which are candidate materials for components of high-temperature diesel engines. The agreement is the first commercial licensing by Energy Systems (rather than DOE) of a patented ORNL development. (The first Energy Systems licensing of a copyrighted ORNL technology occurred earlier in 1985, when Energy Systems gave Environmental Systems Corporation of Knoxville the exclusive rights to manufacture and distribute ORNL's fiber-optic luminoscope, which detects skin contamination.)

The M&C Division has initiated cost-sharing arrangements with five materials suppliers, resulting in industry commitments of up to $1 million over three years to scale up aluminide production to ingot size by commercial casting and powder metallurgy processes. ORNL's industrial collaborators and contributors include Cabot Corporation, Garrett Turbine Engine Company, Combustion Engineering, Homogeneous Metals, Universal-Cyclops, Specialty Metals, and Pratt and Whitney. Each company has different interests in and uses for these materials.

These industrial interests and applications were discussed at a recent workshop sponsored by DOE's Energy Conversion and Utilization Technologies (ECUT) Materials Project. At the ECUT workshop, these results were presented:

- Cabot metallurgists found that their scaled-up ingots of nickel aluminide cracked during hot forging. They hope to achieve better results with nickel aluminide alloys that contain substantial iron additions (15%). In laboratory studies, Liu has found that an aluminide alloy with the correct iron addition can be hot rolled without cracking. In fact, ORNL efforts are now focused on the commercialization of nickel aluminides containing large additions of iron and small additions of cerium. Nickel-iron aluminides are more easily shaped into components at high temperatures than are nickel aluminides lacking iron.
- Garrett's studies of nickel aluminide alloys with small additions of hafnium and boron have yielded mixed results. Turbine engine blades made from single-crystal aluminides have shown better properties than blades fabricated from polycrystalline aluminides.
- Domenic Canonico, a former ORNL staff member now with Combustion Engineering, reports that the company has used air-induction melting and other techniques to produce castings of nickel aluminides.

Besides ORNL's industrial partners, the U.S. government is interested in the modified nickel aluminide alloys because of their energy, defense, and space applications. ORNL researchers have received funding from DOE, the U.S. Department of Defense, and the National Aeronautics and Space Administration to improve the alloys' properties.

The other four projects supported by the Technology Transfer Fund are moving in the direction of commercialization, albeit slowly. According to Jon Soderstrom, director of technology applications at ORNL and a staff member of the Office of Technology Applications, "We will continue support for these projects until their commercial potential is fully assessed by industry. And we will continue to identify other projects at the Laboratory that merit support by the Technology Transfer Fund. One of the modes of transfer that we will be pushing is the display of our infant technologies at trade shows. DOE has lifted restrictions on our participation in trade shows, so we will move increasingly in that direction."

The other four projects receiving funding in 1984 and their technology transfer prospects are described here in detail.

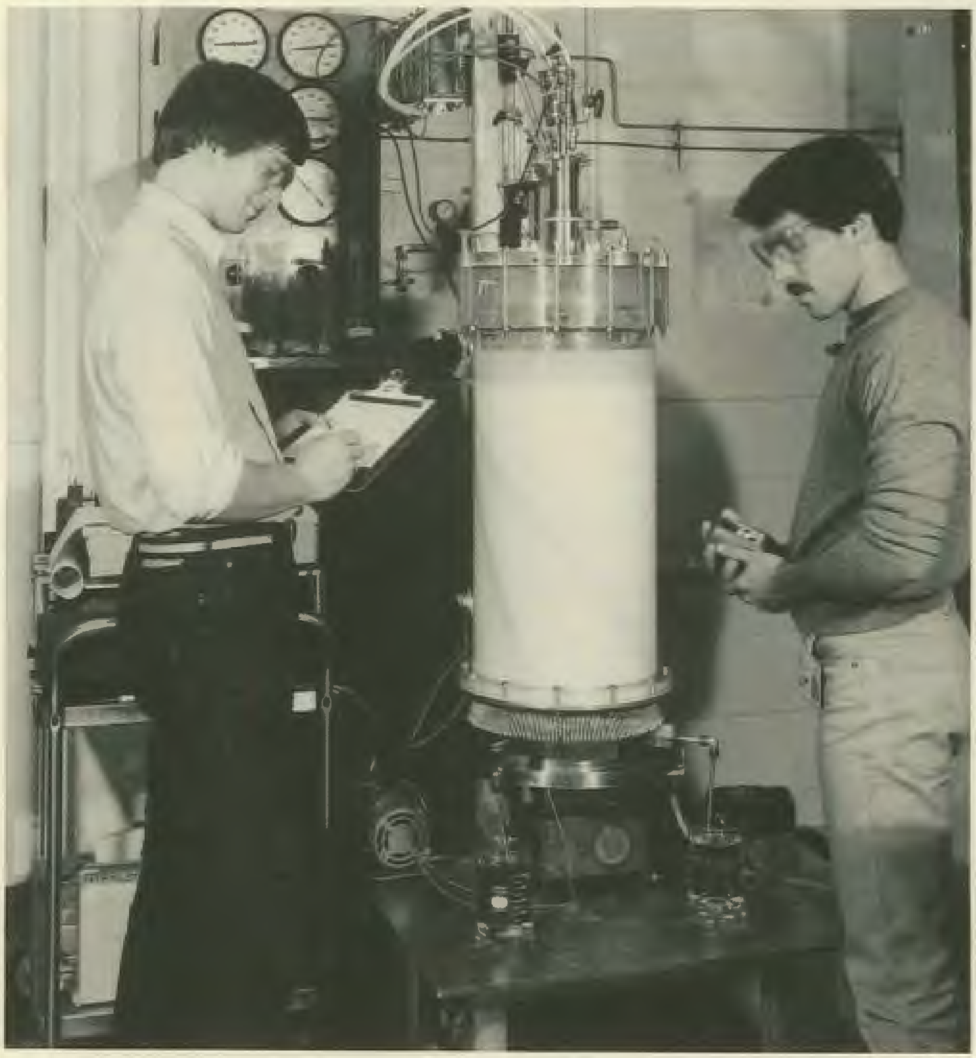
Continuous Annular Chromatography Separates Liquid Components

In 1974 Chuck Scott of ORNL's Chemical Technology Division conceived the idea of developing continuous annular chromatography (CAC) for separating multiple components of liquids. A year later, he built a CAC prototype and demonstrated its advantages over batch liquid chromatography. Since 1975 Scott and his colleagues in the Chemical Technology Division—John Begovich, Charlie Byers, Ron Canon, Warren Sisson, and Roger Spence—have studied the concept and devised a theory to explain how it works and how best to design and operate CAC units. Their papers, which were compiled and published in August 1984 as a book (*Continuous Annular Chromatography Contributions to the Literature, 1976–1984*), have aroused the interest of the industrial world.

"We have received more than 350 requests for reprints of the papers from all over the world, including nations like Argentina, Japan, Israel, and Rumania," says Byers. "Even more gratifying, at least a half dozen outfits in the United States are pursuing commercialization of the CAC concept. Some of these companies have bought CAC units based on the ORNL design from the Oak Ridge firm Keystone Precision Machine and Welding, Inc."

The commercial concerns showing interest in the CAC concept are

- Stearns-Roger Engineering Company, an engineering process design outfit that designs chemical plants and conducts experiments in hydrometallurgical separations to obtain strategic materials, such as cobalt and nickel, from spent copper ores in the Rocky Mountains. Begovich has consulted with the company and has given it ORNL drawings of the CAC. Sisson also has consulted with Stearns-Roger. The company, which is interested in manufacturing and marketing scaled-up CACs, is trying to determine what the market is for the devices and is planning to build and demonstrate a commercial scale CAC unit to show the selling points of the technology.
- Florida Progress Corporation (a subsidiary of Florida Power Corporation), which seeks to use CAC units to separate from fly ash metals such as aluminum and iron and strategic materials like chromium and cobalt.
- Engenics, Inc., which used a CAC unit to separate proteins, including enzymes (highly active substances in living cells that stimulate chemical reactions). Such separations are now listed in the company bulletin.
- A Westinghouse subsidiary that performs radionuclide separations, such as separating zirconium from hafnium for use in nuclear reactors. This company has bought a CAC unit from Keystone.
- Eastman Kodak Company, which purchased a CAC unit from Keystone to do chemical processing. Eastman plans to build bigger CACs [larger than the Oak Ridge models, which are 30.5 cm (12 in.) and 48.3 cm (19 in.) in



Steve Krazniak (left) and Lewis Bender, who conducted research at ORNL in 1982 as Massachusetts Institute of Technology graduate students, carry out continuous biological separations using a 30-cm (12-in.) continuous annular chromatograph.

John Begovich (left) and Warren Sisson perform a hydrometallurgical separation on a 45-cm (18-in.) diameter pilot-scale continuous annular chromatograph.

Charlie Byers (left) and Warren Sisson of the Chemical Technology Division describe ORNL's continuous annular chromatography system in a discussion with Randy Kirkbride of the Exxon Nuclear Idaho Company.

diameter] for large-scale chemical separations.

- Eli Lilly and Company, a pharmaceutical firm interested in using CAC units for purifying drugs and separating isomers and enzymes. Scott has consulted with this company.
- Miles Laboratory, a biotechnology and pharmaceutical firm that has sent staff members to ORNL to study the applications of this new separations tool.

In 1984 the CAC project received support from the Technology Transfer Fund. The money allowed the ORNL chemical engineers to make contacts to help transfer the technology to industry, to experiment with applying electric fields to CAC units (electrochromatography) to separate proteins by charge as well as chemical differences, and to develop a chemical simulator computer code.

Byers has been writing a computer code that uses ORNL's central chemical process simulator, known as ASPEN. Byers's code is intended to predict how scaled-up CAC units would behave in the context of a chemical plant. "If I am given information about a separations process, the feed material it uses, and other data, I can use the code to predict the results of replacing its train of separators with a scaled-up CAC. In many cases, the results could indicate that a CAC module would save energy, use less materials and equipment, and better separate the many constituents in the process stream. In short, the code can determine the costs and benefits of converting from conventional separations technology to CAC technology."

The ORNL code could be a tool that shows the advantages of using CAC units in certain chemical separations plants. In addition, the code could aid engineers in designing new chemical plants.

The key concept that makes liquid chromatography continuous in the CAC system is slow rotation. The principle was first enunciated 30 years ago, but Scott demonstrated its efficacy for liquid separations. Scott showed that the CAC concept's advantages over conventional liquid chromatography are that it eliminates a sequence of steps to process a batch of feed and that it continuously and simultaneously separates many components of a liquid. In short, CAC technology is faster and more efficient than conventional batch liquid chromatography.

In liquid chromatography, feed material is washed down a column by an eluent. The column contains a bed consisting of a separations medium such as an ion exchange resin, silica gel, or molecular sieve. These solids have a different chemical affinity for different compounds in the liquid feed; thus they will retard the flow of some compounds by varying degrees and allow others to move more quickly down the column. Chemically similar compounds will emerge at the bottom of the column at a certain time. In batch processes, these compounds are collected and run through another column (or the same column later) to achieve more separation.

In the CAC concept, according to Byers, a slow-speed drive system is used to move the bed in an annulus surrounding a cylindrical column past the feed point at a rate of 20 to 200 degrees per hour. As the column rotates in this lazy-Susan setup, the separation takes place and each product emerges at the bottom, always at the same place. Each product exits at only one point because it descends in a particular spiraling band that depends on its chemical affinity for the separation medium. Since this band position differs for each compound, each product seeks its own destiny at the column bottom, and multicomponent separation on a continuous basis is achieved. Thus reseparation of feed material is unnecessary, and less energy and equipment are used for CAC separations than conventional batch separations.

Remote Analytical Instrumentation Useful for Hazardous Zones

Imagine that you want to learn something about a mysterious object on the other side of a wall. The wall has a small hole in it, just big enough for you to stick your finger through. An extremely bright light is shining on the other side of the wall, so it would be dangerous to your eyes if you tried to peer through the hole. So you elect to stick your finger in and feel the object on the other side. From the sensory information passing from your fingers to your brain, you infer that the mysterious object is a wad of cotton.

This example illustrates a new concept developed in ORNL's Analytical Chemistry Division—the concept of remote analytical instrumentation. The concept involves putting a measurement system in a hazardous area and using a computer to remotely operate it and make sense from the information it obtains. The links between the measuring instrument and the computer are wires or optical fibers. In the analogy, your finger is the end measurement system; your nerves, the electrical or optical links; and your brain, the computer.

According to Leon Klatt, the developer of the concept of remote analytical instrumentation: "The original purpose of the concept was to perform chemical analysis in the highly radioactive environment of a nuclear fuel reprocessing plant. We're now looking at the potential for technology transfer of this concept.

Leon Klatt shows the remote pipetter (left) at a new technology-transfer exhibit of Martin Marietta Energy Systems during preparations for the Instrumentation Society of America (ISA) trade show. Klatt exhibited his remote analytical instrumentation at the ISA trade show held October 21–24, 1985, in Philadelphia.

"This system is useful in hot cells and glove boxes, where we're trying to determine the quantity of uranium and plutonium present in a nitric acid solution containing highly radioactive fission products. The operation of and processing of data from measurement systems must be done remotely for two reasons: to protect workers from the hazardous environment and to protect the electronic information processing equipment, which is easily damaged by high levels of radiation. Even if the electronic components could survive a highly radioactive environment, they would be so contaminated that they could not be repaired and would have to be discarded. In these situations, the repair mode is replacement."

Harley Ross, Klatt's supervisor, notes that the concept of remote analytical instrumentation can be applied not only to a highly radioactive environment but also to containment areas where work is being done on hazardous chemicals, such as toxins and explosives, or on splicing of genes (where care must be taken to isolate viruses from the environment). In the latter case, such "biological" containments usually have glass shields and are under negative pressure.

"We are trying to interest instrument companies in producing and marketing remote analytical systems," says Ross. "We envision that the end market for these systems would comprise chemical, bioengineering, pharmaceutical, and nuclear reprocessing companies."

To get the word out, the Office of Technology Applications has worked with Klatt and Ross to develop an exhibit to take to trade shows. Klatt exhibited his development in October 1985 at the Instrumentation Society of America conference at Philadelphia. Klatt and Ross are also planning to exhibit the development at the well-known Pittsburgh Conference and Exposition on Analytical Chemistry and Applied Spectroscopy. This annual trade show, which had more than 700 exhibitors in 1985 in New Orleans, will be held in February 1986 at Atlantic City.

Klatt peers into a hot cell where his precision pipetter and titrator are operated remotely in the Transuranium Processing Plant (TRU). This remote analytical instrumentation is used to determine the quantity of uranium and plutonium present in a nitric acid solution containing highly radioactive fission products.

The remote analytical system developed by Klatt has not been patented, although a patent may be forthcoming because of the new emphasis on licensing the exclusive rights to a technology to a private company as a way of expediting technology transfer. Certainly, a part of Klatt's technology could be copyrighted.

"What is original in this system is the software that Leon has developed," says Ross. "If this package of computer programs is not patentable, it is copyrightable."

What does the software do? Says Klatt, "Everything. It runs the mechanical components, takes data from the sensors, converts the data to meaningful numbers, processes the numbers with mathematical algorithms to get results, and displays or prints out the results and updated information for the operator. In addition, the software is tolerant to operator error. Although the operator can make errors in doing the chemical analysis, he or she cannot harm the operating system. Of course, if the operator errs, the system will tell that person what the mistake was."

So far Klatt has used two end measurement systems to demonstrate the concept: a precision pipetter and a titrator. These systems, located in the Transuranium Processing Plant (TRU) in Building 7920, will become so contaminated that they can never be manually repaired; when their useful life expires, they will be taken to the burial ground.

Although similar to commercial instruments, the prototypes built by Klatt were modified to make measurements with a precision required for reprocessing plants. In addition, Klatt designed them to be functional in a hazardous environment—that is, easy to calibrate and repair by remotely operated manipulators. For example, each prototype has a modular design; thus if a module fails, the instrument can be remotely repaired by using a master-slave manipulator to replace the failed module with a new one.

The pipetter delivers high-precision aliquots of a highly radioactive reprocessing solution to a vessel or a sampler. It draws a liquid sample from a sample bottle and then delivers with high precision a very small proportion of that sample to another vessel.

"A high precision pipetter is needed," says Ross, "because to correctly determine the total proportion of uranium and plutonium in the nitric acid solution, we have to reduce the level of radiation from the fission products to avoid interference with our measurements. So we take a very small portion of that sample for analysis and dilute it. When we finally make our calculations, we have to multiply by the dilution factor to make it equal the right level for the sample size. To ensure that this error doesn't blow up in the final result, we want to make sure that the little bit we took is very accurate.

Klatt explains it another way. "If we extract 25 microliters of solution with the pipetter and dilute it by factors of 100,000 to get the radiation level down, the radiation level of that 25 microliters has an uncertainty of several percent. That uncertainty is multiplied by that dilution number to get an even larger uncertainty. What we've been able to achieve with our precision pipetter is to deliver small volumes with a level of uncertainty no higher than a few tenths of a percent. Measurements of nuclear materials must be precise for safeguards purposes."

Besides measuring total uranium and plutonium in reprocessing solutions, Klatt also uses the remote analytical system to measure the total nitric acid concentration in these solutions. The titration system is used for this purpose. Knowing the precise concentration of nitric acid is critical to chemical processing in a reprocessing plant. "At TRU," Klatt says, "if acid titration cannot be done, reprocessing must stop and the facility must be shut down. If the titration system shows that the nitric acid concentration is off, operators will act on this information by making the appropriate adjustments. Then they will ask for more titration samples to check that their adjustments have achieved the proper concentration of nitric acid."

Right now, ORNL's remote analytical system consists mainly of working laboratory prototype systems built by Klatt. "If the system is to be commercialized," says Ross, "commercial firms might like to introduce economies through redesign. We are using a certain computer system, but a commercial company might want to make the system more compact and economical by using a smaller computer."

Klatt says he is genuinely committed to doing his part for technology transfer by interesting the appropriate people in using remote analytical instrumentation and the appropriate companies that are capable of producing and marketing the system. "We are offering the basic technology as it now exists. We can provide technical advice on how to modify the software for specific applications of the system. We are willing to assist instrument companies in developing commercially promising systems for different markets."

The commercial value of the ORNL system has already been demonstrated. In 1984 ORNL sold one of Klatt's precision pipetters to the Isotope Production and Marketing Branch of Canada's Atomic Energy Commission for commercial isotope production. In addition, researchers in the Federal Republic of Germany have expressed interest in the ORNL system for their reprocessing work.

Klatt's future plans for remote analytical instrumentation are to incorporate the concept in a robot and to test other end measurement systems, such as spectrophotometers, which would be linked to the computer by miniature lightpipes, or optical fibers. Meanwhile, he is looking forward to attending trade shows and demonstrating to the world his development.

As Ross puts it, "The Laboratory should plan to exhibit innovations regularly at major trade shows. Displaying new developments at trade shows won't make any of us rich because we're not allowed to make a profit, but it is a useful and effective way of transferring information to help make our innovations more generally available to society."

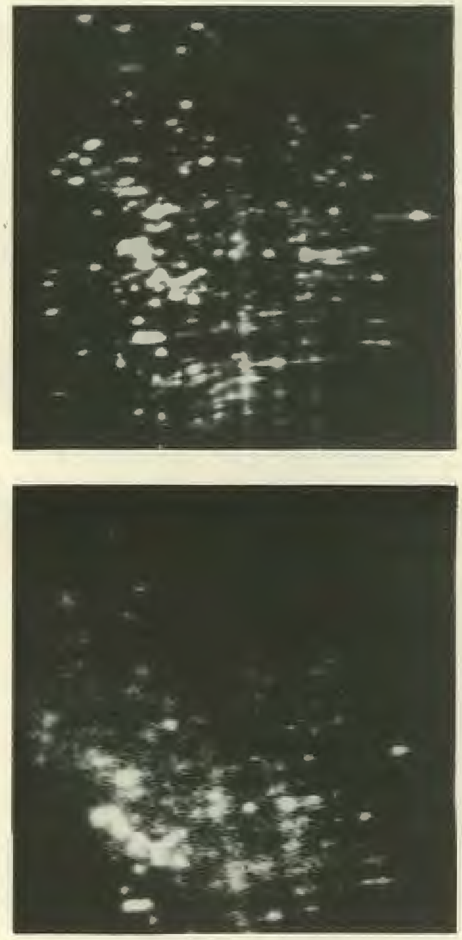
Electronic Device Images Protein Patterns Faster than X-Ray Film

The types and amounts of proteins produced by cells differ according to the kind of cell. The pattern of protein production by a kidney cell is not the same as that of a bone cell, for example. Similarly, a cancer cell may produce a new protein different from any proteins found in normal cells. Thus recognition of protein patterns could be useful in identifying types of cells.

Biological researchers are already using imaging of protein patterns to study differences among various types of cancer cells and between cancer and normal cells, with the long-range goal of using this technique to diagnose cancer. Norman Anderson, a former ORNL scientist, is leading an effort to use this mapping technique to classify all the proteins in the human body. Genetic engineering experts use similar techniques to determine the sequence of DNA base pairs to identify specific genes and to separate out clones of bacteria into which genes have been transplanted to induce the production of desired chemicals, such as insulin, interferon, and human growth hormone. Other potential applications include determining if blood at the scene of a crime matches that of any suspects by comparing protein patterns of blood samples and ascertaining whether certain meats come from animals killed by poachers, including endangered species.

The method used to map protein patterns is called two-dimensional gel electrophoresis. This technique permits researchers to detect, identify, and measure the amount of various proteins, which are extracted from cells and

Jack Davidson adjusts the electronic image detector for electrophoresis and chromatography (EIDEC), which is much faster than X-ray film for imaging molecules used in life processes. EIDEC won an I·R 100 award in 1985.



The top picture shows a conventional film image of tritiated proteins separated by 2-D gel electrophoresis. The exposure time was 48 h. The bottom picture of the same gel was taken with the EIDEC camera in 2 min. (Gel and X-ray picture, courtesy of Eric Lester, M.D., University of Chicago Medical School).

separated by charge and molecular weight on flat gelatin-like materials called gels.

The proteins are detected by several means, depending on the experiment. A protein-selective stain can be used to make the separate protein spots visible in ordinary light or by fluorescence in ultraviolet light. A radioactive label can be introduced into the protein; the spots are located by detecting the radioactivity. Radioisotopes used as a label include phosphorus-32, carbon-14, and tritium, which emit beta particles. By first labeling one of the amino acids (the building blocks of protein) and growing cells in a medium containing this amino acid, scientists can induce cells to make radioactive proteins.

The location of any given protein on the gel indicates the molecular weight and charge (which allow identification), and the amount of radioactivity indicates the amount of labeled amino acid incorporated by the protein. To "see" the location of proteins in a gel, biologists normally expose the radioactive gel to X-ray film. The film shows spots at different locations with different brightnesses; from this information, researchers can identify and quantify various proteins produced by a particular cell (or gene, a unit of cellular DNA that provides instructions for making protein with a particular structure).

Use of X-ray film exposed directly to the beta particles has its disadvantages. Only the betas leaving the gel and striking the film are effective. Many of the weak betas from tritium, for example, fail to escape the gel and are lost. About 10 years ago researchers began soaking the gel with a scintillator and using the light produced by the betas to expose the film. The use of a scintillator greatly increased sensitivity to the radioactive proteins. However, exposure times of days or weeks are still necessary. Another drawback of film is its nonlinear response to light, which makes quantification difficult.

To overcome these problems of low sensitivity and long exposure times, Jack Davidson of ORNL's Instrumentation and Controls Division has shown that a television camera coupled with an image intensifier can record protein patterns 1400 times faster than film with an increase in sensitivity of 100 to 1000 times. The ORNL project is mainly concerned with the location and measurement of radioactive spots but can be used with other methods such as fluorescence. The system is called an electronic image detector for electrophoresis and chromatography (EIDEC).

Davidson's camera device, which received an I·R 100 award in 1985, is sensitive to very low levels of light. As mentioned above, radioactive gels can be made to produce light if they are mixed with liquid scintillators before being dried. Beta particles interacting with the scintillator produce flashes of light that escape the translucent gel even if the beta particles are stopped below the surface. Davidson's camera and intensifier can detect a few hundred photons of light per square millimeter, compared with a few million required to produce a barely visible image on X-ray film.

The camera can also detect protein spots in real time, for all practical purposes. As an example, a protein map from a type of cancer cells was obtained in 2880 minutes (48 h) on X-ray film but in only 2 minutes by the TV camera. The camera displayed the information 1400 times faster than could the film. Furthermore, compared with film, the electronic response to activity is directly proportional rather than nonlinear. For stronger betas, such as those from phosphorus-32, the camera can detect single disintegrations/mm^2 instantaneously. A typical film requires a minimum of 720 disintegrations/mm^2 in a 24-h exposure to detect phosphorus-32.

Davidson, who has worked on biological instruments for many years, had the idea of trying a camera for 2-D gel electrophoresis in the 1970s. But the impetus for working on the project became especially strong in 1980 when he heard a talk on film methods by Eric Lester, a cancer researcher at the University of Chicago. Lester had come to ORNL then to give a talk at the annual symposium series on "Automated Analyses in the Clinical Laboratory," organized and cochaired by Chuck Scott of ORNL's Chemical Technology Division. Davidson told Lester that he thought he could eliminate film by electronic means, and Lester encouraged him to proceed with the development and sent him some gels for his experiments.

Davidson began working on the EIDEC project in 1981 using funds from DOE's Office of Health and Environment Research. In 1984 he received supplementary support from the Laboratory's Technology Transfer Fund. Now that he has shown that his prototype intensifier-camera apparatus works, he is trying to improve it to make it more commercially promising.

"My goal is to make a device that is affordable, even more sensitive to betas, and not restricted to gels of a particular size," says Davidson. "I'm trying to build a more economical camera for a price most laboratories would be willing to pay. To increase the sensitivity, I'm using a new combination of intensifier and camera tube. On the average, the intensifier produces a light signal of 50,000 photons for every photon striking the photocathode. To allow imaging of gels as large as a chest X ray as well as those as small as a 35-mm slide, I'm working on using an optical coupling to take an image of the large gel and focus it onto the intensifier faceplate, where it will be amplified before being picked up by the TV camera tube."

Davidson can combine the TV technology with a computer. The camera can measure the amount of light picked up electronically from any spot on the gel. The computer derives another number proportional to the beta radioactivity and stores the number in memory. In the future, the computer could be used to store images of standard gels and, by using pattern recognition schemes, determine whether other gels have normal or abnormal patterns of proteins. A number of laboratories are already using computers to classify and compare images digitized from film. In clinical applications, Davidson believes that the high speed of electronic detection will be particularly advantageous.

Davidson has received many expressions of interest in EIDEC. More than 100 people worldwide requested reprints of the article that he and Arthur Case published on the technique in the March 12, 1982, issue of *Science*. The article is entitled "Rapid Electronic Autofluorography of Labeled Macromolecules on Two-Dimensional Gels." A number of instrument companies here and abroad, including EG&G Ortec, Beckman Instruments, Inc., and Varian Associates, have contacted Davidson and asked for more information about EIDEC. He anticipates that after the new intensifier-camera has been tested this year, he will eventually be taking it to trade shows. He also expects to consult with instrumentation companies interested in manufacturing it and marketing the technology to biological research laboratories and genetic engineering and biotechnology firms.

Meanwhile, Davidson is also collaborating with a University of Pennsylvania researcher to show that a similar apparatus he is developing can be used as a sort of "lensless microscope" to image the location of labeled drugs absorbed into the brains of rats and birds.

Several groups in ORNL's Biology Division are interested in the development. Davidson confers with them and obtains samples for testing. Reinhold Mann and Betty Mansfield are using 2-D gels with an X-ray film scanner and a computer to study changes in patterns of protein production before and after exposure to chemical pollutants. Use of Davidson's TV technology might help them gain additional insights into the processes by which chemicals cause gene mutations.

Davidson says that this new imaging technology is now possible because of the advances made in making TV cameras more light sensitive to meet the demands of the commercial U.S. networks and in improving image intensifiers to meet U.S. military needs for better night vision. The combination of these enhanced technologies now shows promise for helping biologists fathom the workings of the stuff of life.

Sensitive Pulsed Helium Ionization Detector Developed for Gas Chromatography

The concentrations of various gases in a mixture is of interest to all industries that use process gases to manufacture products (for example, semiconductors) and that must monitor the workplace atmosphere to ensure compliance with environmental regulations. To determine the purity and concentration levels of various gases,

Rose Ramsey and Richard Todd monitor the response of their pulsed-helium ionization detector system, which recently won an I•R 100 award.

gas chromatography (GC) is often used.

In this technique for separating compounds in a mixture, a sample is injected into a column containing an adsorptive, or stationary, bed. The bed consists of a separation medium for which different components in the sample mixture have different chemical affinities. A carrier gas, usually an inert gas like helium, continuously sweeps through the column, moving the sample components. Separation of the compounds occurs because each compound is successively adsorbed and desorbed along the column according to differences in chemical affinity for the bed material. When the separated compounds emerge from the column, they are swept into a detector, which measures the concentration of the constituents. Sensitive detection is required to determine whether gas levels are appropriate for industrial processes or for meeting environmental limits.

Several kinds of GC detectors exist. Among them are electron capture detectors, flame ionization detectors, and helium ionization detectors. The helium ionization detector is one of the most sensitive detectors available for GC. It is capable of directly determining low part per billion concentrations of the permanent gases (e.g., neon, hydrogen, argon, and oxygen). However, because of its lack of stability and reliability, the conventional helium ionization detector has not been widely used.

At ORNL a modified helium ionization detector that promises not only high sensitivity but also increased reliability and stability has been developed. This detector differs from the traditional one in that it operates in the pulsed mode using state-of-the-art electronics. Its developers are Richard Todd, an electrical engineer in the Instrumentation and Controls Division, and Rose Ramsey, a separations chemist in the Analytical Chemistry Division. Their project was first funded by seed money from ORNL's Exploratory Studies Program in 1982 and has since been supported in 1984 and 1985 by the program's Technology Transfer Fund. In 1985 this development received an I-R 100 award.

"One of our goals," says Todd, "was to get the word out to industry by presenting a paper on our development at the Pittsburgh Conference and Exposition on Analytical Chemistry and Applied Spectroscopy. We did that at the New Orleans conference in February 1985."

Ramsey says that they plan to take the development several steps further to promote technology transfer. "We have filed patent applications and are preparing a paper for a technical journal. We also are planning on contacting people who might want to examine our detector, and we will offer prototypes or circuit diagrams to instrument companies like Valco Instruments Company, Inc., which is an American manufacturer of the helium ionization detector."

The ORNL researchers think that many users of gas chromatography would consider purchasing highly reliable pulsed helium ionization detectors if they were on the market. Todd believes that the price of the instrument could range from $2500 to $4000 apiece. The market, they say, could include the semiconductor industry, which uses ultrahigh purity gases in manufacturing processes for silicon chips.

How does a helium ionization detector work? The helium carrier gas is promoted from the ground state to a metastable, or highly active, state by a radioactive source in the detector. These excited helium atoms, in turn, ionize other compounds eluting from a GC column, resulting in a mixture of electrons and ions that produces an electric current when a potential is applied across electrodes in the detector cell. The strength of the current is proportional to the concentration of the analyte—that is, the amount of a compound passing through the detector at the time. The output of the detector is a series of peaks whose locations indicate the identities of the compounds and whose areas indicate the relative concentrations of the gases in a mixture. These peaks are printed out on a strip-chart recorder or displayed electronically.

The conventional helium ionization detector is operated in a direct-current (DC) mode in which a constant polarizing voltage is applied across the cell and the output current is measured continuously. Under these conditions, when high concentrations of an analyte (greater than 100 to 200 parts per million) enter the detector, anomalous peak shapes or polarity inversion may be obtained, making it difficult to interpret the results. Furthermore, if the detector is overloaded with high concentrations, electrical breakdown may occur, possibly damaging the detector itself. In the DC mode the detector is unstable and often unreliable.

To eliminate these problems, Todd modified a helium ionization detector to operate in a pulsed mode. Essentially, he designed a voltage pulse generator and coupled it to a detector. Says Ramsey: "It gives the operator broad control over the output of the detector. The operator can control peak polarity [whether the peaks are positive or negative] by varying the frequency and adjusting the detector to accommodate samples with high concentrations of gases or to sensitively detect ultratrace levels of gases. Furthermore, the operator need not worry about a spontaneous breakdown of the detector due to high gas concentrations."

Todd's closed-loop circuit varies the frequency of voltage pulses required to maintain a constant current. The frequency, or number of pulses per second, can be related to the concentration of a specific gas (whereas in the conventional detector, the amount of current is used as a measure of the gas).

With the ORNL prototype, the operator can set the reference current and baseline frequency. The amplified output of the electrometer controls the pulse rate of the V/F converter circuit, and the frequency is varied to maintain an average detector current equal to this reference current.

As the gas to be analyzed comes into the detector, more electric charges are collected per pulse, so it takes fewer pulses per second to get the same average current. With higher concentrations the frequency will decrease. The change in frequency should be proportional to the concentration of a specific gas.

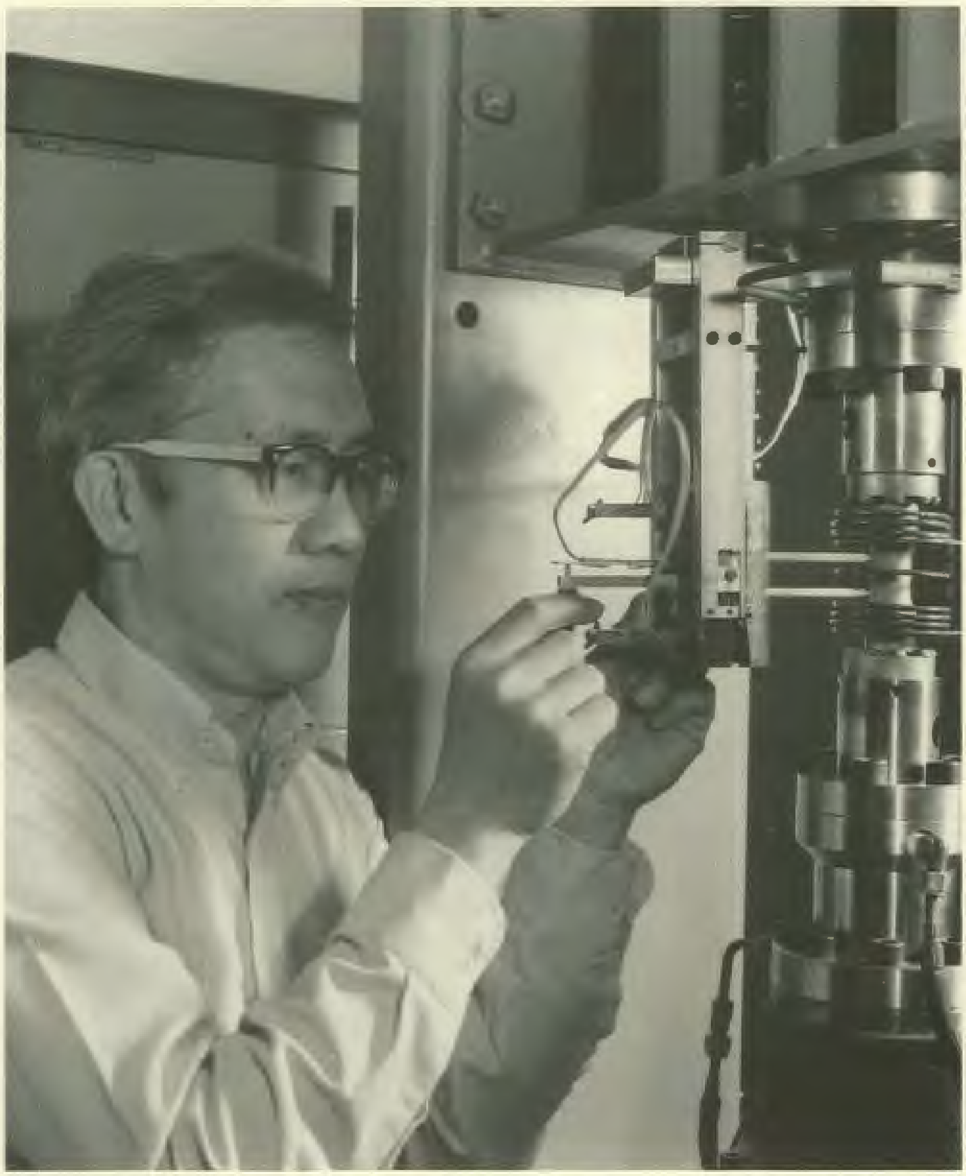
The detector can be operated in either a fixed-frequency or variable-frequency pulsed mode. The electronic design includes a low-noise stable current source; a high-speed, low-noise electrometer; intermediate low-noise gain stages; and a voltage-to-frequency converter circuit. The high-voltage pulser is capable of operating from 0 to 500 V from DC to greater than 300 kHz at the highest voltage.

"Because the overall effect of pulsed operation has been to improve stability and increase the dynamic range of the helium ionizaton detector," says Ramsey, "we hope to expand the applications of this device." ornl

ORNL Device That Measures Metal Deformation Wins I-R 100 Award

In the August 1980 issue of *Metal Progress*, Richard Fields and John Smith predicted in their commemorative article "Mechanical Testing in the 1980s" that advances in high-speed computational capabilities would allow the development of additional unconventional materials testing techniques. As a result, researchers would gain insights into complex material behavior in response to complicated multiaxial loading—that is, strains induced by multidirectional mechanical stresses that pull apart and twist the material at high temperatures. The new devices, state the authors, are needed to generate crucial information that cannot be obtained by conventional extensometry.

ORNL is helping to make this prediction become true. An ORNL researcher has developed a device that measures two-dimensional strains on tubular metallic specimens at high temperatures, thus providing important information on how the material's length, shape, and structure change under conditions simulating those in nuclear and advanced energy production systems.



Ken Liu adjusts the biaxial high-temperature fatigue extensometer, which received an I-R 100 award in 1985.

This instrument, which received an I-R 100 award in 1985 from *Research & Development* magazine as one of 100 U.S. innovations with commercial potential, is the biaxial high-temperature fatigue extensometer developed by Ken Liu of ORNL's Metals and Ceramics Division. Organizations that have shown interest in the ORNL extensometer are Instron, Inc., and MTS Corporation, which manufacture instruments for materials testing, and the Lewis Research Center of the National Aeronautics and Space Administration (NASA). NASA is using the results from surface measurements made by the ORNL extensometer to develop life-assessment procedures for turbine engines.

Conventional extensometry measures only one dimension of strain imposed by mechanically stretching or compressing tubular specimens of metals or alloys. Liu's device, however, can measure two dimensions of strain—tension and torsion. Tension results from pulling the material from both ends, and torsion is produced by twisting the material (shearing it in a transverse direction).

The device allows researchers to perform both laboratory and field strain measurements of solid specimens at high temperatures when subjected to complex thermal and mechanical loading. The information is then used to formulate a mathematical model that best represents the materials' behavior for the design of a high-temperature energy conversion system and to determine the probability of failure to ensure safety and quality control. Such predictions would indicate how long a material is likely to endure such stresses before failing by creep and fatigue.

Using the biaxial extensometer, Liu has investigated the creep and fatigue properties of chromium-molybdenum (2¼ Cr: 1 Mo) steel, which is a candidate material for steam generators in future high-temperature, gas-cooled reactors and breeder reactors. He plans to test the device for characterizing properties of refractory metals, such as vanadium and niobium, which have been proposed for space reactors. He has found that the device is stable enough to measure gradual changes in a material over a long time.

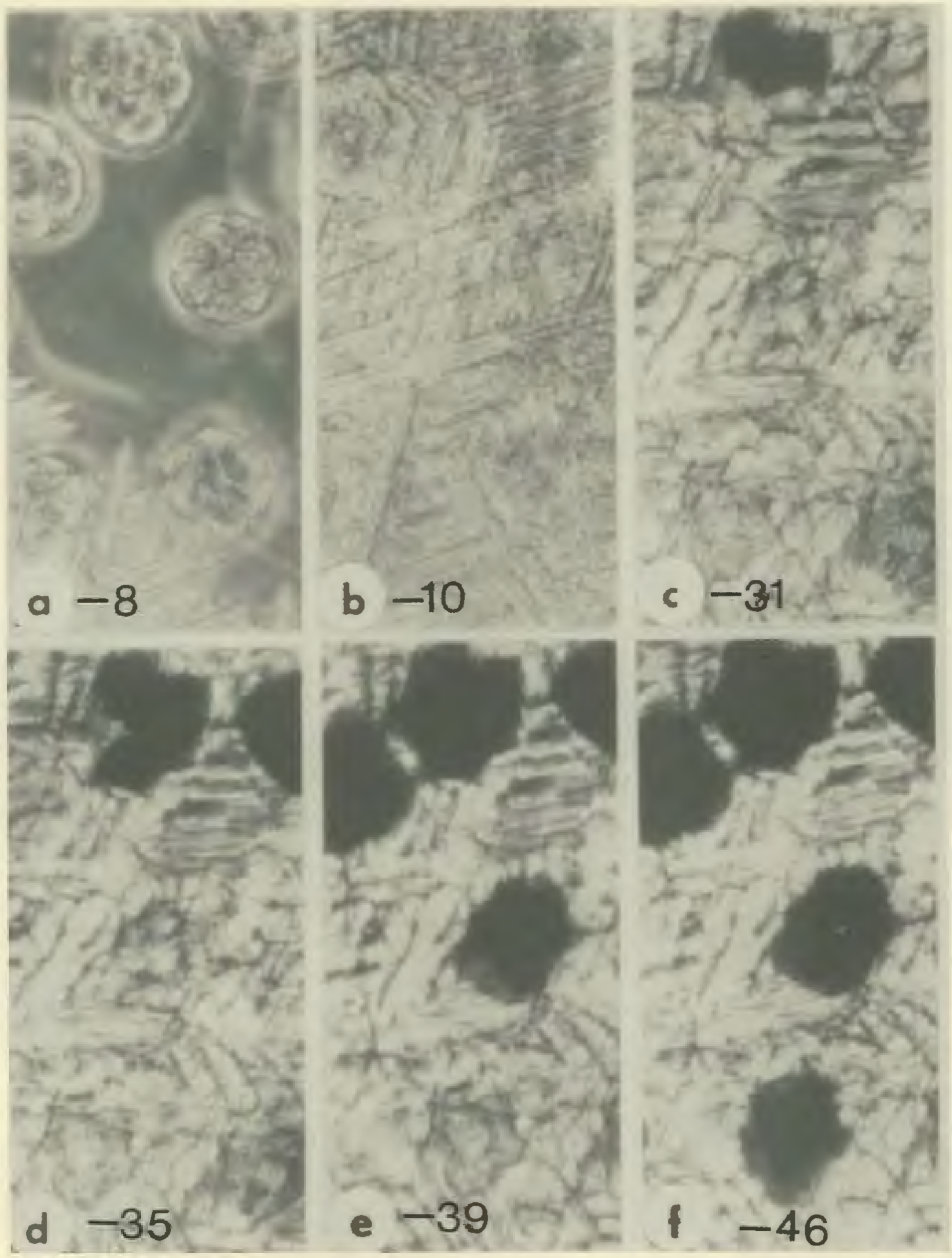
The extensometer has two ceramic probing rods that are spring loaded at two gauge points on the surface of the specimen. As the specimen is stressed, it is displaced circumferentially (torsion), and the rods move gradually and perturb vertical shafts to which they are indirectly attached. These shafts are connected to cantilever-type transducers. As the shafts gently tug on the transducers, the resistance of the transducers changes, thus altering two electrical signals. These changing signals can be related to circumferential displacement in the specimen. The axial differential displacement (tension) is measured directly by the axial transducer.

In the relatively new field of biaxial strain measurements, Liu's device is commercially promising because of its high accuracy, simplicity, and low cost. It may soon be used to test piping and tubing in commercial nuclear power plants.

Frozen Assets: Transferring the Technology of Cell Preservation

Stan Leibo used to walk through a gate to get to his laboratory in ORNL's Biology Division. Now, as vice-president for research for Rio Vista International, he tramps through manure on a cattle ranch to reach his lab near San Antonio, Texas. ORNL Director Herman Postma once asked him how the manure smells. Replied Leibo, "It smells like money to me."

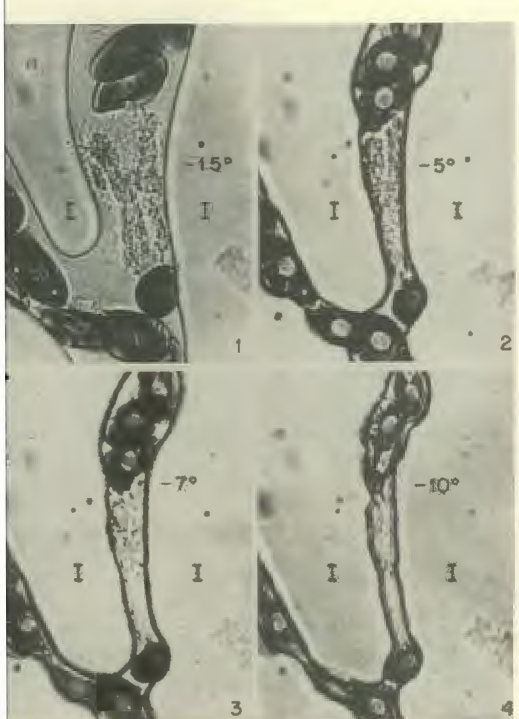
Leibo is part of an emerging $150 million industry in which the production of prize cattle can be increased tenfold.



Intracellular freezing of eight-cell mouse embryos cooled at 20°C/min in dimethyl sulfoxide, a protective additive.

The industry combines the new techniques of using hormones to induce a fertilized prize cow to produce up to 20 embryos (superovulation), non-surgically removing the embryos after they have developed to the blastocyst stage (200 to 300 cells), freezing them, and implanting the thawed-out embryos into many ordinary cows who serve as foster mothers.

Freezing is important because it allows embryos to be held in storage until recipient cows are ready to become impregnated (in heat). Leibo, who collaborated with cryobiologist Peter Mazur at ORNL in determining the best freezing and thawing rates for different kinds of cells, has helped transfer the technology of embryo freezing and thawing to the cattle



Photomicrographs of frog erythrocytes in serum during the course of slow freezing from −1.5 to −10 °C. [From Rapatz et al. (1966).] Note that the cells are confined to the channels of unfrozen solution between the ice crystals (I), that the cells decrease in diameter with lower temperature, and that the cells shrink. The diameters of the unfrozen fraction in the above photograph are 0.23 at −1.5°C, 0.07 at −5°C, 0.05 at −7°C, and 0.04 at −10°C.

industry. Much of this technology of embryo preservation grew out of fundamental research pioneered at ORNL.

The first freezing of mammalian embryos was achieved at ORNL in 1972 in a collaborative experiment involving David Whittingham of the United Kingdom and Mazur and Leibo. Embryos from pregnant black mice were removed, frozen, thawed, and implanted into white mice, who gave birth to live black mouse pups. A photograph of an albino mouse with her black pups was featured on the cover of a 1972 issue of *Science* magazine.

Mouse embryos are now being frozen in ORNL's Biology Division and other laboratories to preserve genetic lines. Frozen embryos can serve as a "yardstick" against which biologists can measure changes such as aging and genetic drift—the slow, subtle shifts in genotypes of animals and their succeeding generations. (Human embryos also have been successfully frozen; several have resulted in live births.)

Mazur, who is leader of the Theoretical and Applied Cryobiology Group in the Biology Division, has concentrated his research on fundamental mechanisms responsible for injury to cells during freezing and warming. This research and other basic findings were recently described in his review paper "Freezing of Living Cells: Mechanisms and Implications." For this paper Mazur was named Author of the Year in 1985 by Martin Marietta Energy Systems, Inc., and was awarded a Jefferson Cup by Martin Marietta Corporation.

Cells can be preserved in a viable state at liquid nitrogen temperatures (−196°C) for probably 5000 years. The trick is to select the rate of freezing (and thawing) that minimizes damage. Whether a cell is damaged depends partly on whether the water inside the cell turns to ice—that is, whether intracellular freezing occurs. Mazur and his colleagues found that freezing injury results if cooling is too rapid because not enough cell water has time to leave the cell osmotically to eliminate supercooling.

"If a cell is cooled slowly enough," Mazur says, "it will remain in equilibrium with the outside medium, and the water inside the cell will leave the cell and freeze externally. If the cell is not cooled slowly enough, it will not lose water rapidly enough by dehydration to maintain equilibrium; thus it will become supercooled and eventually will freeze internally."

Several years ago Mazur developed equations to describe the kinetics of this water loss and permit prediction of the probability that intracellular freezing will occur at any given cooling rate. His predictions agreed well with experimental observations.

Experiments in freezing mammalian embryos showed that a high percentage survive if cooling is slow (<2°C/min), but few or none survive if the cooling rate exceeds 4°C/min. However, slow freezing can still injure cells. One way to protect cells partially against internal damage during slow freezing is to add a protective additive like glycerol. Additives have been thought to serve as a buffer between the cell and the increasing salt concentrations that result as water leaves the cell.

In the last few years, Mazur has sought to understand the cause of damage to cells during slow freezing. He has focused his attention on the water outside cells.

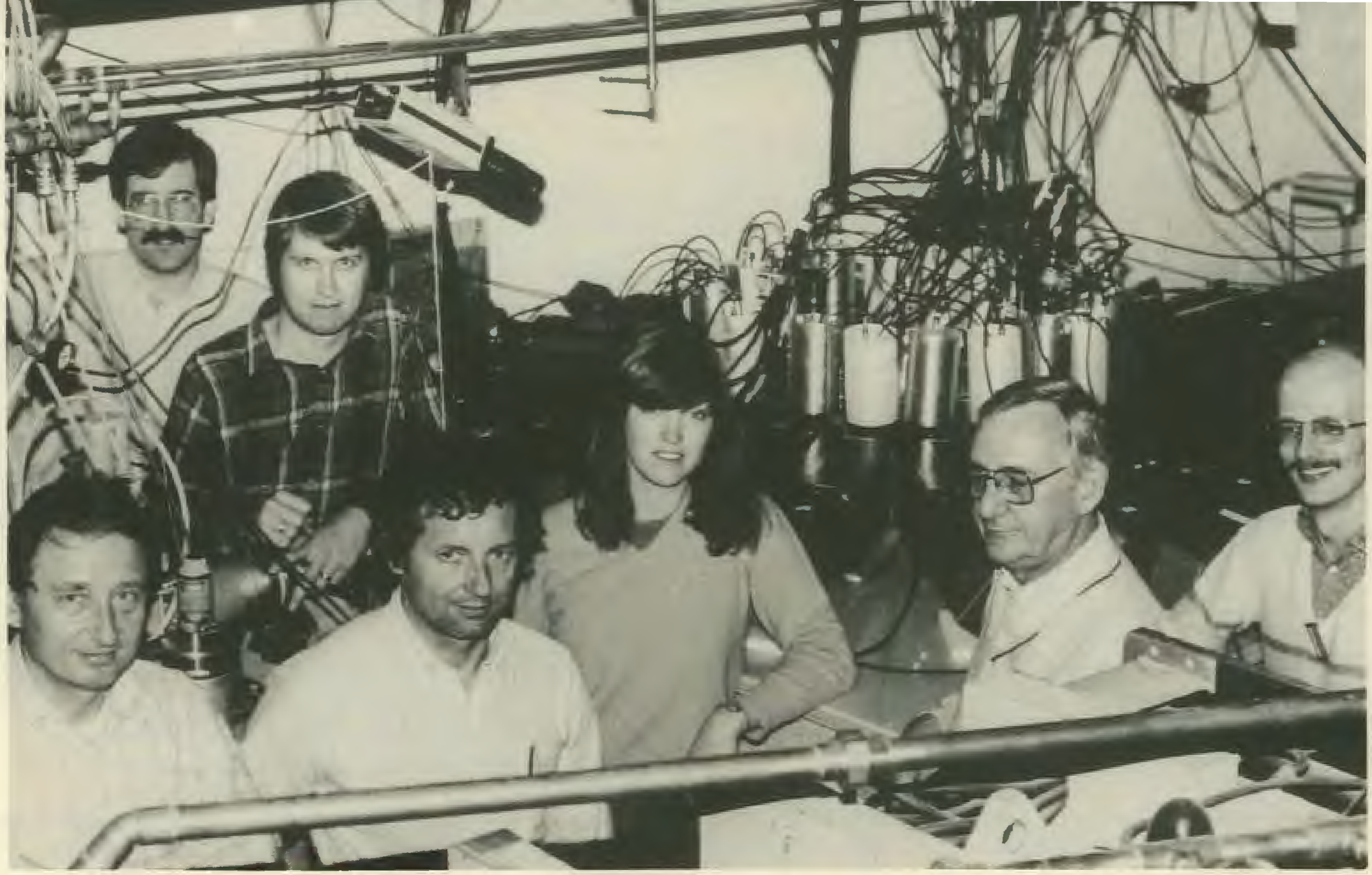
"As ice forms in a suspension of cells," he says, "the growing ice crystals surround channels of unfrozen medium. With continued cooling, these channels decrease in size and contain increasing concentration of solutes, including salt (sodium chloride). The cells lie in the channels and shrink in osmotic response to the rising solute concentration. Cryobiologists have hypothesized that the concentration of solutes or the cell shrinkage caused freezing injury. But our recent experiments on human red blood cells have shown a different cause—a surprising result."

Mazur, Bill Rall, Nick Rigopoulos, and Kenneth Cole have demonstrated that the amount of unfrozen water, not its changing composition or cell shrinkage, contributes largely to cell damage. "The damage," says Mazur, "is due more to the decrease in the size of the unfrozen channels."

Mazur believes that this new view of the mechanism of slow freezing injury may facilitate the development of procedures for the preservation of complex assemblages of cells that up to now have resisted attempts to freeze them based on orthodox theories about slow freezing injury. The new ORNL view has received preliminary confirmation from research in Cambridge, England, indicating that the function of muscle survives better if frozen under conditions that keep the unfrozen fraction high.

These results should be of interest to researchers seeking to preserve endangered or rare animal species and, in the long term, human organs. And they could be useful for improving the survival of frozen cattle embryos and other species used in agriculture. ornl

(Editor's note: *As the* Review *went to press, Mazur received yet another honor. He was the first ORNL scientist and the first employee of Martin Marietta Energy Systems, Inc., to be named a Corporate Fellow.*)



Glenn R. Young, a nuclear physicist with the Macroscopic Reaction Studies Group in ORNL's Physics Division, holds a Ph.D. degree in nuclear physics from the Massachusetts Institute of Technology (MIT). In 1977–78 he conducted research at MIT as a Chaim Weizmann postdoctoral fellow. In September 1978 he joined the ORNL staff as a Eugene P. Wigner fellow. His research has centered on reaction mechanisms of heavy ions. Recently, however, he spent some time studying particle accelerator physics as part of a group designing a new synchrotron accelerator to be located at ORNL's Holifield Heavy Ion Research Facility. Here, Young (left in back) enjoys the prospect of starting a pion emission experiment in collaboration with his colleagues, from left, Peter Paul of the State University of New York (SUNY), Terry Awes (ORNL), Frank Plasil (ORNL), Johanna Stachel (SUNY), Felix Obenshain (ORNL), and Peter Braun-Munzinger (SUNY).

Pion Emission from Low-Energy Nuclear Reactions

By GLENN R. YOUNG

A little over three years ago several of us nuclear physicists in the Physics Division at Oak Ridge National Laboratory considered looking for pi mesons, or pions, that might be created by nuclear collisions at the Holifield Heavy Ion Research Facility (HHIRF). This idea came up during our discussions of experiments we wanted to do with a new, larger booster cyclotron then being proposed as an addition to HHIRF. We were intrigued by the prospect of finding pions emitted at the

A theorist said it couldn't be done, but nuclear physicists at ORNL's Holifield Heavy Ion Research Facility accelerator have detected the emission of pions, short-lived particles that serve as the "glue" in the nucleus, from low-energy nuclear reactions. Current theory is being revised to explain how pions can be produced at unexpectedly low energies.

highest bombarding energies possible with this new machine. The machine is yet to be built, but we have since detected pions produced by low-energy nuclear reactions at HHIRF. This article describes how we produced pions at unexpectedly low energies.

Pions, discovered in 1947 in cosmic-ray photographs by British physicist Cecil Frank Powell, act as the "glue" that holds atomic nuclei together. Pions provide the exchange force between various protons and neutrons in a nucleus—that is, the nucleons (protons and neutrons) sense and respond to each other's presence by exchanging pions. A neutral pion, incidentally, possesses about 264 times the rest mass of an electron.

Unfortunately, the pions in a nucleus have only a fleeting existence, lasting for the time it takes to cover the distance between two nucleons—on the order of about 10^{-23} s, the approximate time it takes light to cross a nucleus. Physicists call such pions "virtual"; the energy required to create their rest mass can be "borrowed" only for a short time.

Pions from Proton Collisions

To see a pion outside the nucleus, a so-called "real" pion, one must supply enough energy to be converted into the pion rest mass (via the Einstein relation $E = mc^2$). Energy is usually supplied by banging two protons together at high velocities. Because the pion has a rest mass of about 140 MeV/c^2 (135 MeV/c^2 for uncharged, or neutral, pions and 139 MeV/c^2 for charged pions; a proton has a rest mass of 938.3 MeV/c^2), two protons must collide in their mutual rest frame with at least this energy (135–140 MeV) to produce a pion. Such energetic particles are normally obtained at the very large synchrocyclotrons and synchrotrons used by high-energy physicists but not at the cyclotrons and linear accelerators (linacs) used by nuclear physicists. (Exceptions are the so-called "meson factories" at Los Alamos, Vancouver, and Geneva. Los Alamos National Laboratory has an 800-MeV proton linac, while the laboratories at the latter two sites have 500-MeV cyclotrons.) By contrast, at HHIRF we have available beams of heavy nuclei with energies of only up to 25 MeV per particle.

Because of the low energies at HHIRF, at first glance it seemed futile to look for pions—their creation seems to be ruled out by energy conservation. In other words, it was thought that because the relative energies of two protons (one in each of the colliding nuclei) would be so low at HHIRF, the necessary energy to create a pion's rest mass would never be available. Such a model assumes that only one proton in each nucleus participates in creating a pion and that the rest of the nucleons in that nucleus are mere "spectators," contributing no energy to the pion production process.

Indeed, early ideas about the mechanism for producing pions in the case of two colliding protons assumed that it involves the collision of one each of the three quarks composing each of the two colliding nucleons. The available kinetic energy was thought to be expended in knocking a quark loose. Then physicists realized that because the strong force experienced by nucleons is most effective at keeping quarks confined inside their respective nucleons, the energy instead appears as the creation of a quark-antiquark pair, also known as a meson. The particular type of meson produced depends on the type of quark-antiquark pair liberated. Because pions are the lightest of the mesons, they are the ones most likely to be created.

Pions from Colliding Nuclei

In 1977 George Bertsch of Michigan State University (MSU) proposed that if nuclei instead of protons were collided, pions would still be produced, even though the kinetic energy per particle would be considerably less than the 135-MeV rest mass of the neutral pion (π^0). This lower kinetic energy is possible because the individual nucleons inside a nucleus execute a random, or "Fermi," motion, which results in a relative energy of the individual nucleon with respect to the nucleus as a whole of about 35 MeV. Thus, two colliding nucleons, one from each nucleus, can collide at an effective energy that is markedly higher than that deduced from the kinetic energy per particle of the nuclei alone. Bertsch [who spent 1984–85 at ORNL and the University of Tennessee (UT) as a Distinguished Scientist] predicted that pions could be produced in nucleus-nucleus collisions at kinetic energies as low as 55 MeV per particle. However, he predicted, below this energy no yield would be seen.

Several pion production experiments were carried out in the late 1970s at the BEVALAC at

Lawrence Berkeley Laboratory (LBL) to test Bertsch's prediction. These experiments were performed by physicists from MSU and LBL under the leadership of MSU's Walt Benenson. The researchers confirmed Bertsch's predictions at bombarding energies as low as 90 MeV per particle.

In May 1981 Frank Plasil and I attended a conference at LBL where we learned that a group at CERN (the big European high-energy facility in Geneva officially called the Organisation Europeene pour la Recherche Nucleaire) had used a carbon-12 beam to detect positively charged pions (π^+) at a bombarding energy of 84 MeV per particle. We also heard rumors that a group at Saclay, France, had performed an experiment using a helium-4 beam at 82 MeV per particle and had detected the emission of π^+ that carried off *all* excess energy in the reaction—a remarkable observation if true. In the spring of 1982, the French group published their results. This discovery prompted Felix Obenshain and me to estimate the number of π^0 that might be produced each day in a pion production experiment at HHIRF with or without the proposed new booster cyclotron. This was the first time we seriously considered producing pions at HHIRF.

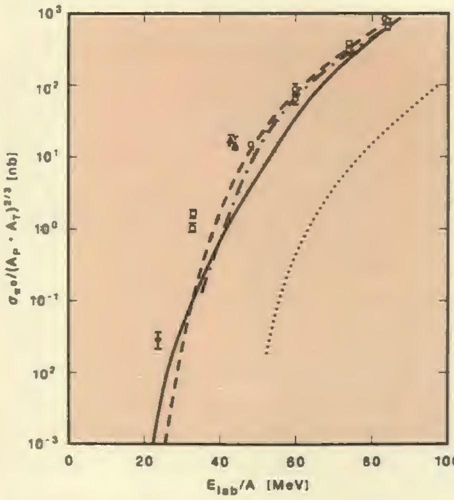
ORNL Gets into the Act

The final impetus to begin experiments at HHIRF came at a conference held in October 1982 at MSU. There I encountered Peter Braun-Munzinger, an acquaintance from my days as a postdoctoral student in 1977 at the Massachusetts Institute of Technology. Peter had recently been promoted to full professor at the State University of New York at Stony Brook and had just spent part of the year at the Gesellschaft für Schwerionenforschung (GSI) in Darmstadt, Federal Republic of Germany. During that time he had collaborated with Eckardt Grosse of GSI on experiments designed to induce and detect neutral pion production, again using the CERN accelerators.

Peter's most exciting news was that they had just tried an experiment at 60 MeV per particle and found many more pions than Bertsch's theory predicted. At the next break in the conference, I discussed this news with Frank, and we sought out Jim Ball, then director of HHIRF (now director of ORNL's Physics Division), who also was attending the conference. We pleaded our case for a discretionary run on the HHIRF accelerators before the Christmas shutdown in 1982. Jim granted our request—provided that we could find the needed equipment in time.

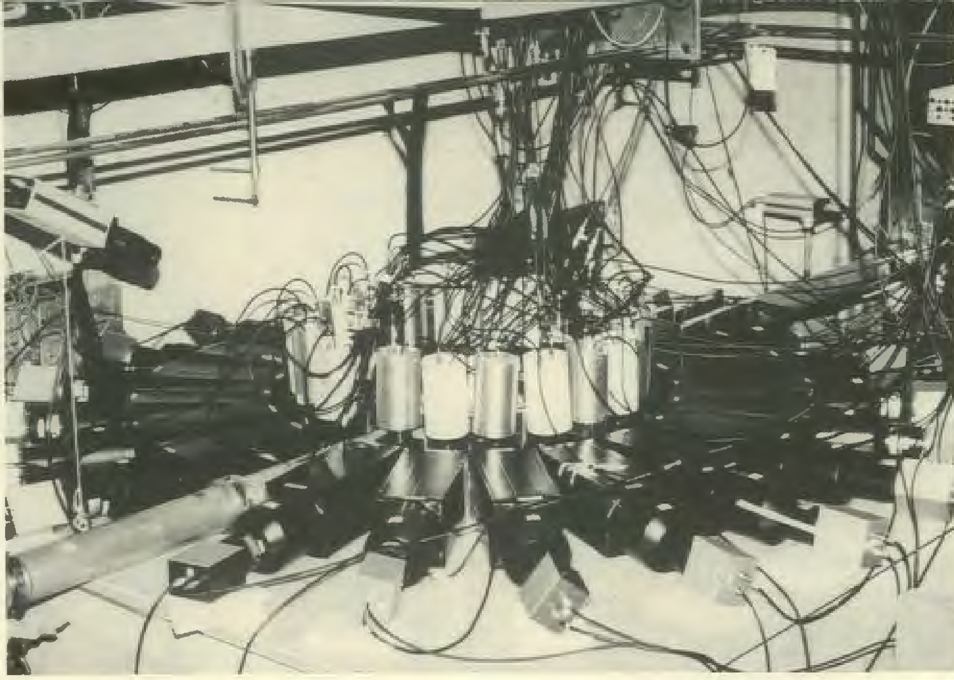
The neutral pion is extremely unstable, breaking down almost instantly to form a pair of gamma rays (energetic photons). Detecting neutral pions requires specialized devices capable of "seeing" photons of energies in the range of 70–100 MeV. (By comparison, photons from a visible light have energies in the range of 1–3 eV.) Specialized detectors are necessary because the rapidly decaying π^0 has an average life of only 8×10^{-17} s, much too short even for it to leave the target where it is produced.

Because one π^0 produces two gamma rays during decay, its presence can be determined by detecting the resulting photons. Several detectors can do the job, but we needed detectors that also had reasonable energy resolution. Felix and I considered using the spin spectrometer for gamma-ray detection but abandoned the idea when we realized that it would not be able to detect the few photons of interest because of background noise from many other photons in the energy range of 0.1–10 MeV. It turns out that glass blocks loaded with lead oxide at 55% by weight make ideal detectors. (They are similar to hot cell windows but contain less lead oxide, which allows them to remain clear to blue light.)



Pion production probability, expressed as a cross section in units of nanobarns (10^{-33} cm²), as a function of the bombarding energy of the projectile nucleus expressed in units of MeV per particle. Our measurements have added the points up to and including those at 35 MeV per particle. The curves are the results of theoretical model calculations that come nearest to reproducing the measured points. George Bertsch's original theory, which predicted a sharp threshold at 54 MeV per particle (no pion yield below that energy), is clearly not borne out by the experimental results at ORNL.

How does this detector work? A gamma ray from a decaying pion interacts with a lead nucleus in the block, producing an electron-positron pair. These particles emit Cerenkov radiation in the form of blue photons (as in the blue glow seen at the Oak Ridge Research Reactor and High Flux Isotope Reactor) until they collide with another lead nucleus. During that collision, they slow down and emit bremsstrahlung ("braking radiation"), which results in more, but lower-energy, photons. The process repeats itself until the electrons and positrons produced in



The lead-glass blocks configured for one of the experiments. The small ($5 \times 10 \times 10$ cm^3) converters can be seen in front of the larger ($15 \times 15 \times 35$ cm^3) absorbers. All blocks have a phototube attached, along with coaxial cables for high-voltage input and signal output. The aluminum pipe is evacuated and contains a set of thin targets to be bombarded by the beam from the cyclotron, which passes down the axis of the pipe.

a given step of the "shower" have too little energy to undergo further bremsstrahlung. They then come to rest by the usual atomic stopping processes. The whole shower takes place in about 15 cm of the special lead-oxide-loaded glass. The Cerenkov photons can be detected by photomultiplier tubes and associated electronics.

We happened to have 20 blocks of the necessary glass on hand. We had borrowed them in 1981 from Tom Kirk of Fermilab in Illinois to conduct some tests at the Tower Shielding Facility (TSF) in connection with a neutron oscillation experiment that a group of us from the Physics Division, UT, and Harvard University were proposing for the Oak Ridge Research Reactor. Because funding for that effort did not seem assured, we were thinking of returning the glass, but fortunately we had procrastinated in doing so.

Each of the fragile blocks measures $15 \times 15 \times 35$ cm^3, has a 12.5-cm-diam photomultiplier tube attached to one end, and weighs around 34 kg (75 lb). The weight of the lead-glass blocks, which had never seemed an issue when we handled them singly or in pairs at the TSF, remains prominent in our discussions about rearranging the 20 blocks for an experiment.

In December 1982, we tried our first pion production experiment. We improvised a target chamber from a piece of beam pipe and made a target of some leftover gold foil used in Felix's earlier experiments. The HHIRF physicists had achieved great success in accelerating beams of fully stripped oxygen-16 nuclei to 25 MeV per particle, the top energy of the Oak Ridge Isochronous Cyclotron, and they directed such a beam to us for our experiment. We hoped to suppress the intense background expected from low-energy (<10-MeV) gamma rays produced in the dominant (but at the moment not of interest) reactions of oxygen-16 with our gold target at an energy of 25 MeV per particle. These hopes were based on tests with intense cobalt-60 and plutonium-beryllium sources.

The lead-glass blocks respond efficiently only to gamma rays with energies exceeding 15 MeV; we were interested in detecting gamma rays at energies of around 50–100 MeV, the signature for pion emission. However, the blocks also detect electrons (albeit inefficiently) that are Compton-scattered by lower-energy gamma rays, as long as the gammas have an energy exceeding 0.15 MeV. Our tests indicated that the blocks have a sensitivity to such gammas of about 5 parts in 10^4. However, hindsight has shown that we were looking for two gammas from π^0 decay out of 10^9 gammas from other reactions—a needle-in-a-haystack problem.

The first experiment was memorable because we lugged endless numbers of lead bricks and concrete blocks around at 2 a.m. in an attempt to shield the glass blocks from background radiation. Some sanity remained after all the huffing and puffing, though not enough to keep Terry Awes, who recalled that π^0 is often referred to as "pi-nought," from renaming all our data acquisition programs PINOT at some wee hour of the morning. Upon discovering this name change, Volker Rauch (our visitor from Strasbourg, France) remarked that he had some much better Pinot (he meant Pinot Noir) at his apartment, but that is a different story.

Surveying our less-than-overwhelming results during the next week, Felix and I concluded that we should add some converter detectors in front of the large glass blocks. These detectors are 5-cm-thick pieces of the same type of glass as the large absorbers. They are deliberately made so thin that they cannot absorb more than 30% to 50% of the energy released in the shower of one of the gamma rays. For our purposes, this attribute was an advantage.

Our arrangement required that two large glass blocks see a gamma ray simultaneously (within 4×10^{-9} s, given our signal processing electronics) and that a converter block placed in front of each of the active large blocks also see part of the energy at the same time. We reasoned that we could force a large reduction, 4 or more orders of magnitude, in the background noise in our experiment, while reducing overall detection efficiency by a factor of only 2 to 4. Normally such a loss in detection efficiency is cause for much alarm and redesign, but the gain in background reduction was too attractive to pass up.

[This background reduction occurs because of two conditions. First, the soft (<10 MeV) background gammas can "fire" only one glass block at a time. Second, the background rate for a set of four glass blocks is the product of the raw counting rates in all four of the glass blocks times the resolving time (4×10^{-9} s) to the third power. If only two glass blocks have to fire, the background rate is the product of the rates in the two blocks times 4×10^{-9} s to the first power. Every extra block involved in detecting a real photon brings in another factor of its counting rate times the coincidence resolving time (4×10^{-9} s). Because the count rates are typically 10^5/s, this factor is 4×10^{-4}. In reality, some of the background gammas can fire multiple blocks, so the rejection factor obtained is not this good. Also, too many extra blocks cannot be added because of loss in detection efficiency for the gammas of interest. A compromise must be struck between rejecting background gammas and having any events to show for the effort at the end of an experiment.]

We persuaded Jim Ball to let us try another discretionary run in February 1983, but we now faced the problem of finding a set of converter blocks in less than a month. To our good fortune, I learned in a phone conversation with Peter that he had created a set of converter blocks (by sawing up an old $10 \times 10 \times 100$ cm^3 glass block donated by a colleague) and that he would be happy to collaborate on further experiments at HHIRF. For our next run, we were thus joined by Peter and by Peter Paul (Stony Brook) and two visitors to Stony Brook, Ludger Ricken from the Federal Republic of Germany and Pei-Hua Zhang of the People's Republic of China. We again used an improvised target arrangement and the oxygen-16 beam and again struggled for two days with background problems. By the end of the run, however, we had managed to get our apparatus to show a few gamma-ray counts, which, after appropriate kinematic analysis, did appear to arise from something with the mass appropriate for a π^0. These scant results were exciting because they suggested that the threshold for pion production was much lower than the 54 MeV per particle originally predicted by Bertsch. Clearly, more experiments were needed to determine that threshold.

Collaboration at MSU

Peter Braun-Munzinger invited us to collaborate with him on the pion production experiment scheduled in June 1983 at MSU's new superconducting cyclotron. We had concluded that an experiment with a higher-energy beam would help sort out the remaining signal-to-noise problems. We wanted to test our prediction that the production cross section—that is, the probability of producing pions—should increase by an order of magnitude with a 10-MeV per particle increase in beam energy, about the increase offered by the MSU machine (35 MeV per particle). The MSU experiment demonstrated the validity of our prediction, and we published our results after a few months in *Physical Review Letters* [52, 255 (1984)]. Besides me, the authors were Peter Braun-Munzinger, Peter Paul, Ludger Ricken, Johanna Stachel, Pei-Hua Zhang, Felix Obenshain, and Eckhardt Grosse.

In the fall of 1983, we persuaded Ed Gross, our section head, to purchase several new glass blocks, small ones to be used as converters and large ones (normally called absorbers unless referred to in coarser terms by the person moving them about). We also realized that we needed faster phototubes and some improved timing electronics, so we began acquiring these components for a third round of experiments scheduled for early 1984.

Procurement went smoothly for most items except for the large absorber blocks. The French division of Corning Glass submitted the low bid for these items. We were not surprised that a French firm won the bid because the process of making good glass is largely a matter of providing sufficient electric power to make the melt, and electric power is quite cheap in France. Because our order went through Corning's New York office and because the engineer in Avon, France, who made the blocks usually left work at 4 p.m. his time (10 a.m. here), some interesting conversations ensued among ourselves, Martin Marietta Energy Systems, Inc.'s Purchasing, Corning New York, and Corning France. We were ably assisted by Joan Copeland in Physics and Fran Varnadore at Townsite, who oversaw the acquisition all the way through the last stages when the finished blocks disappeared for a week in the customhouse at John F. Kennedy airport.

Experiment vs Theory

Our new result suggested the need to reassess the theory of pion production in collisions of heavy nuclei. To explain this result, some theorists looked for a mechanism that pooled the kinetic energies of several nucleons, thus providing the energy required to create the rest mass of the neutral pion. One approach, pursued by David Vasak, Walter Greiner, and collaborators at the University of Frankfurt, Federal Republic of Germany, was to assume the existence of a nuclear "bremsstrahlung" process that radiates pions, analogous to the electromagnetic bremsstrahlung that causes an energetic electron to radiate photons when it is sharply decelerated. A second approach, pursued by Bertsch and Joerg Aichlen of the Joint Institute for Heavy Ion Research at ORNL, was to assume that an occasional highly excited compound nucleus formed in a collision deexcites by emitting a pion. Both theoretical approaches seemed to reproduce the observed production cross sections at 35 MeV per particle.

Our next set of experiments, carried out in April and July 1984 at MSU and HHIRF, respectively, was designed to clarify the characteristics of pions seen at 35 MeV per particle (the MSU run) and to measure the production cross section at 25 MeV per particle (the HHIRF run). The results of both experiments have just been written up for submission to journals for publication. The MSU results indicate that a further twist awaits the theorists—namely, that a large fraction of the pions produced appear to be reabsorbed in traveling out through the colliding nuclei and never reach the detectors. The HHIRF experiments yielded a probability of pion emission that was much too large to be accommodated by either of the theoretical models described earlier and also indicated that reabsorption effects were present, further disturbing theorists' peace of mind.

More HHIRF Runs

We recently completed another run at HHIRF, this time using a beam of sulfur-32 at 22 MeV per particle (lower still and nearer the threshold) to bombard aluminum and nickel targets. These results were analyzed this past summer by Jerry Chance, a student from New College in Florida, who was participating in the Oak Ridge Associated Universities summer student program. The cross section for the aluminum target is about 3×10^{-10} barns (1 barn = 10^{-24} cm^2), to be compared to 2×10^{-9} barns for the 25-MeV per particle runs, 10^{-7} barns for our 35-MeV per particle runs (at MSU), and 10^{-5} barns or more in the early experiments of Benenson. In short, the probability for producing pions rises drastically as the energy per particle in the nucleus increases.

Because these experiments require a week of running to record about three dozen events, we had time to think about second-generation experiments at the higher bombarding energies. In such experiments we could study the nature of the nuclei emitted in reactions that produce pions. We are especially interested in learning whether the colliding nuclei survive the reaction more or less intact (which would favor Vasak and Greiner's picture), whether a single heavy nucleus forms and decays (Bertsch and Aichelin's picture), or whether the two original nuclei decay separately by emitting a few nucleons (which would favor Brown and Prakash's picture described below).

Nearly all of the theoretical models we have seen have difficulty accounting for so large a pion production cross section as we observe. Recently we were told that Gerry Brown and M. Prakash of Stony Brook have resurrected a model first proposed by Brown in the mid-1970s and improved it to explain the HHIRF results. The model assumes that all nucleons in the two colliding nuclei act coherently to excite the delta resonance in one of the nuclei. The delta is simply an excited state of a nucleon; in such a state the nucleon has a spin of $3/2\hbar$, where $\hbar$ is Planck's constant divided by 2π (protons and neutrons normally have a spin of $1/2\hbar$) and a mass about 300 MeV/c^2 larger than that of a proton. It is an extremely short-lived state (actually a number of states exist with similar characteristics) that decays in about 10^{-24} s into a nucleon and a pion. Unless reabsorbed, the pion exits the nucleus and, if we are lucky, enters a detector. By including all intermediate excitations, Brown and Prakash predict a primary cross section larger than that measured. This prediction looks promising and suggests that reabsorption effects may reduce the primary cross section for pion production to a value near that measured at HHIRF.

In the summer of 1985, we found experimentally that a large number of single, high-energy (up to 100-MeV) photons are emitted in the same experiments that generate the pairs of lower-energy (70-MeV) photons associated with pions. These photons appear to be 100,000 times more likely to be emitted from nuclei than the pions. We expect to be busy determining whether a connection between these two phenomena exists or whether it is so much "pi in the sky" in the world of nuclear physics. ornl

awards and appointments

Anthony P. Malinauskas has received one of six Ernest Orlando Lawrence Memorial Awards presented in 1985 by the Department of Energy. Malinauskas was named recipient of the prestigious award for his outstanding contributions to the analysis of the movement of fission products in nuclear reactors, particularly light-water reactors. His studies helped explain why radioactive iodine releases after the 1979 accident at the Three Mile Island nuclear power plant were smaller than expected.

Five ORNL developments received 1985 I•R 100 awards presented by *Research & Development* in recognition of the year's top 100 R&D achievements. ORNL has received 52 I•R 100 awards since 1967, including 45 over the last nine years. The winning entries and developers are lead-iron phosphate glass for immobilizing radioactive wastes for disposal, developed by **Brian Sales** and **Lynn Boatner** (for details, see the *Review*, 1985: Number Two, page 14); a metal oxide varistor to protect electrical equipment, developed by **Bob Lauf** and **Walt Bond** (see the *Review*, 1984: Number Three, page 43); an electronic image detector for electrophoresis and chromatography, which is 1000 times faster than X-ray film in detecting complex molecules that control life processes, developed by **Jack Davidson** and **Art Case** (see this issue, page 26); a high-temperature biaxial fatigue extensometer for measuring two-dimensional strain in materials, developed by **Ken Liu** (see this issue, page 31); and a helium ionization detector for use in gas chromatography, developed by **Richard Todd** and **Rose Ramsey** (see this issue, page 28).

Science Digest has selected four ORNL innovations for awards in their 100 Top U.S. Innovators Award Competition. The winners, announced in the December 1985 issue of *Science Digest*, are the lead-iron phosphate glass, developed by **Brian Sales** and **Lynn Boatner**; the silicon-carbide whisker-reinforced ceramic composites, developed by **Terry Tiegs** (see the *Review*, 1985: Number Two, page 18); a reverse geometry hybrid instrument for mass spectroscopy, developed by **Gary Glish**, **E. H. McBay**, and **L. K. Bertram**; and a spherical tokamak fusion device, developed by **Martin Peng**.

James R. Keiser has been elected vice-chairman of Committee T-2F of the National Association of Corrosion Engineers.

Ernest G. Silver has been elected a fellow of the American Nuclear Society.

David P. Stinton and **J. C. McLaughlin**'s poster placed first in the optical microscopy category during the 1985 Ceramographic Exhibition of the American Ceramic Society. The poster was entitled "Toughened Ceramic Composites Can Be Produced by Simultaneous Chemical Vapor Deposition of Two Phases."

V. K. Wilkinson has been selected Region IV Industrial Engineer of the Year by the Institute of Industrial Engineers. Region IV represents Florida, Georgia, Puerto Rico, and Tennessee.

Martin Marietta Energy Systems, Inc., has selected four ORNL researchers as its first Corporate Fellows. They are **Peter Mazur**, **Eric Hirst**, **C. T. Liu**, and **Thomas Carlson**.

W. G. Craddick has been named head of the Engineering Analysis Section of ORNL's Engineering Technology Division. He replaces **John E. Jones, Jr.**, who was recently named director of ORNL's Civilian Reactor Programs.

Dorothy Skinner has been appointed a national lecturer for Sigma Xi.

Michael Roberts, former ORNL staff member, has received the Exceptional Service Award from the U.S. Department of Energy, where he is director of the Division of Planning and Projects in the Office of Fusion Energy.

Vivian Jacobs has been elected secretary of the national Society for Technical Communication (STC). She was also elected first vice-president of the East Tennessee Chapter of STC. **Jeanne Dole** was elected secretary of the local organization.

Thomas W. Oakes has been appointed coordinator for Environment and Health Physics with the Environment, Safety, and Health organization of Martin Marietta Energy Systems, Inc. Succeeding him as head of the Department of Environmental Management in the Environmental and Occupational Safety Division is **Paul S. Rohwer**.

Douglas H. Lowndes has been named a fellow of the American Physical Society.

Curtis E. Bemis, Jr., has been appointed to the editorial board of *Nuclear Instruments and Methods in Physics Research*, a journal edited by Nobel laureate Kai Siegbahn of Sweden.

Tommy Wright has been appointed to the American Statistical Association's Advisory Committee to the U.S. Bureau of the Census.

Of the 42 employees of Martin Marietta Energy Systems, Inc., who received cash awards ($100 to $1000 per inventor) recognizing the successful filing of an application for a U.S. patent on their work-related inventions, 31 are either ORNL employees or former ORNL employees. They are **Marvin M. Abraham, William H. Andrews, Jr., Carlos Bamberger, James R. Beene, Curtis E. Bemis, Jr., Lynn A. Boatner, Jorulf Brynestad, Anthony J. Caputo, Edward W. Chandler, Yok Chen, W. Kelley Dagenhart, Stan A. David, Stanley R. Dinsmore, Victor L. Fowler, Paul A. Haas, Joseph P. Hammond, W. Bruce Jatko, Robert J. Kedl, Carl C. Koch** (formerly at ORNL), **Manfred K. Kopp, Donald M. Kroeger, Jack Lackey** (formerly at ORNL), **Milton H. Lloyd, Chain T. Liu, David R. McNeilly** (formerly at ORNL), **John E. Mrochek, Thomas C. Quinby, Brian C. Sales, Louis H. Thacker, Mark P. Ternes**, and **James J. Woodhouse, Jr.**

Colin D. West has been appointed to direct the design and R&D phase of the Center for Neutron Research (CNR), particularly the high-flux reactor. **Ralph M. Moon** is responsible for the CNR's neutron beam research facilities and for interactions with potential users and the scientific community in the United States and abroad.

Thomas J. Wilbanks has been elected to the American Geographical Society Council.

Vivian B. Baylor has been named coordinator of ORNL's University Relations Program.

Stanley I. Auerbach has received the Distinguished Service Citation of the Ecological Society of America.

Theodore M. Besmann has received the 1985 Young Members Engineering Achievement Award of the American Nuclear Society.

Patricia D. Parr has been appointed manager for the Oak Ridge National Environmental Research Park.

Andrew S. Loebl has been named director of the Data Systems Research and Development Program of Martin Marietta Energy Systems, Inc. **George A. Dailey** has replaced Loebl as head of the Data and Analysis Section in ORNL's Energy Division. **Robert B. Honea** has been appointed head of a new Decision Systems Research Section in the Energy Division.

Colin D. West has been selected as vice-chairman of a new committee on Stirling machines in the Advanced Energy Systems Division of the American Society of Mechanical Engineers.

Nine ORNL staff members have been elected fellows of the American Association for the Advancement of Science. They are **B. Gordon Blaylock, Donald L. DeAngelis, Dale W. Johnson, Robert J. Luxmoore, Samuel B. McLaughlin, Jr., Stephen H. Stow, Charles R. Boston, Thomas J. Wilbanks**, and **James E. Turner**.

William R. Busing has received the 1985 Martin J. Buerger Award of the American Crystallographic Association in recognition of his contributions to crystallographic computing and the study of interatomic forces in crystals.

Ben Larson has received the 1985 Bertram E. Warren Award of the American Crystallographic Association. This award is given triennially for contributions to the physics of solids or liquids using X-ray, neutron, or electron diffraction techniques.

Debbie A. Bostick, James E. Strain, and **David D. McCue** have received the highest award given by the Department of Energy within the weapons complex. The DOE Weapons Complex Award of Excellence is bestowed on individuals or teams who make significant contributions in support of increasing the quality, productivity, and creativity of the nation's weapons program.

Stan A. David has been named a member of the Organizing Committee for the 1988 World Materials Congress sponsored by the American Society for Metals.

James L. Scott has been elected to the Materials Science and Technology Division Executive Committee of the American Nuclear Society.

Thomas H. Row has been appointed chairman of the National Program Committee of the American Nuclear Society for 1985–87.

At this salvage yard at Y-12, drums temporarily store waste oils and solvents before they are sold, placed in bulk storage, or transported to an approved disposal site.

Managing Hazardous Waste

ORNL Examines the Options

By CAROLYN KRAUSE

"Hazardous waste technology is proving a fruitful area for ORNL researchers who recently completed tasks for the U.S. nuclear waste programs. Our expertise in waste management has become particularly useful during a time of public and regulatory pressure to clean up hazardous waste sites throughout the nation."— Tom Row, director of ORNL's Nuclear and Chemical Waste Programs.

Since 1950 about six billion tons of hazardous materials have been deposited on land or buried underground in the United States. These materials are toxic, ignitable, corrosive, or dangerously reactive. Some can cause cancer, birth defects, miscarriages, nervous disorders, blood diseases, genetic mutations, or damage to the liver and kidneys. They may also cause property damage and degrade the environment.

According to 1981 figures, the sources of these hazardous wastes are largely the chemical and petroleum (71%) and metal-related (22%) industries. The remaining 7% includes hazardous waste generated by all other concerns, including government installations.

Oak Ridge National Laboratory, which for years has focused on the problem of safely disposing of radioactive waste, is now playing a leading role in helping the U.S. Department of Energy manage hazardous chemical wastes generated by DOE defense programs. In addition, ORNL is providing assistance to the U.S. Environmental Protection Agency (EPA) in tracking the disposal of hazardous wastes generated by the private sector, assisting the U.S. Air Force in managing hazardous wastes, and helping the U.S. Army evaluate the impact of disposing of chemical weapons. ORNL is also developing strategies and testing technologies to better manage its own chemical wastes and hazardous materials.

ORNL's effort fits into an emerging mission of DOE's Oak Ridge Operations: to make Oak Ridge a recognized center of expertise on the best available techniques for hazardous-waste management.

In the past few years Oak Ridge has been criticized for its environmental problems partly because of revelations about missing mercury and uranium. More recently, it has been gaining a reputation for finding solutions to waste-management problems. At the Y-12 Plant in Oak Ridge, which produces components for nuclear weapons and houses three ORNL divisions, a breakthrough in waste-treatment technology has proved that the toxic waters of the plant's highly visible, much-criticized S-3 ponds can be detoxified by bacterial treatment. Y-12 researchers showed for the first time that anaerobic (oxygen-shunning) bacteria of the Pseudomonas family could denitrify nitrate-bearing wastewater in open-air ponds. These soil bacteria not only convert nitrates and organic carbon into harmless nitrogen and carbon dioxide gases but also turn soluble heavy metals into an easily handled insoluble form.

The S-3 ponds, which were constructed at the Oak Ridge Y-12 Plant in 1951 for disposal of liquid wastes, are shown in the final stages of in situ wastewater treatment. Now, the water is clean enough to be discharged into a nearby creek.

ORNL is playing an important role in managing the nation's defense-chemical wastes and in devising better ways of dealing with its own hazardous materials.

The award-winning bio-denitrification process developed at Y-12, combined with a new polishing plant, achieves water quality levels at the S-3 ponds that are well below legal limits. After EPA-sanctioned tests, conducted by Jeff Giddings of ORNL's Environmental Sciences Division, demonstrated that the effluent from treated S-3 pond water is not harmful to fathead minnows, EPA granted Y-12 a discharge permit. Thus, the water from what environmental experts once called "the biggest problem on the DOE reservation" can now be legally and safely discharged into East Fork Poplar Creek in Oak Ridge.

Biodenitrification of open ponds is only one of three denitrification processes developed and tested in Oak Ridge. A stirred-tank bioprocess has proved useful at Y-12, and the ORNL-developed fluidized-bed bioreactor for removing nitrates has been implemented at DOE's gaseous diffusion plant at Portsmouth, Ohio, and will be used in a system now being built at DOE's Feed Materials Production Center in Fernald, Ohio.

In addition to helping DOE manage its chemical wastes, ORNL has become involved in helping EPA keep tabs on the management of hazardous wastes produced by the private sector. Under the Resource Conservation and Recovery Act (RCRA), EPA must develop and maintain state-of-the-art data and information systems relating to hazardous waste. These systems employ a massively distributed architecture among all state and regional offices that culminates in a headquarters system, which includes such items as the thousands of disposal sites and leaking facilities in the United States.

Recently, EPA's Office of Emergency Response asked Martin Marietta Energy Systems, Inc., to set up a computerized data system and develop decision support systems and techniques for advanced data base management of most aspects of EPA headquarters monitoring and emergency response. This work includes recording by region the location of various types of hazardous-waste sites and the transport of wastes to facilities for detoxification, destruction, or proper burial. This data system will also be designed to meet the information needs of the National Governors' Association. The $5-million project will be part of the Data Systems Research and Development Program of Energy Systems, directed by Andrew Loebl; the project will be led by Robert Honea, who will supervise the work of staff members of ORNL's Energy Division in collaboration with other divisions such as Computing and Telecommunications.

ORNL and Waste Technologies

ORNL has become involved in examining, selecting, developing, and testing technologies for safely and inexpensively recycling, detoxifying, destroying, or disposing of hazardous wastes.

In June 1985 Bill Rodgers published a 360-page document for the DOE Hazardous Waste Management Program entitled *Technology Review Report: Currently Available Technology*. He compiled information about different kinds of waste streams from industry and EPA and added this information to a waste classification system developed by the University of California at Davis (UCD). He then categorized standard industrial methods for treating hazardous chemical wastes (e.g., biological, chemical, physical, and thermal methods and reuse, recycling, and abatement). Finally, he matched UCD-classified waste streams with recommended treatment techniques.

A user of Rodgers' document can look up a waste stream such as an "aqueous stream with heavy metals" and find that an acceptable treatment method is "reverse osmosis," a separation technique by which a membrane allows certain materials, but not others, to pass through. Or a user can discover that ultrafiltration is a recommended treatment for latex wastes and that liquid-injection incineration effectively destroys hallogenated spent solvents.

The valuable information collected by Rodgers has been turned over to Cathy Fore, information and data systems manager of DOE's Hazardous Waste Management Program, which is staffed by more than 20 experts on loan from various ORNL divisions. Fore has developed for DOE a Waste Information Network (WIN) that links all the DOE operations offices, DOE headquarters, and various contractors. The network, first of its kind for DOE, facilitates information exchange (through electronic mail) and collection, dissemination, and analysis of data on hazardous waste. Fore began work in 1984 on setting up the system, which uses numerous personal computers (PCs) and a superminicomputer as the host computer. She also worked with Energy Systems experts and DOE-Energy Systems subcontractors (including Maxima Corporation in Oak Ridge) to develop the data base system and the software for accessing its various portions.

For the past several months, the network has been providing information exchange—the so-called "electronic newsletter" function. The data system, which is scheduled to operate by early 1986, will collect and provide information on the components of waste

ORNL employees in the Biology, Engineering Technology, and Fusion Energy divisions frequently see the S-3 waste ponds on their way to work at the Y-12 Plant. These ponds had been called a major environmental problem because of the nitrates, organic carbon, and heavy metals dissolved in the water. Recently, Y-12 has treated the water using a new biodenitrification process and a new polishing plant, making it clean enough to legally discharge into East Fork Poplar Creek in Oak Ridge. Here, M. G. Gordon (left) and Lee Reynolds, Y-12 chemical operators, collect a sample of liquid from the S-3 ponds before denitrification of the water is completed. Constant sampling of the ponds during the biodenitrification process was necessary to make sure the microbes used in the process had the best possible environment.

A Serious National Problem

Ironically, careless disposal of hazardous wastes in the United States increased during the past 15 years when environmental awareness peaked and the U.S. Congress approved a spate of environmental-protection legislation. This legislation included the Clean Air Act of 1970, the Safe Drinking Water Act of 1975, and the Clean Water Act of 1977. By complying with these laws and subsequent regulations, many organizations generated wastes that required land disposal. As a result, the ground became a catchall for more and more wastes.

To deal with the problem of improper ground disposal of wastes, Congress passed the Resource Conservation and Recovery Act (RCRA) of 1976. RCRA, which was strengthened in 1984, directed the U.S. Environmental Protection Agency (EPA) to regulate the management of the nation's hazardous waste. The law requires disposal of hazardous wastes at licensed and inspected facilities that are lined with impermeable materials and monitored during operation and after closure to ensure that nearby water supplies are not contaminated. Because RCRA raised disposal costs, many companies reduced production of toxic waste, reused it for energy and raw materials, stored it in tanks, injected it deep underground, or adopted acceptable ways of destroying it (e.g., incineration) or detoxifying it (biological or chemical treatment).

In carrying out their responsibilities, a few companies found it easier and less expensive to turn over their wastes to special contractors. Unfortunately, some contractors dumped them secretly at night into open pits to avoid the cost and responsibility of properly and safely disposing of potentially hazardous materials. The midnight dumpers and other flagrant violators helped create hundreds of abandoned illegal sites that often contain toxic or cancer-causing chemicals.

In 1978 at Love Canal in Niagara Falls, New York, the hazardous-waste problem caught the public eye when buried chemicals oozed to the surface, and leaking drums popped up after a hard rain. Irate citizens at Love Canal demanded action to protect them from ill health effects. Soon after, as awareness of the hazardous-waste problem grew, Americans expressed concern that buried wastes would migrate into groundwater and be transported to drinking water wells. In response to public concerns, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980.

CERCLA created the so-called Superfund—$1.6 billion to be spent by EPA in cleaning up hazardous waste sites or treating releases of hazardous substances from containers or facilities. (To date, only about a dozen sites have been cleaned up, but Congress is expected to reauthorize CERCLA for the next five years, creating a new Superfund of $7.5 billion to $10 billion.) While industrial organizations have tried all possible natural sinks (water, air, ground) for waste discharge and disposal, the existence of CERCLA suggests that the government has come full circle in trying to regulate waste management and prevent possible health problems from improperly managed waste.

How bad is the hazardous waste problem in the United States? According to Tom Row, director of ORNL's Nuclear and Chemical Waste Programs, "Some 250 million to 275 million metric tons of hazardous waste are produced annually in our country. EPA estimates that as a nation we handle only 15% of those wastes acceptably. More than 1000 chemicals are recognized as health or environmental hazards. Some of these chemicals are found in paint thinners, solvents, and detergents that people use in their homes and later throw away in the garbage.

"The nation has 10,000 to 100,000 abandoned sites contaminated with hazardous materials. Of these, about 800 have been deemed threats to the public's health and safety. That number is expected to rise to 2500 in the next five years. In addition, 100,000 of two million underground tanks for storing hazardous liquids are leaking. In another five years, 350,000 will be leaking. In short, hazardous-waste disposal has become a serious national problem that can be solved only by enforcement of federal laws."

streams, different technologies used to treat specific waste components, remedial responses to waste problems, and regulations.

A user at any DOE operations office or facility will be able to call up information on a PC about a particular waste stream and find out how different DOE facilities treat that stream and what other technologies are available for dealing with the problem. A user (say, at a DOE office in California) can "download" data from the host computer in Oak Ridge onto a PC and perform calculations to predict how best to treat waste streams with particular characteristics.

Hazardous-Materials Management System

Like Y-12, ORNL must make sure it is in compliance with state and federal environmental-protection rules. Thus, the Laboratory has developed a firsthand knowledge of which technologies and strategies are effective in managing hazardous materials, including wastes.

ORNL's Department of Environmental Management (DEM) in the Environmental and Occupational Safety Division is responsible for monitoring and sampling hazardous-waste discharges (as well as radioactive ones) to determine ORNL's status in complying with EPA and state regulations. DEM, in cooperation with ORNL's Industrial Hygiene Department, is responsible for tracking chemicals that come to ORNL and ensuring that only authorized people are using the chemicals. DEM is also responsible for following the chemicals as they leave individual laboratories and ensuring that they are discharged appropriately into the process drain system for treatment or packaged and stored until they can be shipped for approved disposal off-site.

The hazardous-materials management system at ORNL was conceived in 1981 by Tom Oakes, now coordinator for environment and health physics with the Energy Systems Environment, Safety, and Health organization (whose policies guide the implementation of the system). In 1982 a paper describing the ORNL system was presented to the National Safety Congress. It won the National Safety Council's Certificate of Excellence for Technical Program Presentation in Research and Development. The ORNL system has since become a model for other DOE national laboratories, several chemical companies (including E. I. du Pont de Nemours and Union Carbide Corporation), and universities.

Two other ORNL developments tied to the hazardous-materials management system are in the process of being transferred to industry. The ORNL silver recovery process used for photographic and reproduction wastes (which received an I•R 100 award in 1983) may soon be employed by a company in Oak Ridge and another in Knoxville.

As part of the hazardous materials management system, ORNL has developed a computerized information system for monitoring the location and movement of hazardous materials. Using bar-code labels on containers of hazardous materials, ORNL's computerized system tracks the containers from receipt through use or disposal. The ORNL system is being adapted for use by industry and will be sold commercially by Axcess Corporation, a start-up company recently organized by the Tennessee Innovation Center.

Cathy Fore (standing) asks Mary Beth Thomas about data available through the Waste Information Network. Fore spearheaded the development of the network.

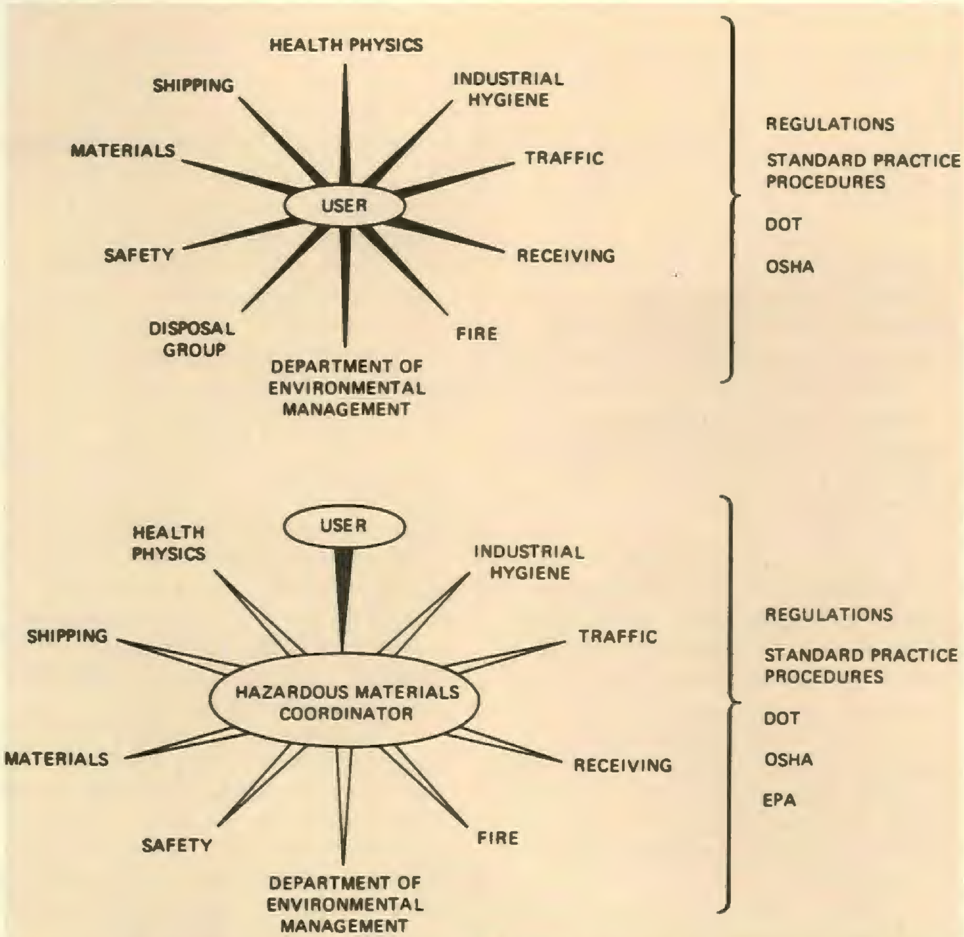
According to Oakes, the development of the hazardous materials management system was motivated by federal regulations published by EPA (as required by RCRA) and by the need to maintain good management, environmental protection, and personnel safety practices in the spirit of RCRA. The system has these features:

• It monitors and controls the procurement, transportation, storage, packaging, and disposal of hazardous materials. (DEM, under Paul Rohwer, is responsible for inspections, audits, and completion of compliance documentation. Frank Homan's group in the Operations Division is responsible for the proper packaging, labeling, storage, and transporting of hazardous materials.)

• The safe use of these materials is monitored by the Industrial Hygiene Department, which has a health coordinator for hazardous materials.

• Environmental protection officers in each division and an ORNL environmental hazardous materials coordinator (within DEM) will execute Energy Systems policies with respect to hazardous chemicals.

• Only ORNL employees on an authorized user list can obtain hazardous chemicals from ORNL's chemical stores. This has not always been the case. The procurement, use, and disposal of each chemical must be accounted for.



To encourage efficiency and compliance with regulations in the use, transportation, and disposal of hazardous materials, ORNL has devised a scheme that involved creating the position of a hazardous materials coordinator. In the past, the user had to deal separately with the various departments involved with implementing regulations pertaining to hazardous materials. Since 1980 the user has been encouraged to work directly with the coordinator, who interacts with all the departments, thus saving the user time and ensuring compliance with all regulations. Recently, a second coordinator was added.

This label appears above all process and sanitary waste drains at ORNL.

• The generators of the hazardous waste (i.e., users of chemicals such as ORNL researchers and technicians) have less paperwork if they abide by the system's procedures, which are explained in the *Hazardous Materials Management and Control Manual* (published in 1981). Under this incentive system, the user no longer has to interact separately with fire, safety, materials, shipping, health physics, industrial hygiene, traffic, and receiving personnel. The user provides information to the two hazardous materials coordinators, who interact with all these groups and determine whether the user has complied with regulations issued by the U.S. Department of Transportation (shipping), the U.S. Occupational Safety and Health Administration (personnel protection), and EPA (storage and disposal).

"If ORNL's hazardous materials management system is implemented successfully at the Laboratory, it can be used about anywhere," says Oakes. "With 1200 labs, 2100 users of chemicals, and 5000 different chemicals in daily use, ORNL is one of the most complex industrial organizations."

Each year about 100 metric tons of hazardous wastes are generated at ORNL. These materials include asbestos, animal carcasses from biological research, compressed-gas cylinders, organic and inorganic chemicals, and waste oils. Asbestos and animal carcasses are placed in dedicated trenches in one of ORNL's solid waste disposal areas and then covered. Hazardous wastes that contain radioactivity (mixed wastes) are placed in aboveground retrievable storage on the site until a suitable treatment method or disposal site is available.

Nonradioactive chemicals and oils contaminated with polychlorinated biphenyls (PCBs) are transported off the site to a licensed commercial hazardous-waste facility for disposal. (PCBs, which are used as coolants in electrical transformers, are classified by EPA as toxic and must, by law, be handled in certain ways.) In some cases, oils from ORNL transformers are purged of PCBs in an exchange process similar to kidney dialysis, which cleanses waste products from the blood. Because not all transformers require PCB oils, a program is under way to replace those that require PCB oils with new ones that do not. According to current plans, PCBs at the Laboratory will be burned in the high-temperature

Managers of hazardous waste generally have four options: they can reuse it, detoxify it, burn it, or bury it.

Recycling is an attractive but little used option in the United States even though it is encouraged by the Resource Conservation and Recovery Act of 1976. However, because federal and state regulations on landfills are making burial of wastes increasingly costly or are forbidding burial of wastes with high levels of toxic materials entirely, recycling will soon be competitive economically with land disposal.

Dean Eyman, manager of DOE's Hazardous Waste Management Program at ORNL, thinks that recycling is particularly desirable for organic chemicals. "Many hazardous wastes are organic solvents," he says. "Most organic solvents are not reused because they do not meet specifications for other processes. However, technology exists for making organic solvents reusable.

"For example, distillation processes can remove impurities so that solvents can be reused in the same process or another process in which the specifications are lower. In the private sector waste exchanges are emerging. One company in East Tennessee, for example, buys used solvents, processes them, and markets them for alternate uses. One product of this company is the solvent used in windshield washers for automobiles."

Another option is to reduce the toxicity of hazardous waste through treatment of the wastes themselves, the groundwater in which they reside, or the surface-water runoff from waste sites. Physical treatment processes include carbon adsorption, sedimentation and filtration, flotation, ion exchange, and reverse osmosis. Chemical processes include neutralization and precipitation (to handle acid wastes), ozonation, chlorination, and wet-air oxidation. Biological treatments include biodegradation, whereby natural and possibly genetically altered organisms digest persistent environmental poisons, transforming them into harmless substances such as carbon dioxide.

A "treatment" option favored by DOE and EPA is incineration—burning materials in the air in a special furnace. It is a form of treatment because it reduces the volume and toxicity of the waste material. Incineration of solids is usually done in rotary-kiln incinerators; liquids are usually burned by themselves or in mixtures with fuel oil in liquid-injection incinerators.

Curtis Travis, coordinator of ORNL's Office of Risk Analysis, thinks that incineration is preferable to land disposal because it is less likely to cause permanent effects. "Land disposal can ruin a piece of nature forever by causing irreversible contamination of groundwater," he says. Another advantage of incineration over land disposal, he adds, is that it is easier to quantify the health risks of incineration.

"Health risks of land disposal are difficult to quantify," says Travis, who is coauthoring a book with Crystal Cook entitled *Health Risks of Hazardous Waste Incineration*. "First, one has to determine the quantities of different chemicals that leach into the groundwater. That's not easy to do since the composition of waste at the site is not usually understood, nor are the characteristics of the soil known unless expensive testing is done.

"Furthermore, it is not known how many people are exposed to hazardous wastes in the ground. The path of exposure is not necessarily limited to groundwater. Some toxic materials seep into surface water. Children playing near a waste site may be exposed to toxic wastes by touching or breathing them. Many of these toxics volatilize, and the vapors enter the air. A 1982 study by the California Air Resources Board estimated that, on a ton per year basis, the quantity of vapors from waste disposal sites in southern California was equal to all industrial atmospheric releases there."

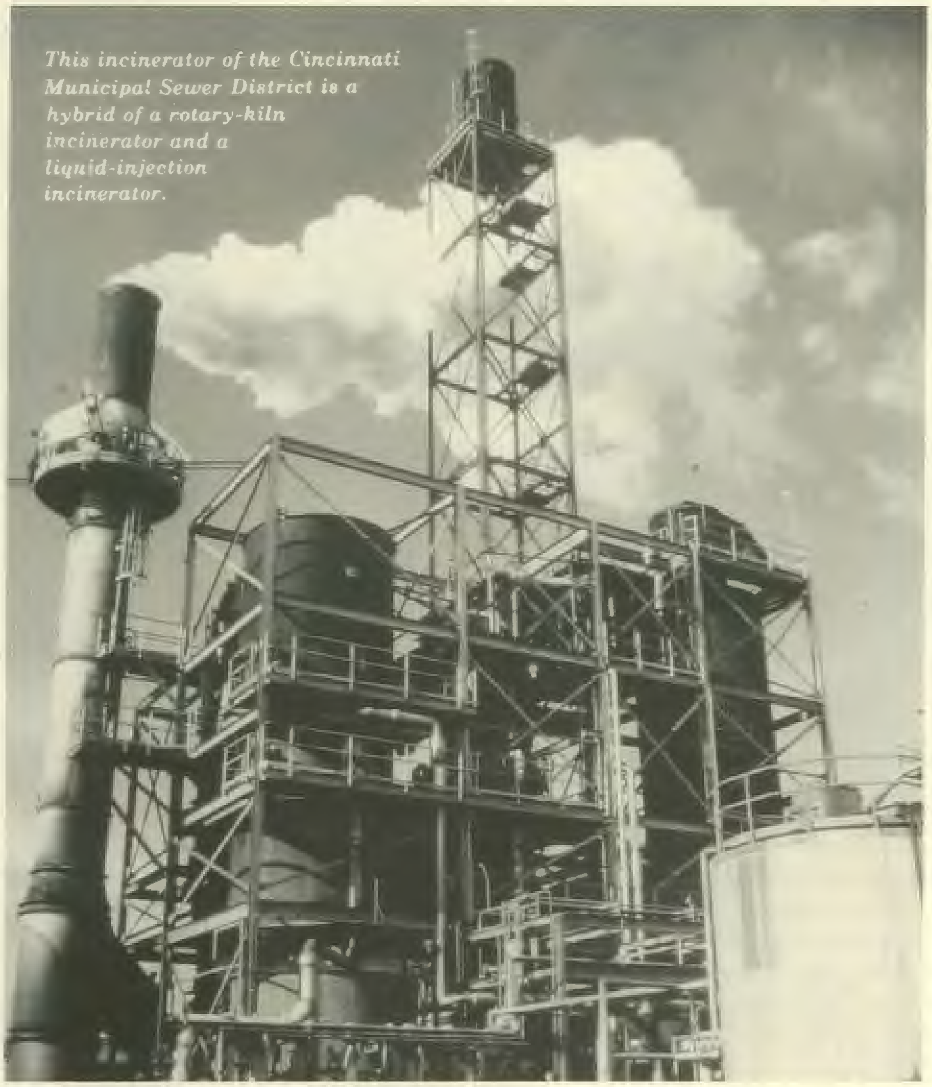
Travis says that it is easier to study the health risks of incineration because (1) emissions go directly into the air where their concentrations can be estimated and (2) the number of people living around an incineration site can be determined.

From the point of view of the individual, it seems less risky to live near an incinerator than a hazardous-waste landfill adjacent to an aquifer from which one's drinking water is tapped. "Incineration," says Travis, "is generally less hazardous because the emitted toxic substances are diluted in a large volume of air and may travel great distances. In the case of land disposal, wastes are diluted but only in a relatively small volume of groundwater trapped around the site."

The chief health hazard of incineration, says Travis, stems from the emission of heavy metals, which are not destroyed during combustion. Lead, cadmium, and chromium are particularly toxic. Lead, for example, can cause anemia and brain damage and mental retardation in children; for these reasons, EPA has instituted controls to reduce the amount of lead in automobile exhaust. One way to cut emissions of heavy metals from incinerators is to use electrostatic precipitators to remove particulates (to which about half of the metals leaving the smokestack are attached). Another solution—one that EPA may insist upon—is to burn only wastes containing no metals.

Another potential hazard of incineration, Travis says, may be products of incomplete combustion (PICs). During combustion many chemicals are broken down into simpler compounds that recombine into other chemicals as they emerge from the stack. These PIC chemicals can include some of the most toxic materials known to man, such as dioxin and furan isomers. Dioxins and furans can be formed when chlorines from burning waste paper or polychlorinated biphenyls (PCBs) recombine.

"I believe that incineration will lower the toxicities of all wastes including



PICs," says Travis. "I would guess that PICs will also not turn out to be a big problem because they are diluted into a large volume of air. But PICs are a worthy subject of investigation because scientists have identified only about 10% of the PICs coming out of incinerator stacks."

The study of incineration and its health risks was launched at ORNL in 1981 by Greg Holton (now at JBF Associates in Knoxville). Travis, Frank O'Donnell, and Elizabeth Etnier helped him on the project. Supported by EPA, the ORNL incineration project encompassed designing incinerators, testing technology to measure fugitive emissions, and sampling. This study was ORNL's first risk assessment of a technology for treating hazardous chemical wastes.

Incineration will not replace land disposal, but it can significantly reduce the volume of toxic waste to be put in the ground. If electrostatic precipitators are used in incinerators, the end result is a toxic residue, a sludge or ash enriched with heavy metals. This residue must be isolated from the environment.

"An attractive solution to the mixed-waste problem," says Eyman, "is to greatly reduce their volume by thermal destruction. The residue, which will be enriched in heavy metals and radioactivity, can then be incorporated by fixation technologies into forms that are highly resistant to weathering and leaching by water. Such waste forms can then be buried safely in the ground or, if politically acceptable someday, in deep-sea beds."

Eyman advocates that radioactive, metal-laden wastes be encapsulated in glass or incorporated in grouts (see box on page 54). He notes that DOE's Pacific Northwest Laboratory has developed a glass melter that takes radioactive waste residue and produces a glass slag that shows potential for long-term land disposal. A similarly designed glass melter has been successfully demonstrated at DOE's Mound Facility in Ohio. Dry, solid low-level wastes, resins, low-level sludges, and low-level contaminated nitrate wastes have been incinerated in this melter. Construction of a similar melter is planned for ORNL.

Although it is expensive to incinerate mixed wastes and encapsulate the radioactive residue in glass, the resultant reduction of the residue volume is significant. The increasing cost of using land disposal for the large volume of untreated mixed wastes, Eyman says, makes incineration, encapsulation, and land disposal of the residues look more economically attractive. The difference is that the latter method poses less hazard to the environment.

Licensed land disposal sites usually consist of trenches lined with clays or some other geological liner that binds to toxic chemicals or retards the infiltration of groundwater. The wastes are placed in steel-lined boxes. And equipment is available at the site to monitor the runoff and treat it if necessary. For these reasons, land disposal is not cheap.

In the United States, where economic survival is the goal, Eyman believes that industry and government alike should take a hard look at the total life-cycle costs of waste management, including the environmental costs. "The costs are always going to be there" he says. "Either government will give industry a greater tax break as an incentive to encourage waste treatment, recycling, and disposal of resistant waste forms in regulated shallow-land burial sites, or more tax money will go into Superfund to clean up waste sites."

incinerator at the Oak Ridge Gaseous Diffusion Plant following its completion in 1987.

ORNL's Role for DOE

Liquid and solid wastes have been produced for years by defense programs of DOE and predecessor agencies. To solve the problem of properly managing these wastes in compliance with the strictest of government guidelines, DOE has assigned lead functions to its operations offices. These offices will have the primary responsibility for conducting DOE's own waste-management program.

Oak Ridge Operations (ORO) was selected as the office to have the primary responsibility for hazardous and mixed (radioactive and hazardous) wastes for DOE's defense programs. Operations offices having the lead responsibility for other types of wastes are Idaho, low-level wastes; Albuquerque, New Mexico, transuranic wastes; and Richland, Washington, high-level wastes.

ORO assigned ORNL the role of lead support contractor. In January 1984, L. Dean Eyman, formerly of ORNL's Environmental Sciences Division, was named manager of the DOE Hazardous Waste Management Program, a part of the Nuclear and Chemical Waste Programs headed by Tom Row. Eyman's job is to manage a technology development program and the implementation of the best available technologies for managing DOE's hazardous and mixed wastes. In addition, the program oversees the adaptation of these technologies to manage hazardous and mixed wastes at all DOE facilities. These technologies include methods of recovering, recycling, treating, detoxifying, compacting, and safely disposing of wastes. The health and environmental risks of these methods are also being studied.

Dean Eyman and Bob Craig (standing) discuss a new Hazardous Waste Management Program report along with members of his managerial staff: (sitting from left to front) Jim McBrayer, Don Burton, Cathy Fore, Bob Fitts, and Jack Petty.

The Hazardous Waste Management Program, which focuses on the adaptation and engineering development of various technologies, will be supported by work at DOE laboratories including ORNL, Pacific Northwest Laboratory, and the Lawrence Livermore, Los Alamos, and Sandia national laboratories. At ORNL, for example, a scoping study will be performed to determine if magnetic separation would be feasible for separating certain materials from hazardous wastes generated at DOE facilities.

According to Eyman, "Nonradioactive chemical hazardous wastes dealt with by DOE are similar to those produced by the private sector. As in industry, degreasers, solvents, process chemicals, organics, heavy metals, and electroplating wastes are found in government facilities including DOE installations.

"However, because of the nature and functions of DOE, many of the waste streams generated in the past are not pure hazardous waste streams but, rather, are mixed radioactive and hazardous wastes. Our dilemma is that while RCRA encompasses mixed wastes as well as nonradioactive wastes, it does not spell out how to safely manage them. But regulations do forbid placing mixed wastes in a licensed hazardous waste landfill or in a low-level radioactive waste disposal site. The government is grappling with the problems of defining mixed waste and determining which agency should regulate it. In the meantime, we may only store our mixed wastes until government policymakers provide guidance on treatment and disposal."

ORNL's task is to work in support of DOE to adapt the best available technology or newly developed technology to the treatment and disposal of hazardous and mixed wastes in DOE's defense programs and at ORNL. In addition, Eyman and his

Trench for waste disposal.

associates are contributing to, and learning from, U.S. Department of Defense (DOD) efforts in managing hazardous wastes.

"DOE and DOD have similar challenges in hazardous waste management except that DOD has a large number of small facilities and DOE has a small number of very large facilities," says Eyman. "But the approaches we will take at both types of facilities will be about the same. DOD has been dealing with its waste problem for about seven years. We believe we can learn from its experience and thus get the DOE program operating in a rather short time. The DOE program will be applied to 58 DOE facilities, including 26 major installations of which 18 are under the purview of the Assistant Secretary for Defense Programs."

ORNL is managing one phase of the Air Force program to identify, quantify, treat, recycle, and dispose of hazardous wastes at 160 air bases in the continental United States. ORNL has been asked to oversee the development of remedial action plans for these sites.

In developing remedial action plans for the Air Force, ORNL and Energy Systems subcontractors survey information on the quantity and composition of wastes at various sites, examine various options for cleaning up sites and treating or reusing removed wastes, and conduct cost-benefit analyses to determine which option is best for a given site. A remedial action plan is then developed to outline what actions need to be taken to solve the problem.

According to Eyman, the Air Force is encountering groundwater contamination by organic wastes and other materials at some of its air bases. The sources of these contaminants are the organics and degreasers used by the Air Force for maintaining aircraft, fuel from spills and tank leakages, and metal-laden wastes from electroplating operations.

One option being considered for dealing with the problem of organics infiltrating groundwater is in situ biodegradation—that is, injecting microorganisms into the water that can break down organics into harmless compounds. Another option is air stripping—pumping groundwater up and running it through activated carbon to remove the organics. A third option is to remove contaminated soils and incinerate or decontaminate them with prototype soil-washing equipment.

Eyman and 25 ORNL staff members are working on the Hazardous Waste Management Program at the Fusion Energy Design Center across from the Y-12 Plant. The program is multidisciplinary and involves eight ORNL divisions: Analytical Chemistry, Chemistry, Chemical Technology, Engineering Technology, Energy, Environmental Sciences, Health and Safety Research, and Instrumentation and Controls. The program also relies on the expertise of employees in Energy Systems' Information Resources Organization and the Engineering Division. The latter division is represented in the program through the work of Dave Campbell on the project to develop remedial action plans for the Air Force. With a large increase in funding from DOE and the Air Force in fiscal 1986, Eyman expects to increase the number of program staff members to 40.

New Capital Projects

At ORNL new capital projects are under way or being planned to deal with the problem of hazardous solids and liquids. Gene McNeese is responsible for the Environmental Restoration and Facilities Upgrade Program, which is one of the Nuclear and Chemical Waste Programs headed by Row. These waste programs are expected to receive $80 million in fiscal 1986; more than half the money, however, will be for nuclear waste management. (As head of the Hazardous Waste Management Program, Eyman also reports to Row.) McNeese's job is to implement cleanup, stabilization, retrofitting, and other actions to bring ORNL into compliance with regulations of EPA and the state of Tennessee. McNeese's program will spend $21 million of the overall waste program budget. A program plan for implementing this restoration effort has been completed.

In fall 1985 a new $2.5 million sewage treatment plant was completed. It is designed to treat sanitary liquid wastes and to bring ORNL into compliance with National Pollutant Discharge Elimination System (NPDES) limits. In the past these limits have been exceeded because of excess levels of ammonia, biological and chemical oxygen demand, total residual chlorine, and suspended

In fall 1985 a new $2.5 million sewage treatment plant was completed at ORNL (round gray structure, lower left). It is designed to treat sanitary liquid wastes and to bring ORNL into compliance with National Pollutant Discharge Elimination System limits (e.g., levels of ammonia and suspended solids), which, in the past, have been violated at ORNL.

solids found in the effluents that flow into White Oak Creek. In addition to this work, sewer lines and underground piping have been fitted with polyester-felt liners to prevent leakages and the infiltration of groundwater and rainwater.

A new $18 million treatment plant for nonradioactive liquid wastes is now on the drawing board for ORNL. It will be built by 1989. Preliminary engineering and design reports have been completed, and an architect-engineer will be selected to do the detailed engineering design. The plant will treat the waste stream from the process drain system, which receives discarded chemicals, hexavalent chromates, traces of radioactivity, organics in greases, and small quantities of other potentially hazardous substances. These chemicals must be removed from Laboratory effluents in compliance with NPDES limits.

According to Lanny Bates of the Operations Division, process waste streams are being evaluated to determine which treatment processes are needed. Chemical and physical processes (such as precipitation and ion exchange) are being considered for removing metals, volatile organics, and involatile organics and for adjusting the acidity level (pH).

McNeese says another approach to reducing the amount of hazardous chemicals leaving the plant is to reduce the generation of the hazardous waste in the first place. This reduction can be achieved by instituting administrative controls to eliminate the use of hazardous chemicals normally discharged into the

Major Ron Vogel (left) discusses work that the Hazardous Waste Management Program will be conducting for the U.S. Air Force. Listening are Dean Eyman (second from left), Bernard Lindenberg (Major Vogel's colleague at the Air Force Engineering and Services Center at Tyndall Air Force Base in Florida), and Bob Craig.

process drain system. For example, ORNL uses a large amount of nitric acid in regenerating ion-exchange systems to remove undesirable impurities from the cooling water in ORNL reactors. The water must be cleaned before it returns to the reactor core to avoid a buildup of radioactivity that would result from exposure of dissolved materials to neutron irradiation. As a result of the use of so much nitric acid, ORNL has to deal with the problem of removing high concentrations of nitrates from the waste stream leaving the process drain system. One way to reduce or eliminate the nitrate discharge is to substitute sulfuric acid for nitric acid in regenerating ion-exchange systems—an example of an administrative control to change a process for the good of the environment.

ORNL plans to build three hazardous chemical waste storage facilities for temporary storage of waste chemicals from laboratory operations. The facilities will resemble warehouses and hold packaged wastes in drums. One facility will hold mixed waste, and the other two will store or repackage nonradioactive wastes temporarily until they can be transported to a RCRA-approved land disposal site.

To help prevent groundwater contamination, ORNL plans to develop an extensive groundwater monitoring network, involving some 800 new groundwater monitoring wells. Each quarter ORNL will sample 300 water quality wells in this network for the 129 hazardous substances on the RCRA list, including toxic heavy metals (e.g., arsenic, cadmium, lead, mercury) and aromatic hydrocarbons. Work is under way at ORNL to insert plastic liners into deteriorating sewer pipes and process waste lines to reduce the possibility of leaks.

Energy Systems is examining options for centralized treatment or disposal of hazardous wastes from the three Oak Ridge plants, including ORNL.

From AI to Antibodies

Artificial intelligence (AI) expert systems, computer programs that give advice based on knowledge and logic, will be employed by Bill Thiessen of the Chemistry Division and John Allen of the Instrumentation and Controls (I&C) Division to predict which chemical methods could detoxify or render harmless specific hazardous substances. Thiessen previously worked with Carroll Johnson of the Chemistry Division in applying AI methods to determine which chemical reactions will convert nerve gases and other hazardous war chemicals into commercially useful materials. In this work for the Toxic and Hazardous Materials Agency of the U.S. Army, Johnson and Thiessen found that obsolete weapons materials containing phosphorus, sulfur, and other elements could be transformed into fire retardants, herbicides, insecticides, chelating agents for extracting uranium from phosphate rock, and solvent extractants for nuclear fuel recycling.

Johnson will work with Curtis Travis of the Health and Safety Research Division (HASRD) to develop for EPA an AI expert system that predicts the extent to which different soils can prevent specific hazardous chemicals from migrating to groundwater and contaminating it.

In ORNL's Engineering Technology Division, Ted Fox and Mack Lackey have been determining the costs and benefits of an Army plan to recover "energetic" wastes from demilitarized weapons explosives

The Grout Fix

ORNL has pioneered a technology for disposal of radioactive wastes that could be used for in situ solidification of hazardous wastes. The technology involves cementing wastes in grouts and pumping them into underground cavities or caverns where they expand and harden. "The advantage of such on-site disposal," says Les Dole of the Chemical Technology Division, "is that it's safer than transporting hazardous wastes on the highways."

In the February 1984 issue of *Environmental Science & Technology*, Chuck Forsberg of ORNL makes a case for burying highly toxic wastes incorporated in grouts in geological repositories 300 to 2000 m underground, in a manner similar to that proposed for radioactive wastes. Because many shallow-land burial grounds have become toxic forever and require perpetual maintenance, many states now restrict shallow-land burial of toxic wastes that are not degradable. Forsberg argues that new bulk disposal techniques such as grouting would allow highly toxic wastes to be permanently and inexpensively isolated in large underground caverns.

Jesse Hoskins, Jr., a junior in Knoxville College's Mathematics-Engineering Program, carries out a colorimeter determination of cadmium on a Hitachi EPS-3T.

Dole, Forsberg, Mike Gilliam, and Earl McDaniel have tailored grouts to the chemical characteristics of particular wastes to prevent them from entering the environment. For example, clays, coal fly ash, and other additives can be mixed with the grouts to immobilize the hazardous wastes and increase their resistance to leaching by water. Recent ORNL leach data showed that EPA drinking water standards were met by water sampled from the outer surface of solidified grouts.

The grouts show promise for the fixation of hazardous wastes such as fly ashes containing toxic metals, pickling liquor sludges, spent limestone-scrubber solids, oils contaminated with PCBs, and polynuclear aromatic compounds. Grouts may be particularly useful for wastes that are slightly radioactive and enriched in heavy metals (mixed wastes).

ORNL has furthered its development of grouting technology through collaborations with two DOE facilities and a small college. Tailored grouts have recently been developed by ORNL for application at Rockwell-Hanford Operations and at Idaho National Engineering Laboratory. For Rockwell, radioactive liquid waste streams are converted into a grout by mixing with a dry-solid blend. This grout is then pumped into specially prepared trenches and covered. For Idaho, grouts were tailored for in situ use in shallow-land burial trenches containing low-level radioactive solid waste.

ORNL has entered a unique partnership with Knoxville College to identify additives that will increase grout retention of boron, nitrates, and several highly toxic heavy metals—namely, arsenic, cadmium, chromium, lead, mercury, and selenium. The additives under study range from apatite to zirconia. Jesse James, professor of chemistry at Knoxville College, calls this arrangement between DOE and an historically black college "the first of its kind in undergraduate education." The arrangement gives college students the opportunity to help solve the national problem of safely managing hazardous wastes.

(TNT, RDX, etc.) and use them to increase the heating content of fuel oil for boilers that produce process steam. A pilot test is being planned at Los Alamos to determine the design parameters for boilers to be fueled by mixtures of oil and energetic munitions wastes.

Four ORNL divisions are involved in evaluating the health and environmental impacts of disposing of U.S. chemical weapons (see sidebar on page 56).

Four divisions—Analytical Chemistry, Chemical Technology,

How Employees Can Help Solve ORNL's Environmental Problems

ORNL will spend $500 million to $700 million over the next 20 years for remedial environmental action, according to ORNL Director Herman Postma. That amount will be needed to correct environmental problems, comply with state of Tennessee environmental regulations, and replace or rehabilitate old facilities.

Postma noted that about 20% of the Lab's FY 1986 budget (or about $80 million) will be spent on remedial action and on research and development, and about 1000 ORNL employees will be involved in the work. However, he urges *all* ORNL researchers to do their part to dispose of hazardous chemical wastes correctly and to reduce the generation of hazardous chemical wastes in research operations through reuse, substitution of less noxious chemicals, and process innovations to cut the need for hazardous substances.

His advice is to

- Buy only the chemicals you need
- Consider the waste-generation impact when you make research proposals
- Think of new processes that will minimize waste (a good model is ORNL's silver recovery process that won an I-R 100 award and has commercial potential)
- Segregate wastes and don't mix chemical and radioactive wastes
- Know the required disposal practices and follow them
- Turn problems into opportunities by proposing short-term R&D projects for waste reduction or long-term projects to develop and demonstrate advanced solutions.

I&C, and HASRD—have developed instruments for monitoring emissions and spills from synthetic fuel activities that could be adapted for monitoring the handling of some hazardous chemicals. These instruments are based on the principle that some potentially toxic or carcinogenic organic chemicals absorb ultraviolet (UV) light and subsequently give off visible light. ORNL's spill spotter can remotely detect polycyclic aromatic hydrocarbons and other organic chemicals in spills by shining UV light on areas where contamination is suspected and by measuring the intensity of the emitted visible light. ORNL's fiber optics lightpipe luminoscope, which will be manufactured and marketed by Environmental Systems Corporation of Knoxville, uses long-wavelength UV light of very low intensity to safely measure skin contamination by organic chemicals. ORNL's derivative UV-absorption spectrometer can identify and quantify specific toxic gases in a chemical worker's environment. Such personnel and workplace monitoring devices could be used to ensure worker safety at hazardous-waste management sites.

In work for EPA, Steve Kennel of ORNL's Biology Division has spearheaded the development of monoclonal antibodies that react with the dioxin TCDD, a potent toxin and carcinogen found in Agent Orange and other herbicides and in hazardous waste. The availability of an antibody to dioxin makes possible the development of immunoassays to measure human exposure to this chemical and of techniques to monitor cleanup of contaminated areas.

A new project that has received support from the ORNL Director's R&D Fund will study microbial ecology phenomena that are important in biotreatment of hazardous wastes. Led by Terry Donaldson of the Chemical Technology Division and John McCarthy of the Environmental Sciences Division (in collaboration with the Biology Division and the University of Tennessee), this project will use monoclonal antibodies to trace the response of microbial populations to changing environmental conditions, and the addition of other microbes in microcosms and laboratory bioreactors. The purpose of the project is to learn how to predict whether desired microorganisms (including genetically altered ones) can be made to grow and function effectively and safely in open environments such as spills, groundwater, bioreactor systems, and ponds (like the previously mentioned S-3 ponds at Y-12). In this project, biodegradation of trichloroethylene and biodenitrification will be studied.

Institutional constraints on the application of innovative technologies impede technology advancement by industry. Application of available technology is difficult, and industry is often frustrated in its attempts. Incentives for the development of innovative technologies to address hazardous waste management by industry are virtually nonexistent.

The proposed Waste Technology Development Center recently announced by ORO is a positive step toward providing a mechanism for advancing hazardous waste management. This center can provide test beds inside the fences of government installations to be used in bridging the gap between R&D and demonstration of technology for treating, recycling, and safely disposing of hazardous wastes. Such test sites could lead to the solution of a serious national problem.

Because of DOE's commitment of millions of dollars to the Oak Ridge plants for environmental cleanup, Row predicts that Oak Ridge will become a sterling example of how to use the best technology to minimize the hazards of its voluminous, complex wastes. Says he, "We are already turning a sow's ear into a silk purse."

Disposing of Chemical Weapons: ORNL Advises the Army about Impacts

The U.S. Army owns more than 450,000 M55 rockets loaded with chemical nerve agents. In 1982 the rockets were declared obsolete; now a decision must be made on how to safely dispose of their contents. The nerve agents, deadly organophosphates called GB and VX, have recently been declared hazardous wastes.

In 1984 the Army Toxic Hazardous Materials Agency asked ORNL to help it assess the health and environmental impacts of disposing of the rockets, which are stored in reinforced concrete bunkers (igloos) at five installations in Alabama, Arkansas, Kentucky, Oregon, and Utah. ORNL was also asked to manage public scoping meetings, collect information on public concerns about the disposal project, and prepare materials to inform interested citizens and federal and state agency staffs about the problem.

The Army is considering three alternatives for solving the disposal problem: continued storage of the munitions in igloos, on-site disposal by high-temperature incineration at each of the five depots, and transportation of some of the rocket stockpile from existing storage depots to other depots for incineration and disposal. ORNL examined the impacts of normal operations and the accident scenarios for each of the three alternatives.

Assessing the transportation-and-disposal alternative proved particularly challenging to the ORNL researchers because the Army wanted to consider a wide variety of options for moving rockets from the depots in Kentucky, Alabama, and Oregon to the Utah and Arkansas depots, as well as to an incineration facility under construction on Johnston Island in the central Pacific Ocean. In their preliminary analysis, ORNL staff members looked at about 40 transport options involving ships, convoys of trucks and trains, and several different embarkation airports for air transportation. Using decision criteria sensitive to both public and Army concerns, the ORNL researchers made a significant contribution to the Army by recommending the elimination of certain transport options.

M55 rockets are stored (top) at these igloos (bottom) at the Anniston Army Depot in Alabama. ORNL has assisted the U.S. Army in determining the health and environmental impacts of disposing of the rockets.

During transportation of the rockets, an accident might occur that could lead to emissions of nerve agent into the atmosphere. In evaluating the potential impact on public health and the environment of this and other accident scenarios, ORNL researchers examined the available atmospheric dispersion models for these toxic gases. They found that the Army's own dispersion code is suitable for predicting near-field concentrations but unsuitable for estimating concentrations more than 20 km from the source. For those instances ORNL is using its modified-box atmospheric dispersion model.

The ORNL effort ended in November 1985 with the publication of several preliminary health and environmental impact assessments. Key contributors were Sam Carnes, Frank Kornegay, John Sorensen, and Martin Schweitzer of the Energy Division. The group received significant support from others in the Environmental and Occupational Safety (Emily Copenhaver), Environmental Sciences (Jim Breck, Lorene Sigal, and Ginny Tolbert), and Health and Safety Research (Guy Griffin) divisions. The Information Resources Organization of Energy Systems also provided support.

"Recently," Carnes said, "ORNL has been asked to expand its work considerably to assess the impacts of disposal of the entire stockpile of chemical weapons in the United States. This work will include the preparation of a programmatic environmental impact statement."

lab anecdote

The Radiation-Danger Symbol

George C. Warlick, Jr., who retired September 30, 1985, after more than 38 years of service at ORNL, has left his mark on the Laboratory. Not only was he responsible for naming ORNL's streets (First Street, Second Street, Third Street, White Oak Avenue, South Side Drive, Isotope Circle, Hillside Drive, and Hilltop Circle), but he also produced the widely used radiation-danger symbol.

In 1947 Warlick was hired by the Health Physics Division of Clinton Laboratories (now ORNL) to conduct a program of educating nontechnical employees about the nature of radioactivity and the need for rules and regulations to govern the handling of radioactive materials. As part of his job he familiarized employees with the Lab radiation-danger tag, which featured red and black letters on a white background.

Later that year, the Lab received word from the National Safety Council (NSC) that the Lab tag did not comply with nationally approved and accepted color codes. Red, NSC noted, was approved exclusively for warnings of fire hazards. NSC suggested that the Lab design new tags, taking into account the assigned significances of different colors—green for safety, blue for electrical hazards, and yellow for caution, for example.

Warlick was assigned the task of designing a new tag using acceptable colors. In his search for model color combinations and designs, he became interested in a tag used by a naval research laboratory in San Francisco. The tag, obtained by Bill Ray, Warlick's supervisor, consisted of the now familiar circle surrounded by three vanes, all colored magenta, on an eggshell blue background.

"Magenta was a color not assigned for any purpose by the National Safety Council," recalls Warlick. "Bill and I favored using magenta as the main color to denote radiation hazards. But we disagreed on the background color. He seemed emotionally attached to blue, which also is my favorite color. But I felt the lack of contrast between magenta and blue was a fatal flaw in the combination."

Warlick set about finding a more acceptable color combination. He asked the help of Glenn Williams, an artist with the Health Division, who had prepared posters and other visual aids for Warlick's educational program. Williams prepared about 10 sample tags using various color combinations that he and Warlick considered promising.

Ray looked at all the sample tags and then again expressed his preference for magenta and blue. But he graciously agreed to Warlick's proposal that the decision be made by a committee.

"He let me select the committee," says Warlick, "and I do admit that the committee was stacked with persons who had little enthusiasm for the blue background. We set up the different sample tags in an outdoor setting, and the committee observed the tags at 10 feet and 25 feet. The committee unanimously voted for the magenta symbols on a yellow background. The committee liked the contrast between the colors and liked the clear message—caution, radiation."

Tags of magenta vanes on yellow were made and used around the Lab site. Several Lab employees promoted the use of the tags at other government installations. Acceptance of the new radiation-danger tag came quickly, and the symbol is now used worldwide.

A Classic Example of Mishandling

The employees at ORNL responsible for purchasing, receiving, and delivering materials as quickly as possible have a tough job that is generally not appreciated, says Warlick, who later in his career moved from health physics education to procurement. On the whole, he adds, these employees perform their jobs well. But, as in every line of work, mistakes do happen. Warlick recalls an episode that he labels a "classic example of mishandling."

In the 1950s ORNL chemist Cole Waggoner developed an advanced spectrophotometer capable of handling aqueous solutions at high pressures and temperatures. This important development, which later received much recognition, required a standard Welch vacuum pump that was larger and more expensive than the models stocked at ORNL. The pump had to be ordered by Purchasing employees and handled initially by the Receiving people.

Because of its size, the vacuum pump was classified as an equipment, or "retirement," item, which thus required a number and property tag before delivery. The Receiving Department took care of fastening the tag to the pump.

Almost immediately after receiving the pump, Waggoner charged angrily into the office of Warlick, who was then responsible for material purchasing in the Chemistry Division. To affix the property tag to the pump, the Receiving Department had drilled two holes for small screws; unfortunately, the holes were bored into the vacuum chamber, rendering the pump useless.

The Property Department replaced Waggoner's ruined pump with a new one that had a more carefully screwed-on tag. Fortunately, unlike the pump it replaced, this new retirement item was not forced into early retirement. ornl

(If you have a Lab anecdote relating to the technical life of ORNL in the past 40 years, please write the Review editor, 4500-N, I-102, or call her at 574-7183.)

news notes

Reagan sees benefits of "joint" research

On September 24, 1985, President Reagan visited the University of Tennessee for a symposium on the benefits of collaborative research by federal laboratories, universities, and private industry. ORNL Director Herman Postma was one of six speakers at the symposium. Postma concluded his remarks by focusing on a case study of successful collaborative research at ORNL's Surface Modification and Characterization Laboratory:

"Surfaces are very important to all of us, and their properties determine very much how we use energy. For example, by cleverly modifying a surface we can make it very smooth to reduce friction and save energy, or we can reduce the corrosion of materials to make them last longer or work in very difficult environments in coal plants, or create better solar cells, or provide catalytic action.

"About a year ago a university faculty member, now at the University of Tennessee, noted that such techniques might have great potential in modifying the surface of implantable hip joints to reduce body fluid corrosion yet keep the desirable properties of lightness and strength. That hunch was a very good one, and during the last year we have been able to prove that commercial titanium metal hip joints modified by implanting atoms of nitrogen can live in corrosive body fluids without replacement. Perhaps you know of many people who have had an expensive and painful hip or knee replacement and then had to have exactly the same operation five to ten years later because the old joint 'wore out'—that is, corroded.

"These newly developed joints, at only a 1% increase in cost, can last for 1000 years—a time that would outlast even the 969 years of Methuselah. A national company in the surgical implant business is rapidly incorporating this process into its line.

"The savings from this basic research finding, in medical costs and time off from work, will amount to hundreds of millions of dollars. The unanticipated discovery from this one example of basic research, collaboration, and subsequent transfer and rapid adoption by industry shows what an effective partnership really can do."

President Reagan and University of Tennessee Chancellor Jack Reese hear how research at ORNL led to an artificial hip joint that could last a lifetime—even for Methuselah. (Photo by Ruth Carey.)

New fusion facility begins operation

In August 1985, the Radio Frequency Test Facility (RFTF) in the Fusion Energy Division was completed on time and $650,000 under budget. The $5-million RFTF will be used to develop high-power antennas for transmitting radio waves into fusion plasmas to heat them. ORNL has the lead responsibility among DOE fusion laboratories for developing radio-frequency heating.

The facility includes a vacuum test chamber sandwiched between two superconducting magnets. Full-size antennas can be inserted into the test chamber, where a steady-state plasma can be formed.

The RFTF will first be used to test antennas that are being jointly designed by ORNL and GA Technologies, Inc., for the company's DIII-D fusion device near San Diego. Later it is expected to be used for testing ORNL-developed components for the Laboratory's Advanced Toroidal Facility and for other U.S. fusion devices. Tentative plans also call for the facility to provide support for collaborative efforts with fusion programs in other countries.

According to project manager Harold McCurdy, the RFTF is valued at several times its $5-million price for construction and equipment, because it incorporates equipment from earlier experiments at ORNL and other organizations.

Congress hears of space power needs

On October 9, 1985, Fred Mynatt, ORNL Associate Director for Nuclear and Engineering Technologies, testified at a congressional hearing on the future of nuclear power systems for space. The hearing was sponsored by the House of Representatives' Energy Research and Production Subcommittee, chaired by Rep. Marilyn Lloyd (D-TN). Mynatt was among more than two dozen witnesses who spoke during three days of hearings.

"Space-based defense systems will require intermediate-level power sources to support high-resolution sensors, advanced radar, platform control, and secure communications systems," said Mynatt. "These uses will require continuous power-generating capabilities ranging from tens to hundreds of kilowatts. Advanced defensive weapon concepts, including neutral particle beams, electromagnetic rail guns, and space-based lasers, have very large power needs. For these applications, power of 100 megawatts or more for periods of hundreds to thousands of seconds will be required."

Mynatt added, "It appears that nuclear fission power is required to meet long-term power needs of 100 kW or more and to provide repeated bursts of high power. . . . It is, therefore, important to commit resources now to space nuclear power development commensurate with the efforts on advanced energy weapons."

ORNL is currently involved in the conceptual design of multimegawatt space reactors and energy conversion and storage systems for the Strategic Defense Initiative. The Laboratory has the lead role in the technology areas of materials, shielding, and energy conversion and storage.

Mynatt listed other areas in which ORNL and other Martin Marietta Energy Systems, Inc., facilities could contribute to the space nuclear power program, including component testing and quality and reliability assurance for the candidate reactor that will be ground-tested at Hanford Engineering Development Laboratory near Richland, Washington.

Fusion magnet facility begins 6-coil tests

In October 1985, the last of six superconducting magnets was installed in ORNL's International Fusion Superconducting Magnet Test Facility. The test vessel was closed and researchers began the seven-week process of evacuating the tank and cooling the magnets to superconducting temperature, 4 K.

The coils are one-third to one-half the size of coils that would be needed for future power-producing fusion reactors. When cooled to near absolute zero by liquid helium, the magnets are designed to produce magnetic fields of 8 T.

The facility includes three coils from U.S. companies and one coil each from the European Atomic Energy Community, the Japan Atomic Energy Research Institute, and the Swiss Institute for Nuclear Research.

The facility and the six coils represent an investment of about $120 million by DOE and the other participants in the international Large Coil Program.

The testing program for the coils is expected to last one to two years.

Life Sciences Complex on drawing board

New facilities that would consolidate ORNL's life sciences programs are now being planned for the west end of the main ORNL complex. The plans call for several new buildings for staff from Biology, Health and Safety Research, and other divisions, as well as a multiprogram support building. The new facilities would be built adjacent to four existing buildings that house the Environmental Sciences Division, which were completed between 1978 and 1983.

The new facilities would allow the Biology Division, which is currently housed at the Oak Ridge Y-12 Plant, to move to ORNL's X-10 site. The Y-12 buildings, originally constructed as uranium enrichment facilities during World War II, are becoming obsolete and inefficient as research facilities. They are also less accessible to visitors than ORNL's other life sciences facilities, because they are located at a weapons plant, where security is a prime concern.

The proposed new buildings would be built outside ORNL's security fence, so visitor access would be convenient.

Futuristic utility system begins operation

Electric power systems in the year 2000 may be dramatically influenced by results from an ORNL-managed project now under way in Athens, Tennessee. The key part of the

A model of the proposed Life Sciences Complex at ORNL. The circled structures are existing buildings such as the Environmental Sciences Laboratory and the Aquatic Ecology Laboratory. The planned buildings will house members of the Biology Division and the Health and Safety Research Division.

project—the most highly automated electricity distribution system in the nation—began experimental operation in September 1985. The project, which is managed by the Power Systems Technology Program within ORNL's Energy Division, also involves the Athens Utilities Board (AUB) and the Electric Power Research Institute.

The system employs computers and two-way communications devices to monitor and control electricity distribution. It can reduce electricity use by water heaters, space heaters, and air conditioners in the homes of 2000 of AUB's 10,500 customers in order to flatten the utility's peak loads. Load control experiments affecting customers' power consumption began in late October.

The system can also control voltage levels and switch loads automatically to increase the efficiency and reliability of distribution equipment. The system promises to be a model for utilities seeking to defer construction of expensive power-generating facilities.

The first experiments, conducted in September, were the "volt/var control" experiment, which controls capacitors and regulators to control voltage and reduce energy losses, and the "system reconfiguration" experiment, which involves automatically transferring electric loads between substations and taking other actions to restore power more quickly after an outage caused by a fault (such as a tree falling across a power line).

These types of experiments, which are sponsored by DOE's Office of Energy Storage and Distribution, will continue for the next several years.

ORNL helps Bureau of Printing and Engraving

ORNL's work for federal agencies other than DOE has recently broadened to include three projects for the U.S. Bureau of Printing and Engraving, which is part of the Department of the Treasury. Carroll Johnson of ORNL's Chemistry Division is the Lab's liaison with the Bureau.

The three projects:

• **Design specifications for an inspection and control system** for high-speed currency presses. The Bureau prints billions of bank notes each year to replace deteriorating currency. (Some 16 billion U.S. bank notes are in circulation worldwide, about half of them overseas. The most common notes, one-dollar bills, last only about 18 months apiece.) The Bureau needs a system that can inspect bank notes for printing flaws as they are being printed by web presses (at the rate of one 32-note sheet every 0.4 second). The system also needs to be able to identify and remove flawed notes and modify the operating conditions of the presses to correct printing problems.

• **Development of an artificial intelligence (AI) workstation** for use in formulating new inks for postage stamps and other securities. The Bureau prints some 32 billion stamps each year. Inks for the stamps must be formulated for both appearance (mainly color) and printability (viscosity, for example). Ink formulation is complicated by the need to vary formulas slightly to accommodate differences in printing presses, papers, and plates, says Johnson. Also, he notes, some successful ink formulations from earlier years can no longer be used because they contain chemicals that are now restricted for environmental or health reasons. The AI system ORNL is helping develop will ease the process of researching existing formulas and developing new ones to fit certain specifications.

• **Counterfeit-deterrence measures.** The Bureau is concerned that an upcoming generation of color copiers may be able to make high-quality copies of money that could pass for genuine currency. ORNL researchers are examining new materials and instrumental methods

HTML rises: ORNL's $19-million High Temperature Materials Laboratory, begun in early 1985, is progressing well ahead of schedule. The contract calls for the completion of the facility in January 1987; at the current rate of construction, the HTML could be ready by September 1986.

that make counterfeit bank notes easier to detect.

ORNL to study JET fusion refueling

In late October 1985, DOE reached agreement with the Joint European Torus project (JET) on a new collaborative program in which ORNL's Fusion Energy Division will play the major role. JET, located at Culham, England, is the world's largest tokamak. The new project involves studying the effect of refueling the plasma in JET by injecting frozen hydrogen and deuterium pellets at velocities of about 2000 meters per second.

A budget of nearly $2 million will be provided to ORNL for construction of a 3-gun pellet injector. Stan Milora, the inventor of the repeating pneumatic injector, will be in charge of the ORNL effort.

The pellet injector is also being used in refueling studies on the largest U.S. fusion reactor, the Tokamak Fusion Test Reactor, located at the Princeton Plasma Physics Laboratory.

Roof Test Center to be built

A $2.8-million facility for testing roofing materials and designs is now being planned for ORNL. The Roof Test Center, which should begin operation in 1988, will provide the roofing industry with experimental data and analysis on the thermal, mechanical, and moisture-related performance of flat roof systems.

U.S. businesses and homeowners currently spend about $10 billion/year on flat roofs, including about $6 billion to refurbish existing roofs. Improved technologies and designs could reduce costs by lengthening the lifetimes of the roofs (currently 10 to 20 years) and by reducing energy losses through them.

The Roof Test Center at ORNL will be a national user facility, open to researchers from industry, universities, and government. An advisory panel of industry representatives will help set priorities and choose experiments for the facility.

technology transfer briefs:

Cummins Engine licensing breaks new ground

Martin Marietta Energy Systems, Inc., and Cummins Engine Company, Inc., have signed a license agreement for commercial application of nickel and nickel-iron aluminide alloys developed by ORNL.

The agreement, which involves the use of new heat- and corrosion-resistant alloys, is the first licensing by Energy Systems (rather than DOE) of a patented, ORNL–developed technology for commercial application. "This important agreement," said ORNL Director Herman Postma, "is a direct result of policies initiated by the federal government, and specifically the Department of Energy, to increase the transfer of advanced technology to American industry."

Cummins, the world's leading designer and manufacturer of heavy-duty diesel engines for on-road vehicles and industrial equipment, has been assigned exclusive rights involving large diesel engines and turbochargers, while Energy Systems will retain other rights.

"All of the funds received from the license by Energy Systems will remain the property of the U. S. Government and will be used to create a technology fund for development and transfer of other inventions having commercial potential," said William W. Carpenter, vice president for technology applications, who negotiated the licensing agreement with Cummins.

Cummins will do further research on the use of ORNL's nickel and nickel-iron aluminide alloys for high-temperature components in diesel engines and components. For some time, Cummins has conducted an advanced research program to improve engine efficiency and reduce costs through the use of ceramics and other high-temperature materials.

Nickel and nickel-iron aluminide alloys, which become stronger at higher temperatures, are the first of a new class of high-temperature alloys made of inexpensive and lightweight materials. Included in the intermetallic family of materials, they share characteristics of both metals and ceramics. But unlike other intermetallics, which are brittle, the ORNL-developed nickel and nickel-iron aluminide alloys are ductile, or nonbrittle, and can withstand temperatures as high as 1000°C.

Additional potential applications for nickel and nickel-iron aluminides, for which other licensing arrangements will be sought, include high performance jet engines, gas turbines, advanced heat engines, and heat exchangers in nuclear and coal-fired steam plants.

Modified nickel and nickel-iron aluminide alloys have been developed at ORNL under the leadership of C. T. Liu of the Metals and Ceramics Division.

ORNL ranks tops in R&D contests

ORNL has won a total of nine awards—more than any other DOE laboratory—in R&D competitions sponsored by two science magazines. The awards were announced in fall 1985 by *Research & Development* and *Science Digest*, which each sponsor an annual competition to select the year's top 100 R&D accomplishments. (See "Awards and Appointments", page 40, for a list of the winners.)

In the I-R 100 competition sponsored by *Research & Development*, ORNL developments won five awards. That number was surpassed only by the six awards claimed by AT&T Bell Laboratories and by Hitachi, Ltd., and the eight awards won by the National Bureau of Standards. Over the 23-year history of the contest, ORNL ranks fifth in the total number of awards.

In the *Science Digest* "Top 100" contest, ORNL developments won four awards. Other top performers in the competition were DOE's Sandia National Laboratory and the General Electric Company, also with four awards each, and General Motors Laboratories and AT&T Bell Laboratories, with six awards each. ornl

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President Reagan listens intently as ORNL Director Herman Postma tells how collaborative research led to a better artificial hip joint. Also listening is Jack Reese, chancellor of the University of Tennessee. For more on the presidential briefing, see "News Notes," page 58. (Photo by Ruth Carey.)