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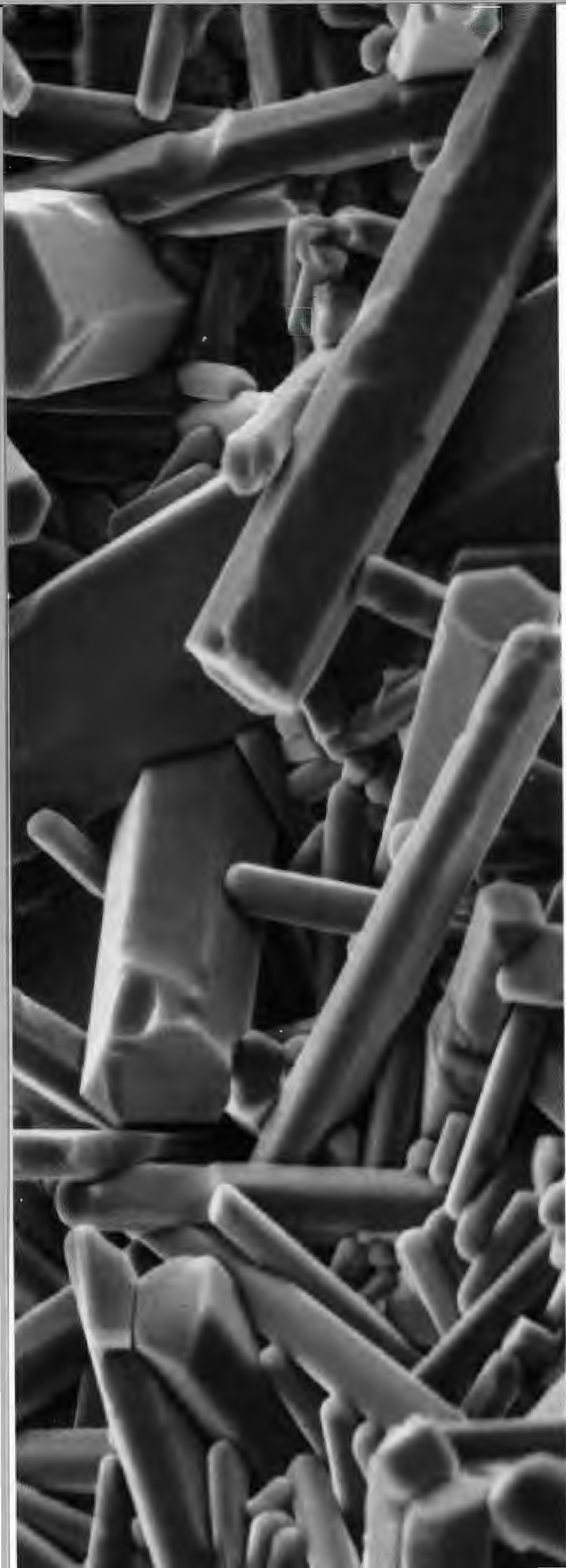
HIGH-TEMPERATURE CERAMICS

MODEL FOR AUTOIMMUNE DISEASE

REGULATING ENVIRONMENTAL CARCINOGENS



ON THE COVER

In this silicon nitride material made by microwave processing at ORNL, the interlocking network of hexagonal fibers (as shown in this electron micrograph by Dorothy Coffey) strengthens the ceramic. ORNL has made important contributions to the processing of silicon nitride for use in high-temperature, energy-efficient engines, as described in the first two items in "Technical Highlights" on p. 56.

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REVIEW

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FEATURES

DEPARTMENTS

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

Scurfy Mice: A Model for Autoimmune Disease

By Virginia L. Godfrey

Autoimmune disease—the condition in which the body attacks its own tissue—has been an object of public concern recently. Former President George Bush and his wife Barbara both are afflicted with Graves' disease in which the body's own immune system attacks the thyroid gland. The safety of breast implants was called into question because of evidence that some recipients had developed autoimmune disorders such as rheumatoid arthritis, systemic lupus erythematosus, and scleroderma. Women, the media pointed out, have a higher-than-average incidence of many autoimmune disorders. These events suggest the need to know more about what makes the immune system work so well and what makes it go awry.

At ORNL's Biology Division, we have made progress in understanding the underlying causes of immune disease by studying mice having a disease that causes them to be underdeveloped; to have scaly skin, small ears, and large spleens; to open their eyes late; and to die early. These "scurfy" mice are helping us better understand the role of the thymus gland in autoimmune disease.

B and T Lymphocytes

Our immune system protects us from diseases by its unique ability to distinguish our own "self" molecules from those of invading microorganisms. To make this distinction, the immune system must first learn to recognize and tolerate self molecules during growth and development. This critical function is performed by lymphocytes—circulating white blood cells that search for foreign cells or microorganisms and directly or indirectly cause chemical attacks on these invaders to inactivate them. Each invader carries antigens—proteins or carbohydrates that, when introduced into the body, stimulate the production of a specific immune response. Foreign antigens are recognized by lymphocytes.

Lymphocytes are divided into two major categories based on their development pathways and functions. B lymphocytes recognize a foreign antigen by their cell surface antibody receptors. When stimulated by the appropriate foreign antigen, B lymphocytes can be transformed into antibody-producing factory cells called plasma cells that secrete antibodies specific for that antigen. Like a protective cover for an electrical outlet, an antibody attaches to the foreign antigen. This antigen-antibody complex then attracts scavenger-type white blood cells called macrophages that ingest and destroy the offending microorganisms.

T lymphocytes are so named because they develop and mature within the thymus, a bi-lobed gland next to the heart. They recognize an antigen by their cell surface protein called the T cell receptor. T lymphocytes develop into two types of cells having different functions: killer cells and helper cells. Killer T cells carry the CD8 cell surface protein associated with their T cell receptors and act to destroy virus-infected cells or cells with foreign tissue antigens (as in graft rejection). Helper T cells are the master coordinators of the immune system. Carrying the CD4 cell surface protein next to their T cell receptors, helper T cells respond to foreign antigens by releasing a host of chemical signals called interleukins. These interleukin molecules call lymphocytes and other white blood cells to the site of the immune response, enable other lymphocytes to proliferate, and help B lymphocytes transform into antibody-producing plasma cells. The CD8 and CD4 cell surface proteins are often referred to as "markers" for the T_c and T_h subclasses of T cells because monoclonal antibodies to these proteins can be used to count these cells using fluorescent staining.

Obviously, anything that goes wrong within this complex, interlocking system can have profound effects on the individual. For example,

"Scurfy" mice are helping us better understand the role of the thymus gland in autoimmune disease.

Virginia Godfrey holds a female mouse (weighing 18 grams) and her smaller male sibling of the same age (weighing about 6 grams). The male mouse has scurfy disease.

the human immunodeficiency virus (HIV) that causes acquired immunodeficiency syndrome (AIDS) attacks and destroys CD4 helper T cells. As a result, the immune system is devastated and the AIDS patient is left vulnerable to a host of life-threatening infectious diseases. Persons or animals born without a thymus (such as the nude mouse) lack T lymphocytes entirely and are, therefore, severely immune deficient. Other inherited immunodeficiencies cause the inability to make some or all types of antibodies.

On the other hand, excessive or incorrect functions of the immune system can have equally harmful effects. These may range from the discomfort of allergies (overreaction to pollens, animal dander, etc.) to life-threatening autoimmune diseases such as juvenile diabetes, systemic lupus erythematosus, or scleroderma. The immune system's mistaken attacks on the body's own normal tissues may be limited to very specific tissues, such as the pancreatic islet cells in juvenile diabetes, or they may involve entire organs or organ systems. Currently, the causes of autoimmune disease are unknown. Treatments consist of powerful immuno-suppressive drugs such as those given to recipients of organ transplants. These drugs have severe side effects and only inhibit the symptoms of autoimmune disease, not the root causes.

Mutant Mice

In 1987, I joined Richard Griesemer's laboratory in ORNL's Biology Division to investigate several mutant mouse stocks as potential animal models of human disease. We quickly settled upon an animal of historic importance in the genetics community—the scurfy mouse.

Close-ups of healthy and scurfy (mutant) mice. At top are two dark mice siblings (the one on the left has scurfy disease), a light-colored normal mouse (middle), and a hairless scurfy–sparse fur mouse (right). Sparse fur is a second mutation that is closely linked to scurfy on the X chromosome. The lack of hair caused by the sparse fur mutation is used as an indicator of the linked gene, scurfy, in mice less than 12 days of age (when lesions of scurfy itself first become visible). In the middle is a hairless, scurfy–sparse fur mouse (right) and its normal male sibling (left). At bottom are the healthy female mouse with her male sibling, which is smaller because of scurfy disease.

The scurfy mutant mouse was discovered by William L. Russell in 1949. Russell, who was scientific director of the Mammalian Genetics Section in the Biology Division, noticed a litter of young mice that contained several runted animals with scaly skin. Thinking that these animals were sick, he promptly discarded them! Happily, when similar offspring appeared in a litter from a closely related female, he immediately recognized their problem as a genetic disease and began to investigate its inheritance pattern. It soon became apparent that only male offspring were affected, whereas female mice were unaffected carriers of the trait, suggesting that the scurfy gene was located on the mouse X chromosome—the first sex-linked mutation to be discovered in the mouse. Because the mode of sex determination had not yet been established for mammals, this conclusion could not yet be a firm one.

However, a few years later, scurfy mice provided the means for demonstrating how sex determination takes place. Occasional female offspring were found that had the scurfy disease. Although they were doomed to die before they were old enough to reproduce, their genetic constitution could be tested by William Russell by transplanting their ovaries to healthy host females. The results of these genetic tests of scurfy females, in conjuction with genetic data and chromosome counts obtained by W. J. Welshons and Liane B. Russell (now head of the Biology Division's Mammalian Genetics and Development Section) for another mutation, enabled the team to prove that the exceptional females possessed only a single X chromosome (XO) instead of the normal two and that the Y chromosome is male-determining in mammals. These findings contributed to Liane Russell's subsequent hypothesis that one of the X chromosomes in females is genetically inactive.

My initial examinations of scurfy mice revealed startling results. Scurfy males had massively enlarged lymph nodes and spleen, a shrunken thymus, severe anemia, and thickened scaly skin. Histologic sections revealed a massive activation and proliferation of lymphoreticular cells affecting lymphoid organs, liver, and skin. These lesions suggested that the scurfy mouse immune system was reacting uncontrollably, possibly against its own tissues.

I attempted to control this immune reaction by surgically removing the thymus gland from scurfy mice on the first day after birth. Thymectomy almost doubled the lifespan of scurfy mice (from 24 to 45 days), but the mice still developed disease and died. This experiment suggested that the thymus gland and its T lymphocytes were important in scurfy disease and that sufficient disease-producing T cells formed in the embryonic stage to cause disease after birth.

CD4 Helper T Cells

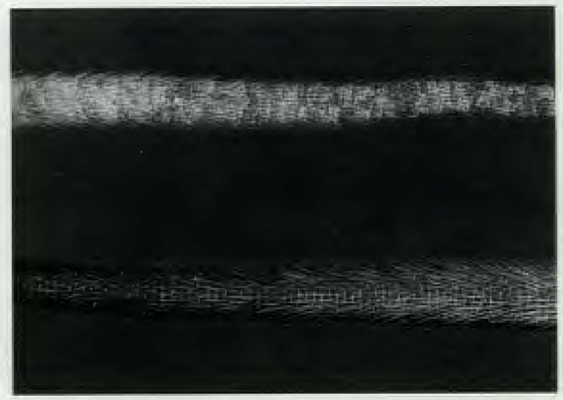
My subsequent work on identifying the disease-producing cell in scurfy mice has largely consisted of crossing the scurfy trait onto various lines of mice having other mutations affecting the immune system. For example, I mated scurfy carrier females with nude mice, which lack a thymus gland (and T lymphocytes). We found that the scurfy-nude mice are free of scurfy disease. Similarly, I crossed scurfy carriers with SCID mice, immunodeficient mice that are unable to form mature B or T cells. I observed that mice bred to be scurfy-SCID have T cells that fail to mature and, thus, these animals are also free of disease. I was also able to transfer scurfy disease to T cell–deficient nude or SCID mice by giving them a transplanted scurfy thymus. These experiments proved that mature T lymphocytes were the critical mediators of scurfy disease.

This experiment suggested that the thymus and its T lymphocytes were important in scurfy disease.

We are now testing scurfy on several lines of "knockout" mice—mice created with specific genetic defects by use of the techniques of homologous recombination and embryonal stem cell transfers. In this technique, an artificially disrupted mouse gene is created in the laboratory and inserted into cultured mouse embryo cells. Some of the mouse embryo cells accept this nonfunctional artificial gene into their genetic material in place of the homologous natural gene. Replacement of the natural gene with the artificial, nonfunctional gene causes the cell to lose the ability to produce the gene product; hence, a "knockout" of the gene function results. The mouse embryo cells containing the knockout

It appears that the culprit cells in scurfy disease are CD4 helper T cells that react abnormally to self-antigens and produce enormous amounts of interleukins.

Julia Haas, technician, holds two 7-day-old mice, one cream colored and the other pink. The hairless (pink) mouse has two mutations—one giving him scurfy disease and one altering his fur. The other mutation associated with scurfy is sparse fur. Affected mice are born with an enzyme defect that delays the formation of fur, but it eventually grows in.



The scaly mouse tail above is a result of the scurfy mutation associated with scurfy disease. Below is a normal mouse tail.

gene are injected into developing mouse embryos that are implanted and brought to term in host mothers.

If the procedure is successful, mice born to these host mothers will carry one knockout gene and one normal gene. These mice are then bred together to create offspring that have two copies of the knockout gene (and no normal gene). Such mice are, therefore, unable to produce the targeted gene product. Many lines of knockout mice that lack various cells or molecules important to the immune system have been produced. For example, mice with knockouts of the CD4 gene lack CD4 T helper cells, whereas mice lacking the ß-2 microglobulin gene fail to develop CD8 killer T cells. We have crossed the scurfy gene onto both of these knockout lines. Scurfy mice lacking CD8 killer T cells still have disease, but some scurfy mice lacking CD4 helper T cells appear to be cured, whereas others have a prolonged lifespan but eventually succumb to scurfy disease. This finding correlates well with recent in vitro studies showing that helper T lymphocytes from scurfy mice produced up to 100 times the amount of interleukins made by the helper T cells of their normal siblings. It appears that the culprit cells in scurfy disease are CD4 helper T cells that react abnormally to self-antigens and produce enormous amounts of interleukins. The excess interleukins are then responsible for the symptoms of scurfy such as weight loss, anemia, inflammation of skin and organs, and chronic diarrhea.

Thymus Fails To "Teach"

Although we may have identified the disease-producing cell type in scurfy mice, we still do not know how or why it is formed. Patrick Blair, a University of Tennessee graduate student in my laboratory, has shown that precursors of disease-producing scurfy T cells are already present in the thymus glands of 14-day-old scurfy fetuses. Thus, scurfy T cells are committed to their abnormal phenotype at the earliest stages of the gland's development.

In contrast to other mouse models of autoimmune disease, scurfy is not a stem-cell defect—that is, the bone marrow precursor cells for T lymphocytes are normal, suggesting that the helper T cells acquire their defective behavior during development in the thymus. It could be that the scurfy fetal thymus fails to "teach" its T cells to tolerate self-antigens, allowing subsequent CD4 cells to react abnormally after the mouse is born. Current dogma suggests that self-tolerance occurs in the thymus by two mechanisms: clonal deletion (killing selfreactive T cells) and clonal anergy (rendering self-reactive T cells unresponsive to stimulation). Defects in either process could account for the T cell–mediated disease in the scurfy mice. In recent experiments, my students have found that scurfy mice *do* appear to have a defect in clonal deletion; clonal anergy in scurfy mice is still under investigation.

If we thoroughly understood these defects, we might discover the basic mechanisms that underlie many autoimmune diseases in both humans and animals. Understanding the autoimmune disease of scurfy mice will lead to greater insights into basic immunologic functions and may ultimately provide better diagnosis and treatment of autoimmune disease.

Biographical Sketch

Virginia L. Godfrey, a board-certified veterinary pathologist, became manager of laboratory animal resources at ORNL's Biology Division in 1989. She received her D.V.M. degree from Auburn University in 1982 and completed a Ph.D. degree in comparative and experimental medicine at the University of Tennessee in 1990. Her research interests include animal models of human disease. For her research on scurfy mice, Godfrey, along with Eugene Rinchik and Liane B. Russell, received a 1992 Technical Achievement Award from Martin Marietta Energy Systems, Inc., for demonstrating the role of the thymus in "educating" T lymphocytes and providing a genetic mouse model for autoimmune diseases.

The Fate of Nutrients in Streams

By Patrick Mulholland

X had marked time in the limestone ledge since the Paleozoic seas covered the land. The break came when a bur-oak root nosed down a crack and began prying and sucking. In the flash of a century the rock decayed, and X was pulled out and up into the world of living things. . . . Between each of his excursions through the biota, X lay in the soil and was carried by the rains, inch by inch, downhill. . . . One year, while X lay in a cottonwood by the river, he was eaten by a beaver. The beaver starved when his pond dried up during a bitter frost. X rode the carcass down the spring freshet, losing more altitude each hour than heretofore in a century. He ended up in the silt of a backwater bayou, where he fed a crayfish, a coon, and then an Indian, who laid him down to his last sleep in a mound on the riverbank. One spring an oxbow caved the bank, and after one short week of freshet X lay again in his ancient prison, the sea.

Aldo Leopold, *A Sand County Almanac*

Traditionally, many people, including the eminent naturalist Aldo Leopold, have thought of streams and rivers as little more than pipes channeling excess water and eroded materials from the land to the sea. This simplistic view of our waterways has been greatly expanded by scientists in the Environmental Sciences Division (ESD) of Oak Ridge National Laboratory, who view streams and rivers as dynamic ecosystems, living laboratories for the study of how organisms interact with and modify their environment. In addition to important basic questions of ecological science, studies of streams and rivers at ORNL contribute to our understanding of how to manage these systems to preserve or enhance their value as drinking water sources, recreation areas, and wildlife habitats.

A factor that affects both ecological and human health is the concentration of various nutrients in streams. If the concentration of a nutrient in a stream is too high, for example, it can become a matter of public concern. Too much nitrate in stream water used for drinking can be potentially toxic to infants. Excess phosphorus can cause algae to grow rapidly in streams and remove dissolved oxygen needed by fish and other organisms; as a result, manufacturers have reduced the amount of phosphates in detergents to lower the amount of phosphorus that is washed into streams.

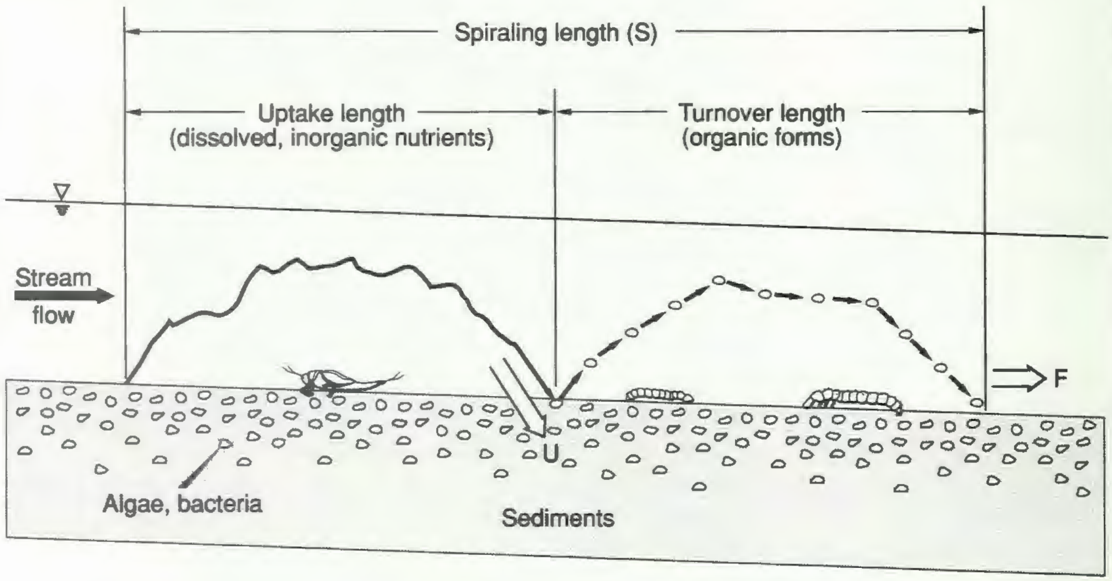
So how do streams and rivers work? Why can't they be considered just pipes transporting runoff from the land to the sea? These questions have served as the basis for a long history of research in ESD on the cycling—use and reuse—of nutrients in streams. This effort spanning 25 years has involved a number of current and former ORNL staff members and guests, beginning with the studies of the late Dan Nelson and Jerry Elwood in the 1960s and early 1970s on the uptake of phosphorus by algae in Walker Branch, a small stream on the Oak Ridge Reservation.

Much of the focus of research over the years has been on the cycling of phosphorus because this element is a critical biological nutrient that often controls the productivity of plants and microbes in aquatic ecosystems. When phosphorus availability is very low, plants and microbes cannot grow as rapidly, restricting the productivity of organisms higher in the food web, such as fish. In contrast, when phosphorus availability is very high, plants and microbes may grow excessively, resulting in the depletion of dissolved oxygen in the water when they die and decompose.

What sets the ORNL work apart from nutrient cycling research conducted at universities and other research institutions is the technique of injecting short-lived radioactive isotopes of phosphorus into streams and tracking their

Studies of streams and rivers at ORNL contribute to our understanding of how to manage these systems.

Patrick Mulholland (left) and Alan Steinman prepare for a radiotracer injection to Walker Branch to determine the spiraling length of phosphorus. A solution containing radioactive phosphate is pumped into the stream, and samples taken at several locations downstream are analyzed for concentrations of radioactive phosphorus.



$$S = \frac{\text{Total downstream nutrient flux}}{\text{Uptake flux per unit length}} = \frac{F}{U}$$

Spiraling of nutrients along a length of stream. Two measurable indices of spiraling are defined: uptake length, which is the average distance traveled by a nutrient atom before uptake by stream organisms, and turnover length, which is the average distance traveled by a nutrient atom in organic form before it is released back to water in inorganic form. The spiraling length is the sum of uptake length and turnover length, and it defines the distance traveled in completing one cycle through the ecosystem.

concentrations in the water, algae, and other stream organisms over time and distance by measuring their radioactivity. ORNL researchers have found that, in field experiments, radiotracers, notably phosphorus-32 (^{32}P), phosphorus-33 (^{33}P), and tritium (^{3}H), provide powerful tools for measuring phosphorus cycling processes under natural conditions. Because of the limitations on public access to Walker Branch and the expertise of ESD staff in the safe use of radiotracers in ecological studies, ORNL offers a unique environment for radiotracer studies in natural streams.

Material Spiraling

Probably the critical event in the development of stream nutrient cycling research at ORNL was receiving a three-year National Science Foundation (NSF) grant in 1978. The NSF-funded project was developed around a new concept in stream ecology—material spiraling. This concept was first proposed several years earlier by scientists at the University of Georgia, but ESD scientists Jerry Elwood, Denis Newbold, and Bob O'Neill developed its mathematical framework and applied the concept to a wide variety of issues in stream ecology, particularly those involving nutrient cycling.

The fundamental premise on which the concept is based is that biologically required materials (i.e., nutrients) in stream water are alternately taken up by organisms, most of which are attached to the stream bottom, and released back to water many times as they are transported downstream. In this way the downstream velocity of nutrients is reduced relative to the flow of water and total nutrient uptake within a given length of stream is increased (see drawing above). The processes of biological uptake and hydrologic transport are treated simultaneously, and the nutrient cycling characteristics of streams can be quantified by an index, known as spiraling length, the average distance traveled by a nutrient atom in completing one cycle—from water to organisms and back to water. The shorter the spiraling length of a given nutrient, the more efficiently that nutrient is used by stream organisms, and in the case of a limiting nutrient, the higher the productivity of the stream ecosystem.

During the first three-year NSF grant and in a three-year renewal grant, ESD scientists determined experimentally that phosphorus does indeed spiral (i.e., phosphorus is taken up by organisms, released back to water, and taken up again a relatively short distance downstream). Then they developed a field radiotracer method for measuring the spiraling length of phosphorus. In several experiments, the ESD scientists continuously added several millicuries of radioactive phosphate ($^{32}PO_4$ or $^{33}PO_4$) to a stream over a 1- to 2-hour period and measured radiotracer concentrations in the water and in organic material on the stream bottom (see photograph at opening of article). Phosphorus spiraling lengths were determined to be on the order of 100 meters in Walker Branch. In other words, on average one atom of phosphorus would complete its cycle every 100 meters.

At ORNL numerous studies of the roles of different types of organisms and the effects of different environmental conditions were conducted during the six years of NSF support for this research. Uptake of phosphorus from water by stream organisms, particularly by microbes attached to the surfaces of nonliving organic matter called detritus, was found to be much more important than purely chemical processes of phosphorus removal from stream water. Experiments also showed that phosphorus was more tightly cycled—that is, it had shorter spiraling lengths—in late fall and winter than in summer in Walker Branch. During the fall, large amounts of leaves fall into the stream and are subsequently colonized by aquatic bacteria and fungi. The leaves provide the carbon necessary for growth of these organisms, but most of the phosphorus to support that growth must be supplied from the stream water, resulting in lower stream water concentrations of this nutrient during this time of year. Other studies demonstrated that stream organisms also altered the chemical form of phosphorus in transport. Although inorganic forms of phosphorus are taken up, organic forms make up a portion of the phosphorus released back to the water.

Ramie Wilkerson (left) and Erich Marzolf collect samples from the laboratory streams. Each 20-m-long stream is continuously supplied with water from a nearby spring and illuminated by an overhead bank of metal halide lamps on a 10-hour light/14-hour dark cycle. Each stream contains 18,000 disk-shaped ceramic tiles that serve as a substrate for algae and sampling units of known surface area.

Stream ecosystems do not develop so as to maximize use of scarce resources, such as phosphorus.

Experiments in Laboratory Streams Conducted

ORNL also received NSF support for construction of a network of four laboratory streams used to conduct large-scale experiments

The biological community could compensate for lower input of nutrients by increasing the efficiency with which nutrients were cycled.

under controlled conditions. These streams, each 40 meters long and 0.3 meter wide and made of fiberglass, were housed in a greenhouse and supplied with water from a spring near the west end of ORNL. This type of research facility is available at only a few other institutions in the United States. We have used these streams for studies of the effects of primary consumer organisms—those that eat algae or detritus—on nutrient cycling in streams. Contrary to our initial hypothesis, we found that primary consumers reduced the efficiency of phosphorus cycling, increasing spiraling lengths in streams. The implication of these results is that stream ecosystems do not develop so as to maximize use of scarce resources, such as phosphorus. However, because of the continuous flow of water, inefficiencies in upstream communities become the inputs to, and resources for, communities downstream. In other words, nutrients not used by upstream organisms are available to downstream organisms.

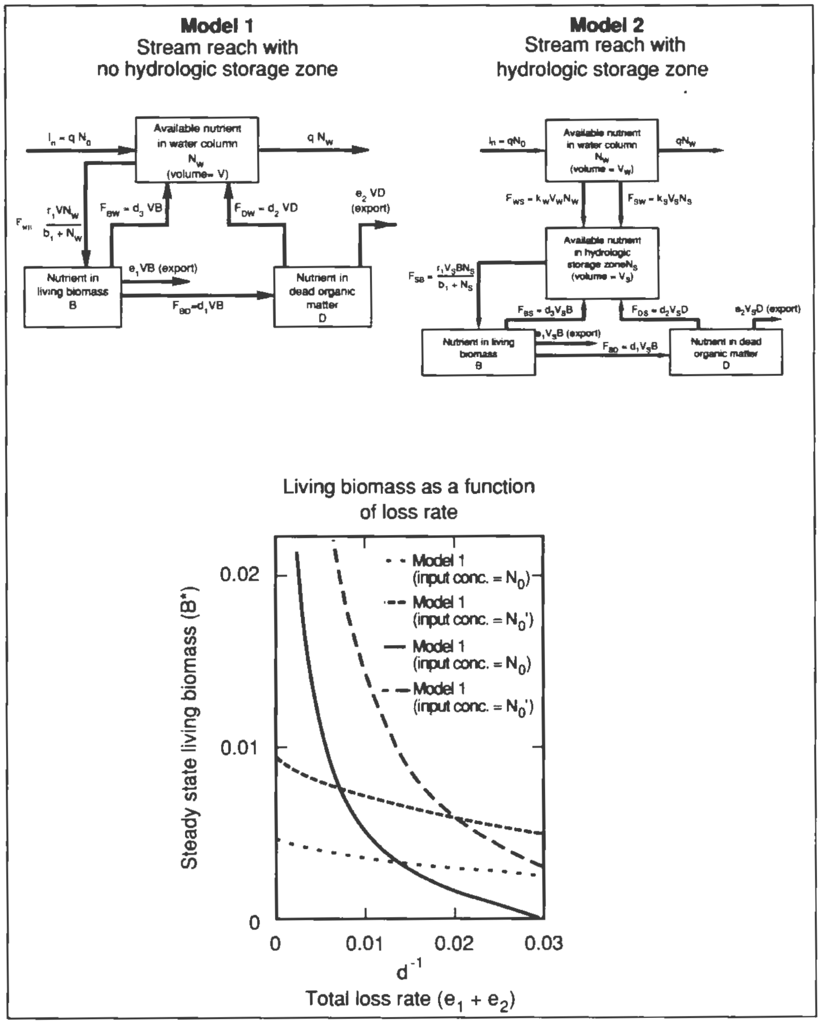
In 1986 a new phase of nutrient cycling research at ORNL was initiated with a third grant from the NSF, in part as a result of the success of earlier work. This new project diverged somewhat from previous studies, focusing on the relationship between nutrient cycling and the rates of recovery of stream ecosystems from disturbances such as adding chlorine or blocking out light. The project was conducted by a team of ESD scientists—Don DeAngelis, Jerry Elwood, Bruce Kimmel, Tony Palumbo, and me—as well as Alan Steinman, a University of Tennessee researcher, Anita Parker; the project technician, and several graduate and undergraduate students from the University of Tennessee, University of Louisville, and Earlham College. Computer models relating nutrient cycling and ecosystem recovery were developed, and hypotheses generated from these models were tested experimentally in the laboratory streams. The computer modeling work, headed by Don DeAngelis, suggested that high rates of nutrient cycling would result in ecosystems that recovered more slowly from disturbances because nutrients would be less available to stream organisms when cycling was disrupted. However, in streams in which plant-eating animals prevented the accumulation of plant biomass, the relationship between nutrient cycling and recovery from disturbance would be weaker because nutrient cycling should be less of a factor in these systems.

To achieve greater replication and environmental control, the laboratory streams were moved inside ORNL's Aquatic Ecology Laboratory and reconfigured as eight 20-meter-long channels with overhead lights and water reservoirs (see photograph on p. 11). Pumps to recirculate water and heat exchangers to control water temperature were also installed. By recirculating different fractions of the flow independently in each stream, we could vary the incoming flux of new nutrients to each stream while maintaining identical conditions of total flow, light, and temperature in all streams. This degree of flexibility in operation of the streams is unique among laboratory stream facilities.

In our first experiments we found that nutrient input had little effect on the amount of algal biomass and productivity in the streams, but rates of nutrient cycling were much higher in low-input streams (streams with 90% of the flow recirculated) than in high-input streams. Our studies suggested that the biological community could compensate for lower input of nutrients by increasing the efficiency with which nutrients were cycled but that this response depended on the accumulation of sufficient biomass to promote cycling. We did not observe greater nutrient cycling in low-input streams in which the biomass of algae was held at low levels by the addition of herbivorous snails.

To test the hypothesis that the rate of recovery from disturbance is inversely related to nutrient retention and cycling, a variety of experimental disturbances were imposed on the laboratory streams and their effects monitored. Disturbances included a 3-hour scour, simulating the biomass-removing effects of heavy rainfall on a stream; a 3-month elimination of light (a "nuclear winter" scenario); chlorine addition; and a drying up of the stream. The immediate impact of these disturbances was related strongly to disturbance type and the amount of algae present but only minimally to nutrient cycling. Impacts of chemical disturbances (e.g., chlorine) were lower in streams with high biomass (no snails), but impacts of physical disturbances (e.g., elimination of light) were lower in streams with low biomass (with snails).

In terms of the rate of ecosystem recovery, the effect of nutrient input, retention, and cycling was not consistent. In fact, only in the case of elimination of light did the ecosystem recover more rapidly when nutrient inputs were high and retention and cycling were low, as hypothesized from the model results. The combination of intense consumption of algae by snails and low nutrient input as a result of high water recirculation resulted in the slowest rates of recovery of the algae from most disturbances, although this was not predicted from the model. Perhaps most importantly, these studies underscored the need to empirically test predictions made from model simulations to evaluate and refine those models before using them to make real-world predictions.



Models of nutrient cycling in stream ecosystems have been developed with no hydrologic storage zone (Model 1) and with a hydrologic storage zone (Model 2). Predictions of the amounts of living biomass (algae) supported at steady state are a function of the loss rates (resulting from such factors as cell death and sloughing) and the nutrient input rate N_0 (with $N_0' > N_0$) but are quite different for the different models. In general, the inclusion of a hydrologic storage zone results in predictions of higher living biomass at low loss rates but lower biomass at higher loss rates than when storage zones are not included.

Research at ORNL on nutrient cycling in streams is continuing with the initiation of a new project in 1991, again with NSF support, to evaluate how stream hydrodynamic features, such as variations in water velocity and exchange rates at different points in the stream, determine the importance of nutrient cycling and response to disturbance. Erich Marzolf and Susan Hendricks, Oak Ridge Institute for Science and Education postdoctoral fellows;

Bonnie Lu collects a filtered sample of water weekly from Walker Branch as part of a long-term program of monitoring stream water chemistry. Continuous records of stream flow are also made at several locations on Walker Branch by recording water level at flumes (such as that shown in the background) using battery-powered data loggers.

This work has demonstrated the importance of water pathways in determining rates of nutrient transport and loss.

Radioactive phosphate ($^{33}PO_4$) is injected into stream water as in previous work to obtain phosphorus uptake rates. The researchers also measure whole-stream rates of metabolism based on changes in dissolved oxygen concentration recorded at two stream locations over a 48-hour period. For the metabolism measurements, propane is experimentally injected into stream water to determine the air-water exchange rate of dissolved gases and account for this exchange in the metabolism measurements. This work is distinct from most other studies in stream ecology today because of its attempt to measure characteristics and processes over an entire 50-meter-long stream segment rather than over a square meter or so.

Ramie Wilkerson, our new technician; and several new graduate and undergraduate students have joined the project.

Our computer models have demonstrated that hydrologic storage zones (zones in which water is generally not flowing, such as boundary layers) strongly influence the amount of living biomass that can be supported in streams by increasing nutrient cycling and retention (see schematic diagrams above). A series of experimental studies has been initiated in the laboratory streams and in several streams on the Oak Ridge Reservation to determine the extent of these hydrologic storage zones and their influence on nutrient cycling.

For these studies, nonreactive tracers (chloride or tritium) are injected into stream water over several hours and a stream hydrodynamic model is applied to the tracer data to obtain the average water velocity and the volume of storage zones.

Walker Branch Watershed Nutrients Studied

Although much of our research on nutrient cycling in streams has been supported by the NSF, DOE's Ecological Research Division (now the Environmental Sciences Division) in the Office of Health and Environmental Research has for many years supported studies of nutrient cycling and transport on Walker Branch Watershed (see Michael Huston's article in the *Review*, Vol. 25, No. 1, 1992, pp. 3–9). Some of this research has focused on the mechanisms controlling the transport and loss of nutrients from the watershed via the stream. This work has demonstrated the importance of water pathways through the soil and bedrock to the stream in determining rates of nutrient transport and loss. As a result of the long history of weathering and biological soil-forming processes uninterrupted by glaciation, soils in Walker Branch are generally deep, with dramatic differences in geochemical, biological, and hydrological characteristics with depth. Water moving through upper soil layers is rather acidic (pH 4.5 to 5.5), low in calcium (Ca^{2+}) and magnesium (Mg^{2+}) ion concentrations, and high in sulfate (SO_4^{2-}) ion concentrations relative to water moving through lower soil layers or through cracks and channels in the dolomitic bedrock. We have used these differences in flow-path chemistry, as well as naturally occurring radon (^{222}Rn) concentrations, to show that the dominant water pathway through the watershed changes dramatically with hydrologic conditions. During low-flow periods the dominant flow path to the stream is deep, primarily coming from groundwater flowing through bedrock cracks and cavities, and the concentrations of nitrogen and phosphorus in this water are moderately high. However, during high-flow periods that follow large rain events, the dominant water pathway to the stream is shallow through the upper soil and the concentrations of nitrogen and phosphorus in this water are low, primarily as a result of very efficient biological removal processes by plant roots and microbes in the upper soil layers.

Future research on nutrient cycling in Walker Branch will focus on water pathways and nitrogen transformations in the near-stream forest, often termed the riparian zone. This work is designed to determine whether the microbial reduction of nitrate to gaseous forms of nitrogen is an important mechanism for reducing transport of nitrate in groundwater to the stream. Nitrate in streams and rivers is of particular concern because of its toxicity, particularly to infants, at high concentrations in drinking water.

Research on stream nutrient cycles at ORNL has demonstrated the value of an approach that meshes computer modeling with empirical experimentation at spatial scales ranging from indoor, laboratory streams to forested watersheds. This work has contributed significantly to the understanding and appreciation of streams as dynamic, biologically active ecosystems capable of altering the amount and chemical form of nutrients and other materials lost from watersheds. Clearly we now know that streams are much more than passive pipes. They are an active, dynamic component in the ecology of the landscape.

Biographical Sketch

Patrick J. Mulholland is a research staff member in the Biogeochemical Cycling Group of ORNL's Environmental Sciences Division. He is also a principal investigator of the NSF-supported project on nutrient cycling in streams. A native of Elyria, Ohio, he received a Ph.D. degree in environmental biology from the University of North Carolina at Chapel Hill in 1979. He joined ORNL's Environmental Sciences Division in 1979. Mulholland's 1981 paper published in *Ecology* was one of the first comprehensive studies of carbon flow in a swamp ecosystem. He received the Environmental Sciences Division's 1991 Scientific Achievement Award for his research on the ecology of streams. Mulholland serves on the Board of Editors for the journals *Ecology* and *Ecological Monographs* and has recently served on the NSF's Special Review Panel for the Long-Term Ecological Research Program. He also holds an adjunct faculty position in the Ecology Program at the University of Tennessee.

New Uses for ORNL's Ultrasensitive Mass Spectrometer

By Marilyn Morgan

Oak Ridge National Laboratory has an ultrasensitive instrument that can reduce the cost of monitoring workers for radiation exposure, determine concentrations of trace elements in tree cores to assess the effects of acid rain on soil chemistry and tree growth, and even identify counterfeit bolts that need to be replaced.

Developed for ORNL's Analytical Chemistry Division (ACD), the inductively coupled plasma mass spectrometer (ICP-MS) has also been helpful to other ORNL divisions in their research. "The new mass spectrometer is creating wonderful new opportunities for ORNL and the Department of Energy," says Joe Stewart, leader of the Special Projects Group in the division.

One area in which the ICP-MS may someday demonstrate its value is in the DOE-required monitoring of workers exposed to radioactive materials such as uranium. The Oak Ridge Y-12 Plant uses alpha spectrometry to check 900 to 1000 employees for uranium exposure on a monthly basis by measuring the alpha-particle radiation emitted by uranium in samples of the employees' urine over a 16-hour period. The alpha-counter method requires a 1-liter sample from each worker collected over a 24-hour period each time the test is due. "Having to collect, store, and analyze this much urine," Stewart says, "presented obvious technical and aesthetic problems."

Cumbersome as the alpha-counting procedure is, the Y-12 effort has been equal to or better than that of any other facility in the DOE system. Recent tightening of the regulations, however, makes it necessary to detect 0.1 picocurie, or 10^{-13} curies, of each isotope of uranium (U-234, U-235, and U-238) per liter of urine.

Stewart believed that the ICP-MS could be used for the urine bioassays, but he had to find a way to improve its sensitivity. The government standard required measurements of concentrations as low as five parts per trillion, or 5×10^{-12} grams per gram dry weight, for the U-234 isotope. This is a quantity about one million times smaller than can be weighed on a sensitive laboratory balance. His group chose to concentrate on U-234, the isotope that is the most radioactive and the most difficult to detect because it is in the lowest concentration in natural and enriched uranium. The researchers knew that if they could detect U-234, they could detect any other uranium isotope.

Origin of the Method

While at home one evening, Stewart read about some related work being done at Argonne National Laboratory. Researchers there had developed a uranium extraction method for measuring uranium isotope ratios to determine the age of dinosaur bones found in tar pits in the West. Their method combined the best features of liquid-liquid and solid-phase extractions to obtain pure uranium samples and eliminate the troublesome interferences of calcium, potassium, sodium, and iron ions.

The next day, Stewart called Philip Horwitz, the Argonne researcher who had developed the method. Horwitz agreed that the method might be useful in solving the U-234 problem and arranged for extraction columns and instructions for their use to be sent to ORNL. Jeff Wade, leader of the Low Level Radiochemical Analysis Group, and Perry Gouge, a technician in the group, began to develop the extraction procedure. Shelby Morton, a technician in the Chemical and Physical Analysis Group, began to test the ICP-MS using effluents from the Argonne columns.

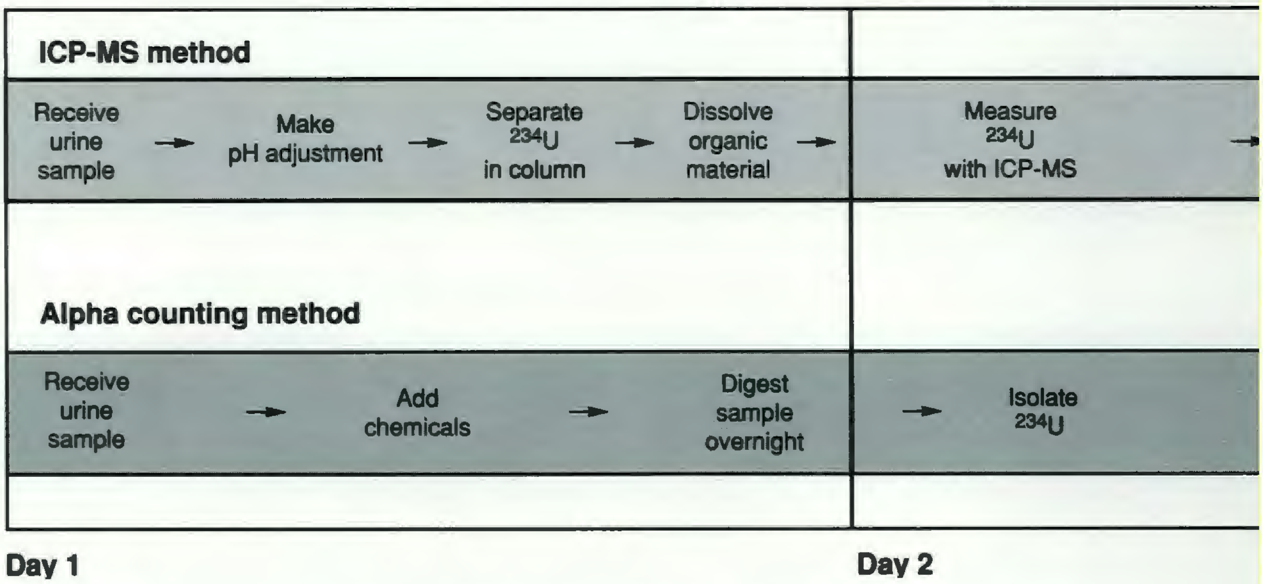
Wade and his colleagues sought to demonstrate the effectiveness of the chromatography material in the Argonne extraction columns to separate uranium from urine. In chromatography, each element or compound moves through a column at a characteristic rate based on its strength of adhesion to the chromatography material, thus making separations possible.

The researchers first used aqueous samples spiked with known amounts of uranium to test the column material. After repeated successful separations with the spikes, the researchers

ORNL has an ultrasensitive instrument that can reduce the cost of monitoring workers for radiation exposure.

Jeff Wade (left) inserts a tree-ring sample into ORNL's new inductively coupled plasma mass spectrometer as Joe Stewart watches.

In one of the first demonstrations of the instrument, scientists analyzed the annual rings of tree cores to determine each tree's exposure to toxic materials.



The alpha counting process for measuring uranium concentrations in workers' urine takes three days, compared with two days for the new ICP-MS process developed at ORNL. For both procedures, urine samples are collected periodically from employees; each worker's sample represents the total urinary excretions for a 24-hour period. For the alpha counting procedure the sample is digested overnight on a hot plate, the uranium-234 is chemically separated from urine components, the alpha radioactivity from the uranium-234 is counted overnight, computer calculations are made, and a report on the amount of worker exposure is written.

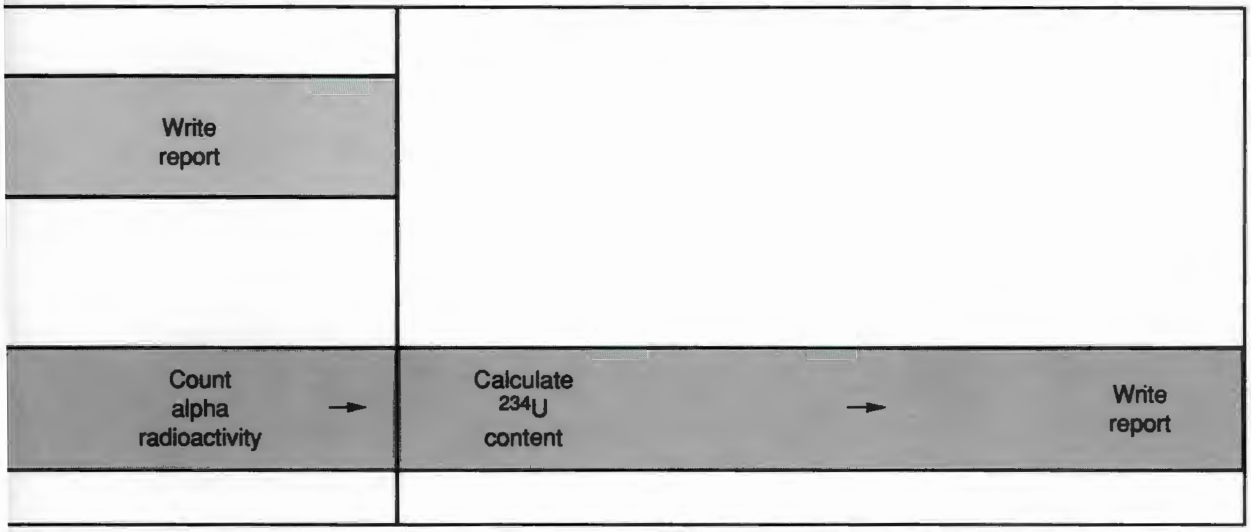
donated urine samples for testing. They succeeded in separating the uranium from a 100-milliliter aliquot of urine and concentrate it into 1 milliliter, "quite an accomplishment considering the complexity of urine," says Wade.

The next step was to find a way to sufficiently purify the separated uranium from the residual organic material that remained in the 1-milliliter solution. Purification was needed, the researchers found, because even trace amounts of organic compounds would interfere with the analysis on the ICP-MS. The researchers discovered that, if the solutions were evaporated in the presence of nitric acid and then placed in a furnace overnight, all of the organic material was easily destroyed. The residue that remained could then be dissolved in 1 milliliter of weak nitric acid for the ICP-MS analysis.

Because the British reprocess nuclear fuel, they are also very interested in new methods of monitoring workers for uranium exposure. VG Elemental, the British manufacturer of ORNL's ICP-MS, worked closely with ORNL and Argonne to perfect the uranium extraction and detection processes. The instrument manufacturer built and tested the electrothermal vaporization (ETV) attachment, which ORNL's mass spectroscopy team now runs with the ICP-MS. Energy Systems purchased the ETV, the first at a Martin Marietta facility.

The new extraction method combined with the ETV attachment for the ICP-MS has drastically reduced the requirements for sample volume and analysis time. "Now we can work with only 100 milliliters, instead of a liter, of urine and still meet the new government standard. We've reduced the counting time from 15 hours to 20 minutes and shortened the overall process from three days to two," Stewart says. "That wasn't supposed to be possible."

Alpha counting may still be used for confirmation of any samples that test positive by the ETV method, but Stewart says that "doing the initial screening with the ICP-MS could save



Day 3

For the ICP-MS process, uranium-234 is co-precipitated from acidified urine with calcium. The precipitate is dissolved in nitric acid and passed through a chromatographic column. The uranium is eluted from the column with an organic material that is destroyed by nitric acid; the final residue is dissolved in weak nitric acid. Uranium in the solution is measured by the ICP-MS. The results are used in the report.

taxpayers a lot of money and help Martin Marietta and DOE take care of their people at the same time." ORNL researchers are now involved in the process of getting their new U-234 detection method approved for use at the Y-12 Plant by DOE and Martin Marietta.

Environmental Applications

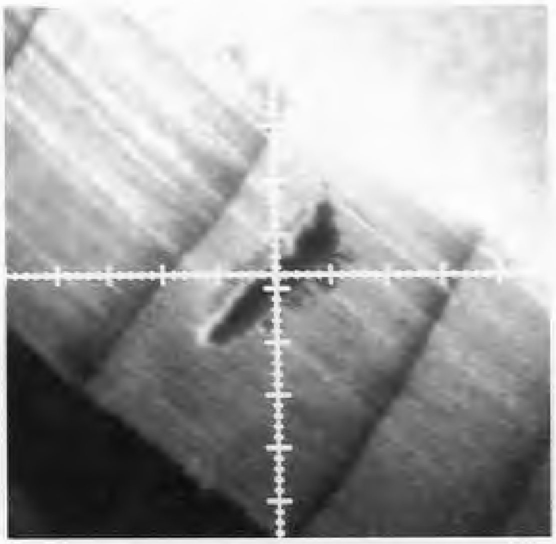
ORNL's Environmental Sciences Division (ESD) has also found uses for the ICP-MS. In one of the first demonstrations of the instrument, scientists analyzed the annual rings of tree cores to determine each tree's exposure to toxic materials at different stages of its growth.

Exposure to toxins may be a factor in forest decline, which has been linked to increases in acid rain and other forms of industrial pollution. Trees in Europe have been dying for decades.

"In this country severe decline in the growth of red spruce trees has been observed in New England and at high elevations in the Smokies," says Sandy McLaughlin of ESD. "We need to know why and what we can do about it.

"The ICP-MS provides an excellent capability for measuring changes in wood chemistry that are linked to the mechanisms by which acid rain affects tree growth. Evaluating the trends over time in concentrations of elements, such as aluminum and calcium, in the wood formed annually in each tree core provides an indication of the extent to which acid deposition has changed soil chemistry and associated tree growth."

McLaughlin and the late Ernie Bondietti had asked Wade and Morton to use the ICP-MS to measure trace amounts of aluminum in growth rings in cores extracted from tree trunks in a nondestructive procedure. The ICP-MS's predecessor, an ICP optical instrument, had measured lead concentrations in the tree rings that correspond with increases and decreases in the use of leaded gasoline. By comparison, the ICP-MS can measure a greater number of



Video image of tree-ring sample during analysis in the ICP-MS instrument.

elements at lower detection limits in the same rings.

Using the laser ablation attachment recently purchased by ORNL, researchers can vaporize trace amounts of elements and identify them with the ICP-MS. The initial "quick and dirty" trial of this automated process was done using a pencil as a surrogate core. The data were crude, but agreed well enough with previous results that ORNL researchers decided to continue the trials. They are currently testing the laser on actual core samples and learning to measure precisely the concentrations of the identified elements.

ORNL researchers have done some initial tests on fish scales, which also have growth rings, looking for signs of mercury exposure. Future projects include studies of oyster shells and tooth enamel.

Other Potential Benefits

Ceramics and steels are also candidates for study using the ICP-MS laser ablation method. These substances are hard to prepare for analysis by conventional methods. If digested—the standard method of sample preparation—the samples are easily contaminated and tend to plate out on the sides of their containers. Laser ablation overcomes these problems by eliminating the digestion step and vaporizing the samples for direct analysis by the mass spectrometer.

The ICP-MS may also help make structures safer for people. Counterfeit bolts, sold in place of the required stronger bolts by organizations looking for an easy profit, threaten the safety of people using tank turrets, helicopter blades, nuclear power reactors, bridges, and buildings. With the new laser technology, scientists can detect counterfeit bolts in less than a minute. With one laser blast, they can tell if the bolt is coated with the required cadmium or with a cheaper substitute such as zinc. With a second blast, they can determine if the composition of the bolt itself meets federal standards.

Scientists are currently working on a third method of testing whether the bolt has undergone the required heat treatment that makes the metal ductile instead of brittle. Once these three tests are consolidated into one efficient detection technique, the safety of many devices can be drastically improved by replacing the identified counterfeit bolts with the required ones. The Department of Defense has not yet provided funding for this project. If funding is provided by the U.S. military, however, ORNL could test the use of the ICP-MS for detecting counterfeit bolts.

Development of the Instrument

The ICP-MS was developed in 1982, when British researchers replaced the ICP's optical spectrometer with a mass spectrometer. The MS is much more sensitive for many elements. Unlike the ICP, it can also detect nonmetallic elements and distinguish between different isotopes of the same element. Before the introduction of the ICP-MS, even tests for elements such as mercury, arsenic, selenium, cadmium, and lead, which could be detected by the ICP, often had to be run using a graphite furnace to meet the required low detection limits. Graphite furnace analysis is expensive and time consuming. Samples can be analyzed for only one element at a time. Stewart knew that, if ORNL had an instrument that could test for most or all of the desired elements at one time and at the required low detection limits, the Laboratory could quickly recoup its investment in the instrument.

Working together, Stewart, David Smith, and Warner Christie wrote the specifications for the instrument they wanted VG Elemental to build for them. "They were tough specs," Stewart says. "We wanted the new ICP-MS to do things no instrument had done before, and we wanted an instrument that would not become obsolete in a short time. We wanted to be able to upgrade the instrument without expensive modifications. We wanted attachments that might be purchased later, such as the ETV and the laser ablator, to be perfectly compatible with the existing unit."

The instrument maker accepted the challenge, even sending an engineer to ORNL from England to work closely with the ORNL MS section. The new instrument arrived on December 17, 1989, and Stewart says it was "a beautiful Christmas present." The ICP-MS, which was up and running by the end of December, was accepted by ORNL in the second week of February 1990.

Origins of Spectrometry

Spectrometry has a long history. Since the early part of the 19th century, scientists have been able to identify elements in a material by looking at its spectral lines—lines of colored light emitted when a material is heated. For example, yellow lines indicate the presence of sodium and green lines the presence of copper.

Over a century later, in the 1970s, British scientists invented an ICP optical spectrometer that could identify and measure concentrations of up to 40 elements at a time at detection limits 100 times more sensitive than ever before. The key to this technology is a radiofrequency power supply similar to one that might power a local FM radio station. It converts an aqueous sample, such as groundwater containing trace amounts of cadmium or lead, into a plasma—a hot mass of positively charged ions and electrons that may reach a temperature of 6000°C. The solution to be analyzed is instantly vaporized. As a result, it gives off light that is diffracted by a grating into the different colors characteristic of the elements present in the sample.

ORNL bought its first ICP optical spectrometer in 1982. At that time, the instrument met all DOE standards for detection limits of trace elements. About 200,000 analyses of materials, such as groundwater and soil samples, were needed each year, and the ICP optical spectrometer met the demand. However, the federal government lowered its required detection limits, requiring ACD to find a new, more sensitive instrument.

In 1985 the division began to consider the inductively coupled plasma mass spectrometer, another product of British ingenuity. Instead of relying on the wavelength emission of light to determine which elements are present, the researchers using this technology measured elemental concentrations using the ions created by the flame torch, which were sent into an ordinary mass spectrometer. In the mass spectrometer, the ions, each with a characteristic mass and charge, travel through magnetic fields and are deflected according to their masses. In this way, isotopes of the same element as well as different elements can be identified and quantified.

With the new laser technology, scientists can detect counterfeit bolts in less than a minute.

The laser ablation attachment has one additional advantage: it can analyze solid samples directly, without digesting them first. Sample digestion usually involves heating the raw sample with a strong acid to bring the desired analytes into solution. The digestion process is time and labor intensive and a frequent source of sample contamination.

Future uses of the ICP-MS at ORNL have yet to be imagined. The Laboratory is in the process of acquiring a second instrument for special research projects. "We're now entering phase two," says Stewart, who thinks the ICP-MS is just beginning to show its research potential. With its help, ORNL should continue as a world leader in mass spectrometry. ornl

Marilyn Morgan, a graduate student in English at the University of Tennessee at Knoxville, served as an intern science writer for the *ORNL Review* in the summer of 1992.

Regulation of Carcinogens: The Problem and a Solution

By David C. Kocher and F. Owen Hoffman

A graduate student doing her dissertation on waste disposal examined two different burial sites for low-level radioactive wastes. The first was a new site currently receiving waste for disposal, and the second was an old site currently undergoing cleanup. She was told that the levels of radioactivity in materials that could be disposed of at the new site are much greater than the goal for levels of radioactivity after cleanup at the old site. When she asked about this difference, she was told that the two sites are regulated under different laws, and the maximum allowable health risk to the public from disposal at the new site is at least 100 times greater than the risk goal for cleanup at the old site.

This hypothetical situation involving two radioactive waste sites illustrates a general problem with laws and regulations for hazardous substances in the environment. This problem and a possible solution are discussed in this article.

Routine exposures to radionuclides and other carcinogenic (cancer-causing) substances in the environment are controlled under a variety of laws and regulations that essentially limit health risks to the public. However, clear inconsistencies exist in the levels of health risk regarded as acceptable for two general categories of standards:

- standards that apply only to radionuclides, as developed under the authority of the Atomic Energy Act, and
- standards that apply to any carcinogens, including radionuclides, or only to chemical carcinogens, as developed under the authority of other laws.

Standards in the first category apply to any radionuclides associated with the nuclear fuel cycle, such as radionuclides produced in nuclear power plants. Standards in the second category apply to a wide variety of other man-made or naturally occurring sources of exposure to radionuclides and chemical carcinogens. All standards for environmental carcinogens fall into one of these two categories. Note that the two categories of standards do not apply exclusively to either radionuclides or chemical carcinogens because radiation exposures can be regulated in either category, depending on their source.

In this article, we first discuss the inconsistency in levels of acceptable health risk for the two categories of standards described previously. This inconsistency arises from the fundamentally different approaches to regulation taken in the two cases.

We then propose a set of principles we believe would provide more consistent regulation of health risks to the public from exposure to any environmental carcinogens. Such a consistent approach would encourage consideration of risks from exposure to any chemical carcinogen or radiation source in the context of the total cancer risk from all sources and would ensure that cancer risks much less than the largely unavoidable background risks do not receive unwarranted attention. Ultimately, a more consistent regulatory approach should save money and benefit public health by ensuring that the greatest emphasis is placed on those exposure situations involving the most important risks.

A more consistent regulatory approach should save money and benefit public health.

Our proposal for more consistent regulation is based primarily on distinguishing unambiguously between unacceptable cancer risks from any source of exposure and risks that are trivial. Our proposal also takes into account such important factors as the costs and benefits of reducing risks, technical feasibility, and public perceptions of risk.

Top-down Approach

The framework for regulating routine radiation exposures of the public under the Atomic Energy Act is what we call a "top-down" approach. This approach has two components. First, a limit on radiation exposure corresponding to an *upper bound* for acceptable risk is established. Then,

Owen Hoffman (right) discusses environmental regulations with David Kocher at the boundary of ORNL's Solid Waste Storage Area 6, where radioactive waste from the Laboratory is stored. *Photo by Bill Norris*

Aerial view of Solid Waste Storage Area 6 at ORNL. This burial ground for radioactive waste is covered with black synthetic polymer "caps" to prevent rainwater from infiltrating into the ground. The SWSA-6 waste site is regulated by two different laws: the Atomic Energy Act for new disposal of waste and the Comprehensive Environmental Response, Compensation, and Liability Act for waste cleanup.

We believe that the fundamental inconsistency in current approaches to regulating exposures of the public to radionuclides and chemical carcinogens can be reconciled.

exposures are *reduced* below the limit by requiring all exposures to be "as low as reasonably achievable" (ALARA). The ALARA principle takes into account costs and benefits, technical feasibility, and societal concerns about cancer risks.

The top-down approach is used in radiation protection standards, which limit the public's total exposure to all sources of man-made radionuclides associated with the nuclear fuel cycle, which includes uranium processing and enrichment facilities, nuclear power plants, fuel reprocessing facilities, and radioactive waste disposal sites. The upper bound on acceptable risk implicit in these standards is estimated as follows. The current limit on radiation dose equivalent for members of the public is 1 millisievert (mSv), or 100 mrem, per year. The International Commission on Radiological Protection (ICRP) recommends calculating the increased risk of developing a fatal cancer as a result of exposure to radiation using a risk factor of 0.05 per Sv. Thus, for continuous exposure over an average lifetime of 70 years, the dose limit corresponds to an upper bound on acceptable lifetime risk of about 4 in 1000. In other words, if a population of 1000 individuals were exposed throughout their lifetimes to the maximum allowable radiation dose, 4 of them would be expected to die from cancer as a result of this exposure.

However, it is very unlikely that the lifetime risk to members of the public from routine exposure to all man-made radionuclides could approach 4 in 1000. The development of many standards that limit doses from particular practices or sources to levels well below 1 mSv per year virtually ensures that the lifetime risk from all man-made radionuclides will not exceed 1 in 1000. Application of the ALARA principle to each practice or source then leads to further reductions in risks.

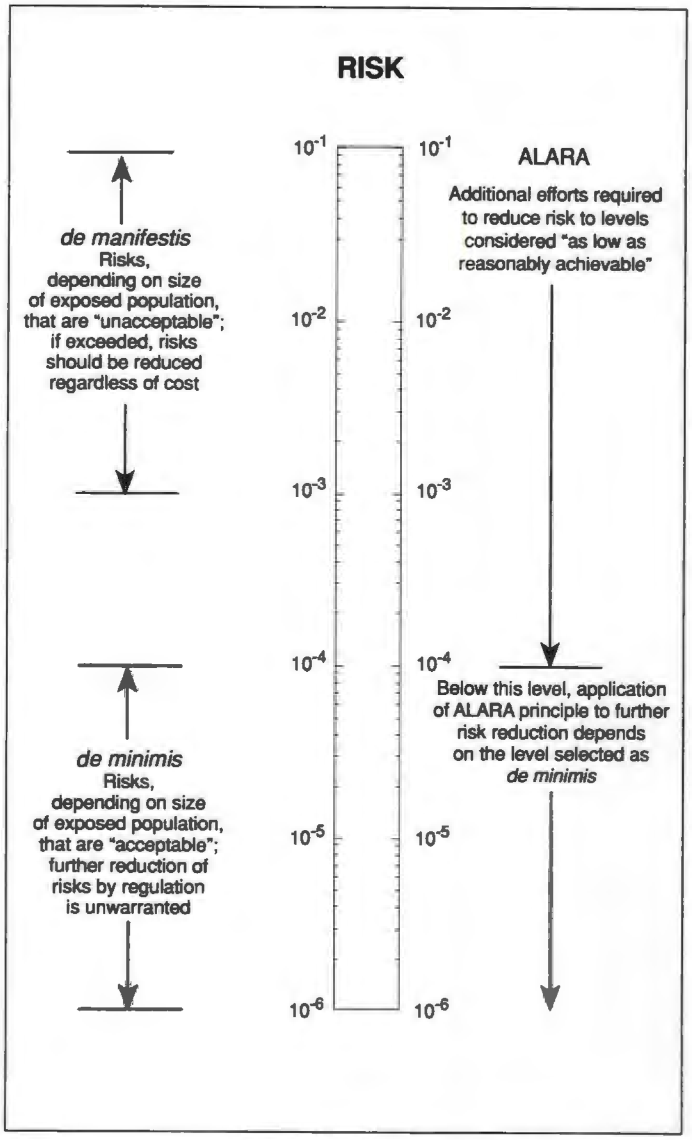
The top-down approach also is used in other standards or guidances for limiting the public's exposure to radiation. These include (1) U.S. Environmental Protection Agency (EPA) standards for naturally occurring radionuclides in uranium and thorium mill tailings, (2) EPA guidance on acceptable levels of radon in homes, (3) a recommendation of the National Council on Radiation Protection and Measurements (NCRP) on levels of external background radiation at which remedial actions should be undertaken, and (4) EPA guidance on appropriate responses to radiation accidents. In each case, the upper bound on acceptable lifetime risk is in the range of 1 in 1000 to 5 in 100, and the ALARA principle is used to reduce risks below these limits.

Bottom-up Approach

The framework for regulating routine exposures of the public to chemical carcinogens and radiation under laws other than the Atomic Energy Act is what we call a "bottom-up" approach. This approach is essentially the opposite of the top-down approach described above.

In the bottom-up approach, there is no standard defining an upper bound on acceptable risk from all carcinogens and sources of exposure. Instead of limiting public exposures to all sources, standards have been developed only for specific exposure situations. For each exposure situation, a *lower bound* on acceptable risk is established as a goal, but this goal may be *increased*, based primarily on cost and technical feasibility.

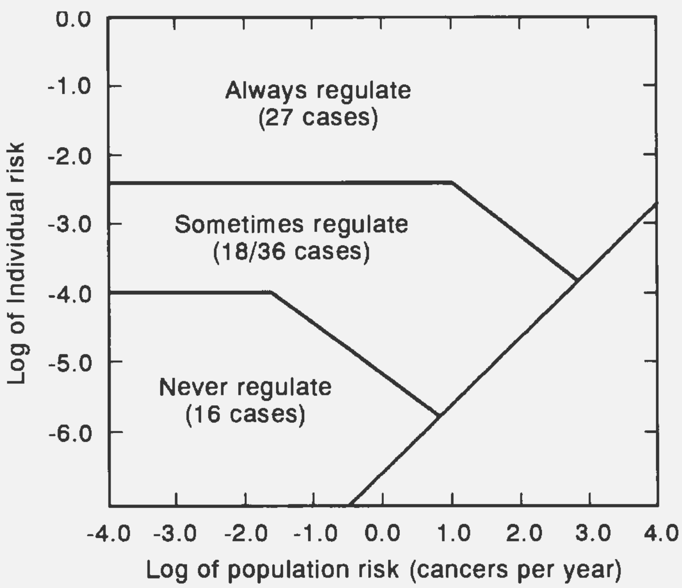
The bottom-up approach was first used in the Delaney Clause of the Federal Food, Drug and Cosmetic Act Food Additives Amendment of 1958. This law calls for zero risk to the public from carcinogenic food additives, such as pesticides. However, because zero risk cannot be achieved at any cost, the EPA usually has permitted carcinogenic food additives if the lifetime risk is less than 1 in a million—that is, no more than 1 in a million individuals consuming such food additives over their lifetimes would be expected to die of cancer resulting from exposure to these chemicals.



Proposed framework for regulating exposures of the public to radionuclides and chemical carcinogens. The vertical scale denotes lifetime risk of adverse health effects, primarily cancers.

The bottom-up approach next was used in EPA standards for radionuclides and chemical carcinogens in drinking water developed under the authority of the Safe Drinking Water Act. These standards specify zero risk from carcinogens in drinking water as a nonenforceable health goal. However, because this goal also cannot be achieved at any cost, the standards then establish legally enforceable limits that must be set as close to zero risk as possible, taking into account cost and technical feasibility. Current EPA standards for radionuclides and chemical carcinogens, which are regulated individually, correspond to upper bounds on lifetime risk in the range of 1 in 10,000 to 1 in a million.

This approach of defining a range of acceptable risk at these levels has since been used in two other sets of standards. First, EPA standards for airborne emissions developed under the authority of the Clean Air Act include standards for



Summary of EPA decisions to reduce risks to the public from chemical carcinogens by regulation prior to the mid-1980s. The three regions where the EPA always, sometimes, and never regulated are consistent with our proposed regulatory framework in the figure on p. 25.

individual carcinogens that are based on lifetime risks that would not exceed 1 in 10,000 for members of the public receiving the highest exposures and 1 in a million for the greatest number of persons in exposed populations.

Second, EPA standards for cleanup of hazardous substances at Superfund sites developed under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) specify that remediation goals shall consider, among many factors, an upper bound on lifetime cancer risk in the range of 1 in 10,000 to 1 in a million. In contrast to the other standards that use the bottom-up approach, the goal for an upper bound on lifetime risk in this case applies to the total risk from all carcinogens.

Proposal for Consistent Regulation of Carcinogens

The top-down approach used in regulating exposures to radionuclides under the authority of the Atomic Energy Act clearly is fundamentally different from the bottom-up approach used in regulating exposures to radionuclides and chemical carcinogens under other laws. As a result, the upper bounds on risks to the public regarded as "acceptable" in the two cases are clearly inconsistent—upper-bound lifetime risks range from about 1 in 10 to 1 in 1000 in the former case but from about 1 in 10,000 to 1 in a million in the latter.

This inconsistency is particularly apparent in the case of disposal of low-level radioactive waste. Currently, acceptable waste disposals under the authority of the Atomic Energy Act present a maximum lifetime risk to hypothetical individuals who inadvertently intrude into disposal facilities of about 1 in 100. However, standards governing cleanup of old waste disposal sites under CERCLA include, as a goal, an upper bound on lifetime risk to inadvertent intruders of between 1 in 10,000 and 1 in a million. This considerable difference in acceptable risks for virtually identical practices seems quite illogical.

We believe that the fundamental inconsistency in current approaches to regulating exposures of the public to radionuclides and chemical carcinogens can be reconciled and that a reasonable basis for more consistent regulation of health risks from exposure to all environmental carcinogens can be developed. Our proposed regulatory framework, shown in the figure on p. 25, contains three basic elements:

- a *de manifestis* lifetime risk in the range 1 in 10 to 1 in 1000, which would define an upper bound on acceptable risk from all carcinogens and sources of exposure and above which regulatory action to reduce risk would be taken regardless of cost;
- a *de minimis* lifetime risk in the range 1 in 10,000 to 1 in a million, which would define

risks from any carcinogens and sources of exposure that are so trivial that regulatory action to reduce risk is not warranted; and

- reduction of risks based on application of the ALARA principle for lifetime risks above *de minimis* levels.

The key to our proposal is to recognize that the lifetime risks of 1 in 10,000 to 1 in a million embodied in many standards developed using the bottom-up approach, in fact, define *de minimis* (trivial) rather than *de manifestis* (mandatory action) levels. In particular, such low risks are not analogous to the upper bound on acceptable risk implicit in radiation protection standards, which are based on the top-down approach.

We would also emphasize that achieving a *de minimis* risk is not the goal of ALARA, because the ALARA principle implies a process to be applied to each exposure situation, not a generally applicable and predetermined result. It could be reasonable in many situations—for example, after consideration of costs and benefits—to decide not to reduce risks by regulatory action at levels well above the proposed *de minimis* values.

The proposed *de manifestis* and *de minimis* risks are given as ranges rather than single values. This approach would permit taking into account the size of an exposed population. That is, the higher values could be used when only a few individuals are at risk, but the lower values could be used for large populations. The use of ranges also would permit considerable flexibility in accommodating the kinds of subjective societal judgments involved in applying the ALARA principle to particular exposure situations. Thus, absolute uniformity of regulatory decisions for limiting cancer risks to the public would not be required.

The interpretation of lifetime risks of 1 in 10,000 to 1 in a million as *de minimis*, which is a key element of our proposal, is clearly supported by an analysis of EPA regulatory decisions for chemical carcinogens before the mid-1980s. This analysis was performed by a group headed by Curtis Travis of ORNL's Center for Risk Management and Richard Wilson of Harvard University. As shown in the figure on the facing page, the EPA always declined to reduce risk by regulatory action when the risk to a few individuals was below 1 in 10,000 or the average risk in large populations was below 1 in a million. This is the meaning of *de minimis*, and the EPA decision in each case is consistent with our proposed *de minimis* levels.

This analysis also indicates a consistency with the other elements of our proposed regulatory framework. First, the EPA always decided to reduce risk by regulatory action when the lifetime risk was above 1 in 100 to 1 in 1000, which is consistent with our proposed *de manifestis* risk. Second, the EPA took regulatory action in 50% of the cases when the lifetime risk was between the *de manifestis* and *de minimis* levels, primarily on the basis of expected costs and benefits. This approach is consistent with our proposed use of the ALARA principle.

Although the EPA regulatory decisions summarized in this figure are consistent with our proposed regulatory framework, these decisions were made on a case-by-case basis rather than within the context of an explicit regulatory framework for all carcinogens and exposure situations. In contrast to the ad hoc approach previously used by the EPA, we are advocating that all elements of our proposed framework be adopted as an explicit set of principles for regulating risks to the public from all exposures to any carcinogens.

We are advocating our proposed framework be adopted for regulating risks to the public from all exposures to any carcinogens.

In our discussions of the top-down and bottom-up regulatory approaches, we indicated that our proposed regulatory framework is consistent with many standards and guidances for both routine and accidental exposures to radionuclides and chemical carcinogens. Our proposed framework also is consistent with exemption (*de minimis*) levels of radiation exposure recommended, for example, by the NCRP, which correspond to a lifetime risk of about 1 in 10,000, and the current action level for polychlorinated biphenyls (PCBs) in fish, which corresponds to a risk of 1 in 1000.

Therefore, our proposed regulatory framework is consistent with virtually all current regulatory policies for limiting routine and accidental exposures of the public to radionuclides and chemical carcinogens. Again, however, a consistent regulatory framework for all carcinogens is achieved only if lifetime risks in the range of between 1 in 10,000 and 1 in a million embodied in many standards developed using the bottom-up approach are interpreted as *de minimis*.

Implementing Proposed Regulatory Framework

Two encouraging developments suggest that the inconsistency between the top-down and bottom-up regulatory approaches and the need to reconcile them have been recognized.

Our proposed regulatory framework for limiting risks to the public from all carcinogens and sources of exposure is useful for risk management but is not concerned with estimation of risks for any exposure situation. However, we believe that certain important differences in risk estimation procedures for radionuclides and chemical carcinogens should be reconciled in implementing our proposed regulatory framework.

The first is an inconsistency in the risk factors that convert exposure (or dose) to risk. Risk factors for radiation exposure, such as those recommended by the ICRP, are intended to be best estimates (mean values). For chemical carcinogens, however, risk factors developed by the EPA are intended to be upper-bound estimates (95% confidence limits) and, thus, provide more conservative estimates of risk. In addition, radiation risk factors take into account cancer risks for all organs of the body, but risk factors for chemical carcinogens usually consider only one organ at risk and, thus, ignore risks to other organs.

Second, the primary measure of risk from radiation exposure is fatal cancers, but the EPA uses cancer incidence as the measure of risk for chemical carcinogens. For organs in which most cancers are curable, such as the thyroid gland or skin, risk estimates based on cancer incidence can be a factor of 10 or more higher than estimates based on fatal cancers. Radiation risk factors that take into account nonfatal as well as fatal cancers have been introduced by the ICRP, and similar risk factors could be developed for chemical carcinogens.

Finally, in assessing radiation exposures, the intent usually has been to provide best estimates of dose using reasonable assumptions for likely exposure scenarios. However, risk assessment procedures prescribed by the EPA for use at Superfund sites, for example, often emphasize unreasonably pessimistic assumptions. Thus, the resulting risk estimates may greatly exceed values that reasonably could be experienced.

Conclusions

We believe that more consistent regulation of risks to the public from exposure to radionuclides and chemical carcinogens along the lines proposed here would have two obvious benefits. First, it would encourage consideration of risks from any carcinogen and source of exposure in the context of the total cancer risk from all sources. In the past, the EPA has undertaken regulatory actions in a rather piecemeal fashion, particularly for chemical carcinogens, primarily because of inconsistent requirements in the many laws under which the EPA operates.

Second, the proposed range of *de manifestis* risks is consistent with lifetime risks from naturally occurring carcinogens. Natural background risks average about 1 in 100 for radionuclides and at least 1 in 100 for chemical carcinogens. Therefore, the proposed range of *de minimis* risks would ensure that cancer risks much less than the largely unavoidable background risks do not receive unwarranted attention.

Can we hope that a more consistent regulatory framework for all environmental carcinogens eventually will be implemented by the EPA? Two encouraging developments suggest that the inconsistency between the top-down and bottom-up regulatory approaches and the need to reconcile them have been recognized. First, the EPA office that administers the Superfund program recently indicated that site remediation need not be undertaken if the maximum lifetime risk to individuals is below 1 in 10,000 and that higher risks would be acceptable when risk reduction is not feasible. Such a policy should help overcome the widely held and unreasonable view that risks above 1 in 10,000 are unacceptable (i.e., intolerable).

Second, the Radiation Advisory Committee of the EPA's Science Advisory Board recently addressed former EPA Administrator William Reilly on the need to reconcile the inconsistent approaches to risk reduction currently used for radionuclides and chemical carcinogens. The committee's primary concern was the evident inconsistency between established guidance on acceptable levels of radon in homes, which corresponds to a lifetime risk greater than 1 in 100, and a proposed standard for radon in drinking water, which corresponds to a risk at least a factor of 100 lower. However, the committee also urged Reilly to consider more consistent approaches to regulating risks from all environmental carcinogens.

The use of inconsistent regulatory policies for environmental carcinogens could unnecessarily increase the cost of complying with regulations, particularly for cleaning up hazardous waste sites under the Superfund program. Thus, the public clearly has an important stake in efforts to promote more consistent regulation of environmental carcinogens to ensure that money is spent wisely to reduce health risks.

The use of inconsistent regulatory policies for environmental carcinogens could unnecessarily increase the cost of cleaning up hazardous waste sites.

Biographical Sketches

David C. Kocher has served as an environmental health physicist in ORNL's Health and Safety Research Division since 1976. He is also a faculty affiliate in the Department of Radiological Health Sciences at Colorado State University and a frequent lecturer on environmental dose assessments and radioactive waste disposal. He received his Ph.D. degree in experimental nuclear physics from the University of Wisconsin. Following a postdoctoral appointment at the University of Birmingham in the United Kingdom, he joined ORNL's Physics Division in 1971. In his health physics research at ORNL, he has developed models for estimating radiation doses to the public from radionuclides in the environment and has been concerned with the scientific basis for environmental regulations.

F. Owen Hoffman, former ORNL ecologist, was recently named president and director of SENES Oak Ridge, Inc., Center for Risk Analysis. After employment with the U.S. National Park Service and the Institute for Reactor Safety in Cologne, Germany, he worked for ORNL's Health and Safety Research Division and then the Environmental Sciences Division from 1976 to 1992. He serves as chief scientist to the International Atomic Energy Agency in Vienna on the validation and evaluation of radiological assessment models. He has visited the former Soviet Union to participate in a joint investigation of the environmental behavior of radionuclides from the Chernobyl accident. Recently, he was appointed by the governor of Colorado to serve on the Colorado Department of Health's Advisory Panel for the assessment of contaminants at Rocky Flats; by Louis Sullivan, then secretary of the U.S. Department of Human and Health Services, to serve on the Centers for Disease Control advisory panel studying deaths from thyroid disease near Hanford, Washington; and by the Tennessee Department of Health to serve on the Health Advisory Steering Panel on radiation dose reconstruction for the Oak Ridge Reservation.

Intelligent Robots: Do We Need Them and Can They Be Built?

By Reinhold C. Mann

For avid watchers of science fiction movies, the mention of robotics and artificial intelligence conjures up images of humanlike machines, as well as memories of HAL, the awesome computer in *2001: A Space Odyssey*. Often, news reports of scientific advances that enable machines to behave in a flexible manner for a limited set of tests draw parallels to science fiction robots. The effect of this unfortunate kind of publicity is that the scientific disciplines of robotics and artificial intelligence are sometimes regarded as a playground for slightly crazed scientists trying to create artificial humans. In reality, the fields of robotics and artificial intelligence can best be described by answering a few commonly asked questions: What is an intelligent robot, anyway? Why would we need things like that? Could we build them and make them reliable for certain uses?

Instead of giving Webster's definition of intelligence or reviewing what has been written on the subject of intelligence, I will present an example of an intelligent machine, or robot, and address the question of whether intelligent robots are needed. I will close by describing the impact of ORNL research on uses for intelligent machines.

Smart Automobiles?

Imagine that you are cruising down a freeway in an automobile. You really have only three ways to control the car: acceleration, braking, and steering. The procedure is simple, but the automobile itself is rather complicated. Many things are happening simultaneously and rapidly inside the engine, and in other subsystems, as you drive at 50 mph (80 km/h). Yet you do not have to bother with all the details; you simply control the speed with two different pedals and keep the car on the road by using the steering wheel. Is the car intelligent? No. The machine itself is not capable of planning, decision making, or perceiving the road conditions—capabilities that go beyond the low-level control of the various subsystems required to drive the car.

What happens if you add cruise control, automatic wheel-slip control, and antilock brakes? You still do not have an intelligent car, but you are now dealing with a system that can very effectively extend human control capabilities for safer operation. Now, add the capabilities to automatically keep the car in a lane at highway speeds and to follow a lead car, even through lane changes. The machine can now process and analyze sensory input and make decisions based on this information. The role of the human operator becomes more flexible because the driver may choose to operate the car directly or to execute primarily supervisory functions. The machine has a significant level of autonomy and intelligence for certain key functions, enabling the human operator and the machine to work together in a symbiotic system.

Robots are being developed to extend human capabilities into hazardous environments.

This concept is not science fiction, by the way. The U.S. Defense Advanced Research Projects Agency (DARPA) has been supporting research that resulted in recent initial demonstrations of these capabilities using prototype vehicles. For a number of years, the European Community has been supporting a major program on intelligent vehicles/highway systems (IVHS), which has demonstrated automobile road following, lane changes, and obstacle avoidance. The United States has a similar IVHS effort under way.

Recently, car rental agencies in the Orlando, Florida, area began participating in an experiment using automobiles equipped with electronic means to obtain position data from the Global Positioning System (GPS). These smart cars can also communicate with sensors installed along the highways and with traffic control centers to obtain map information, as well as the latest news on traffic jams and recommended alternate routes. Combining these features places this kind of automobile in the spectrum of intelligent

Judson P. Jones supervises the ORNL robot HERMIES-III as it performs a surface contamination survey of waste-storage containers.

ORNL now heads the DOE space robotics working group.

Using a standard automobile shown here, ORNL researchers Francois Pin and Yutaka Watanabe tested a fuzzy logic controller they developed to help the driver. The system uses sonar sensors to measure the distance from potential obstacles. It makes recommendations to the driver to slow down, accelerate, turn, or stop.

machines ranging from effective human-machine symbiotic systems to robotic devices that have few requirements for human interaction or supervision.

As increasingly intelligent mechanisms and subsystems are incorporated into the automobile, the environment in which the automobile operates changes. For example, the smart car will be able to locate itself and to avoid traffic jams if the highway system includes an infrastructure of sensors and information and communication systems (i.e., the operational environment of the intelligent machine).

Applications for Robots

A robot has intelligence if it can plan and adapt its actions and behavior to knowledge stored in its computer memory or acquired through sensors or other supervisory input from other robots or a human operator. Distinctions between robots, telerobots, and remotely operated systems and devices are often made to indicate the degree to which sensing, decision making and planning, and acting are incorporated into one device or split between the machine and the human. These distinctions may be useful for categorizing different robot systems. All these machines, however, are being developed for the same purpose: to extend human capabilities into work environments that are hazardous to people; to perform work that people cannot or should not do; and to transcend the limitations of human sensory, manipulatory, and control capabilities.

This is a most exciting time for scientists and engineers who are developing intelligent robots and for everyone anticipating the benefits of working robots. The development of intelligent robots, long a dream, has accelerated because of (1) new, important uses for reliable robots, which exert a significant *pull* that encourages the integration of enabling technologies into robotic test beds, and (2) significant advances in the enabling technologies and research breakthroughs that *push* toward the development of robots that have increasingly advanced capabilities. Examples of both are given here.

This new ORNL robot, which has unprecedented omnidirectional mobility, navigates reliably under fuzzy logic control. The system was designed by Steve Killough and Francois Pin.

ORNL researchers have a successful track record of rapidly moving results from research in intelligent machines into systems that can be tested in the field.

In 1990, Frank Sweeney gave an excellent synopsis in the *Review* (Vol. 23, No. 3) of our efforts to develop robots for nuclear power stations and environmental restoration and waste management (ERWM). Since then the use of robots in nuclear power stations has increased significantly. More than 25 utility companies are using remotely operated robots in nuclear power plants for tasks ranging from pipe inspections to routine in-service surveillance. The ERWM robotics program evolved into a significant multilaboratory effort to combine existing robotics technologies to demonstrate faster, better, and cheaper ERWM operations through the use of remotely operated systems. In addition, the international community for developing fusion energy recognized the need for robotics and remote systems for maintenance of the proposed International Thermonuclear Experimental Reactor (ITER). ORNL remote systems engineering staff are making key contributions to the ITER design project.

In response to the presidential initiative in space exploration, the Department of Energy, through its new Office of Space, is contributing technological expertise to the U.S. space program. The Stafford Committee report identifies robotics as a key enabling technology for all missions planned for the moon and Mars. Lunar missions using robots are being planned for the second half of this decade. ORNL, which brings to the table significant capabilities in many enabling technologies, was assigned to head the DOE space robotics working group.

Robotics and artificial intelligence are on the list of technologies that the Department of Defense considers critical to accomplishing its missions in the world under political conditions that have changed significantly. ORNL researchers have a successful track record of rapidly moving results from research in intelligent machines into systems that can be tested in the field.

Manufacturing has been included in the list of critical technologies that the U.S. government has identified to make our country competitive in world commerce. The United States is rapidly falling behind Europe and Japan in advanced manufacturing capabilities. At least two related problems are of major concern: (1) insufficient mechanisms to move research results and technologies into the commercial arena and (2) difficulties with applying advanced technologies to flexible manufacturing to fabricate high-quality products competitively. Advanced manufacturing, a presidential initiative in 1994, includes computer-aided design and manufacturing (CAD/CAM, or CIM—computer-integrated manufacturing), robotics and automation, "just in time" logistics and supplies organization, nondestructive testing and multisensor monitoring for quality assurance, statistical modeling and testing for quality control,

The CESAR robot now navigates reliably and safely in its work space, although it "knows" nothing about the obstacles that it needs to avoid.

and human-machine interfaces for advanced instrumentation and control of complex processes. Many of these advanced manufacturing capabilities will require intelligent robots.

ORNL's Contributions

An intelligent robot is a functioning system resulting from the integration of many components. To make this systems integration successful, a number of component technologies must come together. These include mobility systems, multiple sensors, robot manipulators (arms), dextrous end-effectors (hands), high-performance computers, communications systems, reliable control and decision-making methodologies, and effective operator control stations. ORNL has helped advance the state of the art in robotics and artificial intelligence in several ways. Since the early 1980s ORNL's

Researchers outfitted this material-handling vehicle with controls that enable the operator to control the forklift directly, rather than controlling each joint of the arm separately.

Can we build useful intelligent robots? Yes, but for quite a while they may not have the "right stuff" for the movies.

Center for Engineering Systems Advanced Research (CESAR) in the Engineering Physics and Mathematics Division has been studying and developing intelligent machines. DOE's Office of Basic Energy Sciences supports our core research program. Other DOE offices (e.g., Nuclear Energy, Environmental Restoration and Waste Management) support our applied development activities. CESAR staff have also successfully met research and development goals for a number of other sponsors, including the U.S. Army, the Air Force Wright Research and Development Center, and the Office of Naval Research. Much of the work done at CESAR has been published in the refereed literature and has had a significant impact on applications.

Many basic problems that humans solve without even consciously making an effort are incredibly difficult for intelligent robots. For example, a person can easily go from one location in a room to another without bumping into things, even if other people or objects are moving around in the same room in a way that is not completely understood. Solving this highly complex problem for a mobile robot is very difficult mathematically, even for computers. No optimal solution can be found in any practical amount of time.

But do we need an optimal solution? Not really. The robot must get from A to B swiftly without having to spend a lot of time replanning when the situation in the room changes, and it needs to get there safely without bumping into people and objects. Ideally, we want the machine to react as quickly as the sensors provide new data. We want it to behave as we would: to react to new, uncertain, and imprecise sensor data by executing appropriate behaviors. We guess the likely motion of a moving obstacle, and we evade an object when we get close enough without being able to say precisely what distance is "close enough."

Some time ago, Francois Pin of CESAR realized that the theory of fuzzy sets and the corresponding fuzzy logic and decision-making theory provide a mechanism for qualitative reasoning. This mechanism may allow a robot to solve the navigation problem as effectively as we solve it. In collaboration with Hiroyuki Watanabe at the University of North Carolina, Pin also found that this kind of decision making can be performed in real time, even faster than the sensors provide the data. Together they developed unique computer boards that incorporate very large-scale integration fuzzy logic (VLSI) chips. The computer boards were mounted on one of the new mobile platforms at CESAR. That robot now navigates reliably and safely in its work space. It "knows" nothing about the obstacles that it needs to avoid. Without solving any computationally complex problems in high-level planning, it reacts to sensor data based on as few as 13 different rules or behaviors. The computing hardware that allows this real-time performance is now being replicated to support further work in real-time qualitative reasoning for other seemingly intractable planning and control problems.

Intelligent machines must learn from and adapt to their environment. For environments with little predefined structure, learning is a difficult, yet essential, task. Most information is sensor-based, and active sensing must be possible to create and continuously update a model of the robot's surroundings. CESAR researcher Ed Oblow has investigated the use of random set representations for probably approximately correct (PAC) learning and reported significant improvements in learning speed. Oblow, Chuck Glover, and the late Gunar Liepins, together with Nageswara Rao of Old Dominion University, investigated the capabilities of a system consisting of n (any number greater than 1) learners combined by an algorithm that can integrate the knowledge generated by the individual learners. Given a system of n PAC learners, a method was developed that makes the composite system perform better than the best of the individual learners.

This work represents a development that benefits applications of machine learning, including identification of parameters that govern complex processes, such as flexible manufacturing systems and adaptive pattern recognition systems for robot sensors and other applications. The results are expected to have considerable impact on the important problem of designing systems consisting of multiple, relatively simple agents that cooperate to solve problems of realistic complexity. Examples include crews of multiple mobile robots, each capable of executing relatively simple behaviors, such as obstacle avoidance, or other control algorithms and capable of adapting their behavior through learning.

Part of CESAR's research addresses issues that arise when the technologies developed in our programs are integrated in robot test beds and prototypes to demonstrate increasingly complex capabilities. In the fall of 1991, Pin and Alex Bangs of CESAR and Steve Killough of ORNL's Robotics and Process Systems Division automated several manipulation and safety-enhancing functions on an outdoor material-handling vehicle prototype (see photograph on pages 34 and 35). The customer, Fort Belvoir Research and Development Center in Fort Belvoir, Virginia, is now field testing the prototype. The operator of the vehicle can now control the position of the forklift directly, instead of having to control separately each joint of the long-reach manipulator to which the forklift is attached, as was the case before the vehicle was outfitted with new controls. This work is a good example of our ability to move basic research results (in this case, control of kinematically redundant mechanisms) into fieldable systems in a short amount of time (in this case, 15 months).

In early 1991 another technology integration demonstrated the ability of ORNL's mobile robot, HERMIES-III, to perform surveys of surface radiation contamination in waste storage containers as a way of reducing hazards to workers at waste facilities. This experiment used HERMIES-III as a telerobot controlled by a human operator (see photograph on p. 30). Many functions were executed automatically, such as path planning, navigation with local obstacle avoidance, range image analysis to locate the waste storage containers, control of the seven-degree-of-freedom manipulator on board HERMIES-III, and positioning of the platform so the robot hand holding the beta-radiation detector could scan the container surface. The experiment was the result of collaborative research among four teams at the universities of Florida, Michigan, Tennessee, and Texas. It involved the integration of over 100,000 lines of software developed by the university teams and at CESAR, running on a total of 27 central processing units on board and off board HERMIES-III in a heterogeneous network. The integration was made possible by the Helix programming environment developed by Judson Jones at CESAR and Phil Butler of the Robotics and Process Systems Division. Helix simulates shared memory on a heterogeneous network of computers. The machines in the network can vary with respect to their native operating systems and internal representation of numbers. Helix, which was designed to present a simple programming model to developers, also considers the needs of designers, system integrators, and maintainers.

CESAR provides undergraduate and graduate, as well as faculty, research opportunities in neural network research for robotics applications.

New Opportunities

Can we build useful intelligent robots? Yes, but for quite a while they may not have the "right stuff" for the movies. Intelligent robots represent exciting new opportunities for research that transcend the boundaries of traditional scientific and engineering disciplines, such as mechanical and electrical engineering, physics, biology, mathematics, computer science, and materials science. The dialogue among experts in these disciplines who are making a serious commitment to communicate and learn from each other is a vital ingredient for a successful program in intelligent robots.

We also must meet new challenges in educating the next generation of experts. Since the start of the CESAR programs, we have been working closely with our colleagues in academia. A great number of undergraduate students have had their first exposure to interdisciplinary research with us. Many graduate students have performed a significant part of their thesis research using our special intelligent machines facilities. We were also fortunate to be able to host a number of pre- and postdoctoral fellows from abroad (including researchers from Belgium, Denmark, Germany, France, Japan, Norway, and South Korea). As part of a new Center for Neural Engineering at Tennessee State University, CESAR provides undergraduate and graduate, as well as faculty, research opportunities in neural network research for robotics applications. The influx of new ideas from all these collaborations keeps the CESAR "old timers" on their toes.

Biographical Sketch

Reinhold C. Mann has been head of the Engineering Physics and Mathematics Division (EPMD) Intelligent Systems Section and director of ORNL's Center for Engineering Systems Advanced Research (CESAR) since 1989. He is also an adjunct associate professor in the Computer Science Department at the University of Tennessee in Knoxville. He received an M.S. degree in mathematics in 1977 and a Ph.D. degree in physics in 1980 from the Johannes Gutenberg University in Mainz, Germany.

From 1978 until 1980 Mann was a research associate in the Biophysics Department at Mainz University and a consultant on digital image analysis and pattern recognition with the Laser and Optics Group at Battelle Institute in Frankfurt, Germany. In 1980 he joined the Image Analysis Group at the Fraunhofer Institute for Data and Information Processing in Karlsruhe, Germany.

Mann was awarded a Feodor-Lynen Fellowship by the Alexander von Humboldt Foundation in Bonn, Germany, which supported his research in pattern recognition and analysis in 1981 and 1982 as a visiting scientist in ORNL's Biology Division. He was a staff member in the Biology Division from 1983 until 1986, when he joined the EPMD to work on multisensor systems for intelligent machines and mobile robots. He was leader of EPMD's Advanced Computing and Integrated Sensor Systems Group from 1987 until 1989.

RE: Awards and Appointments

Kenneth L. Kliewer, formerly assistant vice president for research at Purdue University, has been appointed director of ORNL's new Center for Computational Sciences.

Bill Appleton has assumed the role of acting associate director for the newly created directorate for Computational Sciences, Informatics, and Networking.

Michael J. Saltmarsh has been appointed director of the Office of Planning and Management, replacing **Truman Anderson,** who has accepted a position in the Energy Division to develop a technology assessment program with emphasis on collaborative work between the Energy and Environmental Sciences divisions.

Douglas F. Craig has been appointed director of the Metals and Ceramics Division.

Barry A. Berven has been appointed director of the Health and Safety Research Division, replacing **Stephen V. Kaye,** who has retired after 31 years at ORNL.

Elliot Whitesides has been named director of ORNL's new Computer Applications Division.

Jerry H. Swanks has been appointed director of ORNL's Office of Environmental Safety and Health Compliance.

Dan McDonald has been named associate division director of ORNL's Instrumentation and Controls Division.

Virginia Dale has been named a member of the National Science Foundation Panel for Human Dimensions of Global Change. She has also been appointed associate editor of the new journal *Environmental Reviews*, named to the National Research Council review team for Brazilian institutions, and selected to be an exchange faculty member between the University of Tennessee and the University of Amazonas in Manuas, Brazil.

Rufus H. Ritchie has been elected vice chairman of the Southeastern Section of the American Physical Society. He has also received the degree of *Doctor Honoris Causa* from the Universidad del Pais Vasco in San Sebastian, Spain.

Robert N. Compton has been elected a fellow of the Optical Society of America.

Thomas H. Row has been appointed senior staff assistant to the Laboratory director.

Patrick J. Mulholland has been appointed to a National Science Foundation Special Advisory Panel for long-term ecosystem research.

Keith F. Eckerman has been appointed co-chairman of the National Council on Radiation Protection and Measurements' Scientific Committee 57 on the Dosimetry and Metabolism of Radionuclides.

Norman D. Farrow has been presented a Distinguished Achievement Award for Technical Support by the Environmental Sciences Division.

William Mixon and researchers investigating the use of exterior insulation in the Buildings Research Program in ORNL's Energy Division have been presented an Energy Technology Development Award from the state of Arizona.

Monica Turner has been named a member of the National Science Foundation's Ecosystem Panel. She has also accepted appointments to the editorial boards of the journals *Ecological Applications* and *Landscape Ecology*.

Anne M. Hoylman, a Ph.D. candidate who is conducting her dissertation research at ORNL's Environmental Sciences Division, has received the Science Alliance Award in Biological Sciences from the University of Tennessee. She also received a

Kenneth L. Kliewer

Michael J. Saltmarsh

Barry A. Berven

Virginia Dale

Monica Turner

Katie U. Vandergriff

Student Travel Award from the Society of Environmental Toxicology and Chemistry (SETAC) Foundation to attend the SETAC annual meeting, and she placed first in the 1992 SETAC student presentation competition for her poster on "Uptake and Translocation of Polycyclic Aromatic Hydrocarbons by Vegetation."

Milton Russell has been named an adviser to the U.S. Secretary of Energy on energy and environmental issues.

Donald L. DeAngelis has been named the North American editor of the Chapman and Hall series of books *Population and Community Biology*. He has also been appointed to the editorial boards of *Nonlinear World*, *Nonlinear Digest*, *Ecology*, and *Ecology Monographs*.

The **Environmental Sciences Division** has been cited by the East Tennessee Chapter of the Association for Women in Science (AWIS) for its sustained commitment to creating opportunities for women scientists in research and science management. AWIS also recognized **Marilyn Brown** for distinguished science management and policy implementation and **Helga Van Miegroet** for distinguished scientific achievement.

The **Carbon Dioxide Information Analysis Center** has been cited by the U.S. Library of Congress as a source of information about weather and climate.

Randy Stewart has been named head of the Environmental Projects Section of the newly named Waste Management and Remedial Action Division, and **Leroy Stratton** heads the division's new Environmental Programs Coordination Section.

Larry Hawk has been awarded a Silver Industrial Design Excellence Award by the Industrial Designers Society of America for his work on the direct Braille slate. He was also presented a Community Service Award for 1991 by Department of Energy Secretary James D. Watkins.

Roger Clapp has been named to the Groundwater Committee of the American Geophysical Union.

John S. Cook has been appointed to the newly created position of associate director of the Biology Division.

Katie U. Vandergriff has been selected as an intern in the Leadership Development Initiative program of the American Society of Mechanical Engineers.

Patricia Hu has been appointed to two committees and one task force of the National Research Council's Transportation Research Board.

David J. Pegg and **John C. Miller** have been elected fellows of the American Physical Society.

Stan David and **Frances E. Sharples** have been elected fellows of the American Association for the Advancement of Science.

Francois G. Pin has been named a member of the editorial board of the *Intelligent and Fuzzy Systems Journal*.

Thomas J. Wilbanks has been elected president of the Association of American Geographers.

James E. Turner has been presented a Distinguished Scientific Achievement Award by the Health Physics Society.

Steven Zinkle has received an Excellence in Fusion Engineering Award from the Fusion Power Associates Board of Directors.

Lee Shugart is co-editor, along with David Peakall of the Monitoring and Assessment Research Center, London, of a book entitled *Biomarkers: Research and Application in the Assessment of Environmental Health.* He has also been invited to be a member of an expert group preparing a scoping document on *Indicators of Marine Ecosystem Health* in an effort sponsored by the United Nations' World Health Organization.

Allen G. Croff has been elected chairman of the Nuclear Development Committee of the Organization of Economic Cooperation and Development's Nuclear Energy Agency.

Lynn A. Boatner has been elected a member of the Böhmische Physical Society.

Stephen Stow has been elected to the Executive Committee of the American Geological Institute.

Jean Culver Thorpe has been appointed to a three-year term with DOE's Training Resources and Data Exchange (TRADE) Radiation Protection Training Special Interest Group steering committee.

Gary T. Alley has been selected guest editor of the 1992 Institute of Electrical and Electronics Engineers Nuclear Science Symposia.

William Fulkerson's directorate has been renamed Energy and Environmental Technologies and will be expanded to include Reactor Programs and Nuclear Regulatory Commission Programs. **Nicholas Dominguez** has been appointed Fulkerson's technical assistant.

James Stiegler's directorate has been renamed Engineering and Manufacturing Technologies. The Applied Technology Division will be merged with the Engineering Technology Division. The new division will retain the name Engineering Technology and will be headed by associate directors **John E. Jones, Jr., William R. Martin,** and **William C. McWhorter. Dean Waters** will become director of Defense Programs activities.

David E. Reichle will chair ORNL's new Environmental Restoration and Waste Management Coordination Committee.

Stephen J. Pennycook has won the 1992 Materials Research Society Medal for his outstanding achievements in materials research.

Lynn Boatner, Brian Chakoumakos, Brian Sales, and **Allison Baldwin** won a first place award in the 1992 International Metallographic Contest.

Lynn Boatner, Stan David, Roxanne Steele, and **John Vitek** placed second in the Crystal Photograph Competition held in conjunction with the Tenth International Conference on Crystal Growth.

D. Kip Solomon has been awarded the 1992 Alumni Gold Award from the University of Waterloo in Ontario, Canada.

Lawrence W. Barnthouse has been named editor for hazard assessment for the journal *Environmental Toxicology and Chemistry.*

Nine research teams at ORNL have been recognized by the International Hall of Fame, sponsored by the Inventors Clubs of America, Inc., for their technological innovations. The winners include: **William Griffith, Alicia Compere,** and **William Huxtable** for a "Process for Degrading Hypochlorite and Sodium Hypochlorite"; **Tuan Vo-Dinh** and **David Stokes** for "Surface-Enhanced Raman Optical Data Storage," a technology to increase the storage capability of compact disks; **Carl Burtis, Wayne Johnson,** and **William Walker** for the "Blood Rotor," a new tool for analyzing samples of whole blood; **Mark Janney** and **Ogbemi Omatete** for "Gelcasting," a method for producing high-tech ceramics; **Timothy Scott** and **Robert Wham** for "The Emulsion-Phase Contactor," an energy-saving process for removing solvents from solutions; **Terry Tiegs** and **Paul Becher** for "Silicon Carbide Whisker–Zirconia Reinforced Mullite and Alumina Ceramics"; **Robert Warmack, Thomas Ferrell,** and **Robin Reddick** (University of Tennessee) for the "Photon Scanning Tunneling

Tom Wilbanks

Jim Turner

Lee Shugart

David Reichle

Carl Burtis

Donald B. Trauger

Microscope"; **Don Bible** and **Robert Lauf** for the "Variable-Frequency Microwave Furnace"; and **Don Box** for the "Inchworm," an air-powered robot that inspects pipes by crawling through them.

Glen Harrison has been awarded a Fulbright grant to teach geography at Seoul National University in Korea.

The following ORNL employees will receive royalty income for 1992 as a result of their technology transfer activities: **Michelle Buchanan** and **Michael Guerin,** sample-introducing apparatus; **Millicent C. Clark, Kevin Cooley,** and **James H. Miller,** ceramic fiber–reinforced composites; **Millicent C. Clark** and **Jerry C. McLaughlin,** ultralight EMI shielding; **Elmer H. Lee,** nickel aluminide alloys; **D. Hershel Pierce,** iron aluminides; **Virgil R. Bullington** and **James O. Kiggans,** silicon fiber–reinforced composites; and **Arpad Vass,** amoebae-bacteria consortia.

Daniel T. Ingersoll has received the Annual Distinguished Service Award of the American Nuclear Society's Radiation Protection and Shielding Division.

Carl A. Burtis has been selected by the National Academy of Clinical Biochemistry as the 1992 recipient of the Alvin Dubin Award for outstanding contributions in clinical chemistry.

Kimoko O. Bowman has been named a member of the President's Committee on Employment of People with Disabilities. She will serve on the Disability and Employment Concerns Standing Committee.

Thomas A. Fontaine has been appointed chairman of the Surface Hydrology Technical Working Group of the American Water Resources Association.

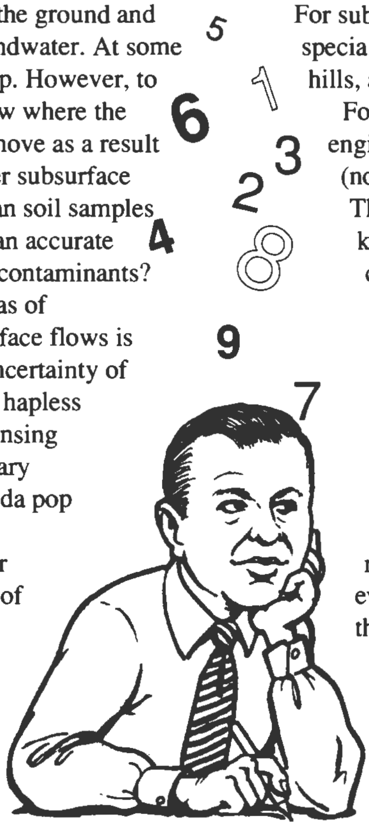
Donald B. Trauger has been recognized by the Consortium of Research Institutions for his personal contribution, insight, and leadership in developing cooperative programs and projects. Trauger retired in January 1993 after 50 years of service.

Olivia R. West has been awarded the 1993 Rocha Medal by the International Society for Rock Mechanics.

RE: Pick A Number

Modeling Subsurface Processes

Recently I spent a day in California looking at hydraulic fluid spills beneath old garages for servicing motor vehicles. Apparently hydraulic lifts leak small amounts of fluid. As a result, plumes of hydraulic fluid percolate through the ground and eventually may contaminate groundwater. At some time these sites must be cleaned up. However, to accomplish this task we must know where the contaminant is and where it will move as a result of cleanup activities. As with other subsurface problems, this question arises: Can soil samples at the contamination site provide an accurate picture of the location of specific contaminants?



Unlike our more traditional areas of engineering, knowledge of subsurface flows is made difficult by the enormous uncertainty of the data collected. For example, a hapless engineer may insert a chemical-sensing probe at the very spot where a weary traveler spilled some unwanted soda pop the night before. In this case, the environment created for the sensor may be totally different from that of the rest of the site. This uncertainty is made more critical by the large cost of collecting soil data—possibly reaching several thousand dollars for a single sampling point. Thus, it is critical that methods be developed soon for economical sampling of possibly contaminated sites.

Statisticians have developed sampling methods that seem almost miraculous. For example, within a few minutes after polls have closed, statistical methodology makes surprisingly precise election predictions. Their methodology is based on so-called "probability" models in which the parameters of interest are permitted to be random but are dictated by certain "probability distributions" indicating that random parameters are inclined to be nearer to certain values than others—much the same as heights of people or the way people vote in elections.

These distributions have been found on the basis of exhaustive analysis of past elections and the determination of small but highly representative subsamples of the population. Peculiarities of certain subcollections of parameters (e.g., teenagers enjoying louder noises than do their parents) are taken into account for the sampling process. For subsurface processes, sources of such special behavior might include soil strata, hills, and the history of the site of interest.

For many years mathematicians and engineers have developed deterministic (nonprobabilistic) models of flow in soil. These models, however, require precise knowledge of such features as contaminant distributions at some initial time and soil parameters at depth. Hence, they are not wholly suitable for the "real world" problem in which such knowledge is not really available.

Recently, statisticians and mathematicians at ORNL have broken new ground by melding their respective perceptions of subsurface events. The mathematicians have models that are totally deterministic, whereas the statisticians have models that are wholly geared to data. By joining forces they have produced new tools that promise substantially improved sampling methods. They will be able to better answer questions of when and where to take samples and what kinds. Their approach is to "teach" the probability distributions to reflect the underlying behavior of processes when they are used to guide the sampling process. The teaching process uses a combination of tools drawn from partial differential equations on one hand and sampling theory on the other.

Using these and similar approaches, eventually an environmental engineer can go to a site needing cleanup and determine from a dialogue with a computer where and when to sample the site to get the most nearly accurate view of underground contamination. Such a capability may even allow the engineer to say with certainty, "Someone spilled some soda here last night."

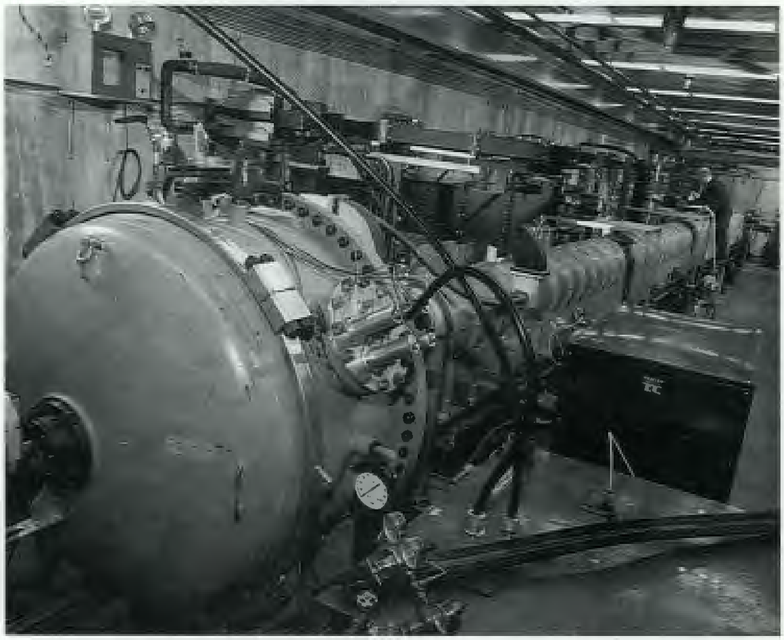
—Alan D. Solomon

"Recently, statisticians and mathematicians at ORNL have broken new ground by melding their respective perceptions of subsurface events."

RE: User Facilities

ORELA: 100,000 Hours And Still Going Strong

In October 1992, ORELA logged its 100,000th hour of operation—an indication of the enduring vitality and value of the research done at the facility.



After 100,000 hours and 23 years of operation, the ORELA accelerator still supports state-of-the-art research in a range of physical sciences.

When the Oak Ridge Electron Linear Accelerator (ORELA) went on line in 1969, the U.S. nuclear power industry was enjoying its heyday, the Soviet Union was supporting communist insurgencies in the Far East and Central America, and Richard Nixon occupied the White House. Nearly a quarter-century later, both the world and the field of nuclear research have seen a lot of changes, but ORELA is still going strong. In fact, on October 13, 1992, ORELA logged its 100,000th hour of on-line operation—an indication of the enduring vitality and value of the research done at the facility.

The facility's accelerator, target room, and several of the test stations are located under a group of grass-covered mounds not far from the Laboratory's main entrance. The more distant test chambers, located up to 200 meters (650 feet) from the target room, can be seen poking up out of adjacent parking lots.

At the heart of ORELA is a 180-MeV electron linear accelerator that uses electromagnetic waves to fire bursts of electrons pulsed from a hot-cathode gun down a 23-meter (75-foot) acceleration tube at nearly the speed of light. At the end of the tube this joyride comes to an abrupt end as the electrons slam into a water-cooled tantalum target, where collisions with the target and the surrounding water produce neutrons with a wide range of energies. This spray of neutrons is then channeled to one or more of the test chambers. Seven stations, located from 10 to 200 meters (33 to 650 feet) from the target, are used because neutrons of varying energies and intensities are needed for different experiments—and these qualities vary with the distance the neutron travels from the target.

ORELA's roots. Jack Harvey, director of ORELA and a research physicist since 1950, recalls that in 1969 the facility represented a quantum leap forward in the technology used to obtain neutron cross sections for various materials.

Cross sections are measurements of the likelihood that neutrons of a given energy will interact with the nucleus of a material, rather than passing through it. Because most nuclear reactions produce a lot of neutrons, nuclear researchers at the time of ORELA's construction were interested in learning more about neutron cross sections to help them develop more effective shielding materials for use in production reactors or nuclear research facilities.

"Thirty or forty years ago," says Harvey, "investigating neutron cross sections became an area of great interest both for people building reactors and those studying basic nuclear physics." Most early research facilities measured neutron cross sections using a "fast chopper" in conjunction with a reactor. "The chopper," says Harvey, "was a rotating cylinder with slits in the sides, which provided microsecond-long bursts of neutrons. This was adequate for measuring cross sections in low-energy regions, up to a few thousand electron volts, but the resolution was not good enough to work at higher energies."

In 1965 plans were announced to build plutonium fast breeder reactors, including Oak Ridge's Clinch River Breeder Reactor project, which was ultimately canceled in 1983. Breeder reactors rely on neutrons given off during the process of nuclear fission by reactor fuel, such as plutonium-239, to transform a blanket of non-fissionable material, like uranium-238, into plutonium-239. This approach to reactor design harnesses the fission process for the production of both fuel and power. Because plutonium breeds fissionable material best at high energies, researchers needed high-resolution information on nuclear interactions that occurred at energies between a few thousand electron volts and a few hundred thousand electron volts. "As a result," says Harvey, "funding was approved for a facility capable of measuring the cross sections for reactions in these regions. That's why ORELA was originally built."

ORELA was designed primarily to measure neutron cross sections of materials thousands of times more precisely than could be done using fast choppers. At the time of its construction, the facility produced neutron bursts that were 10 times as intense and 5 times narrower than those of comparable facilities, filling a gap between experimental results provided by low-energy fast choppers and high-energy cross sections provided by Van de Graaff accelerators then operating at ORNL and other laboratories.

Stretching the neutron. Measuring neutron cross sections of various materials isn't the only activity going on at ORELA, however. Because the facility's pulsed neutron source is so intense compared to its background "noise," it has recently been used to probe the structure of the neutron itself.

The neutron is believed to be held together by the so-called "strong" force, one of the four physical forces in the universe, a group that also includes gravity and electromagnetism. Previous experiments have suggested that neutrons are made up of three subatomic particles, known as quarks. One quark has two-thirds of a positive charge, and the other two have one-third of a negative charge each, making the total charge of the neutron zero. To measure the force holding these quarks together, researchers had to find a way to stretch the neutron, slightly separating the positive quark from the negative quarks.

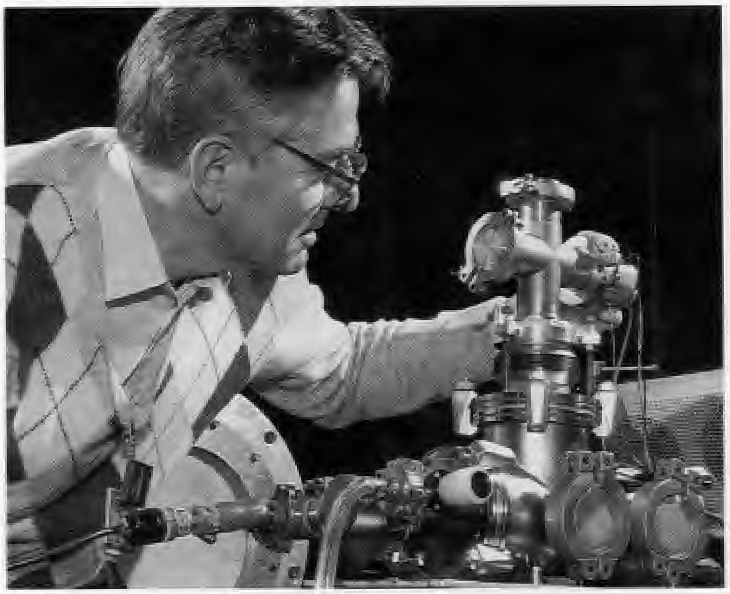
To measure the force holding these quarks together, researchers had to find a way to stretch the neutron.

To accomplish this feat, a group of Austrian researchers, along with Harvey and Nat Hill, a retired researcher from the Instrumentation and Controls Division, fired beams of low-energy neutrons at a target of lead-208, an isotope with an extremely strong electric field around its nucleus. The interaction between this electrical field and the neutron's charged quarks causes the quarks to separate slightly.

Using a new detector and other special electronics provided by the Austrian research team, it was determined that, as a result of this separation, more of the neutrons were scattered by the lead-208 sample, rather than passing through. By comparing the results of this experiment to those obtained when no target was present, researchers determined the change in the "size" of the neutron resulting from its interaction with the electrical field of the lead-208 nucleus, and from that they determined the magnitude of the force holding the neutron's charged quarks together.

"Twenty earlier attempts at measuring this force at other research centers have resulted in values with margins of error that were greater than the values obtained from the measurements," said Harvey. "The value obtained in the work with the Austrians was four times larger than the margin of error."

Phonons and superconductivity. ORELA also provides researchers with an opportunity to study the role of phonons in superconductivity. Superconductivity occurs when electrons in a metal are attracted to each other, but because electrons are all negatively charged, they usually repel each



Using specially designed detection equipment provided by their Austrian collaborators, ORELA researchers recently succeeded where 20 other research centers had failed—they "stretched" the neutron, thereby measuring the force holding it together.

other. Under certain conditions, however, this repulsion can be overcome.

For example, a fast-moving electron traveling through an array of positively charged, slow-moving metal ions attracts the ions, causing them to move toward it as it passes and leaving a concentration of positive charges in its wake. These positive charges may then attract other electrons, causing an indirect attraction between electrons.

The units of vibrational energy that cause the metal ions to move toward the electron in this example are called phonons. Studies of the vibrational spectra, or phonon spectra, of materials that conduct electricity normally in one temperature range and are superconductors in another have shown systematic differences between the two states, but until recently, the hypothesized change in the phonon spectrum at the transition point between the two states had not been observed for the new, high-temperature superconductors.

To get a good look at phonon behavior at the superconducting transition point, Herb Mook and other researchers at ORELA used a technique called neutron resonance absorption spectroscopy (NRAS) to measure the vibrational spectra of the high-temperature superconductor modes of bismuth, strontium, calcium, and copper (BSCCO). The NRAS technique has several advantages, including being able to study the vibrations from each element in a sample separately, obviously a plus when dealing with molecules as complex as BSCCO. Another advantage of NRAS is that it enables researchers to study the structure of non-uniform material by varying its orientation in the neutron beam.

Using this technique, scientists at ORELA were able to observe a change in the phonon spectrum of the BSCCO's copper component at the transition point. This finding shows that there is a close relationship between phonons and high-temperature superconductivity and suggests that any explanation of the high transition temperatures of high-temperature superconductors should take the role of phonons into account.

New tools. The latest addition to ORELA is an intense "slow" positron–generating facility developed by Lester Hulett of ORNL's Analytical Chemistry Division. Positrons are electron-sized particles that have positive charges equal to the electron's negative charge. The new facility takes advantage of gamma photons that are scattered beyond ORELA's primary tantalum target by placing a secondary tungsten target in their path. When the photons strike the tungsten, they are converted to slow, or low-energy, positrons and channeled by a magnetic field into an adjacent experiment room.

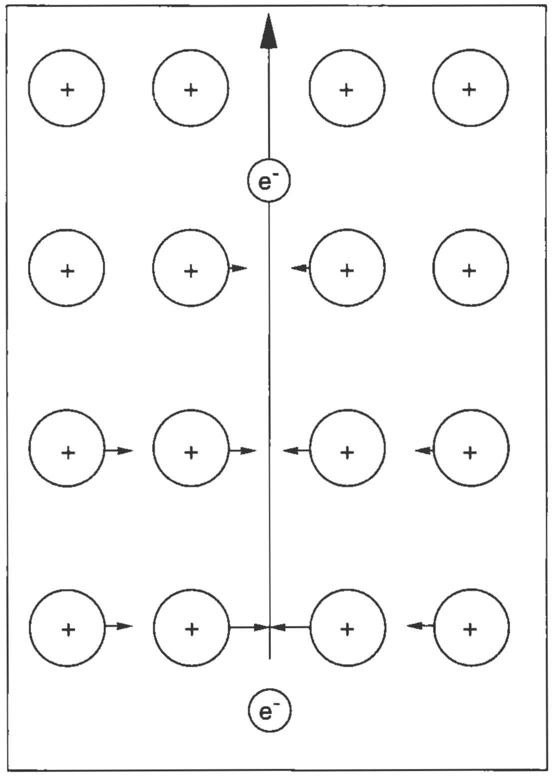
If this gamma radiation weren't a cost-free by-product of ORELA's neutron-producing activities, it would cost about $300,000 annually to generate it. Reseachers are taking full advantage of this windfall by using the resulting positrons to conduct a range of slow- positron spectroscopy studies, such as those planned for a cooperative research and development agreement between ORNL and AT&T Bell Laboratories.

This joint effort will employ slow-positron spectroscopy to develop more effective semiconductor devices. Inefficiencies in semiconductor performance are often the result of defects, such as missing atoms, which trap positrons. The number and distribution of these defects determine how the device's performance will be affected. Once snared by a defect, a positron's lifetime is extended, changing the energies of the gamma rays produced when it finally interacts with an electron and is annihilated. Measuring these gamma emissions enables researchers to determine if defects are present in a semiconductor and whether or not they occur in areas critical to the device's function.

The positron facility is also being used to try to get a fundamental understanding of how organic molecules like benzene are ionized—how electrons are removed—by comparing spectra produced by positrons with those produced by electrons and photons. This line of study may eventually lead to better ways of doing analytical mass spectrometry.

Understanding the ionization process in medium-sized organic molecules, like benzene, may also result in a better understanding of how larger organic molecules, such as DNA, are ionized. Preliminary studies using bacteria have found that extremely low doses of positrons may have mutagenic effects.

What's next? Over the years, thousands of publications, reports, and presentations have documented research results from ORELA, but researchers are not content to rest on their laurels. Plans for the future include continuing the research initiatives mentioned previously, more collaborations with the Austrians—this time hoping to measure the charge distribution of the neutron at lower energies, and further forays into the realm of astrophysics to determine the properties of heavy elements formed in and around stars as a result of lighter elements capturing neutrons. ORELA is also involved in detector development for DOE's multibillion-dollar Superconducting Super Collider project, as well as other radiation damage and characterization studies.



Electrons carry negative charges (e⁻), so when one passes through an array of positively charged metal ions (+), it attracts them, leaving a concentration of positive charges in its wake. These positive charges may then attract other electrons, causing an indirect attraction between electrons, a necessary condition for superconductivity. The units of energy that cause the metal ions to move toward the electron are called phonons, and understanding their behavior may be one of the keys to understanding superconductivity.

"Normally, accelerators have less than a 20-year life span, but we're 23 and we're still going strong," says Harvey, who shows no signs of slowing down either. "We really have an excellent facility here, and it's running well. We've done a lot with it, and I think there's still a lot of good work to be done."—*Jim Pearce*

Normally, accelerators have less than a 20-year life span, but we're 23 and we're still going strong.

EnvironMENTAL Fair Energizes Young Minds

Some of the kids here at the fair today will be the scientists doing the cleanup work of tomorrow.

At the EnvironMENTAL Fair, students participate in an experiment that shows how enzymes protect fresh apples from spoiling after they are cut. The experiment was designed by researchers in ORNL's Chemical Technology Division.

The grounds of the American Museum of Science and Energy in Oak Ridge were a bustle of activity on October 9, 1992, as nearly 3000 area middle-school students streamed in and around candy-striped carnival tents at the first Oak Ridge EnvironMENTAL Fair sponsored by the Department of Energy through its Environmental Restoration Program. Several ORNL researchers interacted with the students and provided information through exhibits and demonstrations in areas such as mercury pollution, indoor radon, degradation of toxic PCBs, and analysis of arsenic levels in the hair and nails of President Zachary Taylor.

Attending the fair for a day of fun and environmental education were sixth, seventh, and eighth graders from Anderson, Roane, Rhea, Meigs, and Loudon counties and city school districts within the selected five counties. Also included were students from the Tennessee School for the Deaf (Knoxville) and Vine Middle School, both of which are part of the "Adopt-a-Schools" program sponsored by Martin Marietta Energy Systems, Inc.

"We really want to involve the surrounding communities in our programs and help them understand all of the hard work that is under way in Oak Ridge related to the environment," said Bob Sleeman, director of Environmental Restoration (ER) for DOE in Oak Ridge. "Of course," Sleeman continued, "we also wanted to make the experience a lot of fun. It's a great way to learn about some very basic issues concerning environmental cleanup work as well as overall global environmental problems and solutions."

Once inside the tents, the students met scientists and workers from ORNL, the Oak Ridge Y-12 Plant, the Oak Ridge K-25 Site, and area DOE contractor employees who offered hands-on learning about environmental work taking place on the Oak Ridge Reservation. More than 50 booths of scientific demonstrations, experiments, and activities related to environmental awareness were featured.

Students and teachers seemed hard pressed to decide which activity to get involved with next. Rebecca Burnette, an eighth-grade teacher from Ten Mile Elementary in Meigs County, stood and scanned the swarm of students. "It's a challenge to learn so much in such a short period of time," she said. "So much of what we have studied in our classes is represented here. The kids are just really amazed. I'm sure when we go back to school, chapter by chapter we'll look back and say 'remember that at the fair?' "

Fran DeLozier, director of the Environmental Restoration Program for Energy Systems said that's just what the program is striving to do through the EnvironMENTAL Fair. "We want to impress upon the students the importance of environmental restoration," she said. "ER is a 30-

year program. Some of the kids here at the fair today will be the scientists doing the cleanup work of tomorrow."

Pamela Jetter, who teaches fifth grade at the Tennessee School for the Deaf, said the fair was shedding entirely new light on the subject of the environment for many of her students. "Some of them have not really been aware of environmental issues," she said. "Some have the chance to watch closed-captioned television news programs, so they see environmental news. Others don't. I think the fair is a good opportunity for them to be introduced to new concepts."

For instance, at a booth demonstrating the dilemmas of waste disposal, some of her students were unfamiliar with the notion of a landfill. "But after I pointed the word out to them and explained what a landfill is and that many are filling up, they became very interested and excited," she said.

A few examples of other environment-related demonstrations included the "Inchworm," an ORNL robot equipped with a TV camera that inspects pipes by crawling through them; an explanation of radiation found in everyday items; naturally occurring microscopic "bugs" that eat waste; and high-tech methods for treating industrial wastewater.

"All in all, it looks like the fair accomplished exactly what was intended because the students learned a lot about the environment and had fun in the process," Sleeman said. "If we can get them excited about science and the environment at this stage, they will carry it with them forever and will be instrumental in making their world a cleaner, better place to live."

DeLozier pointed out that the fair could never have taken place without the support of more than 300 volunteers from Energy Systems, DOE, and DOE contractor employees. "This event," she said, "is just another example of the commitment these employees have to the local community."
—Wayne Scarbrough

Computer Network Links Local Schools with World

Teachers and students at three Oak Ridge schools will soon have the world at their fingertips via the Oak Ridge Educational Network (OREN). Developed at ORNL, this wide-area computer network will allow access to such educational resources as the Earthquake Information Center, the Library of Congress, the National Weather Service, and the Lunar and Planetary Institute.

The development and implementation of the OREN prototype, which was funded by DOE, could set the stage for establishment of wide-area educational networks originating from other DOE national laboratories, providing teachers and students access to technology and information that would otherwise be out of their reach.

Users of the network will have a direct connection to a collection of worldwide computer networks, known as the Internet. They will be able to access public data bases, major university libraries, and electronic mail, which will allow them to communicate with researchers and other educators from around the globe. Approximately one million people use the Internet daily.

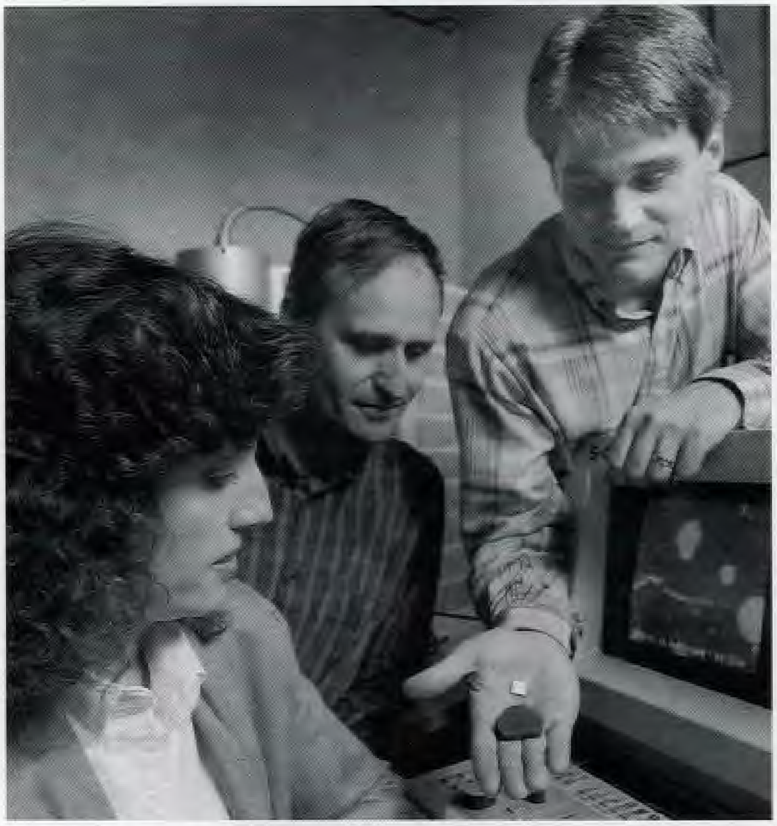
In cooperation with the Oak Ridge school system and SURAnet, the regional provider of Internet services, the system has been installed at three Oak Ridge schools—Jefferson Junior High School, Robertsville Junior High School, and Oak Ridge High School.

The exposure to this type of educational resource will enable students in grades K–12 to better develop the research skills necessary to function in the global community of the 21st century. "Several teachers have already begun to plan ways of incorporating information location, gathering, and assessment into their classrooms, so this project will give us the ability to identify what teachers need and can actually use in the classroom, how students can use the network to supplement their other school resources, and how school administrators will manage and use information resources as we enter the next century," said John Wooten, principal investigator for the OREN project.
—Bunny Tharpe

Researchers interacted with students through exhibits and demonstrations on mercury pollution, indoor radon, and the levels of arsenic in President Zachary Taylor's hair and nails.

Ceramic-Metal Composite Ideal for Cutting Tools

ORNL experts in ceramics and metals put their heads together to make an advanced cutting tool material.



Kathi Alexander, Joachim Schneibel, and Terry Tiegs admire the cutting tools held by Tiegs that are made of composites developed at ORNL. On the screen is an electron micrograph of a ceramic composite showing a crack whose growth is curbed by the presence of nickel aluminide (white blobs on the screen).

If two heads are better than one, could two materials be better than one? ORNL experts in ceramics and metals and an industrial researcher have put their heads together and combined a ceramic and a metal to make an advanced cutting tool material. The new composite, which is made of the ceramic, tungsten carbide chemically bonded with a modified nickel aluminide alloy developed at ORNL, offers several advantages over the commercially used material.

Tests show that the new material is harder and may last longer than the ceramic tungsten carbide bonded with cobalt, another composite used commercially throughout the world for dies to stamp out beverage cans and other items, drilling equipment, and other cutting tools. The new ceramic-metal composite is also less expensive. It contains metals that are readily available because, unlike cobalt, nickel and aluminum have no strategic value during military crises. In addition, because of the excellent high-temperature properties of the nickel aluminide, the material may be used to make tools that can be operated at higher temperatures.

Ceramics are hard but brittle, and metals are soft but ductile—that is, they can be stretched and formed into shapes without cracking. The new composite combines the strengths and overcomes some of the weaknesses of the ceramic and the metal alloy, forming a material that has both high hardness and fracture toughness. It also combines the abilities of the ceramic to resist wear and corrosion with the abilities of nickel aluminide to withstand mechanical shock and deform under stress.

In the 1980s ORNL researchers led by C. T. Liu developed modified nickel aluminide alloys that become stronger with increasing temperature. To make the alloys more ductile so that they can be shaped into components for high-temperature use, impurities such as boron, chromium, molybdenum, and zirconium were deliberately added in precisely measured amounts.

The new composite was made by mixing ceramic powder with a modified nickel aluminide powder, which serves as a bonding agent to hold the ceramic powder together. Heat and pressure are then applied using such techniques as hot pressing, sintering, or compaction.

Tests of cutting tools made of the tungsten carbide–nickel aluminide composite performed by Tennessee Technological University have shown that the new composites are harder than conventionally used cobalt-bonded tungsten carbide cutting tools.

Research begun in 1987 by Terry Tiegs and industrial collaborators resulted in a patent on the use of intermetallic alloys as bonding agents in ceramics in 1990 and another patent on the use of these composites as cutting-tool materials in 1991.

Tiegs and his colleagues in the Metals and Ceramics Division have fabricated composites using several different intermetallic alloys in ceramic matrices such as tungsten carbide, titanium carbide, titanium nitrite, aluminum oxide, and zirconium oxide. The use of a wider range of metallic and intermetallic bonding alloys in non-oxide and oxide-based ceramic matrices is being further explored by Tiegs and Kathi Alexander, respectively.

Joachim Schneibel is developing the required alloys and evaluating their mechanical and other properties. H. T. Lin and Paul F. Becher are examining the properties of model composites to aid in interpretation of the mechanical property results. In a collaborative effort, researchers at the University of California at Berkeley are investigating the fatigue properties of these composites.

Further development of these composites is being supported by the U.S. Department of Energy, Assistant Secretary for Conservation and Renewable Energy, Office of Industrial Technologies, under the Advanced Industrial Materials Program.—*Carolyn Krause*

Enzymes Convert Coal to Liquid Fuel

ORNL researchers have discovered that chemically modified enzymes from bacteria can convert coal to liquid fuel.

"The idea of making liquid fuel from coal isn't altogether new, but until recently, the thought of using enzymes as catalysts in the process was not considered," says Chuck Scott, director of ORNL's Bioprocessing Research and Development Center. In fact, until the enzyme-modification work started at ORNL two-and-a-half years ago, nobody realized that enzymes could effectively interact with coal to make liquid fuel. "That knowledge simply did not exist," Scott says.

However, now that Scott and his colleagues have developed a clean, efficient way to convert solid coal to liquid fuel using chemically modified bacterial enzymes, the idea is being given serious consideration. The resulting liquid fuel is comparable to crude oil and could be refined for use as a clean-burning alternative to gasoline.

Researchers have discovered that chemically modified enzymes from bacteria can convert coal to liquid fuel.

This development is particularly timely, coming on the heels of the National Energy Policy Act of 1992. Among the goals of the act are reducing the nation's energy consumption by 8 billion barrels of oil and promoting the development of clean-burning alternative fuels.

The enzymes Scott and his team are using are similar to those that stimulate chemical reactions in the human body. For example, enzymes in your stomach allow you to digest food; others play critical roles in cell reproduction.

These coal-conversion enzymes normally function best in water, but ORNL scientists discovered that certain enzymes, such as the bacterial enzyme hydrogenase, can be modified with a chemical called dinitrofluorobenzene, allowing them to be mixed with various organic solvents to convert solid coal to a liquid fuel product more efficiently.

To say that Scott's team has made the enzymes "usable" may fall short of expressing the significance of their accomplishment. In fact, the modified proteins are proving to be highly effective at converting coal from a solid to a liquid. The researchers have been able to convert more than 40% of solid coal particles to liquid. "That's a significant quantity," Scott says, adding that the quality of the liquid fuel obtained has been equally impressive.

The solid residue left by this process is still a combustible fuel, so two usable fuels can be obtained from a single source—liquid fuel, for

Chuck Scott observes a fluidized-bed bioreactor in which solid coal is being converted to liquid fuel. Charlene Woodward holds a flask containing a sample of the product, which resulted from the use of bacterial enzymes as biocatalysts for the conversion process.

possible use in engines, and solid fuel, which could be used for a variety of purposes, such as heating water in steam-driven power plants.

The ORNL coal-conversion technique could be scaled up to produce large quantities of liquid fuels. In its current configuration, the system uses a glass column approximately 15 centimeters (6 inches) tall called a fluidized-bed bioreactor. The bioreactor is filled with an organic solvent, such as benzene or purified kerosene, modified enzymes, and coal particles suspended in the mixture.

The solvent, which carries the modified enzymes and hydrogen gas, is constantly siphoned from the top of the column and pumped back up through the bottom to ensure circulation through the suspended coal particles. The hydrogen initiates the conversion from solid to liquid by breaking chemical bonds that hold the coal together. The modified enzymes enhance this hydrogen interaction.

As more solid coal is converted to a liquid, the solvent in the bioreactor becomes increasingly dark. This effect allows the researchers to determine the amount and rate of the conversion process. A darker solvent—one containing a high percentage of liquid fuel—will absorb more light. The researchers can determine the conversion rate by comparing the increase in the amount of light absorbed with each successive test with the time between tests.

These experimental reactions are being accomplished at relatively moderate temperatures and pressures compared to coal-conversion methods used in the past, resulting in much less pollution. If the technique proves economically feasible, Scott says, it may be useful for large-scale production of alternative liquid fuel within the next decade.
—Wayne Scarbrough

More Funding for Genome Research

DOE has begun what could become a multimillion-dollar funding effort for ORNL's work on the Human Genome Project, an international effort to identify and characterize all of the genes in human DNA. DNA (deoxyribonucleic acid) carries all of an organism's genetic information, thereby providing the complete blueprint for life.

"The contract represents the largest single piece of funding for genome research throughout ORNL and is the culmination of painstaking proposals and exhaustive peer review to demonstrate the Laboratory's capabilities in genome research," says Fred Hartman, director of ORNL's Biology Division. The work is being supported by DOE's Office of Health and Environmental Research. To date, the program has received some $600,000. Proposed funding for the 1993 fiscal year puts the total at more than $1 million.

A complete atlas of the human genome will revolutionize medical practice and biological research, and it may be the foundation for alleviating much of the human suffering brought on by genetic diseases, researchers say.

The "open-ended" DOE contract is structured to run for the duration of the Human Genome Project. "The lifetime of the project is indefinite," Hartman said, "but it could certainly run as long as 10 years."

Over the years, Hartman and other division leaders have assembled an elite team of scientists with world-class expertise in genetic research, particularly in mouse genetics. A mouse's DNA has large sections that closely correspond to sections of human DNA. Scientists can therefore glean significant information about human genetic disorders by observing genetic influences on the development of mice.

Hartman said that ORNL's Biology Division offers considerable expertise in gene function and regulation in model organisms, such as mice. "In addition to an enviable 40-year track record of outstanding accomplishments in classical mouse genetics research under the leadership of William L. and Liane B. Russell, the division has recently recruited staff members whose expertise includes state-of-the-art technologies for targeting and manipulating genes in living animals and for transferring

Lisa Stubbs, who heads an ORNL group that is mapping genes, studies a DNA sequencing gel and a lightbox for characteristic dark bands that indicate the composition of DNA samples. The goal is to locate genes on the human genome that may be linked to genetic disorders.

Through a microscope Mike Mucenski views objects that are displayed on the screen. The large strawlike tube (left) shown on the screen uses suction to hold a mouse embryo in place as embryonic stem cells (resembling tiny bubbles) from a different mouse are injected through the slender needle at right. Combining foreign cells with normal cells helps scientists determine the genes responsible for specific functions or diseases.

genes among animals. These are the very tools that will facilitate diagnosing and ultimately ameliorating human genetic disorders."

A molecule of DNA, which is contained in a chromosome, is approximately a meter long but is so compressed that it fits in the nucleus of a cell only one micrometer (1/1000th of a millimeter) in diameter. (For comparison, most cells are so small that a million of them would not be much larger than the head of an ordinary pin.) Genes lie at varying intervals along the strands of DNA.

Every cell in the human body contains the same array of chromosomes and, hence, identical genetic information. All of the structural and functional characteristics (i.e., what it's made of and what it does) that distinguish the heart, lungs, kidneys, brain, muscles, and everything else that compose a living creature are determined by which genes are "turned on" and which genes are "turned off."

By pinpointing a gene's location in a strand of DNA and then deciphering exactly which biological process the gene controls, scientists hope to demystify genetically inherited diseases and to gain the ability to diagnose them quickly and treat them effectively.

The genome program at ORNL, coordinated by Biology Division member Gene Rinchik, comprises four tasks, each separately focused yet relating to the others. All incorporate the use of mouse DNA.

Task I, headed by group leader Lisa Stubbs, concentrates on physical mapping, wherein scientists identify the location of genes as they are situated along a strand of DNA. To date, the approximate positions of some 2300 genes have been charted. The human genome is estimated to comprise at least 100,000 genes, possibly twice that number.

Tasks II and III, under the leadership of division members Rick Woychik and Mike Mucenski, involve methods of determining the function of individual genes or groups of genes. Scientists take from a developing mouse embryo cells that contain strands of DNA. They then insert short segments of foreign DNA into these cells to "turn off" a single gene (Task II) or gene groups (Task III).

When the cells containing the altered DNA are put back into a female mouse and allowed to gestate, the offspring will show observable mutations. The mutation can be readily mapped because the foreign DNA provides an obvious marker. Most mutations are not extraordinary, but subtle, such as altered fur color, ear size, or tail length. However, some of the mutations are more dramatic and relate more closely to humans.

For instance, scientists may notice that mice develop a kidney problem at a particular point in life if certain genes have been "turned off." The researchers can then deduce that the inactivated genes must have something to do with kidney development. By doing similar research with fetal mice, scientists can better understand how an organism develops almost from the time of conception.

The fourth task, involving the science of "informatics," ties the project together in a computer data base, which is being developed by Richard Mural of the Biology Division and Ed Uberbacher of the Engineering Physics and Mathematics Division.

Because of the size of mammalian genomes (one billion to three billion basic building blocks), the international project will generate a vast amount of data. If compiled in books, the data would likely fill 200 volumes, each the size of a 1000-page Manhattan telephone directory. To read all the information completely would require 26 years of round-the-clock concentration.

The informatics data base will allow researchers studying animal chromosomes to quickly access and identify matching sequences of human DNA as they search for genetic clones and will aid in predicting protein sequence and structure—an important step in understanding individual gene function.—*Wayne Scarbrough*

Global Warming Agents: Trace Gases vs CO_2

Although they are less abundant in the atmosphere, trace gases may be worse than carbon dioxide (CO_2) in contributing to global warming, according to a report issued by ORNL's Carbon Dioxide Information Analysis Center (CDIAC). Trace gases include nitrous oxide (N_2O) the chlorofluoro-carbons CFC-11 and CFC-12, tropospheric ozone (O_3), and halocarbons such as methane.

Trace gases may contribute more to global warming than carbon dioxide.

Excerpts from the report were quoted in the January-February 1993 issue of *The Futurist* magazine.

According to the ORNL report, "Although less abundant than either CO_2 or CH_4 (methane), a number of other 'minor' atmospheric trace gases are also able to perturb the radiative energy balance of the Earth-atmosphere system and are, therefore, potentially important contributors to global climate change.

"Extrapolations of current trends in the atmospheric concentrations, along with estimates of their relative abilities to alter the global energy balance, suggest that the collective contribution of the minor trace gases to any future global warming is likely to approach or even exceed the contribution from CO_2."

The source of the information was a chapter written by Bob Sepanski in *Trends '91: A Compendium of Data on Global Change*, a widely distributed CDIAC document.

ORNL Results Help Firm Decide To Market Silicon Nitride

This collaborative work between ORNL and Norton is a good example of how user facilities and personnel can help industrial firms solve problems.

Michael Jenkins examines data on the reliability of a silicon nitride material developed by the Norton Company.

The Norton Company, a ceramic manufacturer in Worcester, Massachusetts, had a problem. The company had developed a new silicon nitride material that might be more suitable for use in high-temperature gas turbines than its current product. Its ceramicists had systematically adjusted the chemistry of its commercial silicon nitride product, NT154, and produced a new ceramic, NT164. However, the Norton researchers were not sure if they had developed a product that was good enough to be marketed.

So Norton turned to ORNL for help through the user program at the High Temperature Materials Laboratory (HTML). Norton engineers in collaboration with ORNL researchers proposed through a user project to test the mechanical properties of NT164 at high temperatures and compare them with the results they had obtained earlier on NT154. In addition they wanted to analyze the two ceramic materials using the HTML's powerful microscopes. The challenge was to find differences in the microstructure of the two materials that might account for differences in mechanical properties.

As a result of the ORNL findings, Norton decided to commercialize NT164, and Michael Jenkins, Matt Ferber, and Ted Nolan, all of ORNL's Metals and Ceramics Division, received a 1992 Martin Marietta Energy Systems Technical Achievement Award. They were cited "for significant materials characterization and analysis contributions to the development and commercialization of a high-performance silicon nitride ceramic."

Silicon nitride is the preferred material for components of high-temperature gas turbines because of its combination of important properties. It is very strong, hard, and highly resistant to wear, oxidation, and decomposition at high temperatures. It is incredibly resistant to thermal shock—large changes in temperature, such as a drop from 1200° to 20°C in a matter of seconds—that would cause ceramics such as alumina and silicon carbide to shatter.

Because the ceramic gas turbine could operate at higher temperatures than the nickel-based superalloy engine, it would use fuel more efficiently and produce less pollution. However, such an engine has not been produced commercially yet because of problems in fabricating dense, precisely shaped components that are reliable at high temperatures. To overcome this problem Norton is developing new silicon nitride materials by adjusting the chemistry of the silicon nitride (Si_3N_4) powders and sintering aids (e.g., oxides of yttrium and aluminum) used to form the material and make it dense.

The ORNL researchers tested the Norton ceramics for high-temperature creep deformation—a gradual change in length, or strain, in a material as a result of prolonged exposure to stress and high temperatures. They also evaluated each ceramic for static fatigue—the time it takes for a material to fail under a constant stress—to determine its long-term reliability.

The ORNL researchers subjected both materials to tensile tests, applying stresses of 100 to 200 megapascals (MPa) at temperatures of 1260°C and 1370°C, the temperature that turbine components must endure. Dumbbell-like tensile specimens of each material held through Supergrip™ couplers were pulled at each end and heated to high temperatures at the center. ORNL results showed that, under the same conditions of 100 MPa and 1370°C, Norton's commercial ceramic deformed at a higher rate and failed after 1200 hours, whereas the new material survived for 4800 hours.

"We found that NT164 lasted four times as long yet accumulated three times as much strain as NT154," says Jenkins, now with the University of Washington in Seattle. "The new ceramic clearly was more resistant to creep degradation and static fatigue and more reliable in the long term than the already commercialized material."

To determine the reason for the mechanical superiority of the new material, the ORNL researchers characterized the microstructure of both ceramics using transmission electron microscopy.

"What we found was that NT164 had very little intragranular cavitation," Jenkins says. "It had little of the Swiss-cheese-like appearance of the NT154."

Commercial silicon nitride ceramics can also be processed to be self-reinforced rather than reinforced with silicon carbide whiskers (which may pose a health hazard if they are inhaled and deposited in the lungs). By using sintering aids such as oxides of rare earths (e.g., yttria, ytterbia, and scandia) and applying proper processing temperatures and pressures, long columnal grains are grown among the uniformly sized grains. The long grains act like whiskers, bridging cracks and toughening the material. During this processing, amorphous, or noncrystalline, material may form between the ceramic's crystalline grains, areas called grain boundaries.

When silicon nitride is exposed to high enough temperatures, this glassy material softens, allowing creep deformation by mechanical and diffusional mechanisms. In mechanical deformation, the silicon nitride grains slide relative to each other; creep cavities or holes may develop, and the ceramic becomes deformed. In diffusional deformation, elemental material (e.g., silicon and nitrogen) may dissolve into the glassy material, forming holes or cavities in the silicon nitride grains, and redeposit or unite with other grain-boundary elements.

This elemental transport took place at junctions between two grains but not at three-grain junctions where enough glassy material was trapped and crystallized. The dissociated elements cannot move through the crystalline regions in these "triple points," which are formed during processing.

"By controlling the chemistry of the starting material and sintering process for NT164, Norton researchers almost eliminated the formation of the glassy material at the two grain boundaries," Jenkins says. "We found that the glassy regions in NT164 were only about one nanometer thick compared with several nanometers in NT154. Norton researchers made grain boundaries so thin that the bulk of the glassy material was forced into triple points where it becomes crystalline."

This collaborative work between ORNL and Norton, says Jenkins, is a good example of how the diverse and unique user facilities and personnel available at the HTML can help industrial firms solve problems.—*Carolyn Krause*

Microwave-Processed Silicon Nitride Is Cost-effective

The Oak Ridge process could produce ceramic parts that are economically competitive with metal components.

Using microwaves, three Oak Ridge researchers have developed a cost-effective method of making ceramic parts for advanced engines for transportation. The Oak Ridge technique produces silicon nitride parts that cost less and are denser than parts made by conventional processes under ordinary conditions. The denser the material, the stronger and usually more fracture resistant it is.

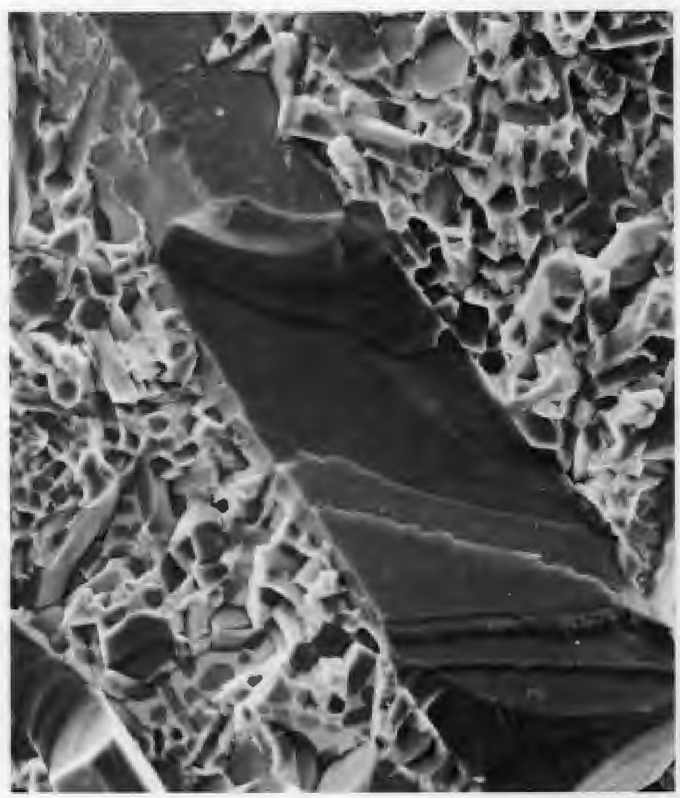
According to Terry Tiegs of ORNL, one of the developers of the technique, applications include components for engines operated at high temperatures, such as turbocharger rotors, valves and valve parts, and pump seals. Other uses could include tools to cut metals and dies for forming aluminum beverage cans.

Silicon nitride is the ceramic material of choice for components of high-temperature engines being developed to improve the fuel efficiency of cars and trucks. It is highly resistant to wear, deformation, oxidation, and decomposition at high temperatures, and it is also incredibly resistant to thermal shock—large changes in temperature that would shatter other ceramics. In fact, the latest silicon nitride materials have been shown to have outstanding characteristics for rotors and stators in gas turbines for cars and trucks and for valve trains in diesel- and gasoline-powered engines.

Some silicon nitride parts that meet the requirements for use in engine applications have been made, but because of the processes used, these components are much more expensive than metal parts. The Oak Ridge process using microwave heating could produce ceramic parts that are economically competitive with metal components. The chief reasons are that the process uses a combination of low-cost raw materials (about one-fourth that of the materials used in other processes) and a simplified processing route made possible by the microwave heating.

The process was developed by Tiegs and James Kiggans, both of ORNL's Metals and Ceramics Division, and Cressie Holcombe, a researcher in the Development Division of the Oak Ridge Y-12 Plant.

In the ORNL process, a silicon nitride ceramic is fabricated in a microwave field. Silicon powder mixed with additives in a preformed shape is reacted with a nitrogen-containing gas as the ceramic part is heated to 1200 to 1400°C by microwave power. As a result, nitridation of the silicon (Si) to silicon nitride (Si_3N_4) occurs.



Electron micrograph by Dorothy Coffey showing surface fracture of a large hexagonal fiber in ORNL's microwave-processed silicon nitride. See front cover for another example.

Without removing the parts from the microwave furnace or cooling them down, the parts are then heated to 1750 to 1825°C, making them extremely dense.

With conventional heating, the nitridation and densification steps have to be done in two different furnaces. By using microwave heating to accomplish both tasks, the fabrication times and labor costs are significantly reduced.

According to the developers, microwave heating offers several advantages over conventional heating. Nitridation begins at a lower temperature and occurs at a faster rate. Nitridation and sintering (heating) are accomplished in one continuous process. Densification rates are increased. Finally, thicker parts can be made because nitridation proceeds from the inside out.

Microwave heating of silicon nitride parts has been done in furnaces in Building 4508 at ORNL. The process has been successfully tested on silicon nitride parts containing sintering aids in a cooperative research and development agreement (CRADA) with the Norton Company, the ceramic manufacturer in Worcester, Massachusetts.
—Carolyn Krause

Don Box watches the Inchworm robot he developed creep through a pipe.—*Photo by Bill Norris*

Inchworm Explores and Cleans Up Pipes

It could be creeping through the pipes under the buildings at ORNL. It may be found in waste lines, storage tanks, or even in a stream. This miniature robot, just one foot long, is called Inchworm, but it doesn't measure marigolds. However, it can measure concentrations of acids and other pollutants in waste streams, according to its inventor, Don Box, of ORNL's Chemical Technology Division.

Ordinary mechanical robots are limited in where they can go. They typically require electrical power to operate, and they have trouble maneuvering in confined spaces and around corners. Inchworm, however, has none of these limitations. Instead of using electricity, it operates on low-pressure air and vacuum. It can go forward, backward, and around corners at 90°, and it can even move vertically.

Inchworm can go through round or square pipes and even small pipe discontinuities. Versions of the robot can be built to fit into either small or large pipes. Inchworm can even move through flowing water or sludge. It carries a video camera and its own light source, and it can be fitted with instruments and tools to perform a variety of tasks.

"If we had a waste stream with many different streams discharging into it and someone discharged excess acid into the stream, Inchworm could help find the source," Box says. "We could put it in the waste stream and measure the pH with a probe as the robot moved along. By observing where the pH changed, we could tell

Inchworm can measure concentrations of acids and other pollutants in waste streams.

exactly where the acid was coming from. If we wanted to know more about the acid, we could put some tubing on the robot and draw up a sample as it entered the stream."

Another possible use for Inchworm is at the K-25 Site, where miles of ducting are contaminated with uranium-235 (U-235). Dry-ice blasting, a new method of cleaning surfaces similar to sand blasting but using solid carbon dioxide (CO_2) pellets instead of sand, could be used to decontaminate the pipes, but no method currently exists for moving the blasting head into the pipelines.

"We could put the blasting head on the robot and let it blast its way down the pipeline as the robot moves along it and then pull the CO_2 back with a vacuum and collect the U-235 particles," Box says. "This way we could clean out these pipes more safely than we could with an acid cleaning system or by cutting the pipe up first and then cleaning it afterward."

The demonstration model of Inchworm is about 0.3 meter (1 foot) long at rest and 10 centimeters (4 inches) in diameter. It has expandable head and tail ends linked by three columns of flexible tubing. Two inexpensive pumps supply the air pressure and vacuum to run the robot. Vacuum and pressure applied to the tubing in various combinations make Inchworm go forward, backward, and around corners.

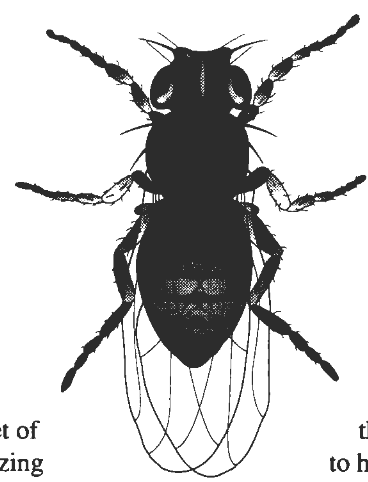
Box controls the robot with a set of switches now, but he is computerizing the control mechanism so that it will work with a joystick. Images from Inchworm's on-board, high-definition color television camera appear on a video monitor magnified up to ten times. In use, the robot looks very much like its namesake. It gives the impression of being a living thing as it crawls through clear plastic tubing in the laboratory.

Several industrial firms are very interested in the Inchworm robot, and Box expects to be involved in a number of cooperative research and development agreements as soon as his patent application is approved. Inchworm will save its users time and money as well as improve worker safety by creeping into places humans can't or shouldn't go because of physical, chemical, biological, or radiological hazards.—*Marilyn Morgan*

Frozen Fruit Fly Embryos Hatched

Researchers have succeeded in thawing and hatching deep-frozen fruit fly embryos.

Researchers from ORNL and the University of Chicago have succeeded in thawing and hatching deep-frozen fruit fly embryos, some 25% of which develop into fertile adult flies. The finding may enable biologists to store, rather than maintain in living cultures, some 15,000 different genetic stocks of mutant *Drosophila*, saving considerable time and money. It may also help entomologists understand the genetic basis of malaria transmission by mosquitos.



For 80 years fruit flies have been useful sources of information on heredity. Geneticists like them because they have a life span of only 10 days, are easy to culture in the laboratory, and carry a small number of chromosomes, some of which are large and easily visible in the microscope at the larval stage. The fly is particularly appealing because it easily undergoes changes in its genes to produce detectable mutations. Furthermore, many of the genetic principles are applicable to human genetics and the human genome program.

Some 15,000 genetically characterized strains of fruit flies, each having a unique set of mutations, now exist in the world. However, only about 20% are in active use; the rest represent completed research or are available for future studies. Geneticists don't like the cost and time required to maintain these stocks in living cultures by frequent transfer of adults for breeding. They also worry that the frequent transfer can result in genetic drift and mistakes that can lead to stock losses.

For almost 20 years scientists sought unsuccessfully to preserve embryos of live fruit flies by freezing them in liquid nitrogen. Ironically, during that time, cryobiologists succeeded in freezing cow embryos from superior cattle, and the technique has been used to increase the production of high-quality beef. Embryos of mouse stocks at ORNL and at the Jackson Laboratory in Bar Harbor, Maine, are now being frozen using a technique based on the one first demonstrated by Peter Mazur, Stanley Leibo, and David Whittingham in 1972 at ORNL.

Putting fruit flies to sleep in frozen storage has been easy, but making sure they will wake up during thawing has been trickier than catching one between your fingers. However, the problem of preserving them for future use was finally solved in 1992 by Mazur, Kenneth Cole, Jerry Hall, and Paul Schreuders, all of ORNL's Biology Division, and Anthony Mahowald of the University of Chicago. Schreuders is also with the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences. They reported on their success in the December 18, 1992, issue of *Science* magazine.

Incredibly, the frozen fruit fly embryos are among the most complex organisms preserved by cryobiologists. These embryos each contain 50,000 cells, whereas the mouse embryos are generally frozen at the 8-cell stage.

To preserve living cells, little or no ice can be allowed to form in each cell and a special chemical must be added to each cell to protect it from freezing damage. Thus, cells must be permeable, like a window screen, so that water can be forced out by dehydration and the cryoprotectant can be forced in. In conventional freezing used successfully with mammalian embryos, water is withdrawn by osmosis from cells and it freezes outside them.

The problem with *Drosophila* is that it is impermeable to both water and the cryoprotectant. So the first task of the cryobiologists was to make fruit fly cells permeable by dissolving the waxes on the embryo membranes. The Oak Ridge group solved this problem by treating the embryos with precisely controlled amounts of a gasoline-like alkane and an alcohol.

Then Mazur and his associates discovered that *Drosophila* embryos are so sensitive to cold that those in the early stages died even before ice had formed in the cells. They decided that con-ventional freezing would not work and that ice formation must be prevented.

To achieve this end, they chose the alternative strategy of vitrification—the formation of glassy, or noncrystalline material, rather than ice crystals. Based on an approach reported by Peter Steponkus and colleagues at Cornell University in 1990, vitrification was accomplished by chilling the embryos to –205°C very rapidly (100,000° per minute) to "outrace" the lethal consequences and by using up to 8 times the normal amount of cryoprotectant (ethylene glycol) to dehydrate the cells and vitrify the water. However, Mazur's group found that this strategy worked well only on embryos in a certain developmental stage—those that were frozen 14.5 hours after the eggs were laid. The Oak Ridge group found that 68% of these embryos hatched to larvae and that 40% of the resulting larvae developed into normal adult flies.

The ORNL strategy may be useful for preserving mosquitos, houseflies, and other nonmammalian embryos. Cryopreservation of various lines of mosquitos could make possible identification of the gene that makes some mosquito types susceptible to carrying malaria and of the gene that makes other mosquito lines resistant to it.

According to the *Science* article by Mazur et al., "The optimal developmental stages being frozen are probably the most complex systems that have been cryobiologically preserved. The embryos are highly differentiated into tissues and organs including muscle and nerve, which indicates that differentiated multicellularity is not a barrier to cryopreservation. The findings also represent perhaps the first case in which vitrification procedures are required to obtain survival."—*Carolyn Krause*

Process Destroys Nitrates, Produces Ceramic

One hundred gallons of liquid waste becomes forty-five gallons of nitrate-free ceramic.

Using the same type of reaction that helps burn holes in safes and military tanks, ORNL researchers have developed a simple process to remove nitrate from liquid radioactive waste, greatly reducing the amount of waste that must be stored. Nitrate, a pollutant in streams and rivers, can be toxic to infants if present at high concentrations in drinking water.

The ORNL process turns the nitrate into ammonia gas while co-producing a ceramic waste form. The ammonia is later burned to form harmless nitrogen and water vapor. The liquid-to-solid conversion can be achieved using recycled aluminum from, for example, beverage cans or radioactive aluminum scrap at Department of Energy sites.

At ORNL radioactive wastes containing sodium nitrate are stored in large tanks. These wastes are the result of large-scale use of nitric acid for chemical processing, especially of nuclear fuel in reprocessing experiments. Some of this nitrate from 50,000-gallon tanks in Melton Valley on the Oak Ridge Reservation is immobilized in cement-based grout. A much larger volume of such waste exists at DOE's Savannah River Site in South Carolina.

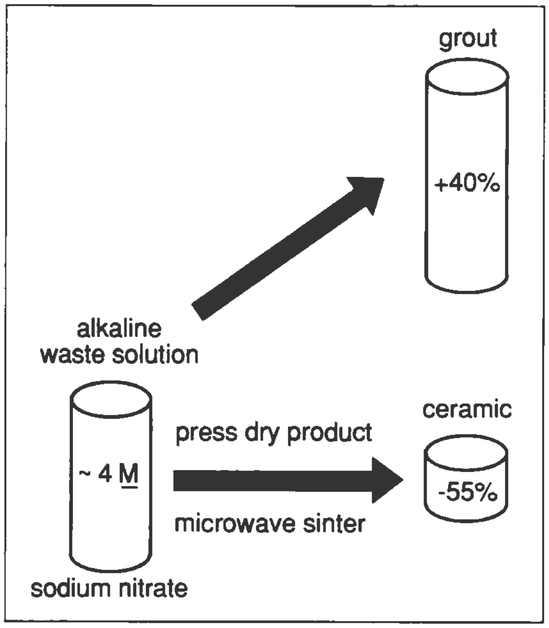
Because nitrate, which is highly mobile in the environment, can cause suffocation by reducing the amount of oxygen carried by red blood cells, the Environmental Protection Agency permits only 44 parts per million of nitrate in drinking water. Thus, DOE sites have been immobilizing radioactive waste liquids containing nitrate in cement-based grout, increasing the amount of waste in the form of grout that must be stored by 40 to 50%. The ORNL process can reduce the original volume of waste by 55%, with good prospects for a 75% volume reduction soon.

"By immobilizing 100 gallons of nitrate-bearing liquid waste, the volume of waste to be stored as grout can increase to 150 gallons," says developer Al Mattus of the Chemical Technology Division. "If we are given 100 gallons of liquid waste to process using the new method, we end up having to store only 45 gallons of nitrate-free ceramic to meet environmental regulations."

Al Mattus shows a ceramic waste form produced by his process of removing nitrate from radioactive waste liquid (such as that contained in the vial he is holding).

In the new process, aluminum powder is mixed with sodium nitrate ($NaNO_3$) in an alkaline solution. By feeding the powder into a chemical reactor at a specific rate and constant low temperature (50°C), Mattus can achieve a reaction between the metal and the oxide of nitrogen (nitrate) that is similar to the reaction exploited by safecrackers. "When powdered aluminum is mixed with a metal oxide and ignited," Mattus says, "the result is a release of stored energy as electrons, with a rapid release of heat as the oxide becomes molten metal." A safecracker would use this reaction along with an explosive.

The products of the reaction in the ORNL process are ammonia gas (NH_3) and aluminum oxide, or alumina (Al_2O_3). This solid material, also known as gibbsite, is mixed with silica to



Grouting increases the original volume of liquid nitrate-containing radioactive waste by 40% in this case, whereas the new ORNL process for removing nitrate from the waste by producing a ceramic reduces the waste volume by 55%.

form a ceramic. The alumina settles out in the chemical reactor, and the ammonia is released and later burned to form harmless nitrogen and water vapor.

Mattus notes that this reaction is the opposite of the process used by aluminum companies to convert alumina from bauxite ore to aluminum. "We use the metal to release the energy put into it electrolytically and form alumina again," he says.

Mattus says that the process will be demonstrated in a pilot plant being built at ORNL (Building 2528). DOE has expressed interest in using the ORNL process to address the massive nitrate problems of Hanford Engineering Development Laboratory and other DOE sites.

A patent on the process has been filed. Martin Marietta Energy Systems, Inc., is seeking to license the technology for commercial use, and several companies have expressed interest in further developing and marketing the process.
—Carolyn Krause

ORNL System Will Save NASA Time and Money

ORNL is developing a system to automatically monitor and verify the status of electronic components in systems used for U.S. space launches. The development is expected to help the National Aeronautics and Space Administration (NASA) reduce its costs and number of launch delays.

Once perfected and deployed, this Intelligent Configuration Identification System (ICIS) will eliminate the need for costly and time-consuming physical inspections of the thousands of sensors on the space vehicle and on the launch pad and the miles of cables running from the sensors to the launch control complex, often called the firing room. The result should be reduced turnaround time between launches and fewer delayed or aborted launches.

This capability would decrease the time needed for repairs between launches.

"The amount of time spent tracking down broken wires in cables or mismated cable connectors is amazing," says project engineer Mike Hileman. "A system like ICIS could save a lot of time and money." The ICIS project, sponsored by NASA, is being carried out by engineers in ORNL's Instrumentation and Controls (I&C) Division.

ICIS was originally conceived as the solution to problems the Laboratory had with several large data acquisition and control systems. "It can be a nightmare trying to determine which of thousands of sensors are tied to which channels of the data acquisition and control system," says Hileman. "We had a real need for something that could automatically determine the configuration of a system."

NASA had the same problem. Ground support personnel were spending many hours verifying the cabling and configuration of their systems. The space agency contacted ORNL after the I&C Division received an IR•100 award in 1987 for work on configuration and control systems. In 1989, DOE and NASA entered into an agreement to develop the technology for NASA's new National Launch System (NLS).

ICIS will eliminate the need for costly and time-consuming physical inspections of the thousands of sensors on the space vehicle and on the launch pad.

Allen Blalock examines an operator's display for the NASA-sponsored Intelligent Configuration Identification System. *Photo by Bill Norris*

In July 1990, I&C engineers put the system through an initial proof-of-concept demonstration for NASA at the Kennedy Space Center at Cape Canaveral, Florida, based on the architecture used for the ground support equipment for space shuttle launches. In January 1992, Allen Blalock, Mike Hileman, and Jim McEvers demonstrated the system again at the Johnson Space Center in Houston, Texas.

ICIS is being developed in support of the next generation of space exploration vehicles as part of NLS. ICIS technology could also be used for military applications, including damage assessment and monitoring the health of ship or vehicle systems; for communications and power systems; or for any large instrumentation and control network that is frequently reconfigured. ICIS can determine the configuration of a system, check for open or short circuits, and keep track of information such as component serial numbers and calibration dates.

NLS will be made up of miles of cables and wires and thousands of sensors and actuators that monitor and mechanically control a system's components. Though not fundamentally different in kind from the current launch system, the NLS will be much more complex. In addition to the manned space program, many more unmanned missions are planned. Faster turnaround times between launches will be essential. The size and complexity of the system will make necessary an automated, real-time quality assurance and monitoring system.

Traditionally, monitoring and control of systems have relied on manual wiring checks. These checks are slow, and they cannot verify that wiring is correct, determine the order of components in a system, or provide information about cables and intermediate termination points in the system. ICIS was developed to remedy these shortcomings.

ICIS requires only three types of components: sensor identification modules at each end point of the system, cable or junction box identification modules at each connection point, and a master module tied to a personal computer. The system uses these modules to poll and monitor the entire electronic network by exchanging signals with individual subassemblies to verify their locations and conditions. "This polling can be done without interfering with the data acquisition system itself," Hileman notes. The procedure also provides information about the integrity of the signal lines; for example, it can locate any short or open circuits.

"For instance," says Jim McEvers, I&C's instrument-development group leader, "ICIS transmits a signal to a sensor, asking, 'Are you out there, and if so, where and who are you?' The sensor then responds with the requested information." Currently, to obtain this type of information, someone must physically verify the location and status of the component in question. "And that is painstaking and costly work," McEvers says.

In the next phase of ICIS development, ORNL I&C engineers plan to reduce the size of the hardware so that the sensor identification and integrator modules fit inside and become integral parts of the cables they will monitor. Also planned are the addition of the capability to identify every cable conductor in a signal path, programmability of identification modules by technicians in the field, development of a programmer's station, and the ability to customize reports and graphic displays for various applications. Ultimately, ICIS technology will be transferred to private industrial firms.

ICIS has applications in all phases of space exploration. It can be useful in pre-launch quality assurance and post-launch assessment. "Even though launch engineers try to protect the hardware, cables may still be damaged in a launch," Hileman says. "After a launch, ICIS could identify which cables need to be replaced. This capability would decrease the time needed for repairs between launches."

ICIS will provide real-time fault detection and monitoring of the space vehicle's power, communication, and data systems. It may also be used on the proposed space station to experiment with different system configurations and for verification of the integrity of the station after a system failure.—*Marilyn Morgan*

Trees' Responses to Rising CO_2 Levels

Trees do not necessarily grow bigger and faster in an atmosphere enriched in carbon dioxide (CO_2), according to a study by Rich Norby, Stan Wullschleger, Carla Gunderson, Gerry O'Neill, and others in ORNL's Environmental Sciences Division. The researchers concluded that at least one tree species may be responding to elevated CO_2 concentrations by growing additional fine roots rather than leaves that take up carbon.

The ORNL scientists are studying the effects of increased atmospheric CO_2 concentrations on photosynthesis and leaf respiration in forest tree species, as well as other responses that may determine how trees in natural forests will grow in the future. Their work is described in detail in an article in the May 28, 1992, issue of *Nature*.

Photosynthesis is the tree's use of energy from sunlight to convert atmospheric CO_2 into carbohydrates. In a reverse reaction process, leaf respiration is the release of CO_2 from tree leaves back to the atmosphere as carbohydrates are broken down for use as fuel by the tree. The two processes together determine the tree's net carbon uptake and potential for subsequent growth.

The yellow poplar trees may be using carbon to grow additional fine roots instead of leaves.

The concentration of CO_2 in the atmosphere is increasing, largely because of the combustion of fossil fuels for energy and the deforestation of the earth, especially the cutting and burning of tropical forests. Many scientists expect increased levels of atmospheric CO_2 to trap more heat near the earth's surface rather than allow it to radiate into space, resulting in a rise in the average surface temperature of the earth, commonly known as the greenhouse effect.

To accurately predict the amount of global warming, scientists must be able to project the atmospheric level of CO_2 at a given time. For these models, they must have information about the uptake, storage, and release of CO_2 by plants.

In the past, most studies have focused on the uptake side of the equation—photosynthesis. Those studies that dealt with leaf respiration have used crop plants such as rice or alfalfa. However, as Wullschleger points out, "You can't use rice as a model for something as complex as a forest ecosystem."

"The trouble is that trees are a whole lot harder to deal with," Norby observes. "Three years is the longest any of these forest trees have been exposed to elevated CO_2, so our results on carbon uptake and release are really very important. We don't know if we can extrapolate the results of

A tree may be most susceptible to the effects of UV-B radiation during its reproductive cycle—that is, when it is producing pollen.

Rich Norby measures the growth of a yellow poplar tree to assess the effects of increased concentrations of atmospheric carbon dioxide on forests.

agricultural studies to forests. Our objective is to provide the right kind of input for such models."

Net carbon uptake by trees is important not only for slowing the increase in atmospheric CO_2 but also for making plant growth possible. "The balance between carbon gained through photosynthesis and carbon lost through leaf respiration is the difference between whether plants grow or not," says Wullschleger. The increased plant growth seen under high concentrations of CO_2 was once thought to be primarily the result of increased photosynthesis. Now it is known that decreased leaf respiration also plays a role, and the ORNL study is the first to document it in forest species.

One surprising finding of the study is that, although the yellow poplars (*Liriodendron tulipifera* L.) used in the experiment did respond predictably over three years to increased CO_2 in the atmosphere by increasing photosynthesis and decreasing leaf respiration, the trees showed no significant increase in carbon storage or total biomass. The reasons for this are not yet fully known, but Norby suspects that the yellow poplar trees may be making adjustments in how they use the carbon, such as growing additional fine roots instead of leaves. These changes may make the tree better suited to the new environment, but at the expense of short-term increases in growth. However, the white oak (*Quercus alba* L.) trees in the same study were significantly larger when grown in high CO_2.

The experiment began in May 1989 on yellow poplar and white oak seedlings, common tree species in the deciduous forests of eastern North America. Yellow poplars and white oaks are important in these ecosystems because of their abundance in the temperate forests of this region. The two species have different nutrient requirements and growth habits, making them good candidates for the study.

Six open-top chambers were constructed, each 3 meters in diameter and 2.4 meters in height (later increased to 3.6 meters in height for the third growing season). Ten dormant seedlings of each species were planted in the ground in each chamber. Later, the saplings were thinned to five of each species. During the growing seasons, April to November, the plants were exposed continuously to regulated levels of CO_2 enrichment. The yellow poplar saplings were harvested in August 1991, and the white oak saplings were harvested late in 1992.

The atmosphere in each of the chambers was carefully controlled. Three levels of enrichment were chosen: ambient, ambient plus 150 parts per million (ppm) CO_2, and ambient plus 300 ppm CO_2. Trees planted today may one day be exposed to these CO_2 concentrations, which are considered likely to occur within the next 100 years.

Several factors differentiate this experiment from previous ones. The trees were planted directly in the ground, not in pots, so the roots do not become pot-bound, and the uptake of minerals from the soil is not restricted. Second, they are not artificially irrigated or fertilized. Third, the CO_2 is provided 24 hours a day during the growing season. This approach makes the experimental conditions as similar as possible to those for trees growing in the wild in a CO_2-rich atmosphere. The ORNL researchers found that the short-term responses to CO_2 enrichment were indeed sustained over several years under realistic field conditions.

Predicting forest ecosystem responses to an atmosphere whose composition is changing will be more difficult than previously assumed. Some research indicates that forests have the potential to take up and store more CO_2 as its concentration in the atmosphere rises, but for accurate modeling of the greenhouse effect and the forests of the future, more long-term studies such as the ORNL experiments will be needed.—*Marilyn Morgan*

Gerald Tuskan uses a bright-field stereo dissection microscope linked to a video screen to examine pollen germination. DNA is visible as dark patches at the ends of the pollen tubes.—*Photo by Tom Cerniglio*

Rising UV Radiation Damages Forest Tree Pollen

The depletion of the earth's protective ozone layer has consequences that range far beyond sunburned beachcombers. As the ozone layer thins, more ultraviolet radiation from the sun penetrates to the earth's surface. This ultraviolet light, which can cause skin cancer and cataracts in unprotected humans, can also be damaging to trees.

To help determine the nature of this damage, geneticist Gerald A. Tuskan, physiologist Tim J. Tschaplinski, and ecophysiologist Nelson T. Edwards, all of ORNL's Environmental Sciences Division, are studying the effects of ultraviolet B (UV-B) radiation on the pollen of various forest tree species. Pollen, the mass of male microspores, is essential to reproduction and the development of seeds.

Biologically active UV-B radiation, whose wavelengths range between 280 and 320 nanometers, is projected to increase by 2% for every 1% decrease in stratospheric ozone that results from reactions with chloro-fluorocarbon (CFC) molecules generated by human activities.

UV-B interacts with the leaves of some plants, decreasing photosynthesis or increasing respiration. Photosynthesis is the process of using energy from light to convert carbon dioxide to carbohydrates, and respiration is the uptake of

The insect-pollinated species, yellow poplar, was more sensitive to UV-B radiation than were the wind-pollinated species.

ORNL researchers are employing computer modeling to design a space propulsion system that may one day be used on missions to Mars.

oxygen and the release of carbon dioxide by leaves as carbohydrates are converted into energy for the plant. Both processes are important to the energy metabolism of the tree.

As a result of the interference of UV-B radiation with these processes, the tree's ability to capture and use the energy of sunlight may be reduced, leading to greater susceptibility to pest damage or other environmental stress. However, a tree may be most susceptible to the effects of UV-B radiation during its reproductive cycle—that is, when it is producing pollen.

"Pollen is the vehicle that ultimately allows all plants to reproduce, adapt to stress, and survive," Tuskan notes. "Unlike leaves, pollen does not have the physiological machinery to adjust to elevated UV-B radiation."

When reproduction is inhibited, the trees' ability to adapt to changing conditions is decreased. Furthermore, global warming may change climate zones, encouraging many tree species to migrate. Without seeds, this migration cannot occur.

Over time, different tree species have adopted different pollination strategies. Loblolly pine and red spruce trees are wind pollinated, and yellow poplar is insect pollinated. Tuskan hypothesized that wind-pollinated species would tolerate UV-B radiation the best, perhaps because this pollination strategy naturally requires pollen to be exposed to the presence of UV-B light. The pollen of insect-pollinated trees, however, may lack this protection.

In Tuskan's experiment, pollen was collected from loblolly pine, red spruce, and yellow poplar and tested for sensitivity to elevated UV-B levels. UV-B radiation was chosen for the study because it is known to cause genetic mutations and because the thinning ozone layer permits proportionately more UV-B to penetrate to the earth's surface than other types of UV radiation.

For the experiment, various samples of tree pollen were exposed to UV-B radiation either at a simulated ambient level or at 30% or 100% above this level for either 4 or 8 hours. These radiation levels correspond to current conditions, a 15% depletion of the ozone layer, and a 50% depletion of the ozone layer, respectively. A 15% depletion is the level projected as a result of current CFC levels in the atmosphere. The ultraviolet light was provided by UV-B-313 fluorescent lights, and the desired levels were obtained using mylar filters.

After the pollen was exposed to UV-B radiation, the ORNL researchers determined the percent germination of the pollen, pollen tube length, percent abnormal pollen tube formation, and the identities and concentrations of secondary plant metabolites that reduce the effect of UV-B radiation on the plant. Pollen germination involves the formation and elongation of the pollen tube through which the pollen nuclei migrate to the receptive egg, resulting in fertilization. UV-B–attenuating secondary plant metabolites are compounds formed in a plant that absorb ultraviolet radiation. These compounds may not be needed for plant growth and function, but they are thought to protect the plant from the damaging effects of ultraviolet radiation.

Under the 8-hour exposures, pollen germination was at or near 0% in all tested species. Under the 4-hour exposures, the insect-pollinated species, yellow poplar, was more sensitive to UV-B radiation than were the wind-pollinated species, as Tuskan hypothesized. Evidence of this sensitivity included decreased germination rates and reduced pollen tube lengths.

In all species, however, the researchers found significant increases in the frequency of abnormal pollen tube formation in pollen exposed to any level of elevated UV-B radiation. For example, a species that normally produces single pollen-tubes produced multiple or branched tubes after UV-B exposure. If the defect prevents the male nuclei of the pollen from reaching the female nuclei (eggs), reproduction will not occur.

By using reversed-phase, high-pressure liquid chromatography, the ORNL researchers found large differences among the species in the types and concentrations of UV-B–absorbing compounds. They are currently attempting to identify the specific UV-B–absorbing compounds and relate these differences among species to their various abilities to tolerate elevated UV-B radiation.

The exact mechanism by which UV-B radiation damages pollen is still undetermined. Damage may be physiological or genetic, or it may result from disruption of the structure of the pollen membrane.

Forests are made up of many species. Some may be susceptible to rising levels of UV-B, and others may not. Tuskan hopes the ORNL work will enable scientists to accurately model the forests of the next century. "This knowledge," he says, "could help policymakers decide how best to protect the stratospheric ozone layer and maintain biological diversity."—*Marilyn Morgan*

Computer Models for Spaceship Design

ORNL researchers are employing computer modeling to design an ion thruster, a space propulsion system that may one day be used on missions to Mars and the other planets. "The fundamental attraction of an ion thruster," explains John Whealton of ORNL's Fusion Energy Division, "is that accelerated ions are a more efficient fuel than chemical propellants. The farther away your destination is, the more important is fuel efficiency."

The ion engine is a type of electric propulsion system based on a concept two decades old. Approximately 30 electric thrusters of other types have actually flown in space. The National Aeronautics and Space Administration (NASA) is looking at ion engines for cargo missions to Mars and beyond. These systems would be advantageous for interplanetary missions because their low propellant requirements make them less massive than their chemical rocket counterparts.

Ion engines use noble gases such as xenon or argon as propellants. Electrons from 10-V filaments strip electrons from the gas molecules, forming positively charged ions. The resulting mixture of ions and electrons forms a plasma. The plasma is kept in a chamber lined with cusp field magnets to keep the charged particles from migrating to the chamber walls. At one end of the plasma chamber is a series of two plates with holes in them.

After the ions leave the chamber through the first plate, they are directed toward the second plate by an accelerator powered by a 1000-V power supply. The ions then escape into space as exhaust plasma, driving the spacecraft in the opposite direction based on Isaac Newton's First Law of Motion: "For every action, there is an equal and opposite reaction."

Electric power for the filaments and power supply could come from either a nuclear reactor or solar cells. Of course, the weight of the power supply could reduce the weight savings from the fuel.

NASA is interested in designing very reliable ion thrusters that will operate for a year or more. The ORNL research, which is sponsored by the space agency, is aimed at working out the fine details of the design, especially those related to plasma edge effects.

At the walls of the plasma containment vessel, an abrupt change in electrical potential occurs. Because this change in potential results in a strong electric field, ions in the plasma accelerate toward the walls at high speed. A hole in the vessel allows ions to be extracted and accelerated to high speed. The paths of the ions, which can be complex, are determined by the shape of the plasma boundaries. If not controlled, the swiftly moving ions can damage the accelerator itself.

"From our fusion research we're uniquely expert at solving plasma edge problems in two and three dimensions," says Whealton. "Our computer software, developed over the past 15 years, is unique in that respect."

Along with Whealton, Richard J. Raridon of the Computing and Telecommunications Division; David A. Kirkman, an undergraduate student at the University of California-Irvine; and Russell Campbell, a physics teacher at Rockville Public High School, are studying the characteristics of ion thruster plasmas in both two and three dimensions. The researchers are attempting to determine the optimum configuration and operating conditions for an engine of this type. Of particular concern are the perveance (the density of the plasma), the geometry of the accelerator, the thickness of the accelerator electrodes, and the density and shape of the exhaust plasma. Working with the ORNL researchers are several high school teachers from the Teachers Research Associates Program and a student from the Science and Engineering Research Semester education program, both funded by DOE at ORNL.

Ion beams can also be used to etch circuits into computer chips and to heat and help confine plasma for fusion energy research.

KATIE helps employees identify problems and understand how to perform the steps needed to correct them.

Interplanetary travel is not the only potential application of the ORNL research. Ion sheath dynamics have uses unrelated to space. "The ability to control the shape and brightness of an ion beam has a lot of applications," says Whealton. "The configuration of an ion source and plasma is relevant to semiconductor manufacturing, where ion beams can be used to etch circuits into chips, and to fusion energy experiments in which ion and neutral beams can heat and help confine the plasma. Also, devices like the proposed Superconducting Super Collider and accelerators for high-energy physics, in which beams of ions must be tightly controlled and directed, could make use of this technology."—*Marilyn Morgan*

Computerized Training for Industry

Today's automated manufacturing plants bear little resemblance to plants of 10 or 20 years ago. The rapid technological advances that have taken place in process control systems during the last decade have resulted in highly sophisticated manufacturing equipment—equipment that challenges operators, supervisors, and maintenance personnel when something goes wrong or needs repairs.

However, a recent development by a team of researchers in ORNL's Instrumentation and Controls Division is helping to solve maintenance and repair problems. Called the Knowledge-Based Assistant for Troubleshooting Industrial Equipment (KATIE), this new computerized system helps employees identify problems and understand how to perform the steps needed to correct them.

"The majority of today's manufacturing systems demand an overwhelming amount of information and expertise by maintenance personnel," said Abigail G. Roberts, a development engineer in ORNL's Instrumentation and Controls Division. To perform maintenance and repair tasks, she said, employees usually need more than written instructions in maintenance manuals.

"KATIE provides more—thorough step-by-step instructions at different levels of expertise and easy access to on-line maintenance manuals," Roberts said. "But KATIE's video images and audio instructions for each step in the process and the 'why' feature are what provide users with a more complete understanding of complex systems and the steps needed to maintain or repair them."

Roberts explained that effective troubleshooting requires a thorough knowledge of the system being repaired. But, because design engineers are usually the only ones with such complete knowledge, the people who actually maintain the system are usually unable to determine all possible causes of a particular problem.

Because it is believed that almost anyone can identify symptoms, she and other team members developed a Symptom Selector feature for KATIE. Roberts said the Symptom Selector contains several full-screen videos, which together show the whole system. She said the computer operator can then select subsystems that are not functioning.

"We developed the shell, and systems experts assisted us in determining particulars about each system, such as the components that should be selectable with the mouse," she said. A mouse is a hand-controlled device that allows a computer user to easily select and manipulate graphics or text shown on a computer's monitor screen.

Roberts believes video images are KATIE's most impressive aspect. "We decided to use still-frame video images over computer-generated graphics because they cost less and give a clearer image. And because each instruction step contains a picture, fewer words are needed," Roberts said.

She explained that KATIE's "authoring" system, a feature that allows personnel familiar with the complex equipment to add information to the knowledge base, is essential to the system's video capabilities. Roberts said that videos are taken of the equipment and of steps being performed, such as screws actually being removed. Then, by selecting video-control symbols on the computer screen with a mouse, the video images are captured, copied, and saved. Clicking on the "capture" symbol results in a full-screen image on the monitor, while a second click captures, compresses, and scales the current image into the computer's video window. Finally, when the desired image is captured, clicking on "save" actually stores the image in a computer file.

John P. Jones and Abigail Roberts go through maintenance procedures for a flow-calibration facility. As the sequence is filmed through the video camera, the procedures, or knowledge, are captured in the Knowledge-Based Assistant for Troubleshooting Industrial Equipment (KATIE), a computer-based maintenance aid for training technicians and helping them diagnose and repair complex equipment. *—Photo by Bill Norris*

KATIE could be customized to fit almost any system and respond to almost any need.

At the bottom of each picture are written instructions for each particular step. However, Roberts said the team that designed KATIE realized some personnel may need more instructions than others. "That's why we decided to include a 'detail' feature, which displays more in-depth information and instruction," she said. "Also, because users are more likely to follow an instruction if they understand the reason for it, a 'why' symbol is available that explains why the step is necessary," she said. "It also helps to further educate the user."

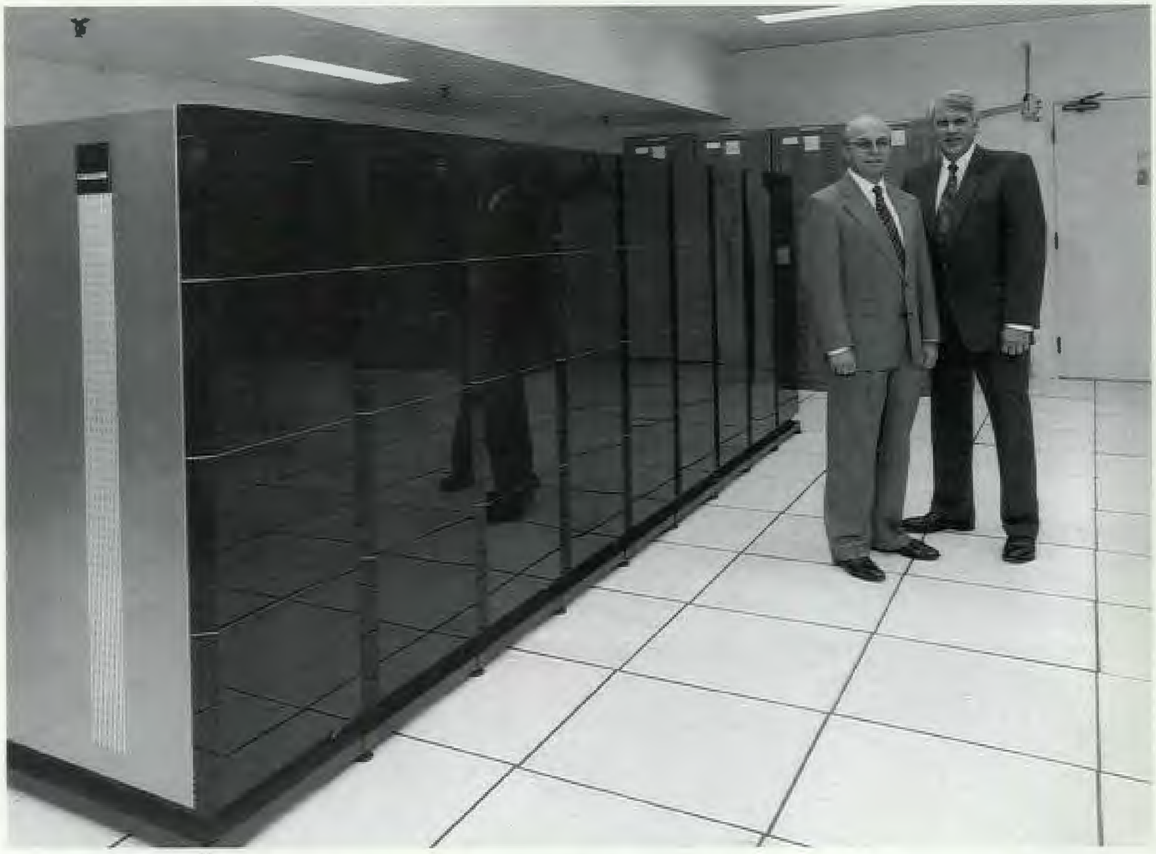
Roberts went on to explain how KATIE handles new components or updated operating procedures. "Each part of KATIE's knowledge base is distinct—the instructions, the video images, everything." Because of this modular design, she said additional capabilities can be independently added to each area through KATIE's authoring system.

Because KATIE is "really just a shell," Roberts said it could be customized to fit almost any system and respond to almost any need—maintenance, troubleshooting, training.

"If the information you need can be expressed in a procedure format, and if those procedures can be made easier by pictures and sound, then KATIE is a good choice."—*Karen Bowdle*

Supercomputing Center Dedicated As Part of CRADA with Intel

The analytical power supplied by this computational juggernaut is equal to that of 15,000 typical desktop workstations.



ORNL recently acquired this Paragon XP/S supercomputer from the Intel Corporation for use in addressing scientific "grand challenges," such as the modeling of fundamental properties of materials and the movement of hazardous waste in groundwater. Admiring it are Ed Oliver (left), director of ORNL's Office of Laboratory Computing, and Bob Ward, director of ORNL's Engineering Physics and Mathematics Division.

"In the political community and now in the academic community, there can be no doubt that Tennessee has a seat at the table among the leaders of the world." That's how Billy Stair, senior policy advisor to Tennessee Governor Ned McWherter, characterized the importance of ORNL's Center for Computational Sciences (CCS) at its November 10, 1992, dedication ceremony.

Ed Masi, president of Intel Corporation, echoed Stair's optimism, declaring "While supercomputing is advancing in cycles of two to two-and-a-half years, there is a chance to dazzle the world and to provide Tennessee with a unique opportunity to become a global player in supercomputer technology."

The CCS is one of only two Department of Energy high-performance computing research centers dedicated to exploring applications of state-of-the-art computer systems to areas of scientific, economic, and environmental importance. The other center is at Los Alamos National Laboratory. DOE's latest efforts in supercomputing come in response to the presidential initiative on high-performance computing, which is the result of the High-Performance Computing Act of 1991, cosponsored by Albert Gore, former Tennessee senator and now vice president of the United States.

The dedication of the CCS was accompanied by the long-awaited startup of the Paragon XP/S supercomputer, custom-designed for ORNL by the Intel Corporation of Beaverton, Oregon. Installation of the Paragon is the latest phase of a three-year cooperative research and development agreement (CRADA) between ORNL and Intel in support of the CCS.

Researchers will use the Paragon to build detailed models of the world's climate, predict movement of hazardous waste in groundwater, and design state-of-the-art metals and ceramics on the molecular level. Later, ORNL scientists will collaborate with university researchers to investigate other complex scientific problems called "grand challenges," such as mapping the human genome and superconductor modeling.

Many of these problems require manipulating huge amounts of data—so many data, in fact, that they simply couldn't be addressed in sufficient detail with less powerful computers.

The Paragon meets this avalanche of data head-on with a concept called "massively parallel processing." In other words, instead of routing all of the data through a single processor, the Paragon divides its work among 2048 smaller processors. The analytical power supplied by this computational juggernaut is equal to that of 15,000 typical desktop workstations, enabling the Paragon to add, subtract, multiply, or divide 150 billion times every second, making it one of the fastest computers in the world.

The center will be the intellectual home for a collaborative effort among three DOE facilities—ORNL, Ames Laboratory, and Brookhaven National Laboratory—and seven major universities, including UT, Vanderbilt University, Rice University, State University of New York at Stony Brook, Texas A&M University, and the University of South Carolina. ORNL researchers will also work with Sandia National Laboratories on supercomputer-based mathematics and science education programs.

To ensure that collaborators across the country have access to the Paragon, it will also be connected to the proposed National Research and Education Network, a federal computer network linking high-performance computing resources nationwide.—*Jim Pearce*

The Paragon provides Tennessee with a unique opportunity to become a global player in super-computer technology.

New Oak Ridge CRADAs for SDI Optical Systems

The high-tech weaponry of the nation's Strategic Defense Initiative Organization (SDIO) owes much of its accuracy to optical systems that use light to locate, track, and intercept targets. In 1988, the SDIO asked ORNL to help private industry find the best ways to manufacture high-precision optical components. The result was the Optics Manufacturing Operations Development and Integration Laboratory (MODIL), an interdisciplinary project involving ORNL, the Oak Ridge Y-12 Plant, and the Oak Ridge K-25 Site. It enables private companies to keep up with the latest in manufacturing techniques to meet stringent SDIO requirements and deadlines for delivering components. Because of its mission to work with industry, the Optics MODIL (through Martin Marietta Energy Systems, Inc.) has entered into several CRADAs with industrial partners.

In space-bound surveillance systems, high-precision mirrors track enemy missiles and reflect the image to detectors. The detectors, in turn, signal interceptor systems to fire an optically guided missile to destroy the target missile. Baffles within the optical systems act as light traps, absorbing stray light so that false readings are minimized; the detector "sees" only the light coming from its target.

Scientists and technicians at the Optics MODIL are now working with Martin Marietta Missile Systems, based in Orlando, Florida, through a CRADA to develop quicker, more efficient, and less costly methods to make better baffles and mirrors from beryllium, a commercially available metal.

Optical baffles must be lightweight to help minimize launch costs, sturdy enough to endure the stress of lift-off, and resistant to flaking when handled to maintain their surface texture.

We are trying to eliminate the need for the mirror-polishing phase for optical systems required by SDIO systems.

Curt Maxey operates a scanning Hartman device that uses laser light to confirm the shape of diamond-turned optical components to better than one-eighth wavelength. This is one of several advanced devices installed in the Optics MODIL established at ORNL to help the U.S. optics industry.

Improving the processes for manufacturing beryllium mirrors is another goal of the Optics MODIL group. The scientists hope to eliminate some time-consuming steps while increasing quality.

To make the mirrors, technicians first machine the unit to a precise shape having the exact amount of curvature needed to properly reflect and guide light through the optical system to detectors. After machining, a reflective coating is applied in a vacuum chamber through a process called sputtering. An ion beam bombards a piece of beryllium, called a target, knocking off the outer layer of atoms. These atoms are deposited onto the body of the mirror. Diamond-tipped tools are then used to machine the finish to a precise smoothness.

"We are trying to eliminate the need for the mirror-polishing phase for optical systems required by SDIO systems," Seals said. "The SDIO program has strict deadlines, and the polishing process is time consuming and very difficult to predict. The sputtering and machining processes we are working on will help private contractors meet those deadlines."

The precise methods developed and tested at the Optics MODIL will also increase manufacturers' ability to repeat the processes the same way every time. According to Seals, this repeatability, which has proved to be nearly impossible for private manufacturers, is crucial to the SDIO program because thousands of optical components are used.—*Wayne Scarbrough*

"Surface features, one of the most important aspects of baffles, influence optical performance and fragility," says Roland Seals, a project manager at the Optics MODIL. Baffles, with their porous surface texture, keep unwanted light from bouncing or scattering onto the mirror and into the detector of the optical system. The scattered light should be evenly dispersed, with low but equal amounts of energy in all directions.

"Surface texture of baffle components influences the amount and distribution of light scatter within the optical system," Seals said. "We are optimizing the coating and texturing process to get a sturdy material that still has excellent optical characteristics."

Second Optics MODIL CRADA with UTOS

Keith Kahl examines an Optics MODIL lathe used to machine ceramic parts faster and more accurately.

Energy Systems has also signed a CRADA with United Technologies Optical Systems (UTOS) to determine the best procedures for making high-precision mirrors from silicon carbide, a widely used industrial ceramic compound. The mirrors will be prototypes of those to be tested for use on the high-tech weaponry of SDI.

SDI tracking and surveillance systems use light to detect enemy launch sites on the earth and to focus on warheads as they arc through space. Meticulously machined mirrors, formed to have an exact curvature, are situated within the SDI optical systems to guide the light to detectors that signal interceptor systems to destroy enemy targets.

The joint work on the new mirrors is being performed by the Optics MODIL. This is the second CRADA that Energy Systems has signed with UTOS involving the Optics MODIL.

Keith Kahl, an ORNL researcher and a project manager at the Optics MODIL, said that until now, silicon carbide has been an underutilized material for making optical surfaces, such as high-precision mirrors, because of its brittle nature. "Optical surfaces need to be as smooth as possible," he said. "Brittle materials often leave cracked or pitted surfaces and subsurface damage after being machined."

To machine the material to a desired shape, it is placed on a lathe and then ground using a wheel that is surfaced with very fine, almost dustlike, diamond grit. The grinding wheel is positioned at an angle against the material's surface so that a very thin layer is peeled away as the lathe turns.

Silicon carbide has specific properties that make it attractive as a mirror-producing material. Because it is very strong, certain grades of the compound can be used to manufacture stiff, lightweight structures.

The UTOS-made silicon-carbide material that Kahl and his colleagues are using at the Optics MODIL poses an additional challenge in that it is actually a two-phase material.

It has a structure that in some ways resembles a microscopic filter of silicon carbide whose spaces are filled with a softer silicon. "The cutting depth must be kept very shallow so that this brittle, two-phase material can essentially be ground away by the diamond grit without causing any cracking," Kahl said.

The Energy Systems and UTOS researchers also hope to lower costs and reduce production time with their advanced manufacturing methods.

We guarantee the waviness of the tools' edge to within 10 millionths of an inch.

Milling techniques available at the Optics MODIL should enable technicians to more quickly produce a mirror that is very close to a desired figure before final finishing is needed. Current commercial techniques yield first-stage-production mirrors that are within about 3% of their final, desired shape. Optics MODIL techniques are expected to bring that figure down to around 0.1%. This vast improvement may allow technicians and scientists to eliminate the lengthy and expensive polishing phase of mirror production, which will further reduce manufacturing costs and time.
—*Wayne Scarbrough*

Diamond Tools Evaluated for SDIO Mirrors

The high-precision mirrors used on SDIO's tracking and surveillance weaponry must be machined to near perfection in terms of shape and reflective finish. Intercepting high-speed missiles at great distances requires bright, distortion-free images.

To obtain a smooth, uniform surface that is devoid of microscopic flaws, technicians rely on high-accuracy natural diamond tools. Therefore, the quality of a mirror's surface depends on the quality of the tool.

To evaluate new high-accuracy natural diamond tools, Energy Systems has teamed with Contour Fine Tooling, Inc., a private manufacturer of high-quality diamond tools. The work is being performed at the Optics MODIL under a CRADA.

"We are now able to produce tools better than our ability to measure within our facilities," said Allen Lake, a representative of Contour Fine Tooling, Inc. "We guarantee the waviness of the tools' edge to within 10 millionths of an inch. At the Optics MODIL, we have been able to inspect the edge to around 5 millionths of an inch, so we're well within our specifications."

Art Miller, manager of the MODIL's Productivity Validation Test Bed, in which manufacturing equipment and tools are tested using methods unavailable to many private manufacturers, explained that if waves or bumps are present on the edge of the tool, these flaws will be imprinted into the material being machined. "The Optics MODIL," he says, "has the most accurate commercially available diamond-turning machine equipment in this country, and it is being used to evaluate this new diamond tool."

Miller and colleagues at the Optics MODIL will be cutting sample mirrors to demonstrate the accuracy of the tools. "We will evaluate the tool's edge, the produced mirror, and the way the mirror scatters light, which is one indicator of surface quality."

If the new Contour Fine Tooling tools are successful, he added, the reliability of the diamond-turning process and the quality of the resulting mirrors should be economically improved.—*Wayne Scarbrough*

CRADA To Develop Ceramic Machining Techniques

The Oak Ridge Y-12 Plant and ORNL have begun a new collaborative research effort with a Delaware firm to help the company develop new, more efficient means of manufacturing ceramic composites for automotive use. The CRADA is expected to help Lanxide reduce future manufacturing costs.

This collaboration with the Lanxide Corporation of Newark, Delaware, uses the precision machining capability developed at the Y-12 Plant in the manufacture of nuclear weapons components as well as the extensive expertise of ORNL in the development and analysis of advanced materials.

Lanxide makes components from a broad range of proprietary composites of ceramic and metal. These composites are lightweight but very strong materials that have ideal properties for many applications. However, because of their hardness and wear resistance, they can be difficult to machine.

The purpose of the collaborative effort is to develop cost-effective machining techniques for these composites. Work also will be done on establishing process control and material characterization techniques. The high cost of machining is considered to be a principal barrier to the use of ceramic-containing composites in the automotive industry.

Initial work will be conducted at the Y-12 Plant during establishment of the Ceramic Manufacturability Center in the High Temperature Materials Laboratory (HTML). The HTML, which is open to industrial users, houses a unique collection of state-of-the-art equipment for analyzing and studying ceramic materials. The Ceramic Manufacturability Center, which is being established under a cooperative program for Cost-Effective Machining of Ceramic Components, is its most recent addition.

Cooperative research and development projects under CRADAs such as this one with Lanxide and earlier agreements with Coors Ceramics Company and the Detroit Diesel Corporation will help U.S. industry to maintain a position of leadership in the machining of precision components and manfacturing advanced materials. It is expected that additional CRADAs will be forthcoming from other U.S. companies.

Specific objectives of this project include improving the accuracy and consistency of critical workpiece dimensions that are generated by processes such as threading, drilling, grinding, honing, cutting, broaching, turning, and milling. The initial focus of the project will be development of techniques and tooling for the cost-effective machining of metal matrix composite connecting rods and brake calipers and rotors.

The existing Lanxide machining processes will be characterized and test bed activities will be conducted in Oak Ridge to demonstrate the feasibility of applying Y-12 Plant manufacturing technology. Test pieces will be provided by Lanxide for the evaluation and feasibility demonstration. Characterization of machined test pieces will be shared by Lanxide and Oak Ridge.

Lanxide Corporation represents the world's largest development and commercialization effort devoted to ceramic and metallic composites, according to Marc S. Newkirk, president and chief executive officer.

CRADA with GM on Nickel Aluminide Components

ORNL and General Motors (GM) Corporation are working under a CRADA to develop longer-lasting, heat-resistant assemblies for heat-treating furnaces used in producing automotive parts. The collaboration focuses on using nickel aluminide alloys developed at ORNL to manufacture assemblies consisting of trays, support posts, and fixtures. These assemblies will be used to hold automotive components as they are being heat treated in specialized furnaces.

The goals of the CRADA for GM are a more energy-efficient manufacturing process for producing automotive parts, an increase in component throughput, and a reduction in cost stemming from longer tool life. To achieve these goals, the ORNL and GM researchers must develop an improved casting process, characterize and modify the alloy to optimize its manufacturability and performance under typical heat-treating furnace operating conditions, and test and evaluate specimens and prototype parts.

ORNL, B&W Team Up on Fuel Studies

A collaborative study between ORNL and the Babcock and Wilcox, Inc. (B&W), Alliance Research Center in Alliance, Ohio, may help electric utilities increase the efficiency of some power plants while reducing pollution.

Researchers from the two organizations have teamed up to study the combustion of certain coal-derived solid fuels, called chars. They hope to use the results to determine the effectiveness of using chars as fuels in steam-driven power plants.

Char is a residue from the production of coal liquids by mild gasification. The liquids are being investigated for use as supplemental engine fuels. However, after gasification, most of the coal's fuel energy value remains in the char, says Stuart Daw of ORNL's Engineering Technology Division. "We want to find an effective use for the chars," he adds, "so that no waste is produced."

Not all chars are the same, and with different types of char come various burning characteristics. Understanding these differences will aid utility operators in selecting the best type of char for use in steam plants.

"Several different techniques are available for mild gasification of coal," Daw says. "Different types of char are produced depending on which technique and which parent coal is used. We want to see how one char differs from another, particularly in the way they burn," he said. "The longer a char takes to burn in the combustion chamber, the greater chance there is for some of it to escape, which means some of the energy value is lost." Also, he said, a chars that burns uniformly, without hot and cool spots, could result in reduced output of pollutants, such as nitrogen oxides.

The information gathered during these studies will be put into an existing data base for comparing the burning abilities of chars and other solid fuels. "This information," Daw says, "can help us determine if char products can compete with other solid fuels on the market,"

Another goal of the cooperative effort is to identify better ways to produce practical alternative fuels by identifying the mild gasification technique that yields the optimum split of liquid fuel and char.

Additionally, B&W will use the information generated in the studies to determine how char fuels will perform in pressurized fluidized-bed combustors in power plants. Fluidized beds are one type of boiler in steam-producing power plants. Some operate at normal, or ambient, atmospheric pressure, and others are pressurized to about 10 times that amount. Daw said that a good foundation for determining chars' burning characteristics in ambient-atmosphere fluidized beds already exists. B&W will use the new data to extend that foundation to see how chars burn in a pressurized environment. This approach, Daw said, is a notable step in developing more efficient, less polluting boilers.

Pressurized fluidized beds are more efficient than conventional boilers in converting the energy potential of coal into electricity because they produce both steam and pressurized gases to drive several turbines.

Fluidized beds help reduce polluting emissions by treating them at the source. The boilers contain limestone that traps much of the sulfur released when coal or char burns. This method of treatment eliminates the need for flue-gas scrubbers, which are expensive cleaning mechanisms required by conventional boilers.

The studies were funded as part of DOE's fossil energy research and developmment program.—*Wayne Scarbrough*

CRADA on Microbes To Remove Uranium

The technology will use micro-organisms to remove uranium from waste streams.

A technology that uses microorganisms to remove uranium and other toxic heavy metals from waste streams is the goal of a CRADA between Energy Systems and Ogden Environmental and Energy Services Company, Inc., of Fairfax, Virginia, working through its German subsidiary. This is the first international CRADA involving a national laboratory.

The environmental remediation technology will involve use of bioreactor columns containing microorganisms (e.g., bacteria or fungi) selected for their ability to remove uranium, arsenic, and other heavy metals from waste streams. The microorganisms will be immobilized within beads the size of pinheads. The beads will be suspended in the bioreactors through which aqueous wastes containing dissolved metals will be pumped. As a result, the metal contaminants will then be adsorbed onto the microbial biomass.

After the technology is developed at ORNL, Ogden will demonstrate its use in the remediation of contaminated water in flooded uranium mines in eastern Germany. The mines were formerly operated for the East German and Soviet governments by WISMUT (a private corporation that was once part of the government). Ogden's German subsidiary, Ogden Umwelt und Energie, will assist with management of the project.

If successful, the technology may be used for various cleanup projects at DOE sites in the United States, including Oak Ridge. It may also "enhance the competitiveness of the U.S. environmental industry in the international market," says Clyde Frank, deputy assistant secretary for Technology Development for the Department of Energy.

Brendlyn Faison examines gel beads immobilizing bacteria in a bioreactor for removing toxic metals from waste streams.

It has long been known that certain microorganisms adsorb heavy metals, but only recently have researchers considered the possibility of using this capability for waste management and environmental cleanup.

Brendlyn Faison, principal investigator for the CRADA and a researcher in ORNL's Chemical Technology Division, has been successful in identifying organic material that adsorbs strontium and cesium from waste streams. For the CRADA she and fellow division researchers Jeanne Bonner, Gene Bloomingburg, John Norman, Brian Davison, and Mark Reeves along with Howard Adler, former Biology Division director now with Oak Ridge Associated Universities, will try to identify naturally existing microorganisms that can remove heavy metals from metal-contaminated water samples at ORNL that simulate the contents of the German pond. These microorganisms, she said, will not be modified by genetic manipulation.

"Our role at first will be to identify the best medium to accomplish the removal of the heavy metals under the conditions at the German demonstration site," Faison said. "The medium probably will be a patented gel developed by Charles Scott and his colleagues at ORNL. Such gels are made from substances from natural sources such as seaweed."

Up to 37 liters (10 gallons) of beads, held in a column less than a meter in diameter and more than a meter tall, can reduce the metal in 3700 liters (1000 gallons) from an initial concentration of 50 parts per million to no more than 50 parts per billion.

The Cl_2EAN OUT™ process employs a catalyst to convert toxic-hypochlorite to salt and oxygen.

According to Faison, the water leaving the column may not have to be handled as waste. Thus, the residual waste material would be only a fraction of the volume of the original waste stream and could be handled in one of two ways.

By altering their chemical environment, the organisms could be forced to release the metal, which could then be retrieved. Or, the beads could be discarded and replaced with new ones. Because the microorganism and gel material in the beads are mostly water, the discarded material could be dried, reducing the mass by more than 80%, or it could be incinerated, leaving only metal compounds.

Different microorganisms have an affinity for different families of heavy metals. Thus, the gel beads containing bacteria that remove uranium may not be equally effective in removing arsenic. However, by combining microorganisms on gel beads, a bioreactor could be tailored to remove several waste constituents at the same time.

Ogden's program manager for this CRADA is senior vice president Kenneth Darnell. Principal participants on Ogden's team include Luke Williams, the project manager, and Leslie Dole, director of technology in Ogden's office in Oak Ridge and a former ORNL researcher.

The costs of the $2-million, three-year CRADA will be shared by Ogden and DOE's Office of Technology Development.

Technology Transfer Awards for Hypochlorite Removal Process

Four Energy Systems employees have been presented awards for excellence in technology transfer by the Federal Laboratory Consortium (FLC). They were recognized for inventing, developing, licensing, and commercializing a process for removing potentially toxic chlorine from waste streams.

Alicia L. Compere and William L. Griffith, both of ORNL's Chemistry Division, William P. Huxtable of the company's Engineering organization, and John Googin of the Oak Ridge Y-12 Plant Development Division received recognition at the FLC's recent National Technology Transfer Meeting in Indianapolis, Indiana. The FLC consists of representatives from more than 700 research and development laboratories and centers representing 16 government agencies. Consortium participants seek to enhance the transfer of federal technology results to domestic users in industry, state, and local governments.

The recipients were among 38 winners selected by the FLC from among 3500 entries. They were honored for developing a simple, safe method for catalytically dechlorinating wastewater streams. The resulting patented Cl_2EAN OUT™ process under pilot development employs a catalyst to convert toxic hypochlorite (chlorine bleach) to salt and oxygen (see schematic at right).

The inventors of the process also received the International Hall of Fame's Advanced Technology Award.

DOE has exclusively licensed the invention to R&D Solutions, Inc., based in Oak Ridge. The president of this company is Chet Thornton of ORNL's Plant and Equipment Division.

R&D Solutions, Inc., received the Hall of Fame's Environmental Award for its efforts in developing the process.

Cl_2EAN OUT™ is expected to contribute to a safer environment because current studies show that it has the potential to decrease stream concen-trations of chlorine, which can be toxic to aquatic organisms. It also could be used to dechlorinate swimming pools and cooling towers for building air-conditioning units.

Compere, Griffith, and Huxtable developed the hypochlorite degradation process in the early 1980s, assisted by Googin, a senior corporate fellow of Energy Systems. ornl

The Cl_2EAN OUT system employs an ORNL-developed catalyst to rid wastewater streams of toxic hypochlorite (NaOCl), converting it to oxygen (O_2) and salt (NaCl).

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ORNL researchers have developed a device that may help industry reinvent ceramic production.

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