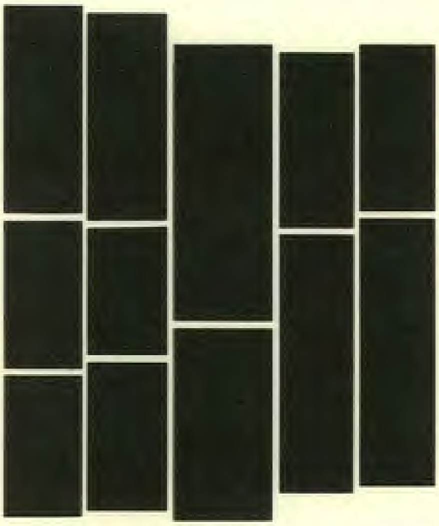
Spring 1981

Oak Ridge National Laboratory review

State of the Laboratory-1980



THE COVER: Productive interaction between government-sponsored research and industrial development has long been a goal of both the public and private sectors. In his State of the Laboratory address early this year, Director Herman Postma cited the instances in which such interaction has been effected over the past year. Moreover, he made the point that each participant instigates action and progress in the other, resulting in what he termed "technology push and market pull," the theme he chose for his talk.

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OAK RIDGE NATIONAL LABORATORY
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State of the Laboratory-1980

Technology Push/Market Pull

By HERMAN POSTMA

This annual summary always gives me a chance to highlight trends and changes in the nature of our work and in the external factors that influence what we do. Coming each year not long after the President's budget message, this talk reminds us that evolution and change, particularly in matters as vital to our national well-being as science and energy, are among the constants with which we live.

The themes of the State-of-the-Laboratory talks in recent years have emphasized a number of important and continuing changes: our work in nontraditional areas, the broadening range of sponsors and collaborators, and our more active role as a consultant to outside organizations and as a manager of R&D in areas where we have particular expertise.

TECHNOLOGY PUSH/ MARKET PULL

Continuing the focus on new missions and areas of interaction, the theme I have chosen is "Technology Push/Market Pull." This is one way to characterize the dynamic relationship between R&D projects at ORNL and the ultimate users of these ideas and innovations. Moreover, it suggests two of the principal types of interactions by which our missions are fulfilled.

By technology push, I mean R&D results or inventions for which there is no predetermined outside interest or application. The development itself, by virtue of the improvement it makes or the potential it creates, is responsible for a "push"—the positive stress on the outside world that causes things to happen. Our technology utiliza-

Ben Benjamin (left) and Bill Rodgers led a research effort that allayed concerns that the process solvent used in pilot-plant tests of a Kerr McGee liquefaction process was reacting chemically with coal-derived materials and thus was lost.

tion/commercialization program may also supply some of this initial impetus. An example of technology push at ORNL is biotechnology, with its potential for contributing in novel ways to energy conservation and production as well as environmental effluent control.

Market pull represents the dynamic opposite. Here, the outside need for a product or process of a clearly defined type prompts the R&D effort. In this case, the Laboratory, as an institution with unique problem-solving capabilities and resources, focuses on items designed or invented specifically to fill a predetermined need or to satisfy a particular customer.

Our work on synfuels, supporting many facets of a major national commitment to reducing U.S. dependence on imported oil, is an example of how ORNL is responding to a strong market pull. Another is technical support for the Nuclear Regulatory Commission.

Clearly, both forces are at work in many projects at ORNL— as when the initial push resulting from technological development is reciprocated by a strong pull as efforts toward commercialization begin. In fact, many will argue that a pull was earlier a push, and vice versa.

Coal Liquefaction

The vast national commitment to the development of synthetic fuels is evident as many projects move from the pilot-plant phase to large-scale demonstration. This is perhaps the most significant recent example of a strong market pull on programs at the Laboratory. Most of the DOE-supported coal liquefaction projects are being carried out by private contractors and managed through DOE's Oak Ridge Operations. ORNL and Nuclear Division Engineering are providing technical support to ORO in areas where staff skills and Laboratory facilities constitute a specialized resource for the government and its contractors.

The SRC-I demonstration plant, to be sited in western Kentucky, is critically dependent on a new Kerr-McGee technology for separating mineral matter and unreacted coal from the liquefaction products. Essentially complete recovery of the process solvent in pilot-plant tests of this separation process has proven difficult, and there were concerns that the solvent might be reacting chemically with the coal-derived materials and thus be irretrievably lost. In response, the process engineering skills of Bill Rodgers and his colleagues in the Chemical Technology Division were effectively coupled with the ^{14}C labeling and analysis capabilities of Ben Benjamin and his group in the Chemistry Division to prove, unequivocally, that chemical reactions of the solvent are of negligible concern. This technical assurance afforded the contractors a much firmer design basis on which to proceed.

Another example from operating liquefaction pilot plants is a serious, unexpected corrosion problem in equipment where the coal liquids are distilled. The problem threatened the viability of both the SRC-I and -II demonstration plants, but a strong collaborative effort involving Jim Keiser, Rod Judkins, and Vivian Baylor of the Metals & Ceramics Division and three sections of the Analytical Chemistry Division with the pilot-plant operators provided insight into the causes of the corrosion problem. These investigators suggested several feasible approaches toward solving this problem. The private contractor has characterized ORNL's contribution as the "pre-

Jim Keiser prepares equipment for tests to screen materials for resistance to stress corrosion cracking. Keiser and his colleagues recently found the causes of the corrosion problem that threatened two Solvent Refined Coal demonstration plants.

mier effort" in solving this problem.

During late September, at the H-Coal Liquefaction Pilot Plant (Catlesttsburg, Kentucky) a heat exchanger failed during normal start-up operation, resulting in a shutdown. Failure was attributed to blowout of 3 of 128 U tubes in the system used to cool the process vapors. Sections of the failed materials were retrieved immediately by the Metals and Ceramics Division for examination, and within two days the plant operators were notified of the cause of failure: stress-corrosion cracking in which chloride ions played a contributing role. Once the cause was known, the operators were able to take remedial action.

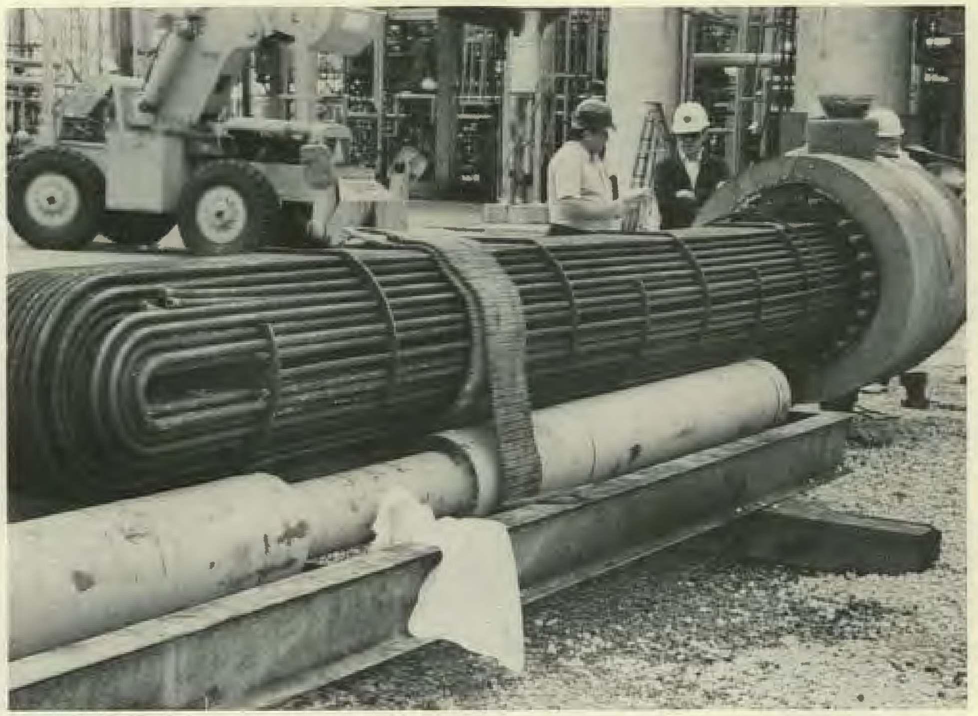
Still another contribution relates to demonstrating the environmental acceptability of the new coal-liquefaction technology. The Energy, Environmental Sciences, Health and Safety Research, and Information divisions are preparing the environmental impact statements for DOE's coal conversion demonstrations. These are pioneering documents that call forth scientific, technological, and political skills in identifying potential impacts. One such impact is the disposal of solid wastes, principally the ash and slag that originate in the feed coal. Coordinated research in Environmental Sciences is providing information on leachates. Another concern is over possible health effects of organic chemicals present in the products, process streams, and wastes of coal liquefaction processes. Here, the Laboratory has conducted a broad, critical review of research methods and results relating to the mutagenicity (and potential carcinogenicity) of these materials which is being used to assess possible environmental and health hazards and necessary mitigating measures.

This pioneering role in the environmental assessment of the emerging synfuels technologies closely parallels our work ten years ago when we prepared the first nuclear-power-plant impact statements in compliance with the then new National Environmental Policy Act.

Magnetic Beneficiation of Coal

A coal-related push is the use of magnetic fields to remove the many inorganic rock and mineral constituents that reduce the heating value of coal, complicate handling and transport, and contribute to airborne pollution and waste-disposal problems. The principle behind magnetic coal cleaning is that sulfur-bearing iron pyrites and ash-forming minerals are weakly attracted by a magnetic field, whereas coal particles are mildly repelled. ORNL was the first to show that magnetic methods can remove almost all of the liberated ash and pyritic sulfur while recovering 90% of the energy content of the feed coal.

Gene Hise and Alan Holman, however, have demonstrated that the required magnetic field shape and force magnitude can be produced with a superconducting solenoid. Since this field is virtually independent of the diameter of the coil, it is possible to generate the separating force in any volume desired. The technique, called open-gradient magnetic separation, can separate materials having a positive magnetic susceptibility as well as or better than existing high-gradient magnetic separation methods. This technique also has the unique capability of separating materials with negative susceptibility, thus significantly extending its applications to ores, minerals,



This heat exchanger that failed at the H-Coal Liquefaction Pilot Plant in Kentucky was found by ORNL to be a victim of stress corrosion cracking in which chloride ions played a role. The missing section was sent to the Laboratory for analysis.

and industrial materials and wastes which have positive as well as negative components. Already, two manufacturers are actively pursuing magnet development.

Conservation Technology

For the near term, the most important technology push from ORNL may be in energy conservation. Several developments deserve mention as examples.

• The heat-pump water heater, recently cited in *EPRI Journal*, is already on the market, with several firms offering units expected to use about half the energy required by resistance-type water heaters for much of the United States.

• Two other subcontracted projects reduce energy use in refrigerator-freezers. A prototype motor-compressor unit is 30% more energy-efficient than the best units previously on the market; and refrigerator-freezer prototypes have been demonstrated that use one-half the energy of the 1978 sales-weighted average of comparable units, without sacrificing user convenience. Both the heat-pump water heater and refrigerator-freezer were developed by subcontractors under a DOE program managed by ORNL's Virgil Haynes.

• ANFLOW technology for municipal wastewater treatment, to be demonstrated in Knoxville in a 200,000-L/d plant under the management of Chuck Hancher and Wes Shumate, meets the Environmental Protection Agency's secondary treatment requirements with less than half the energy consumption of conventional treatment systems.

Extensive tests on the Annual Cycle Energy System over a three-year period have shown it to be a conservation leader in heating, cooling, and providing hot water for buildings. The system, now under the direction of Leonard Abbatiello, uses just 57% of the energy of the control house equipped with one of the best air-to-air heat pumps available.

This year, another appliance-related technology push resulted from connecting ORNL's heat-pump model to a state-of-the-art numerical optimizer developed by Ray Ellison. The purpose was to demonstrate how a sophisticated computer program, based on the physics underlying the technology, can be used as an alternative to traditional "cut-and-try" design methods. One result for a short-term improvement case shows that a steady-state coefficient of performance of 3.97 can be obtained, compared with today's best of 3.1. Ellison's model, on which this work is based, has now been installed on the computers at 11 industrial sites, 8 universities, and 6 other research institutions.

Nuclear Reactor Regulation

Perhaps one of our most important nuclear-related contributions in recent times occurred this year. One of several puzzling aspects of the Three Mile Island accident, investigated by the Kemeny Commission, was the almost negligible release of radioiodine. Only about 15 Ci of ^{131}I were released, compared to about 8 million Ci of ^{133}Xe, even though the inventories of the two fission products were approximately equal at the time of the accident. The expected release of radioiodine was much larger than the actual release, mainly because the staff had recalled the relative releases of the two nuclides experienced in the 1957 Windscale accident in the United Kingdom. Resolving this discrepancy was

Gene Hise checks the open-gradient magnetic separation device that can clean powdered coal by separating sulfur-bearing iron pyrites and ash-forming minerals from coal particles having high energy content. OGMS also has applications for ores, minerals, and industrial materials.

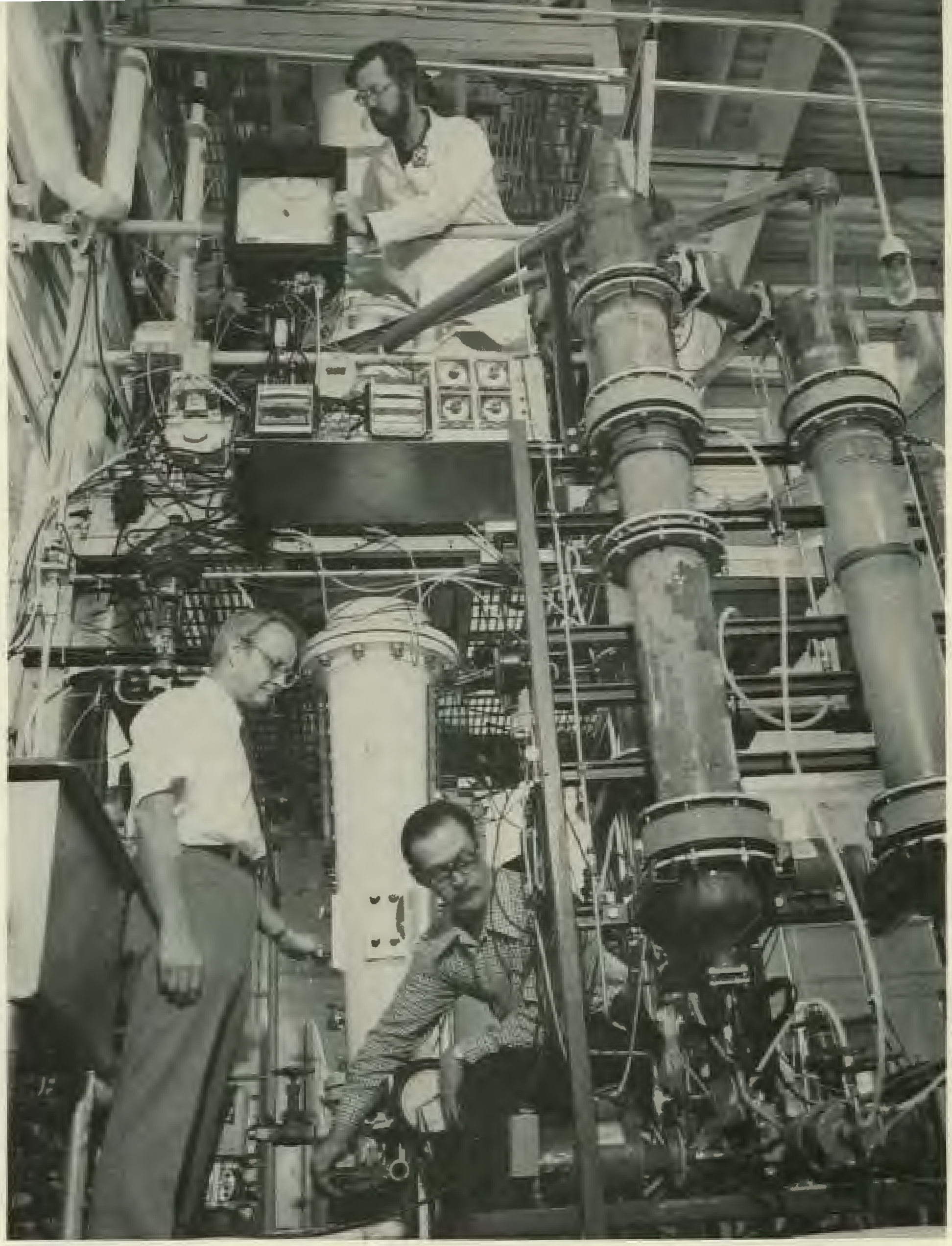
important in view of the supposed high volatility of iodine, which made it the dominant radiotoxic species in reactor site-safety analyses.

Tony Malinauskas and Dave Campbell in the Chemical Technology Division, with collaborators at Los Alamos, set out to review the evidence. They observed that an oxidizing atmosphere prevailed at Windscale, whereas the accident at TMI occurred under chemically reducing conditions. This suggested that fission product iodine is released from fuel as a metal iodide (probably cesium iodide) rather than as molecular iodine, which is contrary to the assumption on which current regulatory guides and licensing models are based. Since cesium iodide is significantly less volatile than molecular iodine, it became clear that release of radioiodine may have been grossly overestimated by the licensing models. This is especially true when one considers that light-water-reactor accidents necessarily occur under reducing conditions.

Their findings, if verified by an Nuclear Regulatory Commission review now under way, can have a significant impact on nuclear reactor safety and the regulatory process. Governor Babbitt of Arizona, a Kemeny Commission member who chairs the Presidential Nuclear Safety Oversight Committee, stated in a December letter to President Carter, "This technical question should be resolved on an expedited basis, for it bears directly on fundamental assumptions underlying some of the most important regulatory issues facing the nation."

Biodenitrification

Liquid nitrate wastes are a continuing environmental problem in several industries, including the production of nuclear fuel. Biological denitrification (i.e., using microorganisms to remove the nitrate contaminant) was successfully implemented at the Y-12 Plant in 1976 using conventional technology. Work then began under Chuck Scott and Chuck Hancher in the Chemical Technology Division and under Chet Francis in the Environmental Sciences Division on advanced systems. The organisms involved—simple bacteria from garden soil—were shown to function over a range of operating conditions, including moderate



Doug Lee (top), Chuck Hancher, and Chuck Scott (standing) examine components of the ORNL fluidized-bed bioreactor that has been shown to reduce nitrate concentrations in wastewater to levels acceptable for drinking water.

radiation fields. They attained a 100-fold increase in the denitrification rate using a new concept, a fluidized-bed bioreactor, in which the active agents were attached to particles of coal.

Now the development has proceeded to the pilot-plant stage, where such treatment of actual and simulated nitrate waste solutions from the Portsmouth Gaseous Diffusion Plant and the Fernald Feed Materials Processing Center has reduced nitrate concentrations to levels acceptable for drinking water. As a result, both Portsmouth and Fernald have included advanced designs of the systems in planned expansions of their waste-treatment facilities. In November, ORNL dismantled and shipped the pilot plant to Portsmouth, where the plant will treat nitrate wastes until the new centrifuge enrichment facility is on stream and requires more capacity. Here again, technological innovation has solved a serious problem by using a concept that promises to have broad application to liquid waste treatment and environmental control.

Ion Beam and Laser Processing

Most often it is the limits inherent in materials that present a barrier to technological advance. The Solid State Division has been at the forefront of applying ion beams and lasers to materials processing. The properties of materials are literally tailored to meet the requirements of the desired applications. Here, as elsewhere, the influences of push and pull are often impossible to distinguish in the vigorous interplay with outside interests. Among the techniques in which ORNL has played a key role are:

- *ion implantation doping*—a precisely controlled method for introducing impurities into solids to change their electronic properties;
- *pulsed laser annealing*—a method of giving materials heating and cooling rates 1000 times as high as those achieved by normal metallurgical methods; and
- *ion beam and laser mixing*—two recent methods for inducing materials interactions in thin films on solid surfaces. These techniques were developed by Woody White, Bill Appleton, Jim Williams, and the Chemistry Division's Gene Kelly.

Possible applications include fabrication of supersaturated substitutional alloys of silicon with 500 times as many dopant atoms in electrically active sites and with unique semiconducting properties; production of thin films of amorphous mixtures, new metastable alloys, and high temperature superconductors; creation of near-surface corrosion-resistant alloys; and the reduction of friction and

Bill Appleton works in the Solid State Division accelerator lab where the techniques of ion beam and laser mixing were developed to tailor the properties of materials to meet the requirements of desired applications.

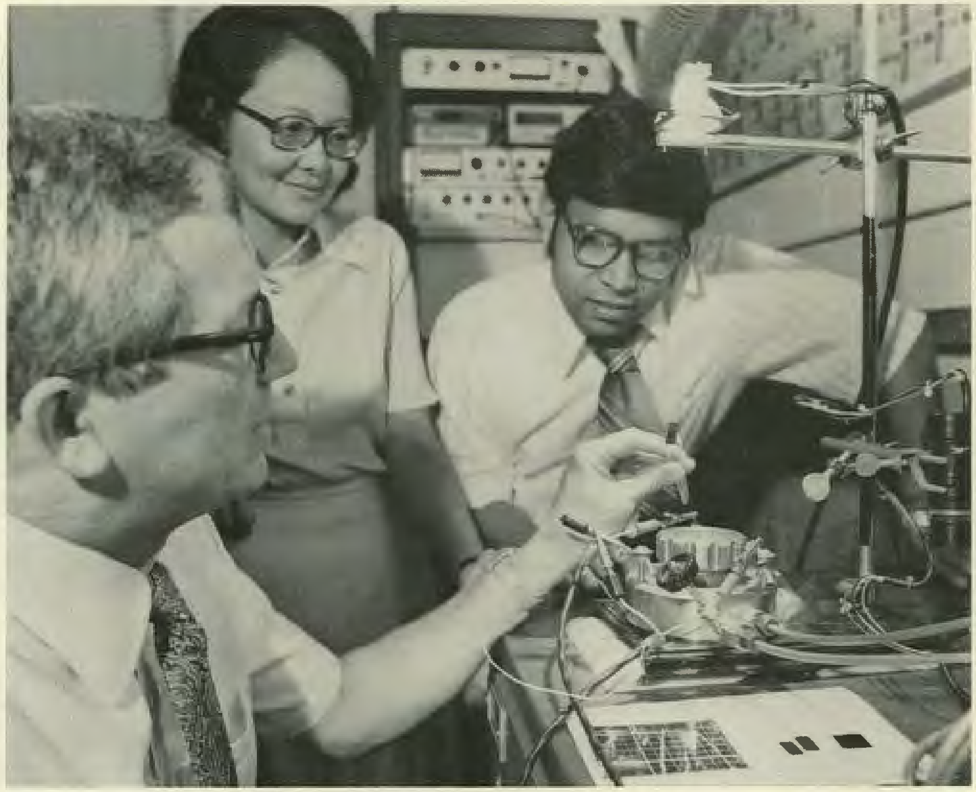
wear in bearing steels, thereby conserving critical materials.

Laser processing of materials used in photovoltaic conversion of solar energy is another impressive example of the progress and potential in this technology. By combining ion implantation and laser annealing with other processing steps using lasers, Dick Wood's group now obtains efficiencies of about 17% in single-crystal silicon solar cells routinely in the laboratory. (The best obtained elsewhere by the most sophisticated techniques is about 18%.) Solar cells made by the low-cost, laser-induced diffusion technique, for which Jagdish Narayan and Rosa Young hold a patent, currently have efficiencies of about 14%. In this method, a thin layer of dopant is deposited on the silicon substrate and diffused by melting the near-surface region with pulses from a Q-switched laser. Improved fabrication techniques should soon lead to even higher efficiencies.

Some of the most exciting developments in laser processing of solar cells have occurred with polycrystalline materials. Wood's group has established that the diffusion of impurities along grain boundaries and the segregation of dopants can be controlled by laser techniques. These results led recently to the demonstration of grain boundary passivation by lithium diffusion. This should result in substantial savings in energy, time, and money. As a result, laser processing systems are already on the market and advanced systems are being designed and built.

Fuel Alcohols from Fermented Material

In the Chemistry Division, Alicia Compere and Bill Griffith have developed low-energy process for removing alcohols from aqueous solutions such as those produced by fermentation. Called Fualex (for *fu*el *al*cohol *ex*traction), it appears to be a promising alternative to distillation. Their tests show that alcohol mixtures obtained from dilute solutions may be incorporated into fossil fuels or further purified for other uses, such as enhanced oil recovery or as replacements for petrochemicals. In the process, they add a small amount of a surfactant and one or more hydrocarbons, such as heptane, toluene, gasoline, diesel, or other fuel oils, to a fermentation broth or similar aqueous solution. This results in the formation of an emulsion enriched in alcohols which can be removed and used either for fuel mixing or purified further for other applications. Fualex requires little of the energy needed for conventional methods of distilling and dewatering ethanol for use in fuels. It also may increase safety and decrease pollution, since the low toxicity of the surfactants is demonstrated by their regular use in foods and personal-care products.



Dick Wood, Rosa Young, and Jagdish Narayan test solar cells made at ORNL using the low-cost,laser-induced diffusion technique. These cells have been found to have efficiencies as high as 14%.

Protection of Synfuels Workers

Elements of both market pull and technology push are evident in contributions by ORNL's Life Sciences Synthetic Fuels and Fossil Energy programs to worker protection in the emerging synfuels industry. The Health and Safety Research, Chemical Technology, and Health divisions have participated in the development and application of a whole new family of monitoring instruments for detecting coal-conversion contaminants. These instruments are now being used in industrial hygiene programs at coal gasification and liquefaction demonstration plants. Three of these are portable systems: DUVAS, a *d*erivative *u*ltraviolet *a*bsorption *s*pectrometer for specific aromatic compounds, developed by Alan Hawthorne and Dick Gammage; a fluorescence spill spotter for general surface contamination, developed under the direction of Dan Schuresko; and Tuan Vo-Dinh's fluorescence light pipe luminoscope, whose primary function is to detect and measure small amounts of residual skin contamination.

Vo-Dinh also has demonstrated the effectivenss of two spectroscopic techniques for trace analysis of organic compounds: room temperature phosphorescence and synchronous luminescence. Most other methods involve a prefractionation step prior to analysis, but the RTP and SL techniques can be used directly to determine the PNA compound present in the raw coal product diluted in ethanol. A companion to these highly sensitive spectroscopic methods is a small integrating vapor monitor worn in the pocket as a personnel exposure meter. Developed by Vo-Dinh and Gammage, it is simply a holder for a disk of filter paper that adsorbs polynuclear aromatic hydrocarbon vapors from the air. RTP is used to identify and quantify selected PNA vapors such as phenanthrene, fluoranthene, and pyrene. The luminescence spectra also can be recorded synchronously for additional selectivity.

Preservation of Early Embryos

Possibly the most significant technology push in our life science areas may result from Peter Mazur and Stan Leibo's pioneering work in the Biology Division on preserving animal cells, organs, and even embryos by freezing. The feasibility of preserving mammalian ova and embryos for extended periods was first demonstrated here in 1972. Mouse embryos survived freezing to and thawing from −196°C, a temperature low enough to produce what can fairly be termed suspended animation. The test showed that frozen and thawed ova and embryos developed into living animals when transferred into suitable foster mothers. The foster mothers used in these tests included rats, rabbits, hamsters, sheep, goats, and cattle.

Consider two important practical implications of this development, the first related to mouse embryos. Natural reproduction of all biological life leads inevitably to changes of the species by genetic drift. This means that experiments requiring long-term examination of whole-animal responses are conducted against a continuously changing genetic background. Since embryos can be stored easily in the frozen state for extended periods, it now is possible to reduce the rate of genetic drift of mouse strains used in such studies. Already, three mouse embryo banks have been established in this country and the United Kingdom, and the International Committee

Neva Harrison adjusts a bench scale fermenter used as part of the experimental Fualex process to extract fuel alcohols with improved energy efficiency.

for Standardized Genetic Nomenclature lists the existence of several mouse substrains carrying the notation "p" for "preserved."

With cattle embryos, selective breeding using frozen and thawed bull sperm for artificial insemination has led to an enormous increase in the quality and productivity of beef and dairy cattle, but it drastically reduces the genetic information carried in cattle. Freezing of embryos, which carry the complete genome of the male and female parents, offers an inexpensive way to preserve the entire available genetic heritage of twentieth century cattle. This suggests that artificial inovulation will soon have as large an impact on cattle breeding as artificial insemination does now.

TECHNICAL HIGHLIGHTS

So much for my theme of technology push and market pull. I want now to mention some examples of other outstanding technical accomplishments during the past year. The first come from the basic energy sciences.

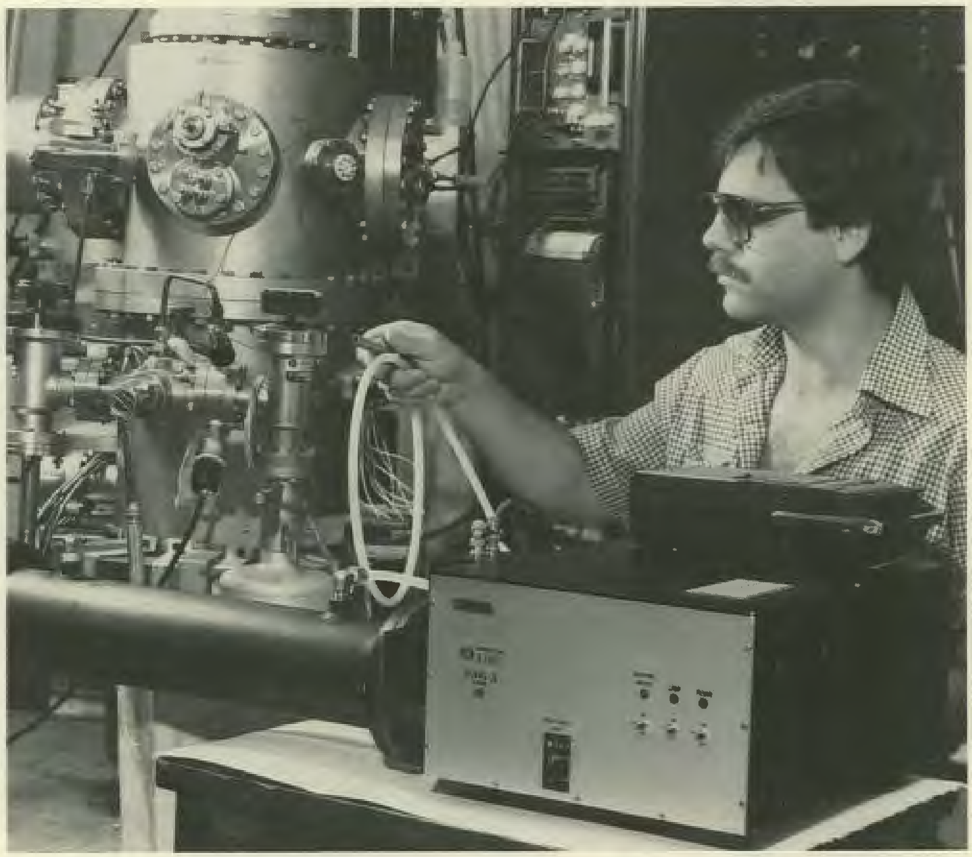
NMR Studies of Coal

One of our goals in the basic energy sciences program is to improve the scientific basis for synfuels processes such as coal liquefaction. This requires a much more detailed understanding of coal structure and of structure/reactivity relationships, a task of major proportions for the organic chemist. This year in the Chemistry Division, Ed Hagaman has applied a superconducting nuclear magnetic resonance device to the problem, with excellent results. NMR is especially well suited to identifying and characterizing molecular configurations containing carbon, hydrogen, and oxygen. Structurally, coal consists of large units formed by fusing several benzene rings together. These units are called polynuclear aromatic structures which, in turn, are linked together by carbon chains, called alkyl bridges, or by ether-oxygen bridges, to form a sort of random polymeric structure. The NMR probe can follow changes in this large random structure during reactions that break down the complex polymers into simpler chemical units. Spectra show the rearrangements of aromatic units and the dramatic results of the completed reaction: broken methylene bridges. The solid-state NMR technique offers a more accurate structural picture of raw coal and its chemical derivatives because the coal does not have to be dissolved before analysis.

Electron Impact on Ions

Another fundamental problem of vital technological importance is understanding how electrons interact with ions in fusion plasmas and the coronas of stars. Dave Crandall, R. A. Phaneuf, and other members of the Physics Division, with colleagues at the Joint Institute of Laboratory Astrophysics in Colorado, are studying important events that happen when a beam of electrons collides with a beam of highly charged ions. In particular, they have examined two processes by which the electron beam strips the ions of an additional electron —either through direct ionization or autoionization. In the former, the impact of the electron beam knocks an electron out of the atomic shell. Autoionization occurs when an inner shell atomic electron is excited to a higher-energy orbit and then relaxes, releasing its surplus energy by ejecting another bound electron. The problem is to determine which process will occur in a specific ion as a function of

This pocket exposure meter developed at ORNL contains filter paper that adsorbs vapors of polynuclear aromatic hydrocarbons from coal conversion processes. The contaminated paper is then analyzed by room temperature phosphorescence to determine if the meter wearer was exposed to hazardous levels of vapors in his work environment.



Alan Hawthorne adjusts DUVAS, a device he helped to develop that can monitor the atmosphere of coal conversion plants for hazardous gases and vapors.

electron beam energy. Preliminary results indicate that the probability of autoionization increases with heavier, highly charged ions that have few outer-shell electrons and more numerous inner-shell electrons. This insight is expected to influence physicists' understanding of the ionic charge-state distribution in hot plasmas, which for fusion is closely coupled to the radiative power loss when heavy-ion impurities are present; this physics is vital to understanding the role of impurities in limiting fusion reactions in tokamak plasmas.

Delayed Lasing

Inventiveness in the analytical application of lasers continues, as evidenced by the development of a technique called delayed lasing by Mike Ramsey and Bill Whitten in the Analytical Chemistry Division. Optical absorption spectrometry is an important analytical tool which is based on the fact that the light a substance absorbs at different wavelengths is characteristic of that substance. Conventionally, optical absorbance is determined by measuring the intensity of light before and after it passes through a sample. The problem is that some materials absorb so little light that there are large measurement uncertainties. The solution, using a laser, involves measuring time intervals instead of the intensity of transmitted light. The technique is based on the fact that a critical number of atoms in the laser crystal must be excited before a laser beam is emitted. With a sample present in the laser cavity and absorbing photons, the onset of lasing is delayed by a time interval that is linearly proportional to the absorbance. Ramsey's and Whitten's experiments have shown that an absorbance as small as 10^{-3} can be measured, and improved experimental design should allow measurements down to 10^{-5}. Because of the technique's sensitivity, potential applications seem likely in the detection of trace quantities of most substances, including both gaseous and liquid pollutants.

Insect Toxicology

Turning to the life sciences, we find that meaningful evaluation of chemical toxicity to plants and animals is a challenge not only to ORNL in its effort to predict deleterious effects of energy-related pollutants but also to the entire science of toxicology. Both the scientific community and the public have questioned the validity of biological assays that report toxic

Dan Schuresko checks the operation of the fluorescence spill spotter used to detect surface contamination by trace amounts of polynuclear aromatic hydrocarbons from coal liquefaction plants.

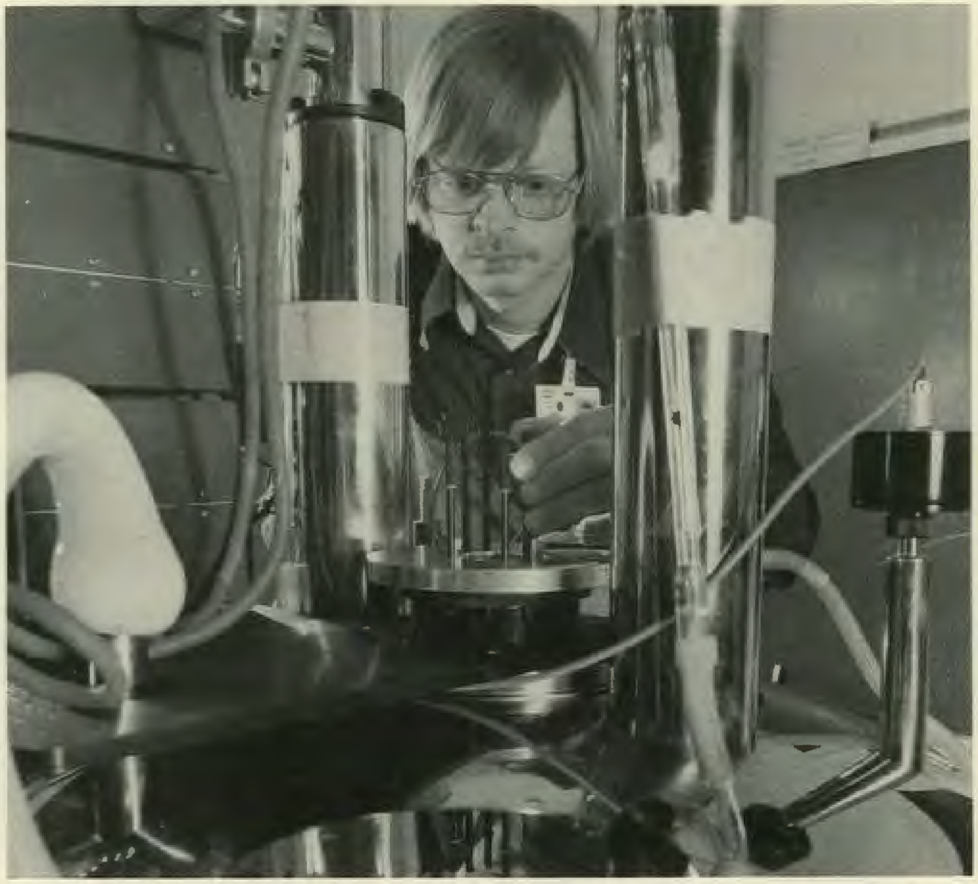
Peter Mazur works in his lab where pioneering studies have been done on preserving cells, organs, and embryos of animals by freezing. (See back cover.)

effects based on exceedingly high concentrations of toxicants that are applied in unnatural ways to specially selected strains of organisms. But now an assay developed by Barbara Walton and Gerry O'Neill in the Environmental Sciences Division holds promise for more realistic assessment of the effects of synthetic fuels on the embryonic development of soil invertebrates. This assay, in which common crickets deposit eggs in sand contaminated with chemicals, is noteworthy because the method of exposure is environmentally based. Further, Walton and O'Neill have shown the assay to be sensitive to very low concentrations of teratogens. The structural abnormalities seen in treated insects, typically in the formation of extra compound eyes and/or heads, are easy to detect. Some of the abnormal insects have been reared to the adult stage and a small percentage of abnormal insects were found among their offspring. These findings are interesting and important because synthetic fuels from coal yield positive results in the assay, but the natural petroleum products tested thus far do not produce extra eyes or heads. (This is also what generally has been observed in the Biology Division using mice, bacterial cells in culture, and other test systems.) The *de novo* generation of extra body parts after treatment of crickets is a phenomenon previously unreported for insects. Apart from its practical application as an assay, this opens new possibilities for looking experimentally at more basic questions of cellular determination and differentiation during embryonic development.

Paleoecology and Climate

The addition of excess carbon dioxide to the atmosphere through burning of fossil fuels is expected to induce changes in the global climate within the next 50 years. Some models predict global warming of at least 2°, which would affect the distribution and abundance of commercially important trees as well as displace crop and natural vegetation zones. Our best analogs for predicting future biotic responses are the climate changes that took place during warm periods of the Quaternary, 5000 to 8000 years ago. The techniques available for interpreting past climatic and vegetational change include (1) variance in the widths of tree rings, (2) chronological changes in the abundances of fossil pollen grains extracted from lake sediments, and (3) simulation modeling of forest succession under hypothesized changes.

Ed Hagaman uses the nuclear magnetic resonance device to learn the detailed structure of coal molecules before and after reactions that break down the complex polymers into simpler chemical units. This work provides a basic scientific understanding of synfuels processes such as coal liquefaction.



In the Environmental Sciences Division, Hazel Delcourt and Allen Solomon have coupled the use of fossil-pollen chronologies with computer modeling in order to reconstruct quantitatively the vegetation changes in the region over the past 16,000 years. They have determined changing frequencies of tree species during late-glacial and postglacial times from radiocarbon-dated sediment samples taken from Anderson Pond in Tennessee's White County and several ponds in Alabama. The results show that during the mid-postglacial period of climatic warming, vegetative composition changed from species-rich mixed hardwood forest to dry oak-hickory forest. Their model simulations can reconstruct characteristics of vegetation which would not be interpreted from pollen evidence alone, including the dynamics of insect-pollinated tree species and detailed structural characteristics of ecological communities. As a consequence of climatic warming, the total biomass and thus carbon storage of Middle Tennessee forests were simulated to have been lower 5000 to 8000 years ago than they are now. Today, forests of this region might provide more of a buffer against induced climate change because of their greater CO_2 absorbing capacity. Working with T. J. Blasing, Delcourt and Solomon are performing broader regional analysis of paleoecologic evidence which should improve predictions of future CO_2-induced climatic and vegetational changes.

Radiopharmaceutical Development

Although still in the preclinical stage, a new class of radioactive imaging agents, developed by the Nuclear Medicine Technology group led by Russ Knapp of the Health and Safety Research Division, shows promise for improved medical diagnosis of heart disease, adrenal disorders, strokes, and brain tumors. The agents, containing isotopes of tellurium and tin, are superior to those currently in use in their ability to concentrate and be detected in target organs or tissues. One of the most important applications of nuclear medicine this year was achieved by Knapp, Kathleen Ambrose, Thomas Butler, and James Hoeschele in the field of heart imaging. These researchers were able to tag fatty acid compounds with tellurium, which not only concentrates in damaged tissue at different levels than in normal tissue but also combines chemically with the tissue, a metabolic trapping which gives clearer images using less radioactivity. Knapp and associates have also developed tin-labeled steroids, the first tissue-specific tin-labeled radiopharmaceuticals ever produced, which show pronounced adrenal uptake in experimental animals. Finally, a newer class of radiopharmaceuticals synthesized at ORNL are tellurium-labeled barbiturates which could be used as noninvasive agents to detect and locate strokes, brain tumors, and other abnormalities characterized by changes in blood flow. These are at the stage of animal testing.

While the agents just discussed will make significant medical contributions in the future, an important development was achieved

Barbara Walton, insect toxicologist, examines an abnormal cricket in her lab. As an embryo, the cricket was exposed to a coal-derived chemical. Walton found that some crickets hatched from eggs in sand contaminated with toxic chemicals were born with three eyes or two heads.

this year in supplying the isotope that is in greatest current demand for diagnosing heart disease. That isotope is ^{203}Tl, which is used to produce ^{201}Tl for heart scans. The ability of the isotope enrichment program, part of Chemical Technology, to respond to this need was enhanced by development of a different charge material, thallous sulphide, used in the calutron ion source. This was done by two groups led by Bill Bell and Joe Tracy. The thallous sulfide has vapor pressure characteristics which permit considerably better control of the ion source and, therefore, of beam current and focus. The result is that almost 3 kg ^{203}Tl enriched to greater than 95% was made available, which translates into doses sufficient for four to five million heart scans—a remarkable contribution to health-care delivery.

Improved Bioassays

Assessment of human health risks from inhalation of chemical substances has been limited to experiments in animals and to the study of exposed worker populations. Investigation of chemical effects on the critical target tissue, human respiratory epithelium, under controlled laboratory conditions has not been possible because methods did not exist to maintain human epithelial cells in the laboratory. Now, in an important advance, Margaret Terzaghi and Andre Klein-Szanto of the Biology Division have developed a method not only of maintaining normal epithelial cells but also of propagating them so that virtually unlimited quantities can be made available. Their technique consists of repopulating denuded and transplanted rodent tracheas with human bronchial cells taken from autopsy material. Once the human epithelium is established in vivo, the epithelial cells can again be isolated and used to reseed a new series of tracheas. This is intended to continuously expand the human cell population originally inoculated, a technique expected to receive widespread application in commercial testing laboratories.

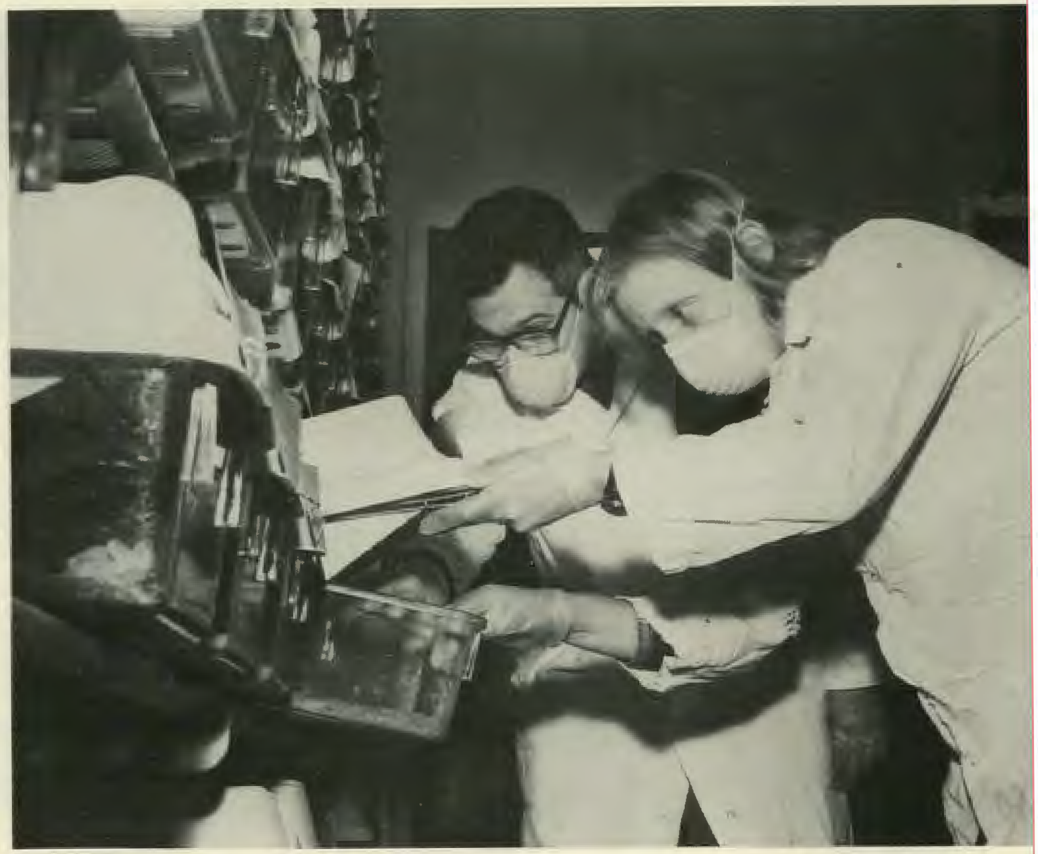
Sodium Boiling in LMFBRs

I turn now to nuclear safety research, fusion, and coal liquefaction.

During normal operation, a liquid-metal fast breeder reactor operates at temperatures well below those necessary for sodium boiling, but during some hypothesized off-normal conditions, boiling might occur. From the predictions of one-dimensional boiling codes, it was thought that any boiling would lead to immediate dryout (removal of the liquid film from the fuel-pin surface), clad failure, and core damage. Hence, an early safety requirement was that no boiling be allowed in the core.

To investigate this premise, John Wantland and Bill Montgomery of the Engineering Technology Division conducted extensive testing of sodium boiling in the Thermal Hydraulic Out-of-Reactor Safety (THORS) facility, an engineering-scale sodium loop which uses electrically heated test bundles to simulate segments of LMFBR core subassemblies. They have recently completed boiling tests with a 61-pin bundle which more closely approximates a reactor core subassembly of 217 pins. As in previous

This image of a rat heart and liver is particularly sharp because the tissue contains concentrations of fatty acid compounds tagged with radioactive tellurium, which combines chemically with the tissue. This metabolic trapping gives clearer images using less radioactivity.

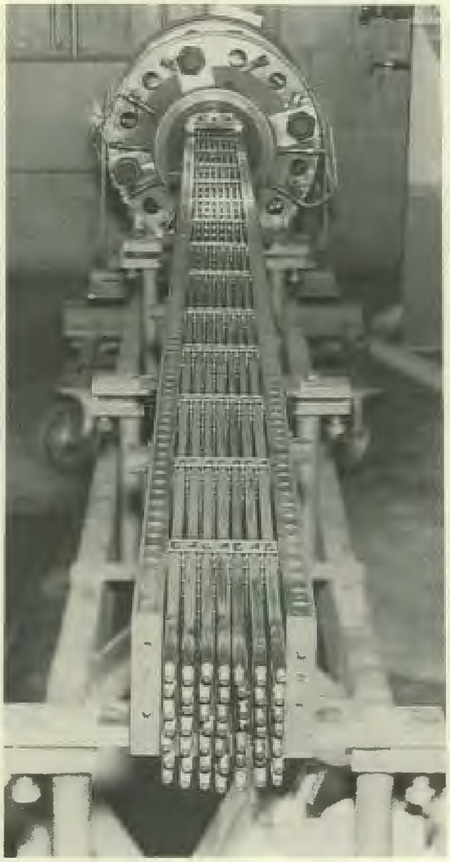


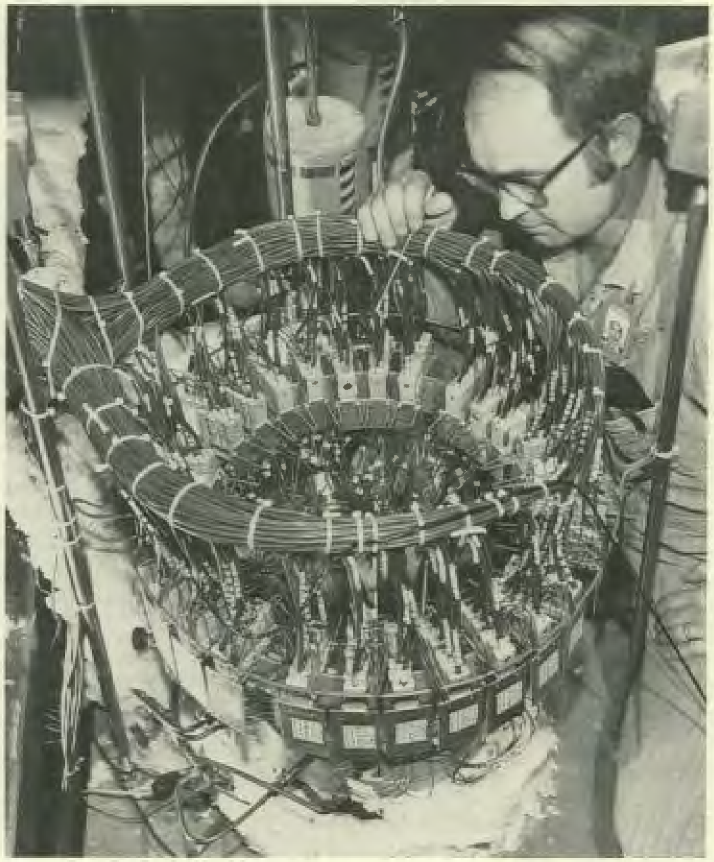
Andre Klein-Szanto and Margaret Terzaghi work in their lab where they developed a method of maintaining and propagating human bronchial cells (from autopsy material) that can be grown on rodent tracheas for tests of the chemical effects of inhaled substances on the human respiratory epithelium. Previously, no method existed for maintaining human epithelial cells in the laboratory.

tests with a 19-pin bundle, dryout did not occur unless and until the boiling region covered the entire transverse area of the bundle. Then, due to the increased pressure drop caused by the vapor blanket across the bundle, the inlet flow decreased dramatically. Skip Dearing, Al Levin, and Simon Rose have reproduced these flow decreases analytically, using an ORNL-modified version of the SABRE subchannel code, and have achieved excellent agreement with the experiment. Extrapolating with this code to a full-size 217-pin subassembly for low-flow, forced-convection boiling, they show that a fairly long time of 5 to 10 s elapse between boiling initiation and dryout. These results are very important for LMFBR safety design and now are being used both at Westinghouse and Argonne National Laboratory.

I have already mentioned a finding from the TMI accident that may profoundly influence regulatory guidelines. TMI also fueled a growing concern over the lack of reactor-core heat-transfer data applicable to various types of accidents whose severity depends in large part on how well the reactor's decay heat is transferred to the coolant. Heat-transfer data that allow prediction of accident consequences and help identify ways to reduce their severity are difficult to obtain, however, because of the typically severe pressures, temperatures, and flow rates involved. Further, the geometry of the reactor core, with bundles of closely spaced rods, makes precise measurements difficult. As a result, analysis often has had to employ correlations developed from data taken inside hollow tubes and then applied beyond the range of data on which they are based.

Doubt over the suitability of this practice led NRC to request that ORNL conduct experiments with the Thermal Hydraulic Test Facility to obtain the needed rod-bundle heat-transfer data. THTF, a full-scale model of a portion of a reactor core which, like THORS, uses highly instrumented electrically heated rods, was NRC's only facility capable of achieving the desired information based on the true geometry and conditions of reactor accidents. Early this year, Bill Craddick and Tom Anklam placed primary emphasis on fulfilling NRC's urgent request for data applicable to small-break loss-of-coolant accidents typical of TMI conditions. More than 63 million data points generated during 1980 will be among the most important resources in NRC's selection of appropriate models for analysis of small-break loss-of-coolant accidents and operational upsets. In meeting NRC's needs, Craddick





This bundle of instrumented, electrically heated rods is used in the Thermal Hydraulic Test Facility to gather data on heat transfer during simulated reactor accident conditions, including those typical of small-break, loss-of-coolant accidents such as the one that occurred in March 1979 at Three Mile Island.

Electrician L. M. Black examines a rod assembly that has been used in the THORS facility for tests of sodium boiling in a simulated LMFBR environment.

and Anklam have also produced data of considerable interest to reactor vendors and academic researchers.

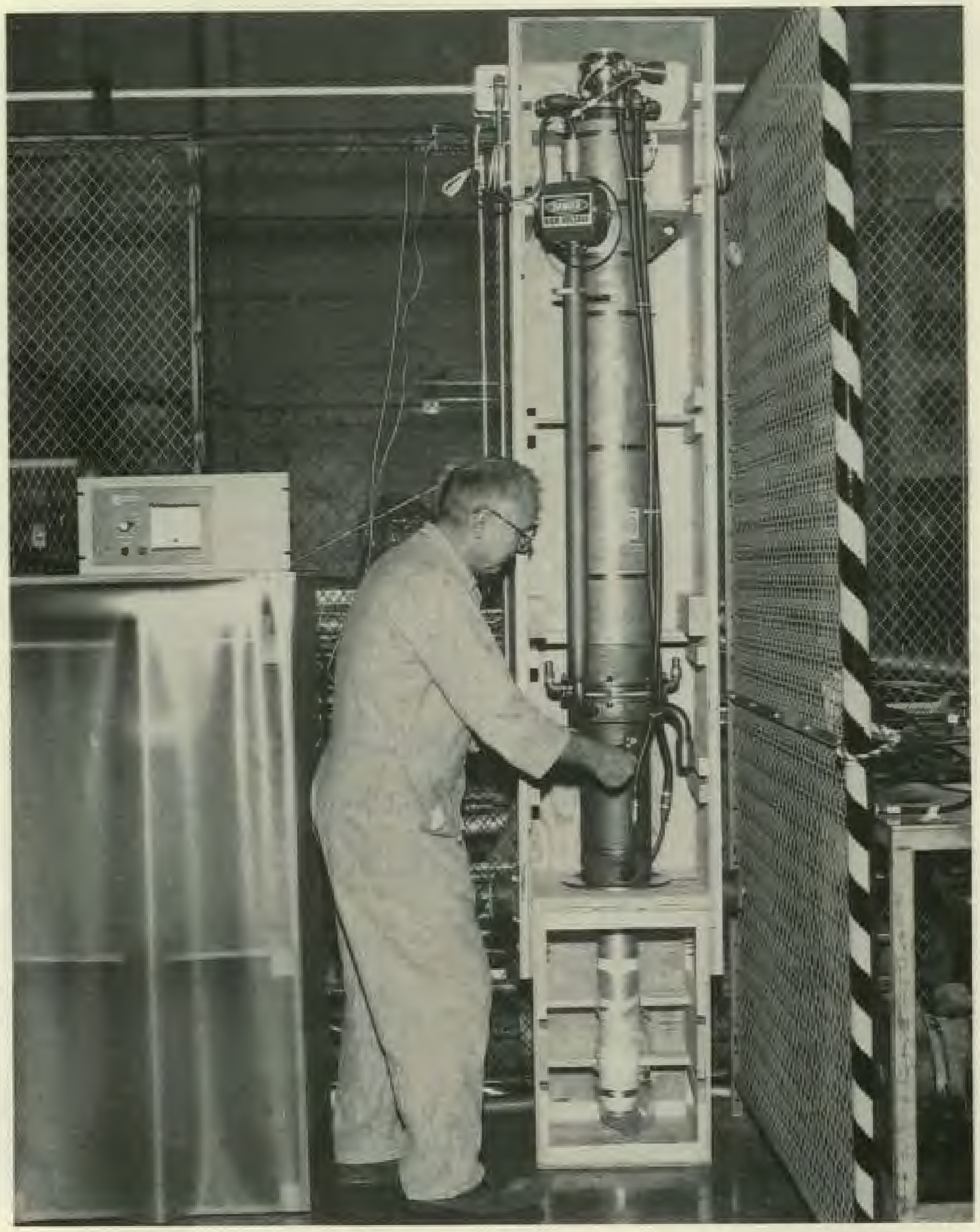
High Beta Studies on ISX-B

In fusion research, the main objective of our tokamak experimental program with the Impurity Study Experiment device (ISX-B) is to study the equilibrium stability and confinement characteristics of what are called high-beta plasmas. Beta is the ratio of the kinetic pressure of the hot plasma to the pressure exerted by the confining magnetic field. Thus, ultimately, it will be a key economic parameter for power-producing fusion reactors, which require a volume-average beta of 4 to 6%. With ISX-B, a group led by John Sheffield and Masanori Murakami has obtained high plasma pressures by using powerful neutral-beam injectors developed at ORNL. This year, Hal Haselton, Walt Gardner, and their colleagues have increased the injection capability to 3 MW at an energy of 45 kV by upgrading the neutral-beam system to accommodate two new 100-amp ion sources. With the injection of up to 2.5 MW into ISX-B, they have achieved beta values of 3%.

This is encouraging not only because values approaching those required in fusion reactors have been attained, but also because they exceed the limit that had earlier been predicted from ideal magnetohydrodynamic stability theory. However, the rate of increase in beta with increasing injected power appears to be reduced at the higher levels. This apparently reflects a degradation of the plasma energy confinement. In the near term, experiments will concentrate on trying to understand and overcome this apparent saturation of beta. Preliminary injection experiments in elongated plasmas are encouraging in this regard. Although the operational parameters were not optimized, the beta was as high as that seen in a circular plasma, while the energy confinement time was significantly better. And even were beta to be saturated, it apparently is high enough to be reactor grade.

Gyrotron Development

In the Elmo Bumpy Torus program, you have read much this year about plans for the next major phase, construction of the EBT proof of principle experiment to be built in Oak Ridge. Dick Colchin and his associates have also enjoyed an important development success with the microwave sources call "gyrotrons" which supply the plasma heating for EBT. Just as with the successful application of ohmic and neutral-



The gyrotron for the EBT-S before installation.

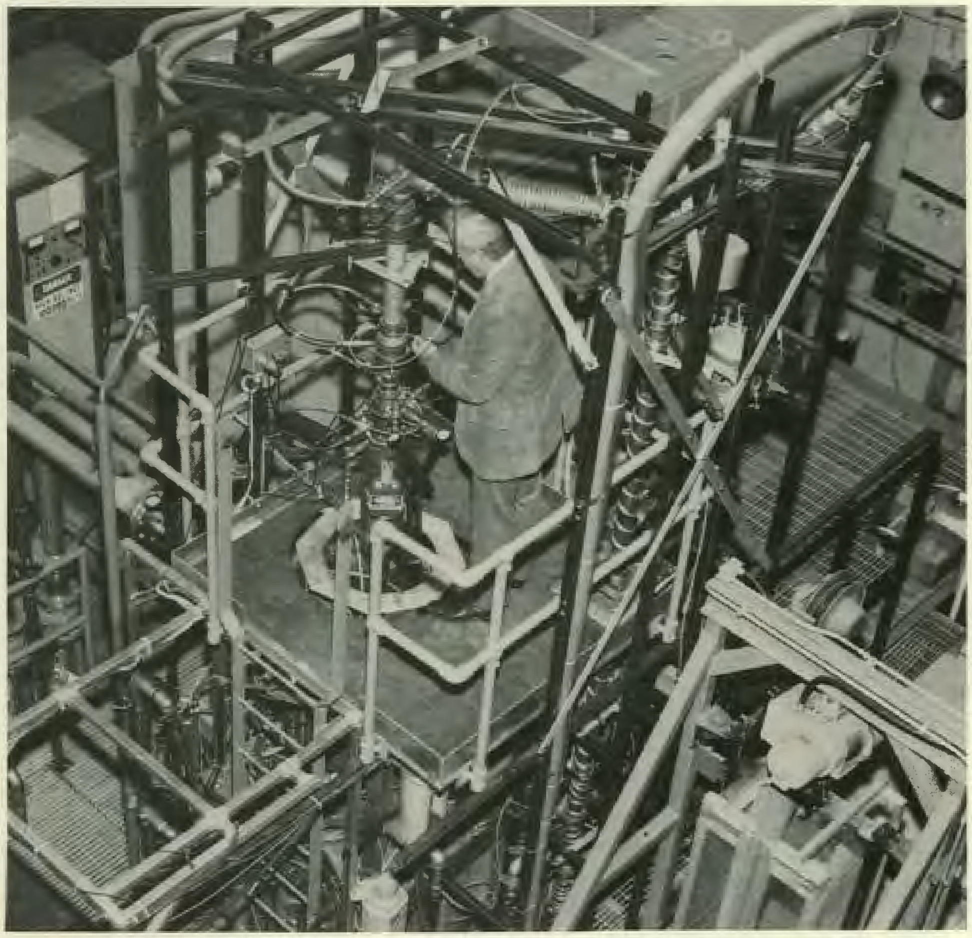
beam heating to tokamaks, another pioneering ORNL effort has been in the application of microwaves to electron cyclotron heating. In EBT, not only is the steady-state plasma heated by microwaves, but also the confinement stability is provided by an intensely hot electron ring plasma created uniquely by this heating method.

Electron cyclotron heating is accomplished by coupling microwave power to plasma electrons at their gyro-resonance. In order to penetrate the dense plasma of fusion interest, very high microwave frequencies and correspondingly high magnetic fields are required. Because hundreds of kilowatts or perhaps even several megawatts of power are required, this method requires multikilowatt microwave tubes operating in the millimeter wavelength region of the spectrum. Since the power output of conventional microwave tube structures is severely limited in this range, a new technique was required.

Our development program, begun in 1975, identified the gyrotron—a form of cyclotron resonance maser that uses fast-wave interactions—as the most promising device for high-power, short-wavelength applications. (Like the tokamak, this is a Russian invention.) Subsequently, we entered into a subcontract with Varian Associates to produce a 28-GHz tube with 200-kW capability. The effort culminated this year with the development of a gyrotron, which delivers over 200 kW of steady-state power at efficiencies of about 50%. By the end of the year, 128 kW of power had been successfully put into EBT. Both plasma density and temperature are found to scale upward with increasing power, opening new plasma parameter regimes for research.

Coil Winding Test Experiment

We also have a substantial development success to report in the area of superconducting magnets. The Coil Winding Test Experiment magnet, developed under the guidance of Martin Lubell in the Fusion Energy Division, represents an impressive advance in the state of the art of superconductivity. It produces a peak field of 8.6 T in the working bore and is the largest superconducting magnet of this field strength made to date. During the initial test in September, it performed to full design current without training or degradation. Owing to its feature of radial access, a linear dimension of about 0.5 m at a working field of 8 T is available for tests of large conductors. In addition, the magnet may be mounted with central axis either vertical or horizontal for flexibility in experiments. It will be used for



This gyrotron on the ELMO Bumpy Torus (EBT-S) experiment is a source of microwaves for heating the electrons in the plasma. The hot electron rings created by microwave heating provide confinement stability to the plasma.

testing large, high-current superconductors being developed for fusion machines. The magnet construction consists of both layer and pancake windings to test a design feature which will be used in the EBT-P superconducting magnets to help cancel unwanted field components. The CWTX magnet also is designed to accept a niobium-tin insert split coil which will increase the field capability to approximately 12 T. This combined system is to be tested early in 1981.

Physical Properties of Coal Liquids

The last technical highlight comes from Bill Rodgers' fossil program in the Chemical Technology Division, where efforts are under way to provide the physical and rheological data for coal-derived liquids needed by the designers of large synfuels demonstration plants. A small-scale, continuous-flow coal liquefaction system, called the Coal Liquids Flow System, is equipped to measure physical properties at process conditions up to 31 MPa and 810 K. Operated by George Oswald, Doug Lee, and Randy Gibson, it has provided the best measurements to date of the dramatic changes that occur as the feed slurry, composed of powdered coal and process solvent, is heated to operating temperature. The observed, increasingly non-Newtonian flow characteristics have been modeled to allow much more accurate piping and heat exchanger designs. Measurements also define for the first time a temperature range of increased viscosity, known as the gelation region, which occurs as the slurry is heated through the temperature range of 590 to 670 K at 13.9 MPa. This is thought to be a region where swelling of the coal occurs. In addition to viscosity and density, thermal conductivity and heat capacity data soon will be available for coal-derived liquids and slurries under process conditions. Although similar data for pure materials and petroleum are readily available, until now none has existed for coal-derived liquids. And few other facilities have attempted to make these difficult measurements under process conditions.

SUMMARY AND OUTLOOK

In summarizing the state of the laboratory, I think that our institutional health and well-being is excellent, as the quality of the work I have cited testifies. We continue to be in the right place at the right time doing the right things—and doing them with ingenuity, skill, and dedication. Among line-item projects, the new budget provides for two important initiatives. One is the finish of design but delay of construction on the long-awaited Energy Systems Research Laboratory, and the other is initial authorization for design and construction of the \$17 million High Temperature Materials Laboratory, to be located in the parking area across the creek and south of the 4500S–4508 complex. In this latter initiative, the Laboratory again will be the custodian of an important national resource. HTML will provide the nation with a much

Herb DeArmond, left, works with Donald James in making adjustments in the Coil Winding Test Experiment (CWTX) magnet, which produces a peak field of 8.6 Tesla and is the largest superconducting magnet of this field strength made to date.

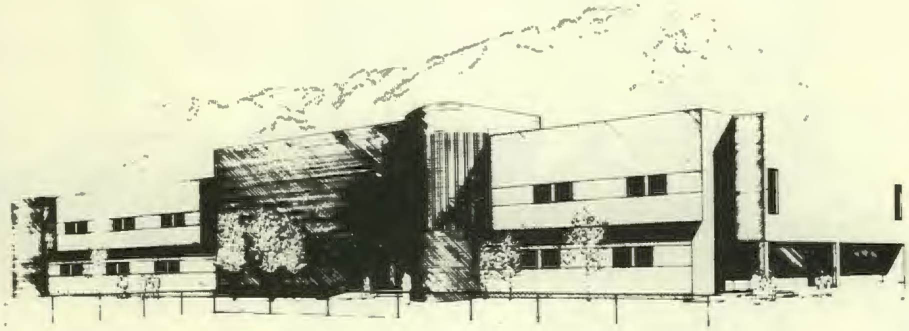
needed laboratory designed for basic and applied research on materials at elevated temperatures. An advisory committee consisting of five university and two industry representatives already is developing plans for its operation as a user facility open to the technical community. About $3 million of the total cost will be used to acquire expensive and unique equipment needed in the specialized areas of high-temperature materials synthesis, preparation, and characterization.

This has been a year when the Laboratory's evolution as a user center has advanced very rapidly. Within a three-month span we dedicated the National Environmental Research Park, the Holifield Heavy Ion Research Facility, and a key new instrument of the National Center for Small-Angle Scattering Research. Each is indicative of past and now anticipated leadership roles for the Laboratory.

Several other important new initiatives are on the horizon and have been discussed in some detail in the *ORNL Institutional Plan, FY 1981–FY 1986* published in December, as well as in the current edition of the staff version, *Trends and Balances*. Several of these recently proposed initiatives are deserving of mention as we look ahead.

One is a program to be called Applied Science/Technology Base. An intensive examination of the R&D base by DOE and the laboratories over the past two years revealed some serious shortcomings, particularly in that the applied science research needed to develop a healthy, competitive set of technology options. Looking at these needs in relation to conservation, fossil, fission, and fusion technologies, we believe that we can make significant contributions in areas such as multiphase flow, instrument development, separation science, corrosion, waste fixation, systems modeling, and, especially, development of materials for service in hostile environments.

Resource recovery from unconventional sources has become im-



Artist's conception of the High Temperature Materials Laboratory.

portant in light of potential shortages of a number of strategic materials, especially metals critical to energy production or conservation. Initially our emphasis will be on recovering useful metals from the solid-waste residues of energy processes (e.g., coal combustion fly ash, coal conversion solids, mill tailings, and oil shale residues). We also expect to examine extraction processes for low-grade ores, recovery of fuel values, multiple products recovery, and conservation. Dilute aqueous sources will also be investigated.

Initiatives in light-water-reactor safety and technology will address problems that affect plant availability and productivity as well as upgrading accident prevention technology (e.g., through improved control-room procedures and diagnostic techniques).

The area of biotechnology offers great promise for both near- and long-term production of fuels as well as abatement of pollution and resource recovery. Building on past strengths, we expect to focus on development of efficient processes for fuel production from biomass, development of efficient waste-treatment techniques, resource recovery, and measurement of biologically important constituents in complex mixtures.

Recently, we have been developing the concept of a utility-oriented coal refinery, applicable to either eastern or western coals, in which the pyrolysis process, either by itself or coupled with coal beneficiation and waste heat recovery, is used as a pretreatment for coal destined for use as a clean boiler fuel—with the bonus of significant by-product liquids and gases. Interest in this approach by EPRI and several utilities is strong and will lead this year both to a joint study of techno-economic issues and to laboratory exploration of combustion properties.

In another initiative this year, ORNL has assisted in the formation of the national Society for Risk Assessment and an attendant professional journal. As an extension of past work on site-specific, regional, and generic assessments of the risks associated with energy technologies, we see the need to develop and apply comprehensive principles of risk assessment that can gain both scientific and policy acceptance. Clearly, practical issues in risk assessment, such as risk apportionment, comparative risks, and risk-benefit tradeoffs, must receive more attention.

Our planning in these and related areas has been stimulated greatly this year by a comprehensive energy policy study called, temporarily, the Oak Ridge National Energy Perspective (ONEP), now being prepared for publication. This study, led by the Office of Program Planning and Analysis, deals with both national and world energy issues and provides the strategic framework through which we can focus our future efforts more effectively. Its conclusions not only are an aid to planning but also are comforting in the optimism they project for the country's energy future if we act aggressively now to reduce dependence on imported oil.

In conclusion, let me express again to all of the ORNL staff my appreciation for their dedicated work and outstanding contributions. They are the source, each year, of what is truly an impressive catalog of accomplishments spanning a broad range of the sciences and the technologies and representing progress both on fundamental issues of importance and practical problems on which our energy future depends. To me, this record establishes ORNL as the premier institution of its type and one whose promise is as bright as its record. ornl

It has been written that not everyone loves a river, but every river has someone to love it. Threaten to dam, channel, divert, dredge, or otherwise modify a stream or river, and people come out of the woodwork ready to defend it. Jerry Elwood's interest in and fascination for rivers and streams were fostered during his childhood in Montana, a state blessed with an abundance of pristine trout streams. Says he, "I loved being around rivers and 'cricks,' listening to their roar, feeling their power while I wade through rapids to reach a favorite fishing spot, and knowing that they are free to flow and do their work as nature intended." Elwood came to ORNL in 1968 upon earning his Ph.D in aquatic ecology from the University of Minnesota. His principal research interests are the ecology of streams and rivers, nutrient cycling in aquatic ecosystems, and the behavior of environmental contaminants in aquatic food chains. He is leader of the Stream Studies Project in the aquatic ecology section of ORNL's Environmental Sciences Division and is one of the principal investigators on the material spiraling in stream ecosystems project.

Spiraling Down the Watershed

How Flowing-Water Ecosystems Cycle Nutrients

By JERRY ELWOOD

Ecologists see ecosystems as energy processors. All ecosystems require both energy inputs and an array of elements for their maintenance and growth. In aquatic systems such as lakes, oceans, and rivers, the rate at which energy is fixed by photosynethetic organisms and metabolized and stored by other, nonphotosynthetic organisms is ordinarily regulated by sunlight or the supply of available nutrients. Because nutrient supply is so crucial to ecosystem persistence and productivity, a substantial amount of ecological research has focused on the mechanisms, pathways, and rates of nutrient cycling in various ecosystems.

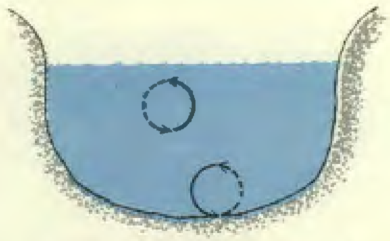
In an essay published forty years ago, Aldo Leopold, naturalist and conservationist, suggested that as nutrients cycle through ecosystems they move downhill. He expressed the view that all land represents a downhill flow of nutrients, and he stressed the importance of biological organisms and food chains in

To estimate the pathways and exchange fluxes of a nutrient through a stream ecosystem, a tracer of the nutrient is released to stream water. Webb Van Winkle, Pat Mulholland, Jerry Elwood, and Denis Newbold (left to right) are shown here collecting samples from Walker Branch following the release of a tracer.

Artificial streams are being used to measure the role of various ecosystem components in controlling the uptake, turnover, and transport of nutrients in streams. Denis Newbold, Jerry Elwood, and Paul Singley (left to right) sample one of these artificial streams during a tracer release. The streams are made in modules so that the length can be varied from 10 to 80 m.

slowing the inexorable movement of nutrients from mountains to the sea. Leopold suggested that if this downhill flow were not slowed, plants and animals would be forced to follow their nutrient salts to the sea in order to survive.

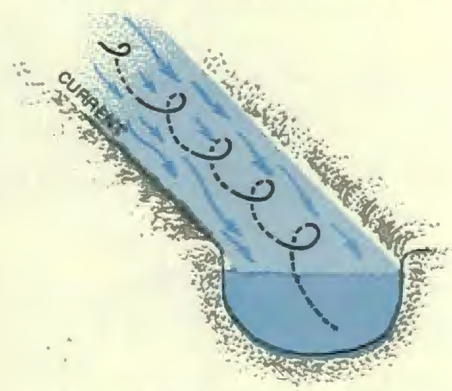
As may be expected, the downhill flow of nutrients is more pronounced in streams and rivers than in other ecosystems because of the continuous, unidirectional flow of water that transports nutrients in dissolved and particulate forms. The importance of retarding this downhill movement is thus correspondingly greater for these flowing water ecosystems. One can argue that because slowing this downhill flow of nutrients is so important to the continued existence of the ecosystem, mechanisms for reducing it should be more apparent in streams and rivers than in ecosystems where the downhill flow is less. The questions that need answering for a clear understanding of nutrient retention in flowing water ecosystems are: How efficiently do streams and



Cycling of phosphorus in a lake or pond

- - - PO_4 in solution in lake or pond water

——— Phosphorus associated with particulate materials (e.g., algae, bacteria, etc.)



Spiraling of Phosphorus in a Stream

- - - PO_4 in solution in stream water

——— Phosphorus associated with particulate materials (e.g., algae, bacteria, etc.)

Nutrient cycling is different in a standing water environment (e.g., lake or pond) from that in a flowing water environment (e.g., stream or river), as can be seen in the path traveled by a nutrient atom in passing through a cycle. For lakes, the cycle is viewed as occurring in place, with no displacement of the nutrient atom during its passage through the cycle. The continuous, unidirectional flow of water in streams, however, results in a downstream displacement of the nutrient as it passes through the cycle. The cycle in a stream, therefore, can be seen as a spiral.

rivers use the nutrients that enter them from the surrounding watershed before these elements are lost through downstream transport, and what are the biological mechanisms that increase this efficiency and thereby retard the downstream flow of nutrients to the sea?

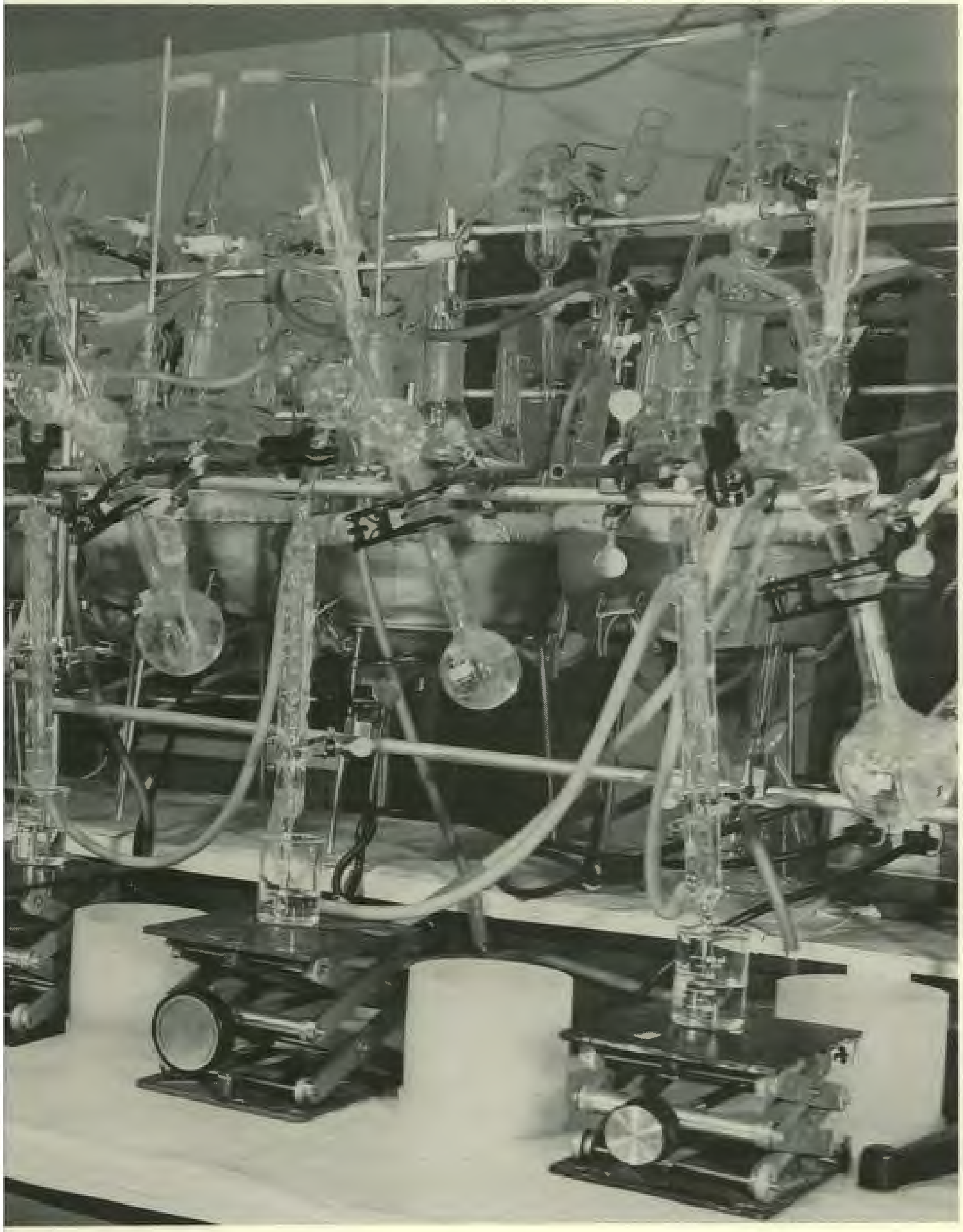
Limiting Nutrients

Under two successive three-year grants from the National Science Foundation's Ecosystem Studies Program, a research group in the Environmental Sciences Division is investigating the retention and cycling of nutrients in stream ecosystems. Members of the group working with me on this project are Denis Newbold, Bob O'Neill, Webb Van Winkle, Pat Mulholland, Bob Stark, Paul Singley, and Carole Hom. What we are trying to do is quantify the cycling of inorganic phosphorus and nitrogen, both of which enter streams via groundwater from the surrounding watershed, and also identify the major biotic and abiotic mechanisms

controlling the retention and cycling of these nutrients. We chose phosphorus and nitrogen for study because one or the other of these elements is generally found to be in "limiting" supply in most aquatic ecosystems. A nutrient is limiting if an increase in the supply of that nutrient increases the rate at which energy is processed in the ecosystem.

Because of the importance of nutrient supply to the stability and productivity of an ecosystem, one would expect the available supply of a limiting nutrient in a stream to be used more efficiently than a nonlimiting nutrient. Biotic processes, thus, should play a major role in the retention and cycling of a limiting nutrient in streams. Further, biotic adaptations which enhance the utilization efficiency of a limiting nutrient should be comparatively more important to the ecosystem than those for nonlimiting nutrients, and the cycling of a limiting nutrient would be expected to be more sensitive to perturbations than that of a nonlimiting nutrient.

Measures of the efficiency with which ecosystems use nutrients are typically based on rates of nutrient cycling relative to the available supply. In general, a nutrient cycle is complete when a nutrient atom returns to a previously visited component of the ecosystem. For most aquatic and terrestrial ecosystems, it is generally assumed that the cycling occurs in place, that is, that there is no downhill displacement of the nutrient atom in completing the cycle. To apply the concept of nutrient cycling to a



In preparation for measuring the ^{15}N:^{14}N ratio of organic nitrogen in organisms and sediments from Walker Branch collected after the addition of ^{15}N-enriched ammonium sulfate to this stream, Paul Singley is distilling the nitrogen which had previously been converted to ammonia. The ammonium borate resulting from this distillation is then concentrated in a solid crystalline form and introduced to a conversion unit attached to a mass spectrometer, where it is converted to nitrogen gas for the isotopic analysis.

stream, however, where the continuous, unidirectional flow of water moves the nutrient atom downstream in its passage through the cycle, requires redefinition of our concept of cycling.

Spiraling

The concept must be redefined for flowing water ecosystems to incorporate the idea that recycling of nutrients is coupled with downstream transport. For example, when a phosphorus atom enters a stream in groundwater or is released from an organism growing on the stream bottom, it moves downstream in the dissolved inorganic form and becomes available either for biological uptake by a variety of microorganisms such as algae, bacteria, or fungi growing on the stream bottom, or for sorption onto stream sediments. Once taken up by a microorganism or sorbed by sediments, the phosphorus atom can (1) be released directly back to water, (2) be absorbed by an animal which feeds on microorganisms, or (3) remain associated with the microbial cell or sediment particle, where it is subject to further downstream transport by sloughing of algae or scouring and resuspension of sediments. The cycle is complete when the phosphorus atom returns to stream water in the dissolved inorganic form. Because nutrient cycling in streams involves some downstream transport before the cycle is completed, one can visualize the path traveled by a nutrient atom as a spiral instead of a closed cycle.

In quantifying the cycling of a nutrient in a stream, it is thus

Snails have been found to be the principal grazers in the streams on Walker Branch Watershed. Here, Elwood and Webb Van Winkle remove dead snails from the artificial streams.

necessary to consider not only the time required to complete the cycle but also the downstream distance traveled by the nutrient atom completing the cycle. We refer to this cycling distance of a nutrient atom as the spiraling length.

For a conservative nutrient (i.e., one without a gaseous phase) such as phosphorus, the spiraling length consists of the average travel distance of the nutrient in *solution* before it is taken up by organisms or sediments on the stream bottom, *plus* the average travel distance of the nutrient in the *particulate* phase before it is released back into solution in the original inorganic form. We refer to the distance a nutrient travels in solution before being taken up from stream water as the *uptake length*. The downstream travel distance of a nutrient associated with particulates before returning to solution is referred to as the *turnover length*. Spiraling length, uptake length, and turnover length are measures of the efficiency with which stream ecosystems use the nutrients supplied from the surrounding watershed. Uptake length is a measure of the stream's efficiency in removing nutrients from water, while the turnover length is a measure of the stream's ability to recycle nutrients from the particulate phase back to water, where they are again available for uptake, and to retard the downstream flow of nutrients associated with particles. The shorter the spiraling length, the more times a nutrient atom is recycled within a given reach of stream.

Phosphorus

Estimating the spiraling length of a nutrient in a stream requires using a tracer of the nutrient to measure the uptake rates from water and the return rate from particulates back to water. We have done this for phosphorus by releasing, over a one-hour period, a solution containing radioactive inorganic phosphorus ($^{32}PO_4$) to Walker Branch, a small woodland stream in the Oak Ridge National Environmental Research Park. We have then measured the loss of the ^{32}P from organisms and sediments on the stream bottom.

Based on a release of ^{32}P to Walker Branch in July and continuous sampling of the stream over a two-month period after the tracer release, we estimated the spiraling length of inorganic phosphorus during this period to be 187 m. In other words, an atom of phosphorus which enters stream water as dissolved inorganic phosphate (PO_4) travels an average distance of 187 m downstream in passing completely through one cycle. Of this total cycling distance, the dissolved phosphorus travels an average of 164 m before it is taken up from stream water. The phosphorus atom then travels 23 m downstream in association with predominantly fine particles before it returns to stream water. At this point, a new cycle of the phosphate atom begins.

Denis Newbold collects and simultaneously filters water from a small aquarium containing suspended sediments and stream water spiked with $^{32}PO_4$ to measure the uptake rate of phosphorus onto the suspended particles. To simulate conditions similar to that in Walker Branch, the growth chamber is maintained at a constant temperature equal to that of the ambient stream water and the water in the aquarium is stirred continuously to cause the turbulent mixing similar to that in a natural stream.

Expressed in terms of a cycling time, as opposed to a cycling distance, a phosphorus atom takes an average of 16 d to complete one cycle in the stream in July. Of this total time required to complete a cycle, the atom, in the form of phosphate-phosphorus, spends an average of only 75 min in solution in stream water and more than 15 d in its particulate form. The travel distance of phosphorus in water (uptake length) is substantially greater than the average travel distance of phosphorus associated with particles (turnover length), despite the fact that a phosphorus atom is in solution an average of only 75 min, because of the velocity with which phosphorus moves downstream in solution compared to the average downstream velocity of phosphorus associated with particles.

Measurements of phosphorus spiraling in Walker Branch at other times of the year show that there is considerable seasonal variation in the length of the cycle. In the spring and summer, for example, the uptake length for phosphorus is over 100 m, ranging from 105 to 164 m. In contrast, during late autumn and winter, when the stream has large amounts of decomposing leaves from streamside vegetation, the uptake length of dissolved inorganic phosphorus is less than 10 m. These seasonal differences in the efficiency of the stream ecosystem's use of dissolved phosphate may be due to either differences in the microbial uptake of this nutrient onto the decomposing leaves in the stream or to differences in the adsorption of phosphorus, resulting from variation in the available surface area of substrates on the stream bottom.

To assess the relative importance of the biological uptake of phosphorus in Walker Branch and its adsorption onto stream sediments, we have conducted laboratory experiments using ^{32}P and sterile and nonsterile sediments. Results of these experiments indicate that approximately 90% of the loss of soluble inorganic phosphorus from stream water is a result of biological uptake by bacteria, algae, and fungi associated with sediment particles, while the other 10% loss is attributed to physical or chemical adsorption. In similar experiments, we examined the effect of microorganisms on the loss of phosphorus from stream sediments. The rate of loss of phosphorus from nonsterile sediments was found to be greater than that for sterile sediments, indicating that microorganisms speed up the release of phosphorus from particulate materials back to stream water. These results suggest that phosphorus spiraling involves predominantly biological processes and that the variations in the uptake length are the result of differences in the biological demand for this nutrient. The implications of this are significant because it indicates that phosphorus concentrations in unpolluted streams may be controlled primarily by microorganisms growing on the stream bottom.

Nitrogen

To measure the spiraling length of nitrogen and to identify the mechanisms controlling the spiraling of this nutrient, we conducted similar tracer experiments in Walker Branch and in artificial streams. These experiments involved the use of compounds of nitrogen, in the form of nitrate and ammonia, labeled with ^{15}N, a naturally occurring stable isotope. Because ^{15}N is already present in the environment, with a natural abundance of 0.365 at.%, enough of it must be added to the stream to measurably increase the natural ^{15}N:^{14}N ratio in water and in organisms that take up nitrogen from water. We can then estimate the rates of nitrogen uptake and loss in ecosystem components by measuring changes in their ^{15}N:^{14}N ratio using a mass spectrometer.

Robert Stark, a technician on the project, is a candidate for the master's degree at the University of Tennessee. For his thesis, he is comparing the uptake of ammonia-nitrogen and nitrate-nitrogen in artificial streams. In addition, he is attempting to identify the major pathways taken in the uptake of these two forms of soluble inorganic nitrogen from stream water. He has demonstrated that the uptake of ammonia-nitrogen from stream water is predominantly a biological process. The uptake length for ammonia-nitrogen in an artificial stream that had been sterilized with chlorine to stop biological uptake by algae, bacteria, and fungi in the stream bottom, for example, was over 300 m. In contrast, the uptake length of ammonia-nitrogen in an identical stream channel that had not been sterilized was only 30 m. Thus, although some nonbiological uptake of ammonia-nitrogen occurs in streams, the predominant mechanism of uptake appears to be biological absorption by algae and other microorganisms associated with stream sediments.

Pathways and Mechanisms

By studying the pathways and mechanisms of nutrient spiraling in streams, we are attempting to identify the major mechanisms that enhance the conservation and cycling of essential elements which otherwise would be unavailable to the ecosystem, and also to understand the relationships between the biological structure of stream communities and ecosystem function as reflected in the spiraling of nutrients and the processing of energy. Conservation mechanisms include those that reduce the loss of available nutrients through downstream transport or those that reduce the storage of nutrients in particulate forms that are unavailable to organisms. In our experiments, we are isolating and controlling components of stream ecosystems in artificial streams in order to study their mechanisms and determine their role in nutrient spiraling. In one such experiment, Carole Hom, also a graduate student from the University of Tennessee, will determine the effects of snails on phosphorus spiraling and primary production rates of stream algae. Snails in Walker Branch are the predominant grazers on algae and bacteria growing on rocks and dead leaves on the stream bottom. Some ecologists hypothesize that by grazing on microbial populations, animals such as snails prevent nutrients from being immobilized in senescing algae and bacteria. In other words, animals may perpetuate nutrient cycling in the ecosystem by preventing or reducing the storage of nutrients in forms that are unavailable to other organisms in the system. The suggestion is that if this did not occur, microbial populations could substantially reduce the available supply of nutrients in an ecosystem and thereby reduce its productivity.

Another technique we are using to determine the role of various components of ecosystems in nutrient spiraling is to experimentally manipulate natural streams. Using this technique in a stream at the Coweeta Hydrological Laboratory in North Carolina, we measured the effect of aquatic invertebrates on phosphorus spiraling. We first treated one stream with a pesticide to remove all the aquatic insects. We then compared the spiraling length of phosphorus in the treated stream with that in an adjacent stream that had not been treated with the pesticide. Preliminary results from this experiment showed that removal of the aquatic insects reduced the downstream transport of particles in stream water. These results suggest that the presence of insects in a stream might increase the spiraling length of phosphorus by increasing the downstream transport of nutrients in the particulate phase.

Another integral part of our studies on nutrient spiraling involves the development and use of mathematical models for analyzing nutrient dynamics in streams. Denis Newbold and Bob O'Neill have developed a series of such models which we use both to analyze the tracer dynamics in streams and to examine the relationships between ecosystem structure and nutrient spiraling. Analysis of these interactions is complicated by the fact that physiological processes of stream organisms that could shorten the spiraling length of a nutrient are coupled with other processes that tend to increase the spiraling length. The net effect of these coupled processes on spiraling length, thus, is not intuitively obvious. Insights into their possible effects can, however, be obtained by modeling these processes. Results from these simulation models show, for example, that at reasonable densities the effect of aquatic animal species feeding on decomposing leaves would be to shorten the spiraling length of nutrients, whereas species which feed on other materials in the stream would either have no effect on spiraling length or would increase it. This suggests that the species composition and abundance of animal communities in streams may have an important influence on nutrient spiraling.

The concept that stream ecosystems spiral nutrients supplied from the watershed has a number of applications in analyzing relationships between the biological structure and the metabolism and productivity of streams and rivers. For example, disturbances to streams that affect biological components could adversely affect the ability of streams to spiral nutrients. This being true, measurements of the spiraling length of essential nutrients could be used as an indicator of disturbance in natural systems. Another important aspect of spiraling in streams and rivers is the effect on the loading of nutrients to lakes, reservoirs, and estuaries farther downstream. For example, spiraling may stabilize the productivity of streams by damping the extreme variations in nutrient supplies associated with fluctuating inputs from the watershed. Efficient retention and recycling of nutrients when inputs are high ensures that a stable supply of nutrients is available to the ecosystem when inputs are low. By the same token, spiraling can also be beneficial when nutrient supplies are in excess. Eutrophication of many lakes and reservoirs, for example, is a direct result of increased nutrient inputs to streams and rivers that flow into these systems. Retarding the downstream loss of these nutrients would reduce the loading rate to lakes and reservoirs into which these streams and rivers flow.

We can see, then, that the ability of streams to retain nutrients and to dampen fluctuations in supplies associated with variations in nutrient inputs from the surrounding watershed, regardless of whether the input variations are natural or man-caused, has important implications for the productivity and environmental quality of the reservoirs, lakes, and estuaries into which these streams and rivers flow.

The Continuum

Aldo Leopold, in his perception of nutrient cycling through ecosystems during their downhill movement, revealed a fundamental concept that ecologists are only now beginning to fully appreciate. Considering all types of ecosystems, streams and rivers appear to best illustrate his ideas concerning both downhill flow of nutrients and the importance of organisms and food chains in retarding this flow.

A stream or river can now be seen to be a continuum, extending from its headwaters to the sea. Such ecosystems have no upstream or downstream boundaries between their source and mouth other than those arbitrarily defined by man. Losses of nutrients and organic matter through downstream transport from one point in the continuum are inputs to another part of the same ecosystem. Perturbations that modify the inputs from upstream, then, may have important implications to processes in downstream areas dependent on these upstream inputs. To manage these flowing water ecosystems and preserve them from human impacts will require an understanding of the spatially dependent linkages among the spiraling of nutrients, the processing of energy, and the biological structure of the system.

Forty years ago, Leopold foresaw what we now realize—the need to know the relationships between disruptions or modifications of these ecosystem processes, components along the continuum, and the propagation or damping of the effects further downstream. ornl

BOOKS

John von Neumann and Norbert Wiener: From Mathematics to the Technologies of Life and Death *by Steve J. Heims, MIT Press, Cambridge (1980). 414 pages, $19.95. Reviewed by Len Gray, Mathematics and Statistics Research Section, Computer Sciences Division.*

John von Neumann and Norbert Wiener are unquestionably two of the most prominent mathematicians of the twentieth century. Von Neumann's collected research papers span six volumes, and the range of subjects investigated is truly astounding: logic, set theory, foundations of quantum mechanics, ergodic theory, rings of operators (now called von Neumann's algebras), continuous geometry (invented by von Neumann), design of computers and automata theory, numerical analysis, game theory, and hydrodynamics. Wiener's interests were only slightly less broad: logic, integral equations, the theory of Brownian motion (Wiener integrals), harmonic and classical analysis, prediction and filtering theory, potential theory, and cybernetics (a subject initiated by Wiener). Almost as remarkable as their scientific careers was their emergence, to a certain degree, as public figures—Wiener by his essays (autobiographical and social commentaries) and von Neumann by his leadership in the field of atomic energy after World War II.

Although von Neumann and Wiener were similar in many respects, they differed significantly in their reactions to World War II and the atomic bomb experience and, in a vague sense, on the issue of a scientist's social responsibilities. This issue, as may be discerned from his choice of subtitles, is the author's primary concern. The two men made significant achievements during the war in both the field of mathematical theory and its applications, but Weiner later refused to participate in any military-related projects. Von Neumann, however, became a key scientific advisor to the Department of Defense and other government agencies and eventually became an Atomic Energy Commission commissioner.

Heims begins this well-researched dual biography with excellent chapters on the childhood of each man. A nontechnical description of a small but significant piece of each man's mathematical work then follows: von Neumann's theory of games and his work on the foundations of quantum mechanics, and Wiener's formulation of Brownian motion. These chapters are less successful, and the section on Wiener's work is especially puzzling. Heims concentrates on Wiener's discovery that the Brownian paths are nowhere differentiable (a tangent does not exist anywhere along the path). This finding is certainly of mathematical interest but is by no means the most important aspect of this significant work. In addition to being *the* example of a continuous-parameter stochastic process, Wiener's measure on the Brownian motion curves (and the related Wiener integral) is intimately related to the Feynman integral, which was devised by Feynman to provide an alternate (variational) formulation of quantum mechanics, (Wiener's discovery is now a widely used tool in physics.) As this is another connection between Wiener and von Neumann, and since Heims's background is physics, it is very surprising that this was not the focus of the chapter.

The remainder of the book deals mainly with their lives outside of mathematics proper, especially the postwar period. This is a vast area (particularly for von Neumann) that could easily be the subject of a book on each man. In addition to trying to cover a large subject area, Heims is handicapped by his own prejudices (freely admitted in the preface) which tend to view Wiener as the good guy and von Neumann as the villain. Even a reader sympathetic to Heims's philosophical position is likely to be annoyed by the constant bias and, in some instances, totally unnecessary comments.

Having to shuffle back and forth between Wiener and von Neumann does not aid the flow of the narrative, and Heims's propensity for going off on philosophical tangents does not help matters. His style is not about to make him the Barbara Tuchman of the scientific world. Heims's idea, however, is an excellent one; the role of mathematics in modern society is unexplored territory, and he has chosen new extraordinary subjects. Von Neumann, a mathematical equivalent of Einstein, is virtually unknown to the general public. Unfortunately, the end result is a less-than-definitive study of mathematicians and their mathematics.

The following books in print have members of the ORNL staff as principal authors or editors:

Laser and Electron Beam Processing of Materials, edited by **C. W. White** and P. S. Peercy, Academic Press, New York (1980).

Nuclear Air Cleaning Handbook, by **C. A. Burchsted**, U.S. Department of Energy, 3rd edition (1980).

Maximum Likelihood Estimation in Small Samples, by L. R. Shenton and **K. O. Bowman**, Macmillan Publishing Company, New York (1977).

Selected Tables in Mathematical Statistics, Vol. IV—Dirichlet Distribution-Type 1, by Milton Sobel, **V. R. R. Uppuluri**, and K. Rankowski, American Mathematical Society, Providence, Rhode Island (1977).

Moving Boundary Problems: Proceedings of the Symoposium and Workshop on Moving Boundary Problems, at Gatlinburg, Tennessee, September 26-28, 1977, edited by **D. G. Wilson, Alan D. Solomon**, Paul T. Boggs, Academic Press, New York (1978).

Carroll Johnson, now on leave for a year at the Naval Research Laboratory where he is working in the field of artificial intelligence, is a crystallographer with ORNL's Chemistry Division. He came to ORNL in 1963, four years after earning his Ph.D. in biophysics from the Massachusetts Institute of Technology. In 1975 he took a leave of absence to study the applications of the artificial intelligence of computers to protein crystallographic problems at Stanford University and the University of California at San Diego. In 1977 Johnson served as president of the American Crystallographic Association.

Artificial Intelligence is Coming

Applications at ORNL

By CARROLL JOHNSON

It is always interesting to observe the response of an audience introduced to the research field called artificial intelligence. The very term implies that a computer can be programmed to reason like a person. The concept may seem frightening, preposterous, or stimulating, depending upon the listener's viewpoint, and these reactions are often reflected in the comments from the audience.

The field of artificial intelligence, or AI, is an interesting amalgamation of two dissimilar disciplines, computer science and cognitive psychology. AI is concerned with understanding the logic of human reasoning and with writing computer programs which model human reasoning logic. Research in AI often leans toward one or the other of the two parent disciplines. The psychologist is concerned with discovering the mechanism of human reasoning processes, while the computer scientist is interested in understanding the logic of human problem solving and in implementing that logic through the most appropriate programming methods, without regard for psychological fidelity. My interest in AI follows the latter orientation with a specific interest in the application of AI methods to physical science research problems.

Prominent contemporary research areas of AI include robotics, visual-scene understanding, speech understanding, natural-language text understanding, and knowledge engineering, to name just a few. We at ORNL are most interested in knowledge engineering, also called expert systems. Expert systems programs attempt to model the reasoning used by experts in such diverse activities as diagnosing medical disease, analyzing electronic circuits, and writing computer programs.

Expert systems are called rule-based systems because in order to acquire and store the necessary knowledge and to be able to reason with it, expertise must be coded into situation-action rules (also called production rules) that take the following form:

Pedro Otaduy, Jim Mullins, and Dave Patek, from l., all of the Reactor Control Group in Instrumentation and Controls Division, confer at one of the AI meetings.

IF some set of conditions,
THEN perform some action or reach some conclusion.

To give an example from a mass spectrogram interpreter, IF high peaks are at atomic number/charge points 71, 43, and 86, and IF there is any peak at atomic number/charge point 58, THEN there must be an n-propyl-ketone 3 superstructure.

From Stanford to ORNL

I got started in the field of AI during a year's sabbatical at Stanford University in 1975 and 1976 working with the Stanford Heuristic Programming Project. My role was that of resident crystallographer advisor for a National Science Foundation-funded project undertaken jointly by Stanford University and the University of California at San Diego. The project, CRYSALIS, involved the application of knowledge engineering AI techniques to protein crystallography, particularly for the interpretation of electron density maps. I served as "domain specialist," and my approach to problem solving was observed and modeled for input to the program. This is a common practice in expert systems projects. The role of domain expert is both an interesting and a frustrating experience. It entails, among other exercises, meticulous analysis of the often fuzzy reasoning used in solving day-to-day problems.

Following my return to ORNL, I continued to participate in the CRYSALIS project on protein density-map interpretation. My participation included interactive access to the Stanford SUMEX-AIM computer system over the TYMNET network. The concepts developed during the discussions at Stanford began to take shape here in a running computer program.

Other developments took place at Stanford as well during the intervening period. Experience with the Stanford program MYCIN, an expert system which aids in diagnosing bacterial infections, led to a generalized program called EMYCIN, which in principle could be

University of Tennessee Professor Sara Jordan is employed halftime in the Computer Sciences Division. She is a pioneer in AI.

Karl Heuslein, l., and Jonas Holdeman of Computer Applications in the Computer Sciences Division have supplied the necessary expertise in the computer science area.

applied to almost any consulting problem. Other generalized consulting program systems were developed at other AI centers (such as EXPERT at Rutgers University). The research trend was to determine how useful the new knowledge-engineering methods were in a variety of applications, and it was clear that we should be trying some of those methods on problems at ORNL.

I prepared a research prospectus memorandum outlining several possible knowledge-engineering applications, with a brief background on AI methods, and sent it to managers and researchers in several ORNL and UCC-ND divisions. The response showed that many were interested but that no one group could undertake the proposed project alone. It became clear that the best approach was to gather an interdisciplinary critical mass of individuals interested in AI for an unofficial discussion.

The Computer Sciences Division agreed to let Sara Jordan and Karl Haeuslein spend some time on the computer science aspects of the project. Further inquiry showed that the Analytical Chemistry Division was willing to let Bruce Clark and Michelle Buchanan work part time on a spectroscopy application of AI. The Chemistry Division then agreed to let me head the project, again on a part-time basis. John Allen, a physicist then consulting with the Industrial Safety and Applied Health Physics Division, was another of the founding members. Jonas Holdeman and Bob Meacham of the Computer Sciences Division and Ed Hagaman of the Chemistry Division joined the panel later. The AI Programmed Reasoning Methodology Panel met for the first time on October 2, 1979. Weekly two-hour meetings have been the schedule since then.

In the early stages of the study panel, we concentrated on developing familiarity with basic AI concepts and programs. In addition to studying published articles, we relied heavily on access to the Stanford SUMEX computer for firsthand familiarization with classic AI programs such as PARRY, a paranoid patient modeling program, and MYCIN, the bacterial infection diagnosis program mentioned earlier. We studied in detail a half dozen other expert systems on SUMEX. Much of the fundamental information concerning AI is available only as text files and programs on computers at AI centers or as technical reports issued by various AI computer science departments, so anyone starting research in the AI field without a good connection with an established AI center is at a serious disadvantage.

One of the initial projects undertaken was a tutorial lecture series for the ORNL staff. Sara Jordan and I presented the first few lectures. Professor Jordan did her Ph.D. dissertation in AI at the University of Wisconsin and has been teaching AI courses at the University of Tennessee since then. She works half time at ORNL and was involved in the Russian language machine translation pro-

Steve Hurrell, l., and Davis Hurt, of the Engineering Technology Division, discuss applications of AI for materials control in fuel reprocessing with John Wachter, standing, who is with the Fuel Recycle Division.

ject here in the early seventies. During the first year, eleven AI lectures were sponsored by the panel, of which four were given by panel members and seven by outside lecturers. Most of the outside lectures were part of the consultant program begun in February 1980, when seed money funding became available.

Implementation

We found that several AI expert systems developed elsewhere could be implemented on the ORNL DEC System-10. The first one was the FORTRAN-based consulting system EXPERT, written at Rutgers University. EXPERT is a rule-based knowledge system designed for medical consulting. At Washington University in St. Louis, sets of situation-action production rules specific for medical specialties such as rheumatology have been written for this system. EXPERT uses the rule sets to form chains of reasoning during interactive dialog with the physician, and the system can explain to the physician how it came to any particular conclusion by displaying the rules applicable to the clinical symptoms of the patient. We found two ORNL applications of EXPERT to non-medical problems.

Another rule-based knowledge system operational at ORNL is the Carnegie-Mellon system OPS-5 which is implemented in MACLISP, the Massachusetts Institute of Technology dialect of the programming language LISP. A powerful programming language, OPS-5 is applicable to a broad range of AI problems. There are at least two applications of OPS-5 to problems at ORNL, and Bob Meacham can be credited with the successful implementation at ORNL of EXPERT, OPS-5, MACLISP, and other systems.

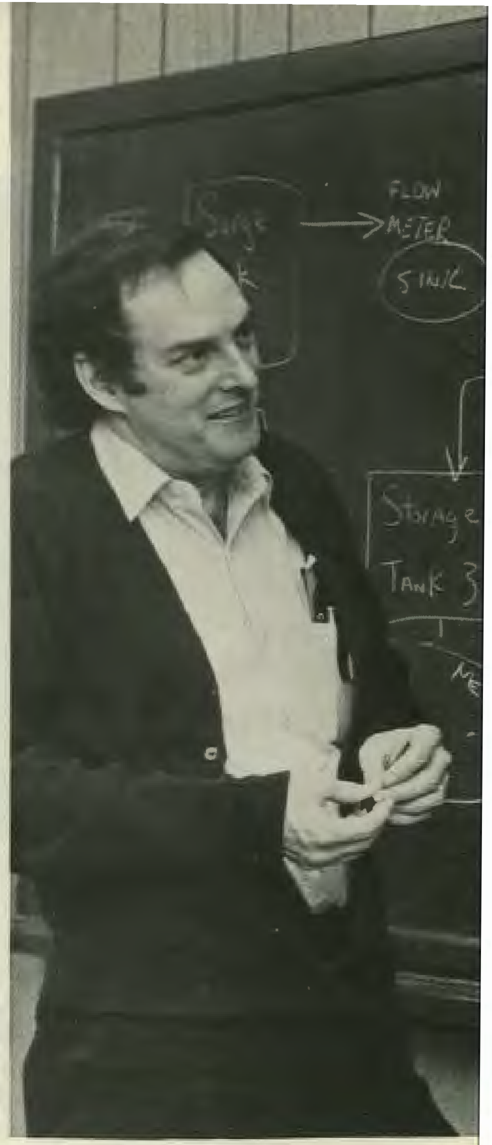
In a major program development, Karl Haeuslein is rewriting the Stanford INTERLISP-based EMYCIN system in Pascal. The Pascal version will permit the writing of consulting systems that run on mini- and microcomputers, thus making the system available to a much wider clientele.

During the first year, we started four application projects in AI in the domains of spectroscopy, environmental management, nuclear fuel reprocessing, and programming assistance.

Spectroscopy

The panel's main project is the spectroscopy rule-based system for the joint interpretation of infrared, nuclear magnetic resonance, and mass spectral data. The spectroscopy experts are Michelle Buchanan, Bruce Clark, Ed Hagaman, and John Allen, with Allen also coding the knowledge rules by using the system EXPERT. Currently, the rule set has about 230 rules and can identify functional groups on organic molecules containing up to 15 carbon atoms. Future plans involve implementing the spectroscopy interpretation system on a minicomputer which can be interfaced to separate IR, NMR, and mass spectral computer-controlled instruments.

The spectroscopy rule set will



Spectroscopy expert Michelle Buchanan, center, has come from the Analytical Chemistry Division to help set up the spectroscopy rule set.

also be useful to check out the ORNL Pascal version of EMYCIN when that system becomes operational. In addition, there are plans for implementing the rule set on the LISP-based OPS-5 system for comparison purposes.

Spill Countermeasures

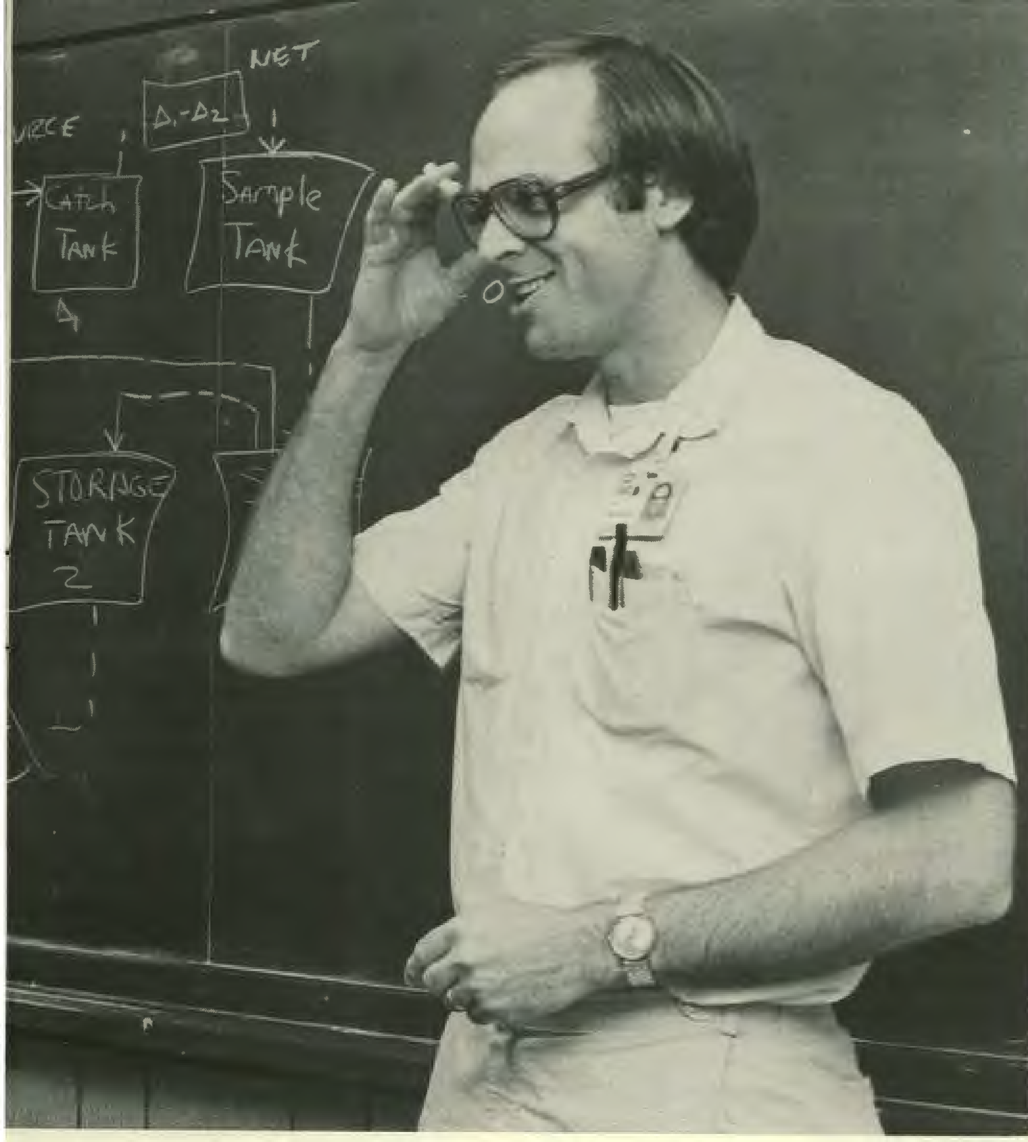
The second major application involves countermeasures for oil and hazardous chemical spills. This project is implemented in collaboration with Tom Oakes, Brian Kelly, and Chris Bird of the ORNL department of environmental management. An emergency response application such as this requires a considerably different approach from that used for the spectroscopy problem. Sara and I made a systematic analysis of the overall problem and wrote an 80-page manuscript describing the problem in detail. This extensive documentation enabled the spills problem to be used as a "mystery focus problem" at Rand Corporation's recent workshop on expert systems, where representatives of eight different expert systems worked on a common problem in a field in which none of the participants had previous experience. The systems represented were AGE, EMYCIN, and RLL from Stanford; KRL from Stanford Research Institute; EXPERT from Rutgers; HEARSAY III from Southern California; OPS-5 from Carnegie-Mellon; and ROSIE from Rand. A detailed documentation of the comparison will appear as a Rand report. Sara and I acted as the workshop's "mystery experts" on spills. The approaches used in solving the problem were very diverse, and several of the resulting systems could provide excellent starting points for an operational spills countermeasures system. The OPS-5 version started at the workshop will be the initial system implemented at ORNL.

Safeguards

The panel's third application is in the area of safeguard monitoring of the chemical processes involved in nuclear fuel reprocessing. The AI part of that project is being carried out by John McDermott and Charles Forgy from Carnegie-Mellon in collaboration with Davis Hurt, John Wachter, and their coworkers from the Oak Ridge Consolidated Fuel Reprocessing Facility. The AI project is funded by a grant from the Department of Defense's Defense Advanced Research Projects Agency (DARPA) to Carnegie-Mellon, so the panel's involvement was simply to bring the two groups together. A group at Carnegie-Mellon is currently analyzing a small subset of the entire problem using data from a recent test run at the Barnwell reprocessing plant. The Carnegie-Mellon researchers will be spending a fair amount of time in Oak Ridge and the panel expects to learn a great deal from watching the project develop.

JCL Advisor

The fourth application is in the programming assistance area, where we hope to see how useful a consulting AI system can be in what amounts to a tutorial application. Using the Rutgers EXPERT system on ORNL's DEC System-10, the application involves a rule set designed to aid International Business Machine users in setting



John Allen, a consultant at the Laboratory from ProPhysica, Inc., discusses a flow chart with CSD's Bob Meacham.

up and debugging their job control language. If the system proves useful, other programming assistance aids such as a graphics program advisor and a magnetic tape advisor may result.

Other AI Applications

AI programming methods are becoming increasingly important in a wide variety of application areas. The Schlumberger Company, for example, has begun a major effort in the application of knowledge engineering to oil exploration. In addition, computer manufacturers such as IBM, Hewlett-Packard, and Texas Instruments are beginning to use AI in the computer-aided design of very large-scale integrated circuits.

The U.S. Navy is developing a Center for Applied Research in Artificial Intelligence at the Naval Research Laboratory in Washington, D.C., where I am currently a visiting scientist on temporary assignment from ORNL. One of several projects under way there is an automated message center, to be used with a strategic operation, that features machine interpretation and assessment of dispatches passing through it. The information derived will update a dynamic model of the overall situation, which in turn may update and reroute the messages. Also planned is work on an AI consultant system coupled with automatic test equipment to help technicians troubleshoot electronic equipment.

Another increasingly active area of AI research is robotics. Industrial applications of robots for tasks such as welding seem to be the only key to survival for distressed industries such as shipbuilding. There are currently over three times as many industrial robots in Japan as in the United States. The spectacular Japanese productivity is providing an industrial impetus—much like Sputnik in the fifties—which may give U.S. robotics research a long overdue boost. The current industrial robots do not incorporate particularly impressive AI reasoning, but that situation may change drastically in the near future. Some research in robotics is going on in the Instrumentation and Controls Division and at NRL. Robots are particularly useful for work in hazardous environments such as high radiation areas (ORNL's interest) and deep-sea submarines (NRL's interest).

Looking Ahead

The ORNL effort in AI is an interdisciplinary exploratory project designed to evaluate the potential usefulness of AI methodology for problems at the Laboratory. A wide variety of projects was chosen to provide as broad an evaluation as possible. The preliminary results all seem very encouraging and one cannot help but predict that eventually AI approaches will have considerable impact on computer programming at ORNL. The influence of AI on medical diagnosis, oil exploration, and a broad spectrum of other activities is beginning to emerge throughout the country. With AI techniques such as the use of heuristic reasoning and rule-based knowledge, programmers can approach unusual and complex problems which previously seemed intractable. ornl

take a number

BY V. R. R. UPPULURI

Dice Experiments Yielding Numbers Divisible by 11, 111, ...

The number of dots that appears on the throw of a standard die can be 1, 2, 3, 4, 5, or 6. If 3 (dots) shows up, then its opposite side has 4 (dots); in other words the total number of dots on the face showing and its opposite side is always equal to 7.

Suppose we throw two dice on a table, and 1 (dot) and 3 (dots) appear face up. Then write the nmber 1364, where 6 corresponds to the opposite face of 1 and 4 corresponds to the opposite face of 3. It is interesting to note that this number 1364 is divisible by 11, and that $1364 = 11 \times 124$. Then divide 117 by 9 and obtain 13, which is the outcome of the original pair of dice. This is true whatever the outcome of the two dice.

The above result can be extended to three dice. Suppose we have the outcome 236; then form the number 236 541, which is divisible by 111 to make 2131; subtract 7 to obtain 2124. Note that $2124 \div 9 = 236$, the original roll of the three dice.

These ideas can be extended to guess at the roll of n dice.

Only True for n = 4, 5, ...

10^{10} is a large number and $10^{10^{\cdot^{\cdot}}}$ is an extremely large number.

Suppose we wish to form the largest number with three twos; then it is easy to see that it is not 222, nor $2^{2^2} = 2^4 = 16$, nor $22^2 = 484$, but it is $2^{22} = 4194304$. Thus

$$2^{22} > 22^2 > 222 > 2^{2^2}.$$

Similarly, if we wish to form the largest number with three threes, then it is easy to see that it is not 333, nor $3^{3^3} = 3^{27}$, nor 33^3, but it is 3^{33}. Thus

$$3^{33} > 3^{3^3} > 33^3 > 333\ .$$

It is interesting to note that this induction stops here. If we have three fours, then

$$4^{4^4} > 4^{44} > 44^4 > 444\ .$$

And for $n \geqslant 4$, n^{n^n} is the largest number that can be formed with three n's.

Emily Copenhaver is a policy analyst in the office of integrated assessments and policy analysis of ORNL's Health and Safety Research Division. She was recently assistant chairman of the Third ORNL Life Sciences Symposium on Health Risk Analysis. At ORNL since 1962, she has served as editor, as information specialist, and, for five years, as director of the Environmental Resource Center and Toxic Materials Information Center of ORNL's Information Center Complex. Phil Walsh is leader of the health effects and epidemiology group of the Health and Safety Research Division. He joined ORNL in 1976 as a research staff member of the Environmental Sciences Division. From 1968 to 1976 Walsh was radiation physicist at the National Institute of Health's National Institute of Environmental Health Sciences and served as adjunct assistant professor at the University of North Carolina, from which he earned his master's and doctorate degrees. His training and interests include physics, health physics, industrial and air hygiene, public health, epidemiology, inhalation toxicology, and biomedical engineering. Here the authors rest between sessions at the Health Risk Analysis symposium in Gatlinburg.

HEALTH RISK ANALYSIS

Science, Politics, and Public Concern

By EMILY COPENHAVER and PHIL WALSH

Every day we face risks from the food we eat, the liquids we drink, the air we breathe, the cars we drive, the sports we play, and even the jobs we hold. From our morning meal of eggs with cholesterol, bacon with nitrites, and coffee (latest on the carcinogen-of-the-month list) to an after-dinner beer or cigarette, we are bombarded with risks to our health, making it difficult to judge which danger we dread the most.

How can we balance the risks and benefits of the drugs and chemicals we use daily? What are the risks to the health of people exposed to the toxic chemicals buried at Love Canal in Niagara Falls, New York? Is it possible to analyze the extent to which suspected carcinogens (substances producing or inciting cancer) actually contribute to the nation's number two cause of death? Which is more dangerous: a cup of coffee, a cigarette, a saccharin-sweetened diet drink, hair dye, emissions from diesel engines, or asbestos in consumer products?

"The search for an accurate way of measuring [health] risks is a risk in itself, a risk all of us Americans—indeed, all human beings—share." Ruth Clusen, Assistant Secretary of DOE for Environment, used these words at the Third ORNL Life Sciences Symposium on Health Risk Analysis to sum up the vital stake that scientists, politicians, and the public at large have in health risk analysis. Despite clear evidence that by most simple measures health is better now than it was 100 years ago and is still improving, the public has become increasingly sensitive to many dangers not considered or not in existence 100 years ago.

Richard Wilson of Harvard believes that the public is reacting to the greater attention now being given to risk and to the large number of risks we now consider

"The search for an accurate way to measure risks is a risk... all human beings share."

Ruth Clusen, DOE

regulating. Both Wilson and Chet Richmond, ORNL's associate director for biomedical and environmental sciences, believe that educating the public about risks is an important step toward making regulation of risk taking clearer and more effective, since risk decisions are ultimately made by the public. Indeed, it may even be said that more widespread understanding of the subject, with the resultant effect on public action, could actually work toward reducing risks. The public is vitally concerned, and the news media provide them with much of what they know about risks. If scientific facts regarding a risk are not clearly explained or put in the proper perspective, neither the public nor its elected representatives can be expected to understand and correctly use such data in making informed decisions about the risk.

Risk analysis for decision making must include scientific data collection, assessment and comparison, and a societal decision as to what risks are acceptable. Scientific issues should be separated from value judgment issues, and the resolution of issues should be left to the appropriate decision makers. Scientists must develop the needed data and logical risk methodologies to the highest degree possible, and the public and political decision makers must use these approaches to assist in making their decisions.

Legislative Approaches

Given that public sentiment and congressional action, among other forces, demand that some method be developed to measure or estimate risk in general and health risk in particular, the best approach to risk analysis has yet to be identified. Both Tom Moss, a member of the congressional staff, and Dick Bates, of Clement Associates, subdivide the wide range of approaches that have evolved from some 34 health-related laws into these major categories:

- risk as the only criterion (e.g., Delaney Clause),
- technological feasibility criteria (e.g., Clean Air Act), and
- costs and/or risks vs benefits (e.g., Toxic Substances Control Act).

The first category, in which risk is the only criterion considered, is often called the zero-risk approach. The Delaney Clause of the Food, Drug, and Cosmetics Act (1938) is the best-known example of this approach; the clause prohibits the deliberate use of any food additive shown to be carcinogenic. When the clause was added to the act in 1958, science could not determine "safe" levels of a carcinogen, and Congress expected the question of chemical carcinogens in food to arise rarely. Now that the number of chemicals thought to be positive carcinogens has risen from 10% of those tested in 1958 to 80–93% of those tested today, the Delaney Clause has become highly controversial. Though the Delaney Clause, or zero-risk approach, has been well publicized, only 7 of the 34 health-related laws employ this approach.

The second category, that of the technological feasibility criterion, or "best available technology," calls for the reduction of risk as much as possible via application of the best control systems technology can offer, such as scrubber systems for pollutants being emitted by power plants. The Clean Air Act is one of two laws using this approach.

The third category, which balances costs or risks against benefits, gives discretionary authority, in varying degrees, to the regulatory agencies so that they can perform risk analyses including criteria such as total exposure to the public, environmental effects, availability of substitutes, and economic consequences. This approach is the most common; 25, or 74%, of the laws specify some form of balancing risk and cost. While it represents the most logical framework, it requires a wider range of valid data and is subject to broad and often inconsistent interpretation by regulators and even by the judicial system in those cases where differing views have led to litigation. A good example of an

Copenhaver

Dick Wilson, Harvard

Ellie Huberman, Biology

Herman Kraybill, NCI

Ian Munro, Canada

Norton Nelson, NYU

ideal balanced approach is Wilson's organizational framework, with all analysis stopping if the risk is calculated to be very small, a circumstance referred to as "de minimus risk." Richmond points out that still at issue is how small is "very small": according to which group or person, and how do we establish qualitative or quantitative reference systems that can be used by others to make the "very small" decision or comparison?

While Congress has attempted to legislate the best and most sophisticated risk analysis methodologies available at the time the laws have been enacted, Fred Hoerger of Dow Chemical Company argues that this evolutionary approach to risk analysis, while consistent to some degree with the state of our health effects-testing technology, has deterred the development of comprehensive risk analysis by legislating very specific approaches into law. He classifies the congressional approaches by the following categories and notes their limitations:

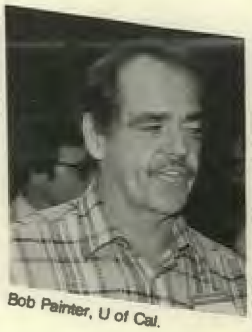
- Yes/no classification of hazards—Decisions that sanction either outright ban or uncontrolled use. This approach is too simplistic, given today's knowledge of health effects.
- Presence or absence—Same as the first category except that it pertains to a hazardous substance contained in a product rather than to the entire product.
- Burden of proof—Difficult to prove the safety or degree of risk definitively in accordance with legal concepts such as burden of proof.
- Weight of the evidence—Examines the quality of available information but fails to integrate all data in making judgment.
- Criterial definitions—Sets standards based on key area, but denies evaluation and balancing of *all* data.
- No-effect level plus safety factor—Uses a generic assessment of safety, with little case-by-case consideration and data collection.

Just as there are those who use and trust risk analysis, there are also those who say that risk analysis is not sufficiently developed to be used in decision making, that it merely appears to present a rational approach to regulation without identifying the underlying uncertainties that sometimes make it suspect. However imperfect the data and methodologies may be, they continue to be used because complex decisions must be made *now*. How then can we improve our data, methodologies, and their use in decision making?

More Data Needed

Much of the uncertainty in risk analysis stems from a lack of crucial data about the populations at risk and their exposures from all sources; about the effects of concurrent exposure to many different pollutants in many different media such as air, water, and food; and about the predictive capability of biological testing, such as animal, cellular, and subcellular bioassay, as well as human studies. Regulatory agencies, such as the Environmental Protection Agency, require information that can be immediately useful to decision-making authorities. Unfortunately, many of the experiments of the seventies have not been designed to develop the data needed for comprehensive risk assessment: much of the animal bioassay testing for carcinogenic risk only indicates a yes or no answer, not quantification of the risk, and exposure studies have focused on the number of people associated with a chemical or toxic agent, without comprehensive exposure profiles. These comprehensive exposure profiles require several types of data: ambient monitoring (e.g., air and water), exposure models to link specific uses or releases of a chemical to exposure, monitoring of exposed human tissues, and development of surrogate approaches, such as when the behavior of one chemical may be predicted using the known behavior of a structurally related chemical.

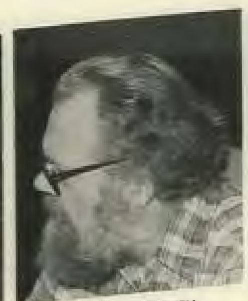
The health risk analysis symposium addressed these uncertainties by examining the scientific basis of human health risk estimates from


Bob Painter, U of Cal.


Dick Bates, Clement Assoc.


Betty Anderson, EPA


Ken Chu, OSHA


Bob Cumming, Biology


Dennis Parzyck, HASRD

biological effects data gleaned from epidemiological and clinical-laboratory studies, animal bioassays, cellular and subcellular tests or screening systems for toxicological effects, and dose-response models. Though the full review of methodologies and their applications, advantages, and limitations are available in the proceedings, published by Franklin Institute Press this spring, some of the appraisals of these methodologies are highlighted here.

Epidemiology, that is, the study of the incidence, distribution, and control of disease or pathogens in people, tends to take three forms: (1) concern with occupational groups where workers may have experienced concentrated and long-term exposure to potentially hazardous substances, (2) case-controlled studies for investigating illnesses which occur with relatively low frequency, and (3) indirect studies that compare vital statistics data on groups rather than individuals, usually grouped by geography, ecology, or some other category. Epidemiologic methods identify moderate to high levels of risk reasonably well but are weak in detecting low levels of risk because such detection requires very large population groups. Much of the epidemiology of the 1970s has been directed at identifying whether evidence of cancer has increased in various defined human populations, suggesting a cause-and-effect relationship, but enough data to validate the estimate of risk is lacking. Ian Nisbet of Clement Associates expresses the need for more quantitative documentation of the circumstances in which people come into contact with chemicals, whether in their jobs, in food or other consumer products, or in the environment generally.

The use of laboratory animal bioassays to estimate human risks provides at least a qualitative surrogate for humans, and lifetime exposures of mammalian test species are a generally accepted method of estimating human risk. Steve Gage of the EPA believes that methods available for estimating chronic toxic effects from short-term, in vivo exposures must be examined to learn if they can quantitatively predict long-term effects of exposure. However, Bates questions the ability of bioassays in experimental animals to provide sufficiently accurate data without the use of a prohibitively large number of animals, and states that attempts to devise general principles of dose response from these bioassays have been unsuccessful. Osterman-Golkar of Stockholm University points out that among the major difficulties in extrapolating data from animals to man are the qualitative and quantitative differences in how different species metabolize and respond to toxic agents.

Bates notes that cellular and molecular studies may be used to extend dose-response curves to lower levels because "the ability to detect changes in a few cells among hundreds of thousands or in a relatively few molecules from a large target population should permit dose-response studies of much greater sensitivity than is possible when looking for a few tumors in a few hundred animals at most. Pharmacokinetic studies should give better information on effective exposure of target cells than can be obtained from the dose administered."

Many in vitro testing systems are available, and tier testing schemes including cellular-level and higher-level organisms have been designed to rank chemical toxicants. However, no accepted methodology is available for extrapolating the results to determine human health risks.

Paul Ts'o of Johns Hopkins University has outlined the extensions or extrapolations of data from cellular and subcellular studies to quantitative human risk analysis, the most important being the extrapolation across the organizational barrier from molecules and cells to living, individual animals and from results obtained between different mammalian species (i.e., animals and humans). Ts'o says future studies should focus on investigating human cells, on comparative studies of the

Kenny Crump, SRS

"... when ... estimates are used to set regulatory standards, the regulated industries may reasonably question the validity of basing regulations on data this uncertain."

extrapolation across the organization barrier in an appropriate mammalian model, and on the extrapolation from human cells to man as a whole.

Further study by Dick Albertini of the University of Vermont on mutation in human cells demonstrates the advantages of direct in vivo testing of human cells. It allows

- metabolic and pharmacokinetic realism,
- measurement of genotoxic effects of actual environmental mixtures of agents,
- detection of individual differences in genetic susceptibility to environmental agents, and
- mutation data for individuals which can be correlated with their health, revealing whether the test predicts human disease.

Throughout the discussion of these experimental testing schemes, we have addressed the relationship of exposure, or dose, to the response of the agent studied. There are also statistical procedures or mathematical models that relate the probability of a response to the dose rate. These models assume that each individual in the population has his own tolerance to the test substance, and the choice of the tolerance distribution is largely arbitrary. Using such models, Ian Munro of Health and Welfare, in Canada, has demonstrated that a virtually safe level of exposure may be defined by determining the acceptable amount of added risk above background exposures.

Munro, B. Altshuler of New York University, and others note that the state of the art is not advanced enough to allow the choice of any one model with confidence. The shape of the dose-response curve at moderate and high doses does not continue for the low-dose response, so Altshuler argues that the models do not reflect true behavior at low doses. Altshuler seeks to preselect the dose-response curve in the low-dose range on theoretical and mechanistic grounds, rather than extrapolating through use of a dose-response model whose shape is controlled by the available experimental data.

Kenny Crump of Science Research Systems, on the other hand, believes that a multistage model with a linearly extrapolated low-dose relationship can be used to estimate cancer risk from low doses using animal bioassay data. He notes that differences in extrapolated values in the range of an order of magnitude are not large when compared with the large uncertainty associated with the total process of estimating low-level human risks from animal data. However, when such estimates are used to set regulatory standards, the regulated industries may reasonably question the validity of basing regulations on data this uncertain.

Where do all these conflicting views and uncertainties leave us in applying health risk analysis in decision making? Obviously we cannot as yet give individuals a "hazards counter" that can be used for counting hazards like a calorie counter counts calories so that one does not exceed his approved daily intake. We can still attempt to compare these health risks in an orderly fashion. Though risk analysis may not yet be without drawbacks, perhaps Fred Hoerger focuses on the basic issues:

> We will make great progress in the next few years in sound and comprehensive risk assessments if we, as scientists, insist upon peer review of our experimental programs and if we are aggressive and comprehensive in our design of the data generation needed for a sound risk assessment. Perhaps more important, we must become active in the policy arenas and insist upon the time to get adequate data for sound risk assessment. It is very superficial to argue whether or not risk assessments are valid if we do not focus discussions upon the generation and quality of data needed for sound risk assessment. ornl

Health Risk Analysis at ORNL

A growing realization of the political nature of policymaking and the need to communicate effectively has led to increased activity in risk analysis. Many organizations are beginning to examine what constitutes risk; others are identifying ongoing work that is risk related. At ORNL, an integrated health risk assessment program has been identified as a new initiative in the Institutional Plan for Biomedical and Environmental Sciences, even though ORNL has engaged in risk-related research and development for many years.

The mammalian genetics section of the Biology Division under Bill and Liane Russell was founded about 30 years ago to use mouse experiments to estimate human genetic risk from ionizing radiation. It is now also evaluating the genetic toxicology of environmental chemicals. This is only one example of how the Laboratory's Biology, Health and Safety Research, and Environmental Sciences divisions, in collaboration with many other divisions—Analytical Chemistry, Chemical Technology, Computer Sciences, and Information, to name a few—have collected basic data and developed and applied health and ecological risk assessment methodologies for many years. Over 200 assessments of energy technologies and various components thereof have been completed, and the Laboratory has expertise in almost every area of risk assessment.

A need to focus on potential human health problems was recognized and organizationally accommodated with the establishment of the Health and Safety Research Division. A component of HASRD's responsibility is to develop methodology and perform human health risk analyses. The health effects and epidemiology group under Phil Walsh in HASRD's health studies section is charged with two primary goals: (1) development of comprehensive health risk analysis methodologies for comparison of energy technologies on a common scale, and (2) development of a collaborative supporting research capability to test models in the analytical methodology and to collect timely data for specific assessments. Members of the group possess expertise in many areas covered at the symposium, including mathematical modeling, dosimetry, and epidemiology. Research in every area except epidemiology is conducted in collaboration with other divisions to focus a broad range of research on assessment methodology development. An example of this collaborative effort is the research on human cells being conducted by Guy Griffin of HASRD, Dave Novelli of the Biology Division, and Alan Solomon of the University of Tennessee Memorial Research Hospital. The diversity of disciplines represented in this group requires that their methodology development and testing be an integrated process.

In addition to the mammalian genetics, the cellular and comparative mutagenesis programs under Jim Epler in the Biology Division are examining short-term assays and comparison of systems, the correlation of genetic damage in vitro and in vivo, and extrapolation of test data to man. Mike Fry's carcinogenesis toxicology programs are addressing the dose-response relationship in chemical carcinogenesis.

Bob Cumming in Biology has served as chairman for a group establishing an international society for risk analysis and serves as editor of its new quarterly journal, *Risk Analysis*, published by Plenum Press. Chet Richmond, Ram Uppuluri of the Computer Sciences Division, and George Flanagan of the Engineering Physics Division are members of the steering group. The first issue of *Risk Analysis* appears this spring.

Curtis Travis and Liz Etnier of HASRD recently co-chaired a session on health risks associated with energy technology at the American Academy for the Advancement of Science annual meeting in Toronto. This session dealt with public perception of risks; risks specifically related to the nuclear, coal, and renewable energy fuel cycles; and risks of energy production on a global scale (e.g., CO_2 and acid rain). The proceedings will be published in book form later this year.

In view of the growing emphasis on this work at ORNL, Richmond has appointed a task force to establish the ORNL strategic program plan for risk assessment. The task force will work to expand and develop risk-related activities across the entire Laboratory. They will consider the components of a risk analysis program, methodology development, the resources required, potential funding sources, and linkages to developing energy technologies. Members are HASRD's Herbert Inhaber, chairman; Conrad Chester, Energy Division; W. A. Coghlan, Metals and Ceramics Division; Doug Crawford, HASRD; Jim Epler; George Flanagan; Tim Ensminger, Information Division; Carl Gehrs, Environmental Sciences Division; Elwood Gift, UCC-ND Operations Analysis; Ruth Gove, Information Division; Harry Hoy, Energy Technology Division; Helen Pfuderer, Central Management; and Walsh.

information meeting highlights

This high-resolution transmission electron micrograph shows the lattice planes in three grains of silicon nitride and an amorphous region (no fringes) at the intersection of the three crystalline grains. ►

Metals and Ceramics, Nov. 12–13

Reactor Materials and Analytical Electron Microscopy

When an electron beam interacts with a solid material (such as phosphors on a television screen), an array of signals is produced. The only signal the TV viewer cares about is composed of photons of light that make up the picture. However, metallurgists studying various materials are interested in all the signals emitted in response to the impingement of an electron beam on a specimen, because these signals contain information about the composition and structure of that specimen.

To capture and analyze the majority of these signals, metallurgists are now turning to the relatively new, powerful techniques of analytical electron microscopy. These techniques complement conventional transmission electron microscopy, which provides structural information at resolutions of 0.2 nm (2 Å) by additionally providing compositional information at 10-nm spatial resolution.

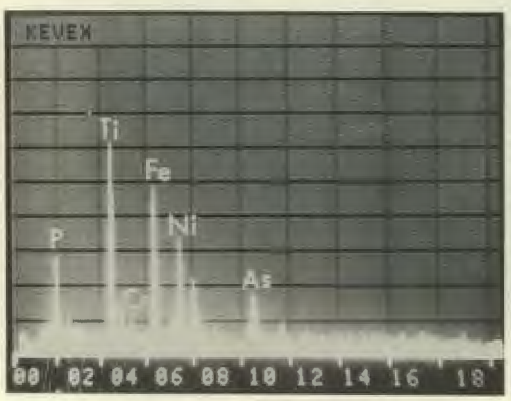
Jim Bentley (task leader), Phil Sklad, Ed Kenik, and Alex Fisher of the Radiation Effects and Microstructural Analysis Group (REMAG) in ORNL's Metals and Ceramics Division have made significant strides in improving and applying AEM techniques to understand the structure and composition of various alloys and materials that are potential candidates for energy facilities, such as breeder reactors, fusion devices, and coal conversion plants. Their AEM studies have revealed information on the structure and composition of the minute microstructural features that influence an alloy's properties.

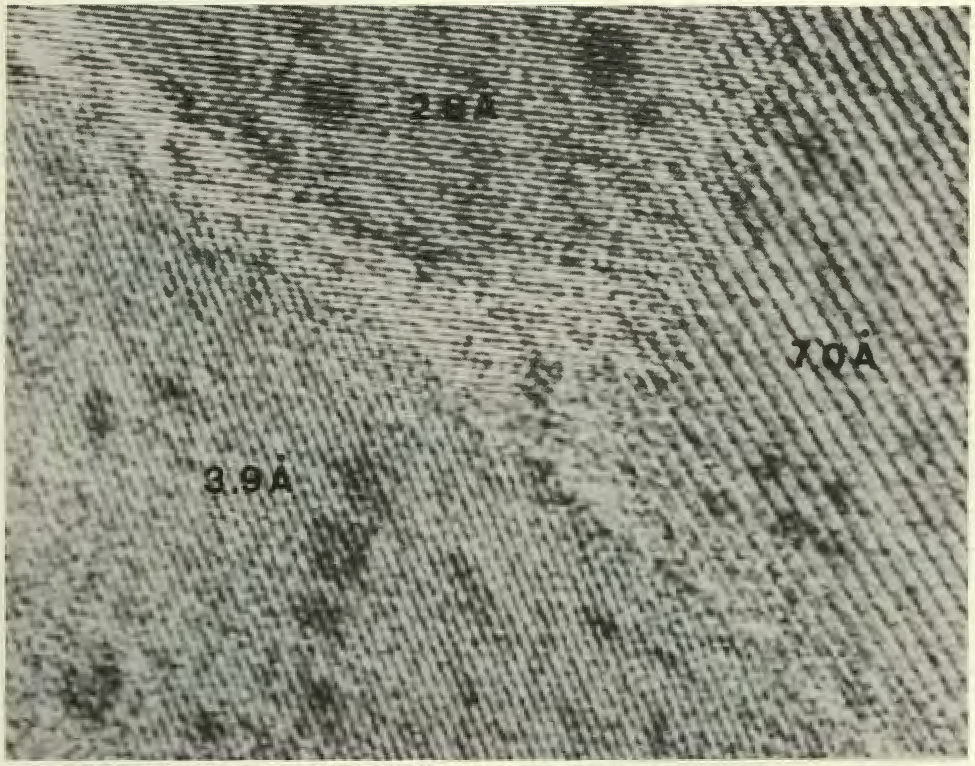
One of the targets of AEM studies at ORNL is precipitates in alloys. When an engineer chooses a stainless steel for some structural component, what he asks for is not necessarily what he gets. For example, he may want a steel that contains 2% titanium because a deliberate addition of titanium strengthens steel. However, during the manufacturing process and subsequent thermal aging, some of the titanium may react with atmospheric nitrogen to form titanium nitride, an undesirable precipitate that degrades the alloy's performance. Undesirable precipitates may also be formed when stainless steels are irradiated in breeder or fusion reactor environments.

Recently, Arthur Rowcliffe and his associates in REMAG found as many as 16 different precipitates in irradiated type 316 stainless steel, which can alter the chemical and mechanical properties of the steel. Of these, some precipitates create voids that make the steel more susceptible to cracking and swelling, while others may reduce these effects. In fact, in 1975, Rowcliffe and his colleagues found that adding elements such as silicon and titanium in the right amounts to type 316 stainless steel can make the material resistant to swelling during neutron bombardment. Consequently, this modified steel is a candidate material for future breeder and fusion reactors.

An understanding of which metallurgical processes eliminate undesirable precipitates and which processes enhance the formation of beneficial precipitates such as titanium carbide could facilitate determining how to make new radiation-resistant alloys with potentially longer lifetimes in reactors. The AEM methods

Precipitates extracted from a specimen of type 321 stainless steel are shown in this micrograph. In the energy dispersive x-ray spectrum at right, we are shown the composition of part of the precipitate arrowed in the micrograph, revealing it to be a complex phospho-arsenide.





have been used to identify precipitates and to resolve the fine details of structural and compositional changes that occur in an alloy after irradiation. Because there is a correlation between each alloy's microstructural details and its properties, ORNL researchers, by analyzing the structure of alloys with different properties, may now be able to design an alloy with more favorable properties such as improved resistance to swelling and fracture.

The members of REMAG have also used their microscopic techniques to study ceramic materials such as silicon nitride, silicon carbide, and composites of titanium diboride and nickel.

Sklad has been working with Vic Tennery, also of the M&C Division, in studying titanium diboride, a potential cutting-tool material because of its hardness and resistance to wear. The appeal of titanium diboride as a cutting-tool material is that it could replace the currently used material consisting partly of cobalt, a metal of strategic importance which is imported from nations not always friendly to the United States. Titanium diboride bonded with nickel is under study at ORNL because it also is a potential candidate for letdown valves in coal liquefaction plants, where the structural components are subjected to the abrasive effects of solid particles in high-temperature liquids and gases. Sklad has been using AEM to examine the composition of the phases present and the interfaces between the titanium diboride and binder phases to determine what changes might be needed to strengthen the bonding and improve the properties.

To probe the structure and composition of alloys and ceramics, Bentley and his team are concentrating on quantitative analysis of three of the "signals" produced when the 120-keV electrons in a 10-nm-diam beam strike the target material. Although some electrons are backscattered, most of the electrons pass through the thin (~100-nm) specimen and either are elastically scattered into diffracted beams or undergo small energy losses in inelastic collisions. One important inelastic-scattering process involves inner-shell ionization of the target atoms which then decay from their excited state by emitting Auger electrons or x rays. The spectra of x rays from the specimen are detected by energy dispersive x-ray spectroscopy, and provide compositional data accurate to 2% when the x-ray intensities characteristic of each element are analyzed using an on-line minicomputer. To date, EDS has been the most often used technique.

The second process, electron energy loss spectroscopy, is not quite as accurate as x-ray analysis, but it is the principal method for detecting elements lighter than sodium, such as carbon and oxygen, which play important roles in many precipitates and are major constituents of ceramic materials. The energy lost by electrons that have passed through a thin specimen is analyzed by a magnetic spectrometer (the lower the electron energy, the more the electron beam is deflected by the magnet). Compositional data are again available from intensities at the characteristic energies for inner-shell ionization and again require computer analysis. The EELS identifies carbon, for example, by detecting those electrons which, in penetrating the specimen, have lost an energy of 283 eV—that required to eject an electron from the K shell of a carbon atom.

The third microanalytical technique makes use of electrons diffracted by the specimen to form a convergent-beam-electron-diffraction pattern, from which information on the specimen's crystalline structure and atomic arrangement is available. Various problems require the use of different microanalytical techniques, but the power of AEM lies in the use of many signals simultaneously from regions of the specimen with a mass of only 10^{-19}g.

Working at magnifications of 4.8×10^5 times to resolve the lattice planes in stainless steels, Bentley has also studied how precipitates fit into the crystalline structure of the steel and how misfits are accommodated by interfacial dislocations. A better understanding of the structure of boundaries between the matrix and precipitates can contribute to finding ways to design alloys with improved properties.

Kenik uses a high-voltage electron microscope to do in situ studies. For example, he may oxidize or strain a specimen while observing it with his 1 MeV instrument to see what happens to its structure. Kenik is also responsible for the share program, which is a cooperative effort with Oak Ridge Associated Universities whereby university researchers work with the analytical systems in the M&C Division in collaborative experiments with REMAG metallurgists.

Although Bentley and his colleagues are searching for the very small, their findings could well have a large influence on the types of materials that will be used in energy facilities of the future.—Carolyn Krause

awards and appointments

The East Tennessee Chapter of the Society for Technical Communication has announced the winners of this year's competition. Entries were solicited from areas where no competition is held and included, as always, those from nonmembers as well as members. Consequently, entries were submitted from more than half the states in the Union. As was done last year, the local competition was judged elsewhere, this year by the Miamisburg, Ohio, chapter. The following ORNL staff members were winners.

In the topical reports category, first prize, Engineering Technology Division, **Larry Wyrick** and **Ann Ragan** for the division's *Long-Range Plan, 1980–85*; second prize, **Elizabeth Giddings** and ORNL's Technical Publications Department for *Workshop on the Global Effects of Carbon Dioxide from Fossil Fuels*; and fourth prize, ORNL's Technical Publications Department, Program Planning and Analysis Office, and **Colin West** for ORNL's *Institutional Plan, FY 1980–FY 1985.*

In the annual reports category, first prize, Lamar Toomer of Oak Ridge Gaseous Diffusion Plant, **Charles Carmichael** and **Ginger Turpin** for *Uranium Enrichment 1979 Annual Report.*

In bulletins and brochures, second prize, **Charles D. Scott** and **Amy Harkey** for *Symposium Announcement and Call for Papers: Third Symposium on Biotechnology in Energy Production and Conservation*; third prize, **Sherry Hawthorne** for *Information Center Complex-Information Division*; also third prize, **Hawthorne** and **Alice Richardson** for *Atomic and Plasma Physics Research Program.*

In journals, second prize, **William Cottrell**, the Nuclear Safety Information Center, DOE's Technical Information Center, **Ragan**, and **Jane Parrott** for *Nuclear Safety.*

In house organs, first prize, **Barbara Lyon, Carolyn Krause,** and **Bill Clark** for the *ORNL Review*, Spring 1980; also third prize for *ORNL Review*, Summer 1980.

In newsletters, first prize, **Susan Buhl**, for *Lab News*, August 1980; also second prize for *Lab News*, September 1980; another second prize, Toomer, **Carmichael,** W. R. McCauley, and Kim Sneed for *United States Enrichment News*, March 1980.

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In journal articles and conference papers, third prize, L. P. Leach, G. D. McPherson, ORNL's Nuclear Safety Information Center staff, **Ragan**, and **Parrott** for "Results of the First Nuclear-Powered Loss-of-Coolant Experiments in the LOFT Facility" (from *Nuclear Safety*).

In periodic progress reports, first prize, ORNL Engineering Technology Division Reports Office and ORNL Graphic Arts Department for "Poster Sessions: Engineering Technology Division 6th Annual Information Meeting, September 17-19, 1980."

In handbooks and manuals, second prize, **AnnaJo Shelton, Greg Whitt**, and ORNL's Technical Publications Department for *Guide to the Nuclear Standards Program*, by the Nuclear Standards Management Center; third prize, ORNL's Nuclear Data Project for *1979 Recent References (Cumulation)*.

And, finally, in news articles, first prize went to **Buhl** for "Interest in Mt. St. Helens Erupts at ORNL" (from *Lab News*), and third prize to **Carolyn Krause** for "RIBS: A Gain for Solar" (also from *Lab News*).

James L. Scott has been elected a fellow of the American Society for Metals.

Bill Burch has been appointed director of the newly formed Fuel Recycle Division. He will continue as director of the Consolidated Fuel Reprocessing Program Technical Management Center, an office that reports directly to the Department of Energy.

Loucas G. Christophorou has been named a Corporate Research Fellow of Union Carbide Corporation.

Phil Perdue has been presented with the Distinguished Service Award of the East Tennessee Chapter of the Health Physics Society in recognition of his outstanding contributions to the technical advancement of health physics in the form of nuclear instrumentation development.

John Sheffield has been named associate director of the Fusion Energy Division.

C. Y. Wong has been named to the editorial board of the new magazine, *Chinese Physics*.

Guven Yalcintas is chairman of the Organ Dose in Nuclear Medicine Committee, part of the American Nuclear Society's Biology and Medical Technology Group.

Pedro Otaduy has been awarded one of this year's Eugene Wigner Scholarships. He will be employed in the Instrumentation and Controls Division.

Fred Mynatt is replacing **Herb Hill** as director of the Instrumentation and Controls Division, following Hill's acceptance of a position with Beckman Instruments, Inc., in Fullerton, California. **Pete Lotts** will assume Mynatt's former responsibilities as director of the Nuclear Regulatory Commission programs at the Laboratory. **Tom Row** will replace Lotts as director of Nuclear Waste programs.

Fred Hartman, Lew Keller, Warren Masker, Salil Niyogi, Audrey Stevens, and **Dorothy Skinner** have been elected fellows of the American Association for the Advancement of Science.

Dick Hahn is the new chairman-elect of the American Chemical Society's division of nuclear chemistry, and **Joseph Peterson** is its treasurer.

Newly elected fellows of the American Physical Society are **Frank Plasil, K.T.R. Davies**, and **Nobuyoshi Wakabayashi**.

Tsuneo Tamura has been named Fellow of the American Society of Agronomy and the Soil Science Society of America.

OAK RIDGE NATIONAL LABORATORY *REVIEW*
P.O. Box X, Oak Ridge, Tennessee 37830

While on leave from ORNL at the Basel Institute for Immunology, Stan Leibo stored rabbit embryos in liquid nitrogen (–190°C) for several weeks, and then transferred them to the uterus of an albino "foster" mother, who subsequently gave birth to the dark baby rabbits shown here. (See p. 8.)