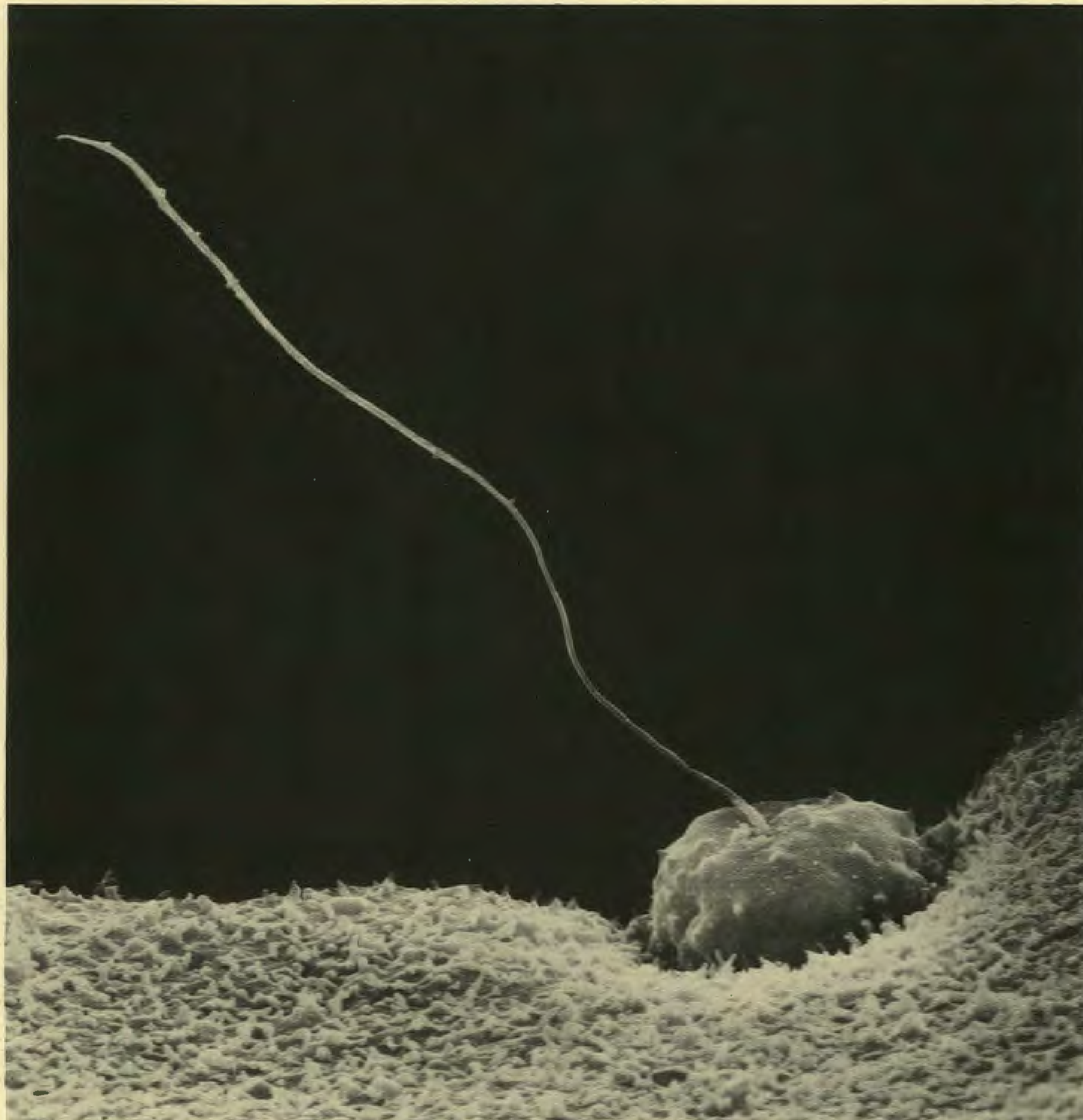
Winter 1981

Oak Ridge National Laboratory review



THE COVER: A team working with the scanning electron microscope in Jim Dumont's laboratory in the Biology Division has managed to catch the precise moment of fertilization of an egg. Anna Ruth Brummett and Carole Richter, along with Dumont, took this extraordinary picture of the beginning of life for a fish (Fundulus heteroclitus), *in which the sperm has just penetrated the egg. For more SEM work at the Laboratory, see the article on the facing page.*

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review

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DEPARTMENTS

OAK RIDGE NATIONAL LABORATORY
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Bob Crouse leads the metallography group of the Metals and Ceramics Division, which he joined in 1949. He has been involved in electron beam microanalysis since 1965, and he is now a member of the Microbeam Analysis Society, is membership chairman of the International Metallographic Society, and is a member of the Committee on Metallography of the American Society for Nondestructive Testing. He is shown here with Barbara Ashdown, former technical editor on assignment to the Metals and Ceramics Division from the Information Division, at one of Metals and Ceramics' two scanning electron microscopes. This is also the only one at ORNL capable of handling highly radioactive samples (up to 0.0258 C/kg·h of β and γ radiation). This shielded SEM is a modified, small commercial unit. The sample chamber has been interfaced through a transfer device with a shielded cubicle, where the researcher readies samples for insertion into the SEM. A steel blister shield of 50-mm (2-in.) thickness surrounds only the sample chamber, allowing easy access to the electron gun for filament changes. An optical periscope, the secondary electron detector, and an energy-dispersive x-ray spectrometer penetrate the shield. Extending and redirecting the stage controls allows stage manipulation by the operator. Additional lead-brick shadow shielding protects the operator from the ionizing radiation from irradiated stainless steel, one frequently examined type of sample. To date, little radiation damage to the detectors and internal mechanism has been observed.

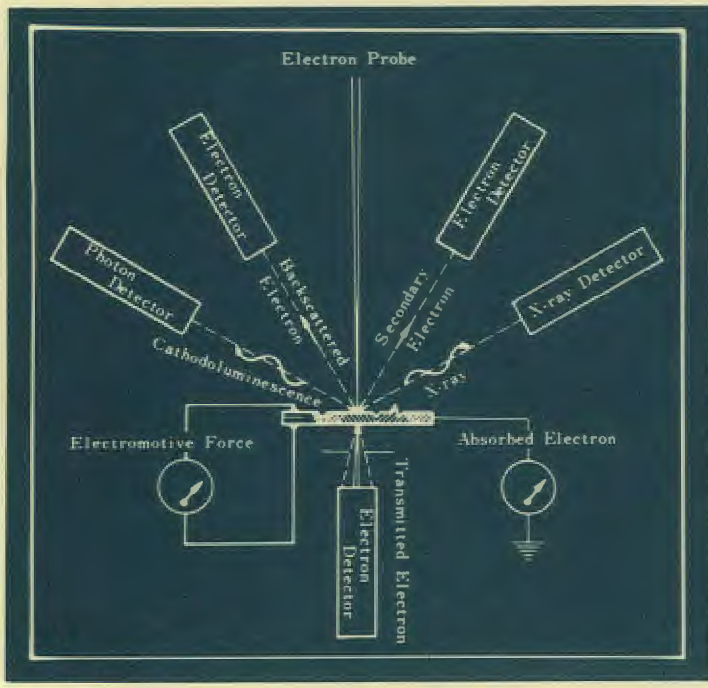
SEM AT ORNL

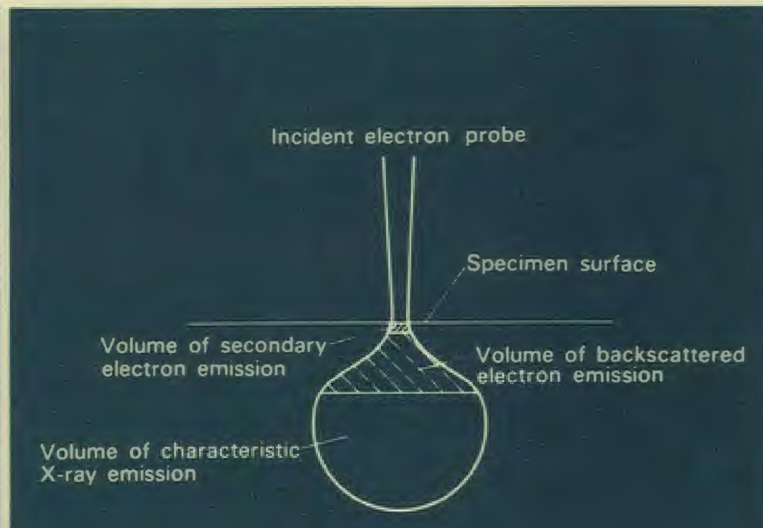
A Picture Story

A major research tool at ORNL is the scanning electron microscope, used primarily for physical and chemical analyses of specimens ranging from crystal formations to biomass fossils. Nine such instruments are at the Laboratory, and most of them are available upon request for use by staff members. Bob Crouse is in charge of two units in the Metals and Ceramics Division, Allen Solomon supervises the one in the Environmental Sciences Division, Jim Dumont manages one in the Biology Division, Bob Birkhoff is primary user of the unit in the Health and Safety Research Division, Les Hulett supervises the instrument in the Analytical Chemistry Division, Scott Aaron is in charge of the Solid State Division microscope, and Charlie Culpepper and Ed Beam coordinate the unit in the Chemical Technology Division. The following micrographs show how these instruments are being used and give a general idea of their capabilities for other research.

This article is compiled from material gathered by Bob Crouse and Barbara Ashdown.

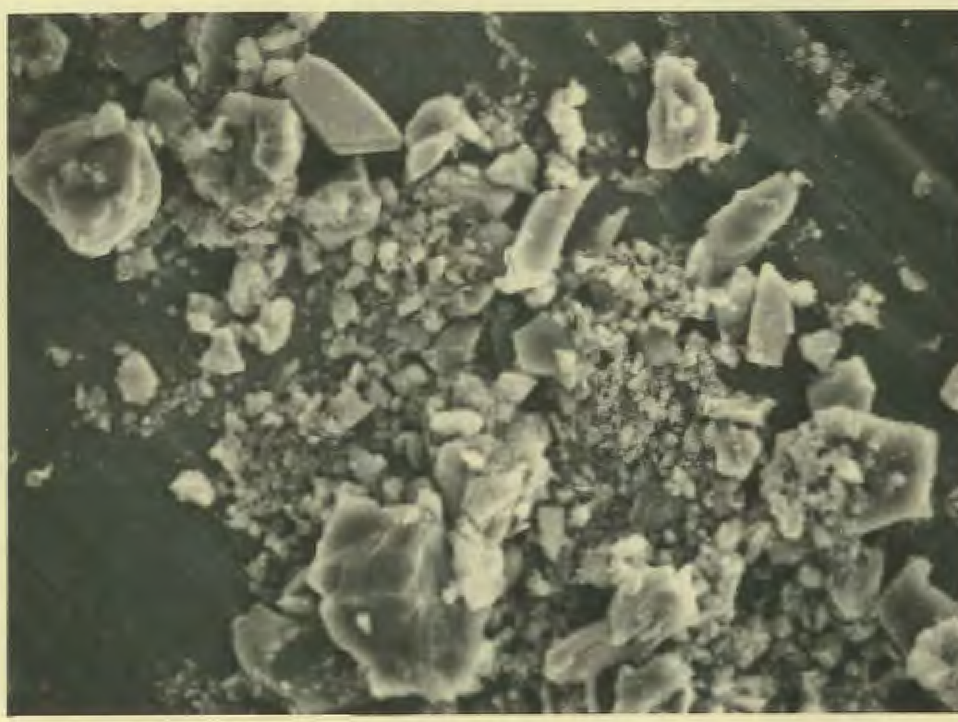
HOW IT WORKS: The beam in an SEM is a stream of electrons from a heated filament, usually tungsten, focused by electromagnetic lenses to a diameter of about 5 to 10 nm. This beam strikes the sample at one point at a time, building up an image as it scans the surface in the pattern, called a raster, that creates a television image. A cathode-ray tube, scanned in synchronization with the beam while monitoring a signal from the sample, produces the image to be viewed or photographed. A variety of signals is generated when the beam interacts with the solid sample. Besides the secondary electrons that form the image on the tube, two reflective beams are backscattered to furnish further information about the sample. Electrons are bounced back onto a detector in a way that shows variations in atomic number to differentiate elements, and x rays, generated by the interaction of the electrons with the elements in the sample, are differentiated with respect to their energies by a solid-state detector in a spectrometer. This latter process is called energy-dispersive x-ray spectrometry, abbreviated to EDX or EDS.

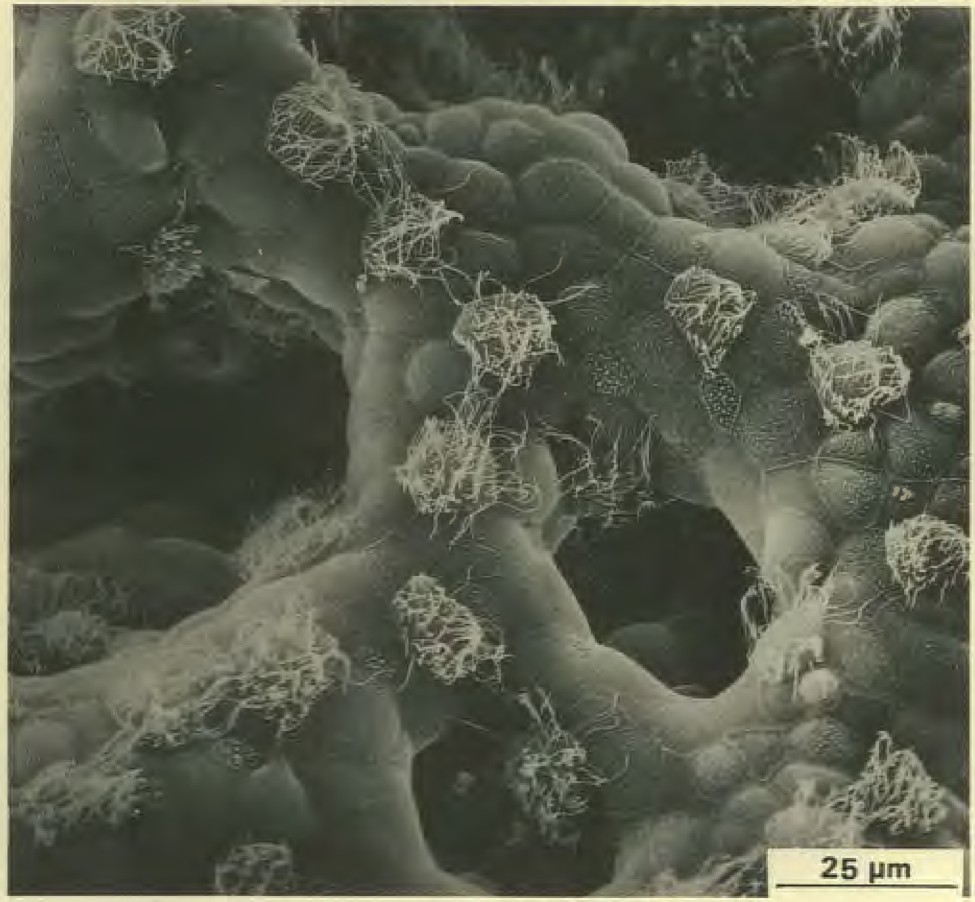




Schematic diagram of signal emission area.

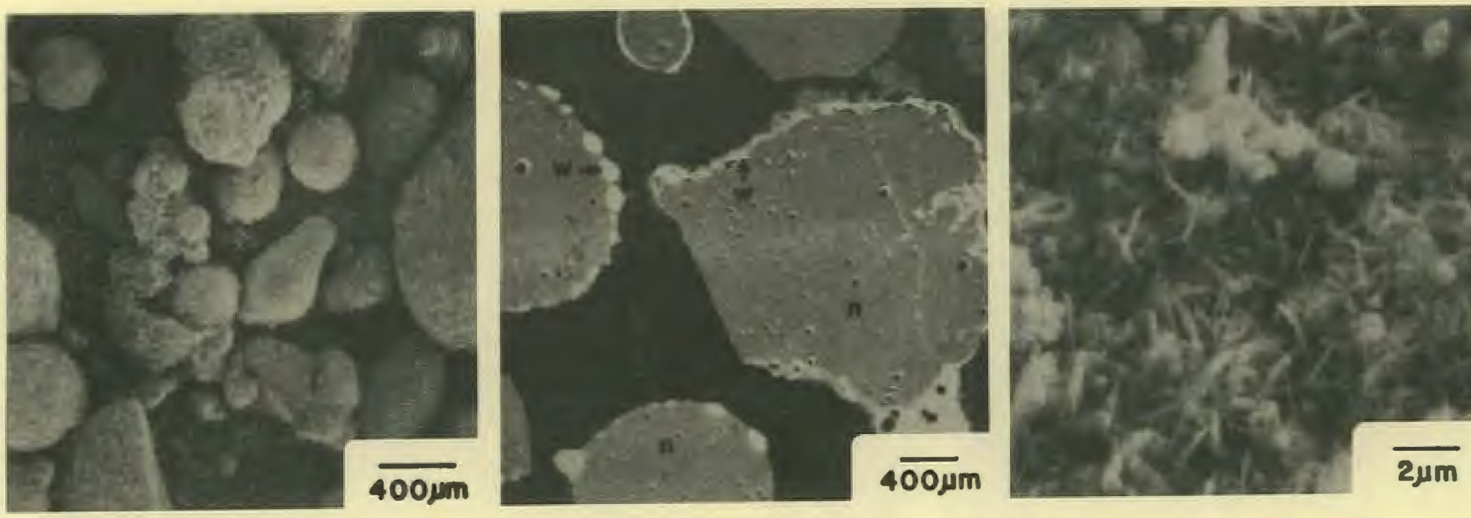
In this micrograph of Mount Saint Helens ash, note that the fragments do not have the spherical droplet shapes characteristic of fly ash. Optical microscopy by Mike Naney, a geologist in the Chemistry Division, confirmed the presence of several common minerals characteristic of volcanic rock. These minerals include plagioclase, hornblende, quartz, hematite, hypersthene, augite, and magnetite, as well as volcanic glass. Sulfur was not found on the particle surfaces, but John Dale used x-ray photoelectron spectroscopy to perform a more sensitive surface analysis that showed the presence of chlorine.



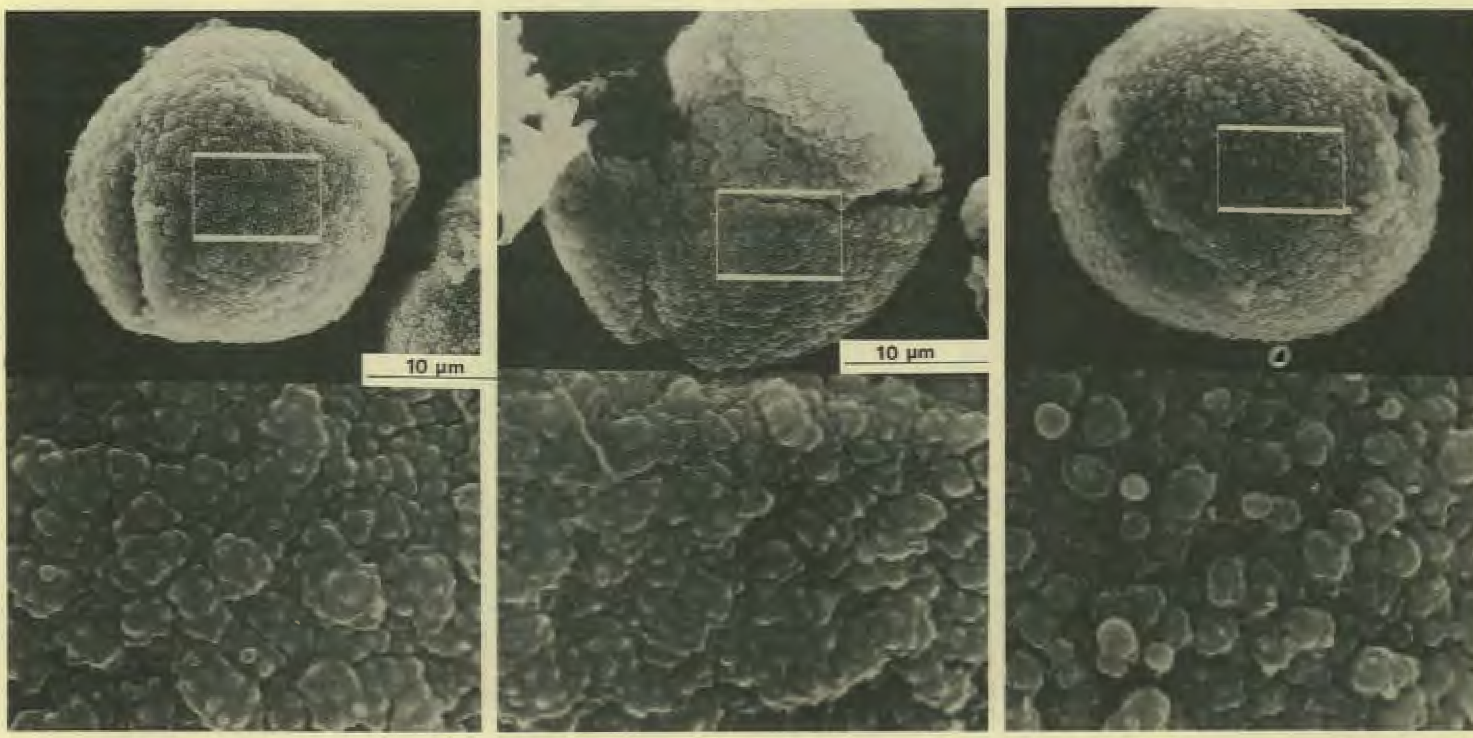


In the Biology Division, Jim Dumont is using the SEM to study the effects of environmental pollutants on amphibian development. The left micrograph shows the abnormal gill growth of a tadpole that was raised in a solution of 5 ppm acridine in water. Acridine is an organic compound found in coal conversion processes. The developing gills have fused with each other and are covered by ciliated and mucus-secreting cells. The gills on the right, which are developing normally, remain separated.

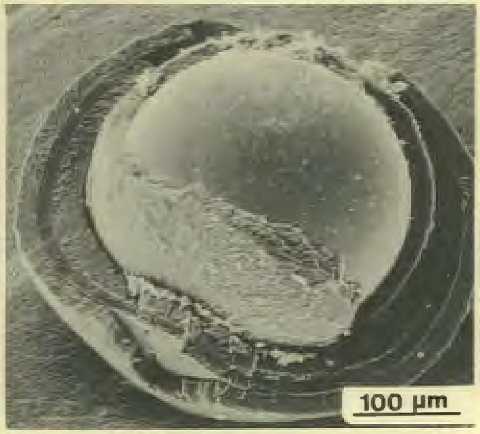
As part of the Environmental Sciences Division studies of the effects of coal conversion products on the environment, Gerry O'Neill uses the SEM to examine the effects of these products on crickets. The micrograph on the left is of a normal cricket nymph 24 h after emergence from the egg. Note the large, multifaceted, normal eye. On the right is a three-eyed nymph 14 d after emergence from an egg exposed to a coal liquefaction product. The extra eye is smaller and appears above the normal eye. This is a dose-dependent, teratogenic effect; the concentration in this case was 44 µg of coal liquefaction product per gram of sand. This effect was seen in approximately 0.1% of the cases treated at this concentration. Other observed effects include extra antennae and, in some cases, an extra head. The photograph on the right has been chosen by Science *for a cover illustration.*

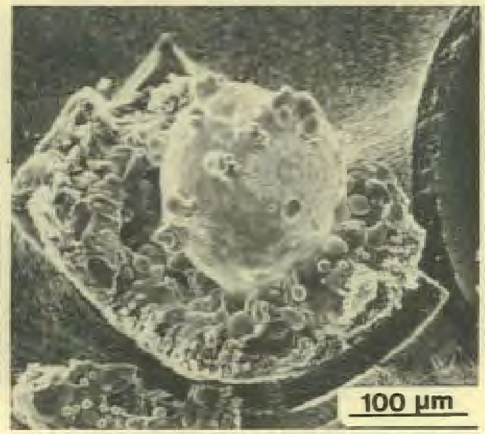


In the Environmental Sciences Division, S. Y. Lee is using the SEM to characterize waste generated by a coal gasification pilot plant. The spherical particles on the left have an iron-rich coating, which is shown in cross section in the middle picture. The micrograph on the right is a closer view of the same material after weathering has washed away the sulfur and revealed the iron hydroxide crystals. The iron- and sulfur-rich phase of the solid waste is a potential source of acid and trace metals that are hazardous to the environment.



Through use of the SEM, paleoecologists in the Environmental Sciences Division are identifying fossil pollen thousands of years old. Pollen of modern species is used to help characterize old pollen, as shown in these micrographs by Allen Solomon. The one on the left shows a typical modern pollen grain of a black oak (Quercus velutina), *and the higher magnification shows warty projections that have a pebbled surface. In the center is an 11,000-year-old pollen grain from Anderson Pond in White County, Tennessee. While the shape of the pollen grain provides little information, the coarseness of the pebbled warty projections and the lack of fusion between projections allows the inference that the fossil pollen is also from a black oak, as distinct, for instance, from the white oak pollen, shown far right. Such fossil pollen studies allow very precise reconstruction of vegetation changes during past climate periods, some of which are thought to be much like the future climate expected because of increased atmospheric CO_2 caused by burning fossil fuels.*



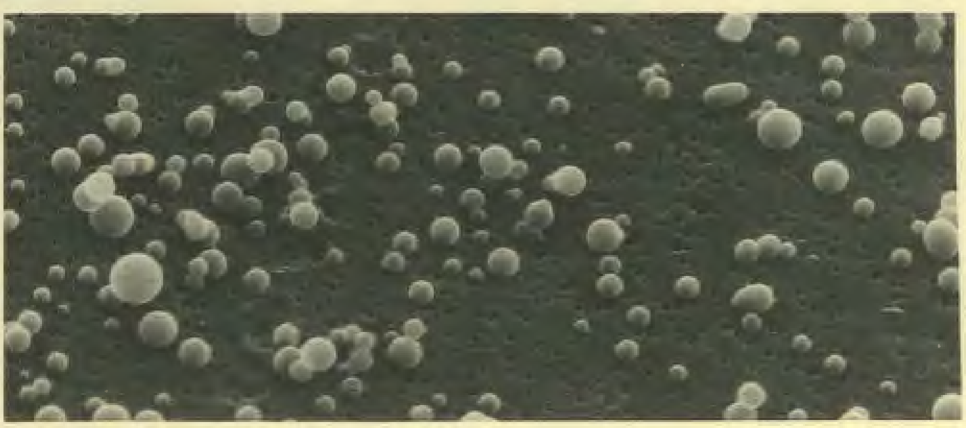


Gas-cooled reactor fuel particles are coated with layers of pyrolytic carbon and silicon carbide to contain the fission products that are created during operation of the reactor. Irradiation results in important morphological and chemical changes that can be studied through use of the SEM. These micrographs were made by Tommy Henson on the Metals and Ceramics SEM for Terry Tiegs, also in Metals and Ceramics. The one on the left shows a deliberately broken particle before irradiation. The particle on the right shows the changes caused by irradiation.

In the abrasion of normally brittle ceramics, sufficient energy transfer to cause local melting is thought to accompany particle impact. A mullite (alumino silicate) sample was abraded at room temperature and the impact area examined through the SEM by Bob Crouse. This micrograph shows the elongated stringers and flow patterns indicative of melting.

A chip made of an electrically conductive material can be coated with an organic compound called photoresist and then selectively exposed by etching with an electron beam, after which the exposed material can be dissolved away, leaving the holes as shown. John Little, a graduate student from the University of Tennessee, working with Bob Birkhoff in the Health and Safety Research Division, is using the SEM for electron beam lithography by computer programming the beam to make microstructures. Holes made by this method are shown on the left. On the right, he has used negative photoresist, which, as the name implies, becomes insoluble when exposed, leaving cores instead of holes.

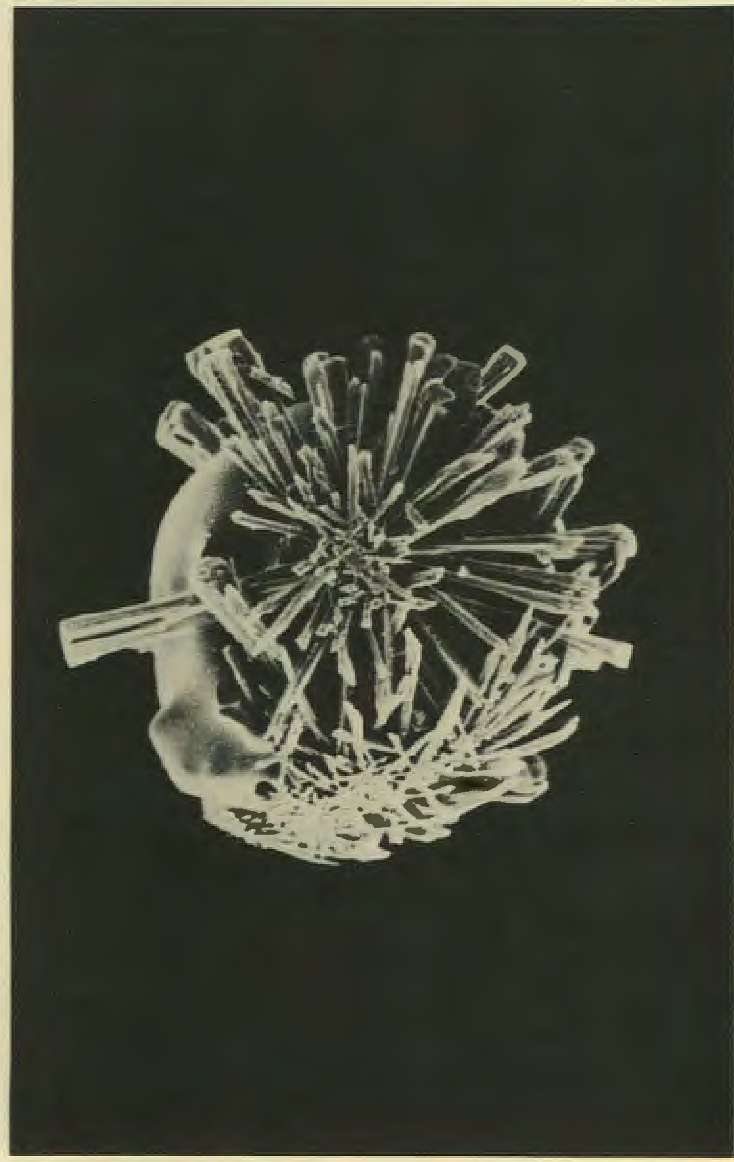
Little is also performing radiation dose profiles, shown here. Shooting the microscope beam at a thick layer of photoresist, and then developing it to create the holes, he shows in a cross section the teardrop shapes of the holes thus made. The shape of a hole gives an accurate isodose curve that is useful in checking calculations in radiation microdosimetry.

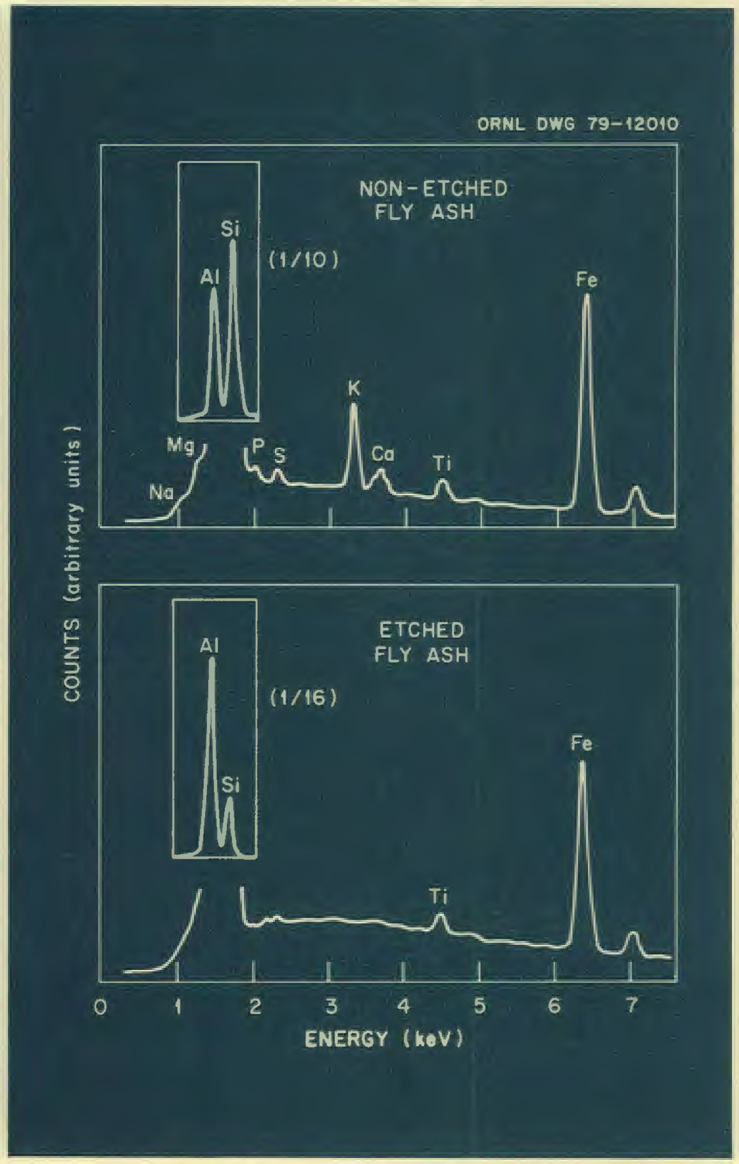


Bob Holmberg is characterizing cigarette smoke with the SEM in the Analytical Chemistry Division. This micrograph shows smoke particles collected on the surface of a Nuclepore filter. The smoke is not composed of cigarette ash; rather, these aerosol particles are minute liquid droplets of the tars. To preserve their airborne size and shape, Holmberg has fixed them through reaction with methyl 2-cyanoacrylate vapors before filtration. The largest particles are about 1 μ in diameter.

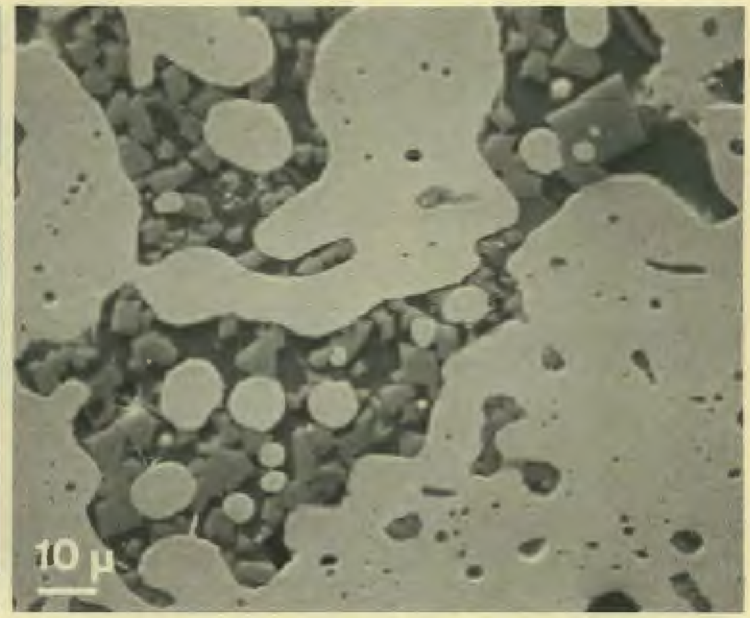
Gene Hise, in the Engineering Technology Division, is using the SEM to study effective methods of preparing coal for clean burning. The goal is removal of the pyritic sulfur- and ash-forming minerals from the coal before combustion so that the amount of sulfur and ash that must be removed from the stack gases can be reduced. The sticklike particle in the middle of the photo on the left is a fragment of fusinite, a form of coal found in small quantities throughout coal seams. Because of its mineral content, the fusinite can be magnetically separated from crushed coal. A closer look at this material, in the micrograph on the right, shows that it is filled with micrometer-size crystals of pyrite, which cause sulfur oxide pollution when burned. Though possible, it is not commercially feasible to crush the fusinite to separate the carbon from the pyrite; thus, the magnetic removal of this source of sulfur and ash is accompanied by a small but unavoidable loss of heating value.

Robin Taylor is using the SEM to study semiconductor materials in support of the Solid State Division's photovoltaic research program. This SEM is equipped with an electron beam-induced current (EBIC) option which images local electronic responses of the solar cell. The induced current image is compared to the secondary electron image on the cathode-ray tube in order to correlate electronic dysfunctions with specific microstructural artifacts in the semiconductor material. On the left, the secondary electron image of a polycrystalline silicon chip is shown. This imaging technique can reveal surface topography as well as subsurface details, such as grain boundaries, stacking faults, and "twins," indicated by the parallel lines. The photo on the right shows the EBIC image of the same area. The dark areas indicate electron-hole pair recombination sites, which are detrimental to the efficient function of the solar cell. The accelerating voltage of the electron beam can be adjusted to vary the penetration of the primary electrons into the semiconductor and hence provide information at incremental depths. This technique is particularly useful when studying laser-annealed samples in that the extent of the laser effect can be approximated.

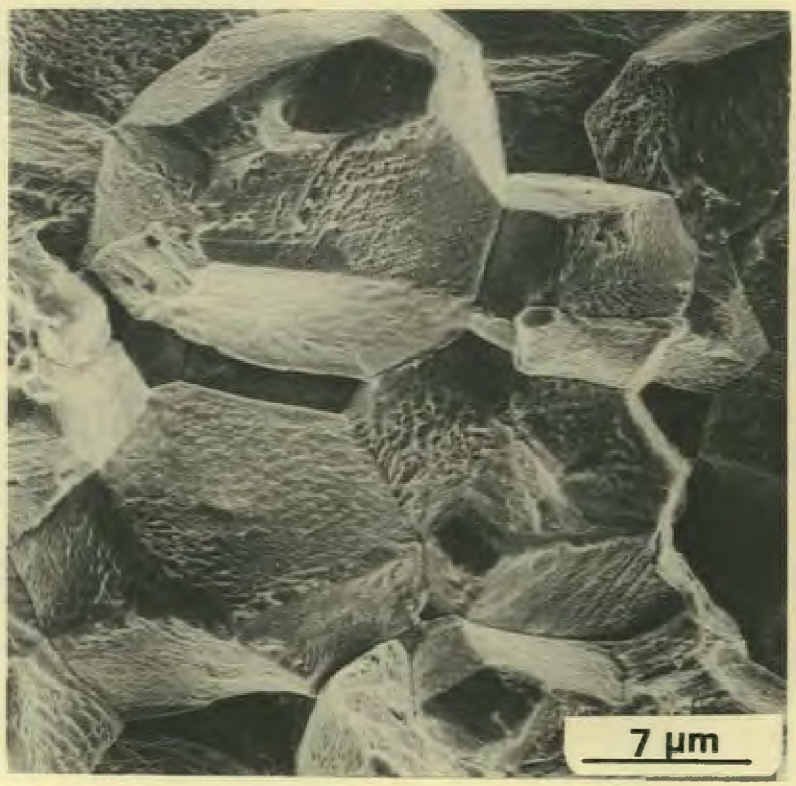




Les Hulett, in the Analytical Chemistry Division, has used the SEM in conjunction with the EDX spectrometer to determine the internal structure of fly ash that comes from the stacks of coal-burning power plants. The micrograph here is of an etched fly ash particle that has an internal skeleton of mullite, as is often the case. The graph shows EDX spectra of such a particle before and after etching. Note that the aluminum concentration is much lower than the silicon concentration before etching, but after etching, the aluminum-to-silicon ratio is about 3 to 1, which corresponds to the composition of mullite, a silicate of aluminum. Thus, through proper chemical processing with dilute hydrofluoric acid, toxic elements such as silicon can be etched away, resulting in a high-purity material that could be a valuable recoverable resource. Mullite is widely used in the fabrication of furnaces, refractory components, electrical insulators, and china.

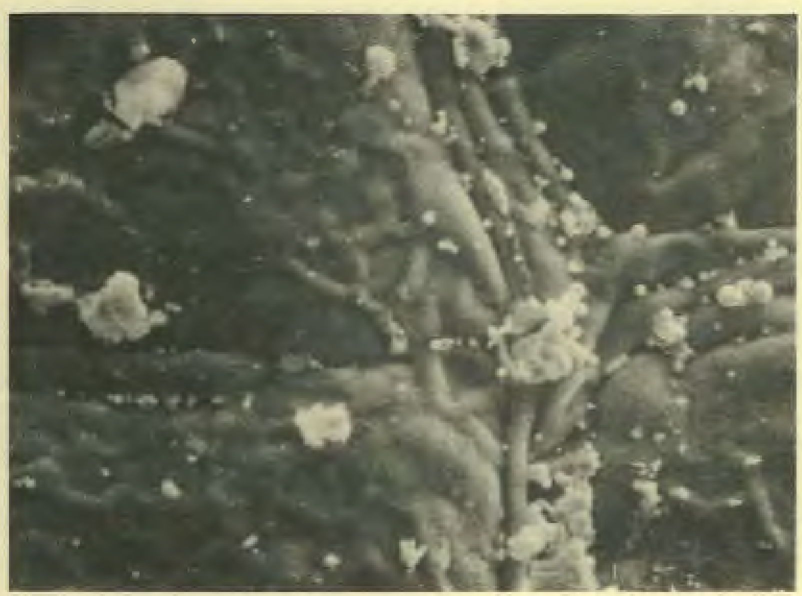


In the Isotope Research Materials Laboratory of the Solid State Division, Scott Aaron used the SEM to characterize cermets that were being developed as an alternative to the solidification and fixation of high-level radioactive wastes. The hollow spheres on the left are calcine particles generated by the reactive spray calcination of high-level radioactive waste and such additives as titanium or aluminum in a molten urea solution. This calcine, which is made up of reducible and nonreducible oxides, was then subjected to chemical reduction. Only the reducible oxides are converted to metal in the reduction process. The result is an intimate mixture of metal and oxides which are subsequently densified to yield the final cermet waste form, of which an example, made from high-level waste from the Savannah River, is shown on the right. Although the process is in use elsewhere in the Laboratory, now that it has been demonstrated to be effective, further work on it has been discontinued in favor of fixation in glass.



A platinum alloy, which was examined in the Metals and Ceramics Division for use as a containment material for the Jupiter Orbiter Probe's radioisotopic heat source, is shown here after a brittle fracture occurred. The thermo-electric generator was to use copper selenide at a high temperature, so this environment was simulated for the alloy. This micrograph shows that the selenium reacted with the platinum to form a grain boundary phase that reduced the alloy's ultimate tensile strength. The crystalline nature of the break surface shows the brittleness, and the selenium-rich phase is visible as the ripple pattern on the facets. The generator using selenide has been removed from the mission, and iridium has now replaced the platinum.

This micrograph shows a backscattered electron image of an arc-melted alloy of uranium, silicon, palladium, and carbon, taken by Charlie Culpepper in the Solid State Division for Terry Lindemer's group in the Chemical Technology Division. Lindemer and his colleagues are studying the reactions of fission products with silicon carbide, the material that coats the fuel microspheres in the high-temperature gas-cooled reactors during reactor operation. Separation into three phases is shown here as white, light-gray, and dark-gray areas. The black areas represent voids. The elemental distribution of uranium, silicon, and palladium in the phases can be identified by the energy-dispersive x-ray spectrometer.



Scanning electron microscopy has proved useful in ecological studies of the processes of atmospheric deposition of particulate pollutants on vegetation and of the consequent interactions of the pollutants with acid rain. This micrograph shows fly ash, released during coal combustion, on a chestnut oak leaf. The sample was collected at Walker Branch Watershed, which is 20 km from the Kingston steam plant, 18 km from the Bull Run steam plant, and 1.6 km from the Y-12 steam plant. Since the particles constitute a vehicle for deposition of heavy metals from the atmosphere, their size, morphology, chemical composition, and distribution on the leaf are essential information for predicting the effects of airborne pollutants on vegetation. The SEM work is by Steve Lindberg and Dave Shriner of the Environmental Sciences Division and by Frances Ball of the Analytical Chemistry Division.

information meeting highlights

Energy, August 19–21

Building Conservation Study

In compliance with the National Energy Conservation Policy Act of 1978, all but one of the states have been collecting data on energy consumption in institutional buildings. Those under study are schools, hospitals, local government buildings, and public care institutions such as nursing homes and day-care centers. The act requires the Department of Energy to administer what is known as the Institutional Conservation Program to reduce energy use in institutional buildings.

In theory, the data could be used to identify buildings that are particularly energy intensive, to determine the conservation potential of the institutional building sector, to evaluate building conservation programs, and to improve existing energy end-use computer models. In practice, the states have found the process of collecting and analyzing data to be fraught with problems. ORNL's Energy Division has examined these problems and is developing possible solutions and recommendations.

ORNL's buildings conservation analysis and evaluation group, led by Eric Hirst, has identified several major problems: (1) inadequately designed preliminary energy audit questionnaire forms were developed by most states; (2) the states were inconsistent in their interpretation of Congress' intent in collecting energy use data; (3) the limited computerization of the data seriously hampered state and federal use of them; and (4) lack of time, staff, and money for data analysis and validation plagued many state energy offices.

Hirst, Jackalie Blue, and Phyllis Zuschneid, Energy Division, and Janet Carney and Pamela Knight, Computer Sciences Division, have looked at ways of validating the quality of the data and of detecting errors, such as in a hospital fuel use total that deviates considerably from the norm for that building type and size. In his study of the data collected by the Minnesota Energy Agency, Hirst and Christopher Eastes of MEA developed regression equations to explain the variations in use of fossil fuel, electricity, and total energy as functions of several independent variables. The Energy Division group has demonstrated that the data can be computerized and automically checked for errors and that the data can be validated by both a common sense approach and by statistical tests such as the one being developed by ORNL's John Trimble.

The ORNL group made these recommendations to enhance the states's efficiency in data collection, analysis, and validation: (1) DOE and the states should jointly develop well-designed data collection questionnaires for future federal conservation programs before the programs begin; (2) the federal government should develop clear instructions to ensure uniform interpretation of the law; and (3) the federal government should cooperate with the states in developing computer software to locate, manage, and analyze errors in data before a data collection program for states is ever begun.

Later this year, the states will be implementing DOE's Residential Conservation Service program in which energy auditors will collect data on energy use in homes (as well as advise residents on what they can do to conserve energy in a cost-effective way). It is hoped that the lessons learned in the Institutional Conservation Program will make the RCS program a more efficient source of information on energy use.

Solid State, October 1–2

Fundamentals of Magnetism

John Cooke, Harold Davis, and Jeff Lynn have performed calculations to study the fundamentals of magnetism in iron and nickel, 3d transition metal ferromagnets. (Lynn, a graduate student working in the division at the time, is now with the physics faculty at the University of Maryland.) Magnetism is present in materials under a variety of circumstances: in the rare earths, for instance, magnetism results from unpaired electron spins which are localized at atomic sites. In the transition metals, however, magnetism appears to be caused by electrons traversing the lattice. In both cases, as the materials are heated, they lose their magnetism. Why this is the case in the rare earths is fairly well understood; in the ferromagnetic metals, however, it is not. Data gathered from inelastic neutron-scattering experiments that have been performed on iron and nickel at the High Flux Isotope Reactor indicate that the ferromagnetic energy bands have little or no temperature dependence. Angular resolved photoemission experiments, however, which have been performed elsewhere, attribute a strong temperature dependence to the energy bands. Using first principles calculations based on the itinerant electron theory propounded early in the century, Cooke and his colleagues have demonstrated that there is very good agreement, both qualitatively and quantitatively, between the theory and the experiments at HFIR. Their conclusion is that there can be little or no temperature dependence of the energy bands, and, therefore, the correct interpretation is that of the neutron-scattering experiments performed at ORNL.

Engineering Technology, September 18–19

Magnetic Coal Cleaning

It is becoming increasingly important, both from economic and environmental standpoints, to remove the unwanted impurities of ash and sulfur contained in raw coal prior to combustion. The technology for preparing large lumps of coal exists; however, the technology for preparing dry, fine coal is just beginning to emerge. The need for this technology arises from use of the poorer quality coal seams which produce higher quantities of impurities and from modern mining methods which produce higher quantities of impurities and fine coal.

An emerging technology for dry, fine coal preparation is magnetic separation, which can be performed by either the high-gradient magnetic separation process or the open-gradient magnetic separation process. HGMS is a commercially demonstrated technology which removes the impurities by passing the raw coal through a magnetic filter. The filter consists of steel fibers placed in a magnetized cavity. This arrangement causes extremely high separation forces to be generated near the fibers. When raw coal is passed through the filter, the coal is repelled by the fibers and falls through, while the impurities are attracted to and collect on the fibers, thereby effecting a separation.

OGMS is accomplished in an open magnetic cavity without the aid of steel fibers. The magnet is designed in such a way as to produce a magnetic field gradient perpendicular to the direction of the particle flow. When raw coal is passed through this type of device, the coal is repelled down gradient to the lower magnetic field region while the impurities are attracted up gradient to the higher field region, thereby producing a continuous spectrum of material. A separation is achieved by introducing a splitter at the desired location of the spectrum. Since the splitter can be located at any desired point (or even several points if multiple splitters are used), OGMS offers more flexibility than HGMS. Allen Holman and Gene Hise have tested OGMS with two different magnetics and have designed other configurations which generate higher separating forces resulting in better and more selective separations. Currently operating in the Engineering Technology Division is a laboratory-scale OGMS magnet capable of processing 300 kg/h of raw coal while removing the pyritic sulfur and 60% of the ash, with heat value recoveries in the clean coal in excess of 90%. ornl

Herbert Inhaber acquired a measure of renown last year with his report, published in *Science*, on relative risks of energy systems; the resultant brouhaha in the letters columns of the scientific press revealed a controversy that attained spectacular heights in academic invective. He came to the Laboratory last year from the Canadian Atomic Energy Control Board, a group analogous to the U.S. Nuclear Regulatory Commission, and he has been designated to head a task force to establish an ORNL program plan for risk assessment. He holds three degrees in physics and mathematics from McGill University and the universities of Illinois and Oklahoma. He is an editor for the new journal *Scientometrics*. His interest in policy questions led to the research resulting in the accompanying article.

GOLDEN DAYS—or BRASS?

By HERBERT INHABER

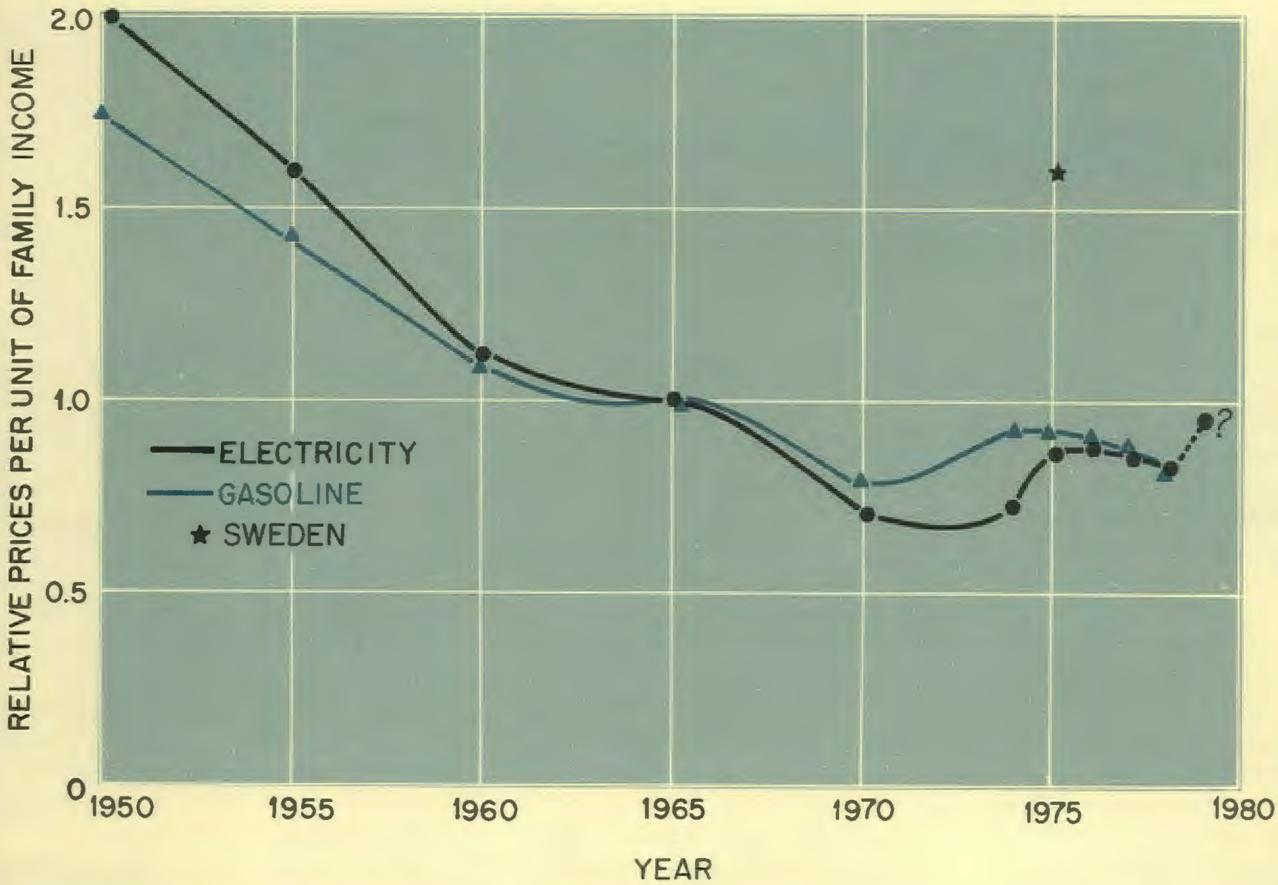
"Golden days, in the sunshine of our happy youth." These words, from Sigmund Romberg's operetta, "The Student Prince," are applied to many phenomena and are often used to describe the good old days of energy. Sometime in the fifties or sixties, depending on whom you're talking to, gasoline was almost free, OPEC (Organization of Petroleum Exporting Countries) either didn't exist or was a sleeping tiger, and electricity was as inexpensive as water. At least, that's the rosy haze that has settled over the period of the last two or three decades—it was a time of cheap and abundant energy.

Or was it? Could it be, heresy of heresies, that today is the golden age of energy, or at least not too far from it? Some evidence exists to support the latter suggestion. The kindling is already being prepared for the stake.

The Income Factor

To investigate what was and what was not the golden age of energy prices (abundance is another matter), we can consider real energy prices, that is, those adjusted for inflation. However, when you buy gasoline you don't work out the inflation rate for the last few months or for the last year to decide whether you're getting a good buy. Perhaps the fairest measure of how energy prices affect the average person is to divide these prices by the average family income. It seems logical that someone with a family income of $5,000 will make different decisions about energy than someone with an income of $50,000 will.

Results of these calculations are shown in the accompanying figure.



Relative energy prices, as defined in the text, fell rapidly from 1950 to 1965. Since that time, they have both risen and fallen, but they are still lower than they were in the 1950s. Recent price increases for gasoline have boosted its curve higher than electricity. By way of comparison, relative gasoline prices in 1975 in Sweden were at about the 1952 level.

The year 1965 was chosen as a base year, and a value of 1.0 was assigned to it. The value was derived by dividing that year's electricity cost (2.1¢/kWh) by the average family income ($6960). The other ratios of electricity cost to average family income were adjusted accordingly and can therefore be called relative prices. The same procedure was followed to establish relative prices for gasoline. So the higher the point in the figure, the higher the relative price.

Most of the data were taken from issues of *Statistical Abstracts of the United States*, with some data from *Historical Abstracts of the United States* and *Platt's Oilgram*. For 1978, data on family income were unavailable at the time of writing, but the total U.S. disposable personal income and the number of families were available. The ratio of these two quantities was calculated for the three preceding years, and assuming that this ratio held for 1978 as well, the 1978 family income would be about $17,800. Conclusions will not be strongly affected if this rough calculation is slightly off. For electricity, prices were based on an assumed use of 500 kWh per month.

1966-73: Energy Prices Lowest

What do the results show? Rather than being golden days of energy prices, the fifties and early sixties were, at best, brass. The golden days were the late sixties and early seventies, when energy prices were at their lowest level of the three decades. Since that time, the situation has become worse, but by 1978 it still wasn't as bad as it was, relatively speaking, in 1960.

How can this be? Some of us have

"...not much progress has been made in saving energy, despite an unprecedented ...barrage of conservation messages..."

fond memories of gasoline at 30¢ or even 25¢ a gallon, and surely things have worsened since then. Those memories are accurate enough, but we tend to forget that we had much less money to spend in those days. For example, gasoline in 1950 cost an average of 27¢ a gallon, a pleasant thought if there ever was one. However, family income was only $3300 a year, something not so pleasant in light of today's prices.

The graph suggests why not much progress has been made in saving energy, despite an unprecedented peacetime barrage of conservation messages from governments and private industries. While relative prices have risen since 1973, they haven't kept pace with the ratio of demand to supply. One can pass laws and make regulations favoring conservation, but as long as relative prices in the late seventies were at about the 1967 level, the effectiveness of these measures is questionable.

Take a closer look at the graph. Relative electricity prices fell more strongly than relative gasoline prices did between 1950 and 1960, primarily because electricity prices held almost constant while family incomes increased. In fact, electricity prices rose only about 5% from 1950 to 1970. Gasoline prices rose faster, but not as fast as family incomes.

From 1960 to 1965, the relative prices fell much less strongly than they did from 1950 to 1960, but not because of any great increase in energy prices. Because of the recession of 1960 and 1961, the rate of increase of family incomes from 1960 to 1965 was not as high as it was in the previous decade.

After 1965, the strong decrease in relative energy prices resumed. Relative gasoline prices did not drop as fast as electricity prices, but by 1970 both were less than half of what they had been in 1950. The golden years were clearly the late sixties and early seventies, if one wishes to characterize a period of great waste and inefficiency with those words.

By 1974, the year after OPEC first really flexed its muscles, everything had changed. Or had it? Gasoline prices at the pump had risen from 36¢ a gallon in 1970 to 55¢ in mid-1974, an increase of 53%. However, family incomes had also risen, though not as fast. The result was that relative prices had risen to the 1967 level, which was still less than half of the 1950 level.

Electricity prices rose at a slower rate from 1970 to 1974, increasing from 2.1 to 2.8¢/kWh. Family incomes rose at almost this rate, making relative electricity prices in 1974 almost the same as they were in 1970. The big rise in electricity prices occurred in 1975, when they rose to 3.6¢, an increase of 28% in one year. This increase pushed the relative price back to the 1967 level, but it was again less than half of the 1950 level.

1974-78: Fast-rising Incomes

What happened from 1974 to 1978 is intriguing. Prices rose—gasoline from 55¢ per gallon to 63¢—but family incomes rose faster, producing a decrease in relative prices. By 1978, the relative prices of both gasoline and electricity were at the 1968 or 1969 levels, clearly levels of golden years.

Aha, you may say, all of this is of historical interest, but what about 1979 and 1980, when energy prices seemed to skyrocket out of sight? Isn't this the energy crunch that we were warned about?

Before discussing these two years, let's go back to 1973. Gasoline prices rose from 40¢ a gallon to 55¢ in one year, an increase of almost 40%. This is reflected in the curve, which shows that the 1974 relative gasoline price is above that of 1970. However, it is not off the graph, and in fact it was followed by a period of declining relative prices as the economy digested the indigestible. Much the same happened for electricity.

The main problem with discussing 1979 and 1980 is that much of the data is not yet available. The only data for these

"... we tend to forget that relative prices once were much higher than they are now and that our bills are greater ... because we have more appliances and drive more."

two years in the latest *Statistical Abstract* (1979) is the June 1979 price of gasoline: 86¢ a gallon. This marked a 36% increase from the 63¢ of 1978, but it was relatively less than the 1973 to 1974 jump.

Family income in 1979 is not specified, but as a rough guess one can assume it rose about 10% from 1978. If the percentage was slightly different, the results would not be substantially different. Using this estimate gives the point for gasoline that has a question mark, indicating that it is somewhat uncertain. This point is of course above that of 1978, and even above that of 1974, but not by much. And remember that the relative price of gasoline in 1974 was at about the 1967 level. The pump price rose even higher in 1980, but so did income. Without data, it is difficult to estimate relative prices, but my guess for mid-1980 would be a relative gasoline price equaling that of 1962 or 1963.

Electricity prices for 1979 and 1980 are not shown in the latest *Statistical Abstract,* so no points are plotted for those years. However, judging from the relationship between gasoline and electricity relative prices for the years 1970 to 1974, relative electricity prices probably have not increased as fast as gasoline prices. The two curves may meet if relative gasoline prices fall as they did from 1974 to 1978.

Relative Energy Prices Lower Now Than in 1950s

Innumerable prophets have lost their heads trying to predict energy prices. To keep my head in place, I won't say what energy prices will be in the future. In spite of this self-imposed caveat, I'll venture to say that the experience of 1973 to 1978 may repeat itself: there may be a fairly sharp rise in relative gasoline and electricity prices, followed by a leveling off or even a decline. If this is true, the relative prices would eventually be around the 1965 or 1966 level. It seems highly unlikely that the relative prices will rise, in the foreseeable future, to the 1950 level. If they already had, we would have paid about $1.60 a gallon in mid-1979, instead of the actual 86¢.

By way of contrast, European relative prices tend to be much higher than American ones. The relative price of gasoline in Sweden in 1975 is shown in the graph; as you can see, the price level at that time is similar to the 1952 relative gasoline price.

Why are people so perturbed about energy prices, even though the graph shows that relative prices are still fairly low compared to those from two or three decades ago? Although practicing psychology without a license is illegal, I can think of one reason. People either consciously or unconsciously expect relative prices to fall as they did from 1950 to 1973. People come to believe that the trends of more than two decades are laws of nature, rather than economic coincidences. Thus, when the decrease in relative energy prices turned to a leveling off and later to a slight increase, people felt somehow cheated of the benefits they believed to be rightly theirs. From this came the disappointment, and the eventual anger and rage.

In summary, our memories tend to be selective, recalling only some things and blurring the rest. Ask someone what happened to the stock market during the Great Depression, and chances are you'll hear that it fell into a pit and recovered only after World War II. The "Little Bull Market" of the early thirties and the recovery until the drop-off in 1937 have been forgotten by most. Ask someone else about his teenage years, and you might hear about the days of glory—acne and worrying about exams and dates are forgotten. In terms of energy, we tend to forget that relative prices once were much higher than they are now and that our bills are greater mostly because we have more appliances and drive more. While the golden days of the late sixties and early seventies are gone, probably not to return, we still haven't quite reached the days of brass. ornl

Savings Plans

By HUME R. CRAFT

ACROSS

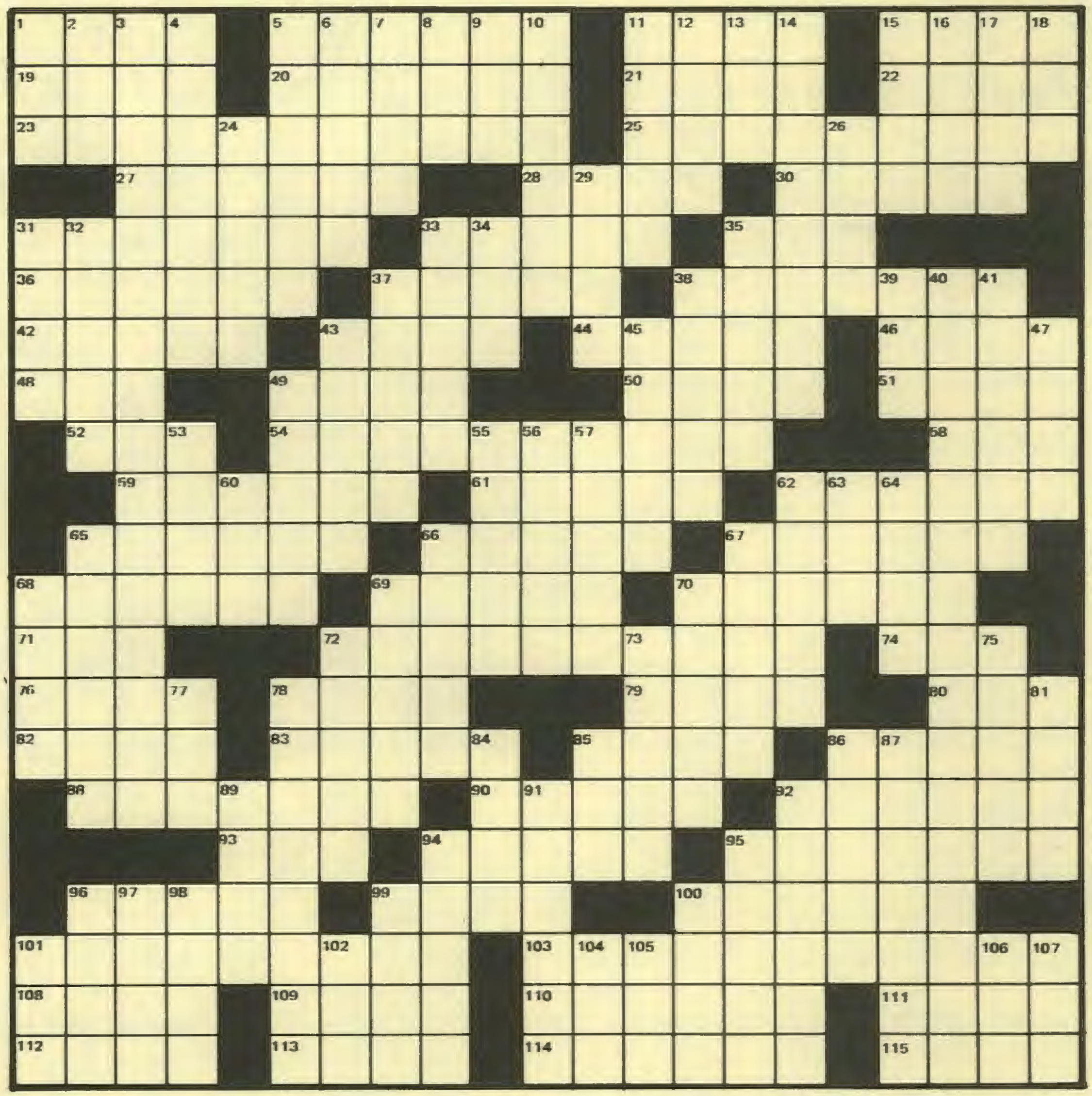
1 Way in
5 Fourth of July bonus
11 Conservation, in a sense
15 Energy source
19 Done in Domremy
20 Member of a clone
21 Companion of Baker and Charlie
22 Dies ___
23 Energy-saving TV image
25 Space vehicle's power unit
27 Element's kin
28 Blunt point
30 Ships, to poets
31 Professional informer
33 Bosc and Seckel
35 Letters on cars
36 Jollifies
37 Musical composition
38 Emulate Burbank
42 Obsequies
43 Aretha's music
44 Microscope shelf
46 Something put on
48 "*Après ___ le déluge*"
49 Ollie's sidekick
50 Days before
51 Fuel guzzlers, no doubt
52 Big bang abbr.
54 Heat generator of the sixties
58 Crèche palindrome
59 Musical scales
61 Aix chums
62 Sea anemones
65 Rasp
66 Monody writer
67 Shoulders, on type
68 Compounds with two carbonyls: suffix
69 Spooky sound
70 Means: slang
71 Gershwin
72 Fuel-saving transportation: sl.
74 Gardner
76 Taj Mahal site
78 Spectral type
79 Colonizers
80 McMahon et al.
82 Film star
83 First asteroid
85 Very French
86 Mideast oil saver
88 Freudian topics
90 Newspaper items
92 Overturn
93 Poet's word
94 Calamander
95 Located, as a function
96 Bucephalus, e.g.
99 El ___: city

DOWN

1 Fore's partner
2 Gambler's cube
3 Dividers used in bundling?
4 Measure volumetrically
5 Eighty-eights: sl.
6 Descriptive of Brownian particles
7 Church tribunal
8 Iron or copper
9 "___ *Alte*"—Adenauer
10 Set of nine
11 Laughing, et al.
12 Hautboy
13 "King's men" count
14 Conservationists' concerns
15 Discoverer of protactinium
16 Kind of test
17 Speaker's stand
18 Slippery customer
24 Montmartre goodies
26 Guard or end
29 Links persons
31 Skin
32 "Five-foot shelf" man
33 Ezra Loomis
34 Make bigger: abbr.
35 Spleen
37 Stadium sounds
38 Prefix with drop
39 Nonpro athletes: abbr.
40 Conservation measure
41 Boy Scout units
43 Solid, e.g.
45 Belief
47 Concorde et al.
49 Runs before Boreas
53 Mountain lake
55 Region of SW Germany
56 Distaff's kayak
57 Underwriter's concerns
60 West
62 Goriot and Dumas
63 Natural resource
64 Toledo's neighbor
65 Space between two electrodes
66 "___ Ben Jonson!"—epitaph
67 Classifies
68 Console feature
69 Hampshire housekeepers
70 Borge and Hamlet
72 Dutch painter (1626–1679)
73 Academy Award film: 1955
75 Astaire
77 26.6 cm in Malabar
78 Timetable
81 Citizen Kane's "Rosebud"
84 Truman's epithets
85 Sn
86 Proverbial Newcastle cargo

100 Spinning machine
101 Reducer of energy levels
103 Recorders of government lows
108 Part of Q.E.D.
109 "___ for a century dead"—Tennyson
110 Sanctuaries
111 "___ boy!"
112 Famous Virginia
113 Fluffs
114 Incapable of decay
115 Set to drive without gas

87 Something "bon"
89 There are two in Yucca Flat
91 Evangeline and Edwin
92 $C_3H_6O_3$
94 Merits
95 City on the Sozh, SSR
96 Antitoxins
97 Pete or Nick
98 Punta del ___
99 ___ production: nuclear force
100 Plagiarize
101 Outstripped
102 Men in blue: abbr
104 Radioactive: sl.
105 Highest note
106 Mao ___ Tung
107 Kind of sack



Answer on page 24.

Hume R. Craft

Mark Mostoller came to ORNL in 1969 a magna cum laude graduate and Ph.D. from Harvard. During his scientific career in the Solid State Division, he has studied atomic vibrations in solids; defects in insulators; alloys; and, recently, surface physics, the subject he discusses here with Dave Zehner and Harold Davis. Biographical notes on his coauthors appear in the text of the article.

Skimming the Surface

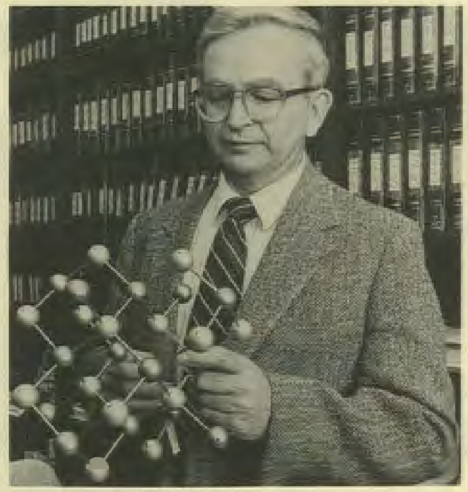
An account of theoretical and experimental collaboration

By MARK MOSTOLLER, HAROLD DAVIS, AND DAVID ZEHNER

Surfaces would be of little interest to physicists if so many things did not occur at them; corrosion, catalytic reactions, adsorption of foreign molecular species, and the successful operation or degradation of devices such as solar cells are a few examples of surface-controlled material properties. Despite the importance and intrinsic interest of surface problems in materials science, basic research in this area is only now developing into a mature discipline.

The reasons for this lateness of bloom are straightforward. On the experimental side, it has been difficult until recently to prepare clean, well-characterized samples and to measure their properties without degrading them. A very novel method of sample preparation, which has produced metastable surface structures not heretofore obtained by any other technique, is the subject of the last part of this article. Theoretically, surfaces are much more difficult to treat than the hypothetical, infinite crystalline solids dealt with in most solid-state-physics texts. Large-scale calculations on present-generation computers are required in order to analyze experimental data in terms of realistic physical models. A number of groups and individuals scattered among several divisions at ORNL are now doing basic research on surfaces, too many, in fact, to enumerate without risking omission of names that should be included.

Since the advent of ultra-high-vacuum technology in the mid to late sixties, low-energy ($\lesssim$300 eV) electron spectroscopy has been perhaps the most fruitful source of



Near left, Les Jenkins adjusts the seal for the state-of-the-art vacuum system while John Noonan, foreground, examines a sample in the window of the spectrometer.

Far left, Harold Davis explains the surfaces being studied as they show on a silicon atom model in his office.

information about surface structure and properties. Elastic and inelastic scattering of the electrons from the surface region can tell much, for example, about where atoms sit and how they are bound. Unfortunately or otherwise, depending on your prejudices, close collaboration between experimentalists and theorists is at the very least beneficial and at times imperative for analyzing the data produced by electron spectroscopy. This article describes some of the electron-scattering work—theoretical and experimental—done in the Solid State Division. Before presenting the state of the art and unveiling new patterns, it is appropriate to recite a little history.

The Electrons Arrive

It was Les Jenkins who began the experimental program in electron diffraction in the Solid State Division. Les first came to the Laboratory in 1950 with his undergraduate degree in hand, stayed two years, and returned for good in 1956 after earning his Ph.D. at the University of North Carolina at Chapel Hill. In the late sixties, Les was a reformed chemist working on the kinematics of crystal growth with Fred Young, Ugo Bertocci (now at the National Bureau of Standards), and Les Hulett (now in the Analytical Chemistry Division). Step motion on the surface appeared to be the rate-controlling factor in the growth processes being looked at. At about this time, high-vacuum electron spectrometers for surface studies were becoming commercially available, so Jenkins ordered one from Varian.

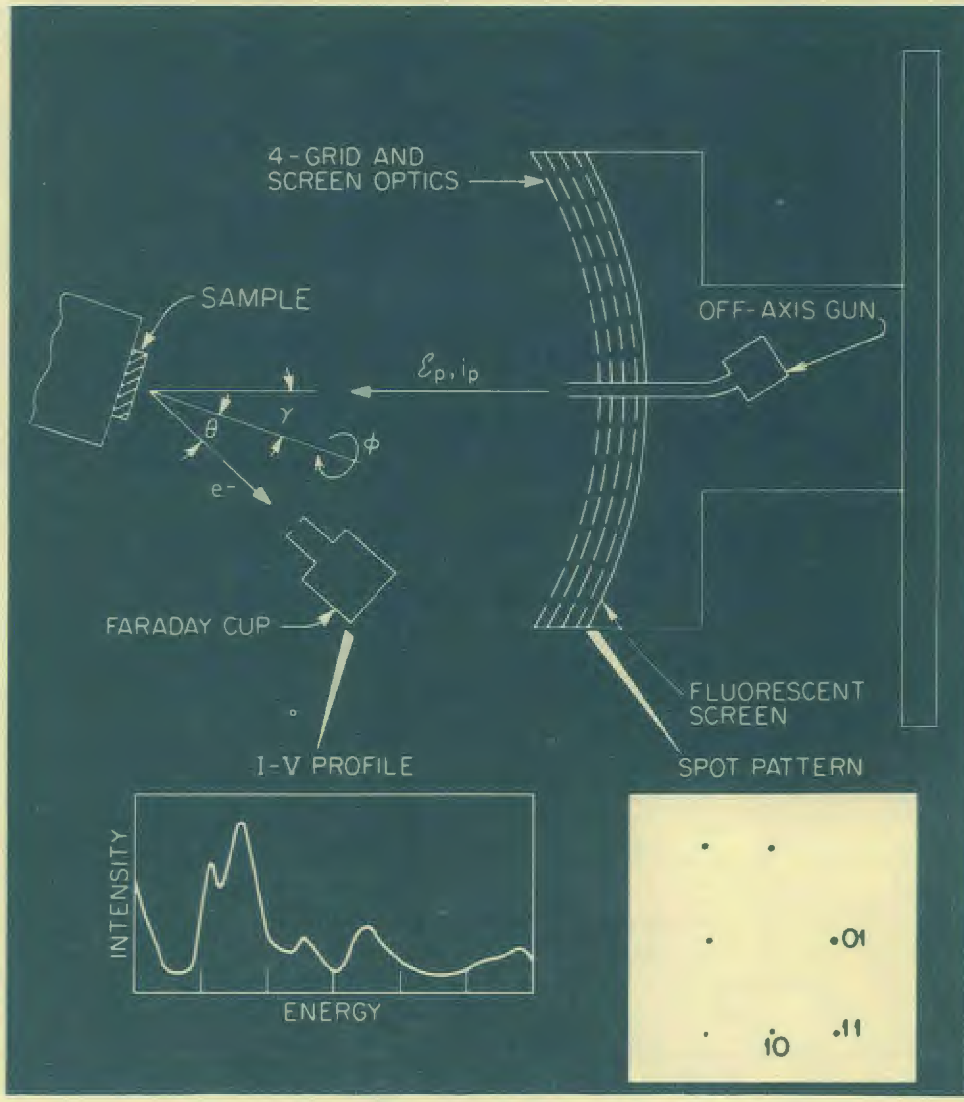
The spectrometer and Mui-Fatt Chung both arrived in 1969, the latter to hold Jenkins' hand in this new venture. Chung had just been a post-doctoral student under Farnsworth at Brown University; Farnsworth was one of a handful of scientists who had kept the light of electron diffraction alive between the pioneering experiments of Davisson and Germer in 1927 and the development of ultra-high-vacuum technology in the sixties. A good vacuum nowadays is one that contains only about 10 to 1000 times as many molecules per unit volume as exist in outer space.

It took two carpenters the better part of a day to free the spectrometer from its shipping crate, and only when the final breakthrough was achieved amid a pile of carefully splintered plywood did they discover that they could have achieved the same result by releasing the clamps at the bottom and lifting the protective shell up and off in one piece. Jenkins and Chung set to work getting the spectrometer in operation but were frustrated for weeks by vacuum leaks. When Farnsworth was consulted and was told that Les had cunningly included no fewer than 13 separate bakeable valves in the system to allow various gases to be introduced into the vacuum chamber, he said, "No wonder it leaks."

Most of the valves were removed, and Jenkins and Chung were able to begin doing some research. In some of this early work, they refined Auger analysis techniques used to identify which atomic species are present at surfaces and showed that electron-loss spectroscopy could identify high-order harmonics of plasmons in solids.

Dave Zehner, who was Farnsworth's last Ph.D. student at Brown, came to ORNL in 1970, just after Chung left to join the faculty of the University of Singapore. The group expanded in 1974 with the arrival of two Johns from the University of Illinois, John Noonan and John Wendelken. The invaluable technician, Gary Ownby, was hired in 1977, and has done most of Dave Zehner's work in the lab since then. The latest addition to the experimental staff is Gwo-ching Wang, who came in July 1980. The instruments available to the group now include two low-energy electron diffraction spectrometers, an electron-loss spectrometer, and a

In a LEED experiment, electrons from the off-axis gun are scattered from a sample and monitored by either a fluorescent screen, where a spot pattern is observed, or with a Faraday cup for more detailed analysis of the individual spots or diffracted beams.



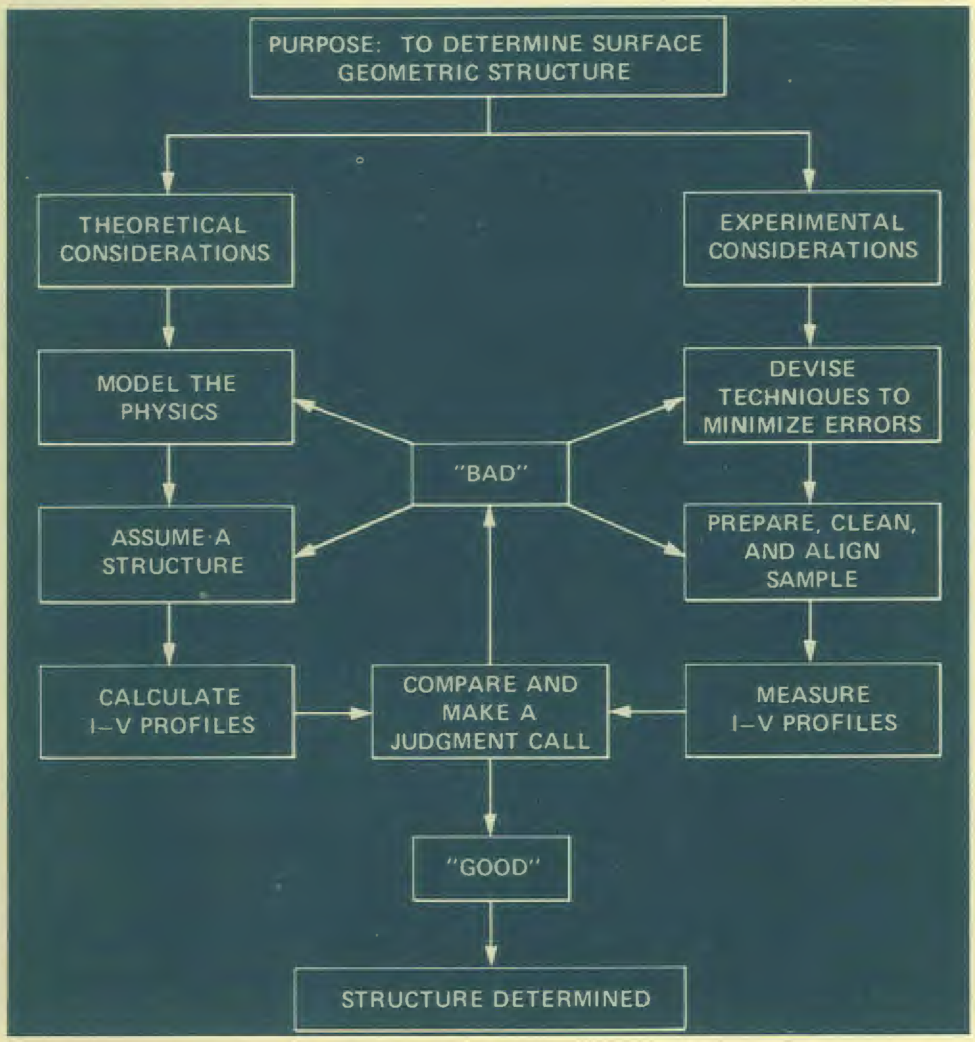
multipurpose instrument with photoemission capabilities. All are equipped with LEED displays for structural determinations and Auger units for chemical analysis.

Theoretical research on surfaces in the Solid State Division started somewhat later; it can probably be dated from 1976, when Ted Kaplan and Harold Davis published a paper interpreting some of the Auger electron emission data of Zehner, Jenkins, and Noonan. Harold had come to the Laboratory in 1964 as a member of the Metals and Ceramics Division and transferred to Solid State in 1969. After his work with Kaplan, Harold very quickly and methodically transformed himself into a surface theorist specializing in the large computer calculations that are required for detailed analysis of experimental data. He and the surface experimentalists have been symbiotic since 1977. Although Harold is the only Solid State theorist working (almost) exclusively on surface physics, he now has some company from Kaplan, Mark Mostoller, and Mark Rasolt, who came to ORNL from Battelle Columbus two years ago and is an expert on the electronic properties of solids.

LEED: The State of the Art

LEED is an acronym for low-energy electron diffraction, and it is the main technique now in use for surface crystallography, the determination of the atomic arrangements at surfaces. Electrons with energies in the range of, say, 20 to 300 eV have short mean-free paths in solids, typically on the order of 3×10^{-10} to 8×10^{-10} m (3 to 8 Å). It is these short mean-free paths that make electron diffraction ideally suited for the determination of surface geometric structure. In fact, soon after the wave nature of the electron was first demonstrated, it was realized that electron diffraction could serve as a method for surface crystallography. For example, in 1929, in the journal *Zeitschrift für Physik,* Lester Germer wrote, "The circumstance that electron waves are scattered very efficiently by the surface atoms of the crystal and are consequently extinguished on penetrating into the crystal at a very rapid rate, opens to us the possibility of the use of electron diffraction as a means of studying surfaces." However, it required four decades of theoretical and experimental work before the LEED technique could in fact be used to determine the geometric structure of a surface with a reasonable degree of reliability. Even now, much more work remains to be done before LEED surface-structure analyses can rival the successes achieved by x-ray diffraction in determining the structure of bulk solids.

LEED experiments are performed inside an ultra-high-vacuum chamber, in which a suitably prepared sample is bombarded with



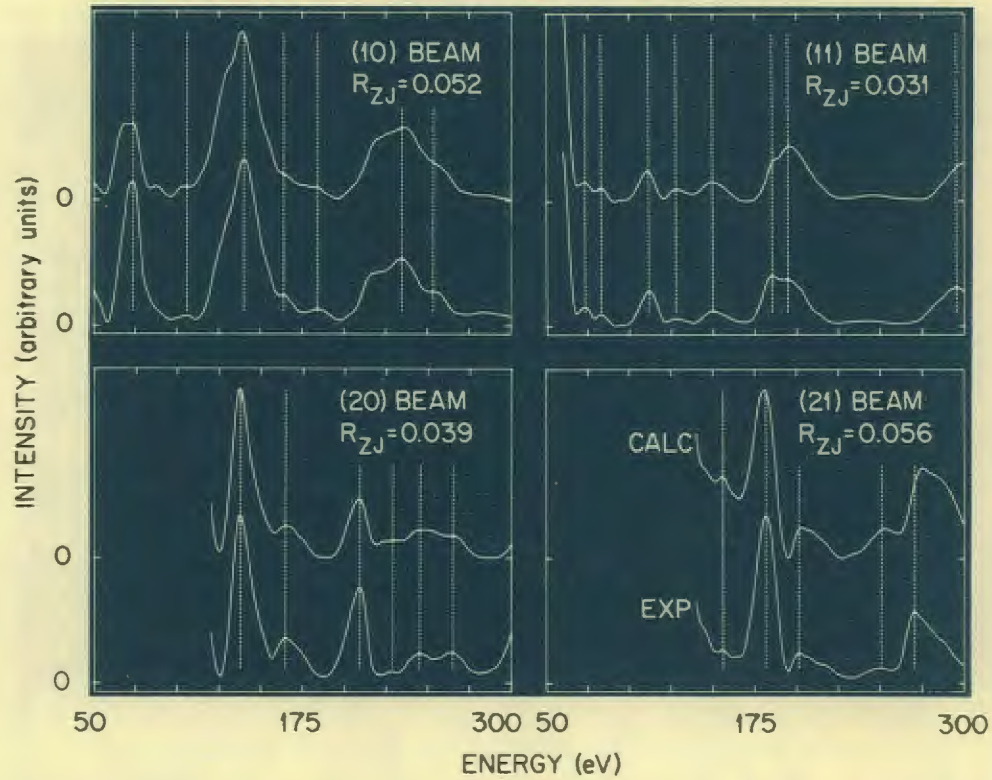
This algorithm shows the interaction between theorists and experimentalists in the pursuit of knowledge about crystal surfaces.

a beam of monoenergetic electrons. A study is then made of the elastic diffraction of the incident electrons. The elastically scattered electrons can be monitored by either a Faraday cup or a fluorescent screen. When the fluorescent screen is viewed through a port in the vacuum chamber, a geometric diffraction pattern is observed, sometimes called a spot pattern because it consists of a regular array of spots for an ordered surface. The geometry of a spot pattern is directly related to the two-dimensional symmetry of the surface being investigated, and the distances between the spots are related to the distances between rows of atoms in the surface. To obtain more detailed information about the surface—in particular, to find how the interplanar spacings vary in the surface region—it is necessary to measure the intensities of the diffraction spots as functions of the accelerating voltage, or the kinetic energy, of the incident electron beam. Such data are called I-V profiles, and can be measured with a Faraday cup. When a LEED analysis is used to determine the atomic arrangements in a surface, I-V profiles are collected for a number of diffraction spots (also called beams), and then compared with the results of theoretical calculations.

A LEED analysis is a trial and error process in which measured and calculated I-V profiles are compared and a judgment call made as to whether the comparison is good or bad. Not too many years ago, the judgment was visual, but more quantitative criteria are now used. The surface structure determined in a LEED analysis is that for which the calculated I-V profiles are in best agreement with the measured ones. Of course, perfect agreement between experimental and calculated profiles is never achieved, so the question at the bottom line is always, How accurate is the structure determined by the analysis? Some recent work by John Noonan and Harold Davis has established the present limits of precision of LEED structural determinations.

The Cu(100) surface had been examined before by others, but this had been done much earlier, when modern LEED was in its infancy. Cu(100) was therefore a logical subject for new and careful analysis. [A copper crystal has a cubic structure, with atoms at the corners and the centers of the cube faces. The (100) surface, pronounced "one-oh-oh," refers to a specific crystallographic face, like one of the facets on a jewel.] In the measurements, great care was taken to minimize experimental uncertainties. For example, when the incident electron beam is oriented normally (perpendicular) to a surface like Cu(100), symmetry demands that certain of the I-V profiles be identical. The property

This comparison of calculated and experimental I-V profiles for Cu(100) illustrates the present level of accuracy of LEED analysis. The numbers R_{ZJ} are numerical measures of the quality of the agreement; values less than 0.2 are normally considered good. A very small change (-0.6%) in the spacing between the first and second layers at the surface is determined from the comparison.



was used to align the incident beam precisely along the surface normal direction, and after the data were collected, results for symmetrically equivalent beams were averaged.

On the theoretical side, several physical processes had to be modeled. These included the transmission of electron waves into and out of the surface region, the multiple scattering of the waves from the atomic sites, damping by inelastic processes, and thermal vibrations of the atoms. A systematic study was made of the sensitivity of the calculated I-V profiles to physically realistic variations of the "nonstructural" parameters involved in modeling these physical processes.

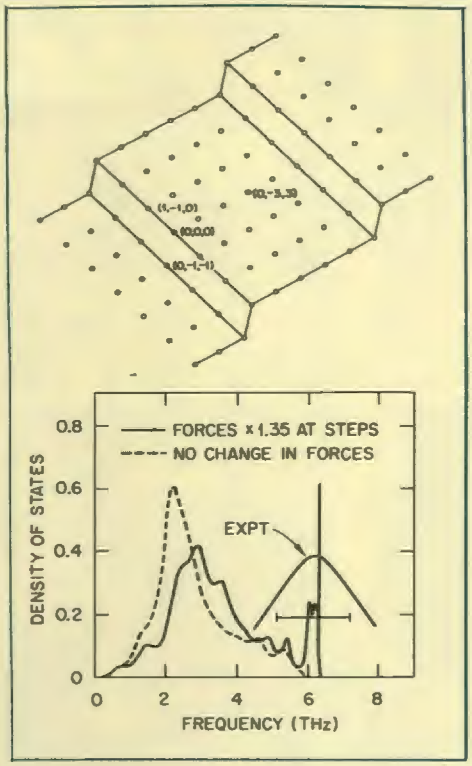
The final agreement obtained between calculated and experimental I-V profiles for Cu(100) was quite striking; it was, in fact, the best ever obtained in any LEED analysis. An important conclusion was that the results were sensitive to changes of the order of 2×10^{-12} m (0.02 Å) in the interplanar spacing at the surface. Subsequently, Noonan and Davis investigated the Ag(110) surface, and again found a sensitivity of about 2×10^{-12} m (0.02 Å). Prior to this work at ORNL, it was generally thought that LEED analysis was sensitive to changes of 5×10^{-12} to 1×10^{-11} m (0.05–0.10 Å) in the interplanar spacing. Noonan and Davis showed that greater accuracy was possible, provided that sufficient care goes into both the data collection and the theoretical analysis.

Lose a Little, Gain a Little

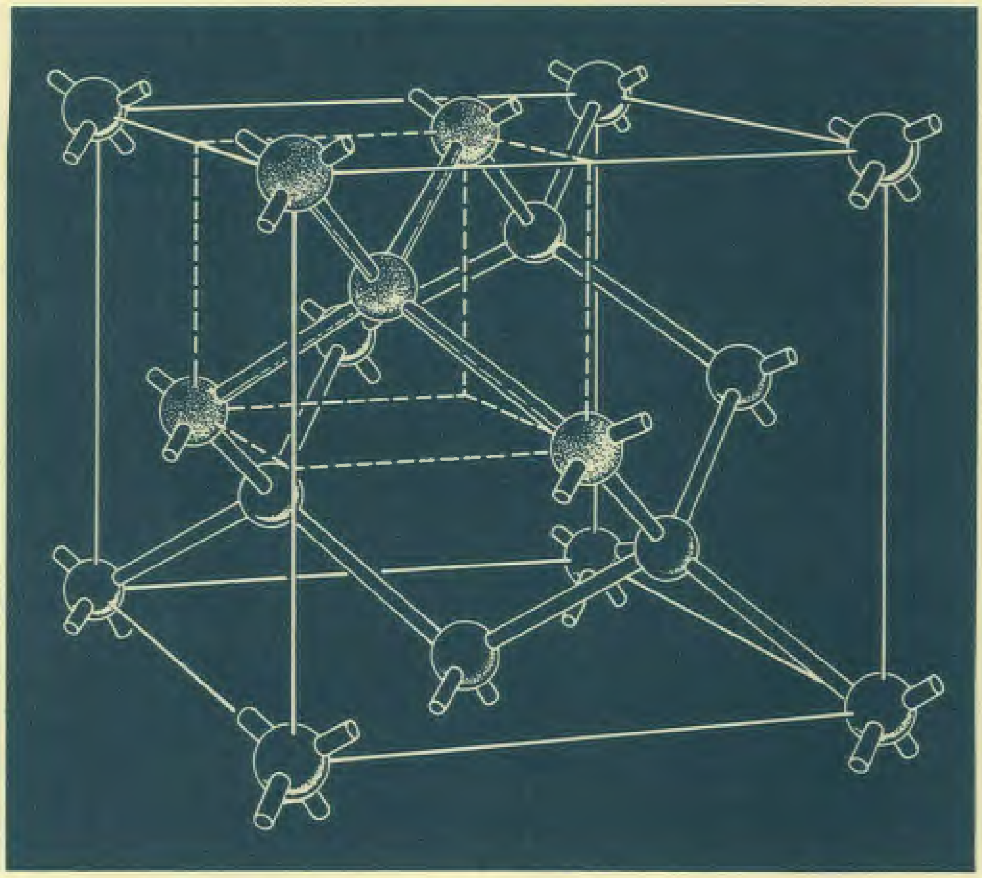
The focus of this article is on elastic scattering of electrons from surfaces. The state of the art in this spectroscopy has just been described, and an entirely new structure studied by the technique will be discussed shortly. Inelastic scattering is also very useful in surface studies and deserves brief attention.

When an electron interacts with a surface, it may lose or gain energy, or it may be elastically scattered like a billiard ball on a friction-free table. LEED measures those few percent of the incident electrons that are scattered elastically. Most of the electrons in the incident beam, however, give up some part of their energy to excitations in the surface region—for example, to atomic vibrations or to transitions between electronic states of the sample. By measuring the energy losses of the inelastically scattered electrons, one therefore can measure the characteristic energies of vibrational and electronic states in the surface region.

Electron-loss spectroscopy (ELS for short) has been particularly useful for studying adsorbed atoms and molecules. From ELS data, one can deduce information about the preferred locations of adsorbates; adsorbate bonding to the substrate; and, for molecular species, changes in the intramolecular forces and dissociation energies relative to values in the gas phase. This technique makes it possible to look in detail at the constituents and processes operating in catalytic reactions. John Wendelken, just back from a year at Julich, Germany, where H. Ibach and his group have developed ELS into a fine art, has done a number of studies of adsorbates on metal surfaces. Recently, for example, Wendelken used ELS and LEED to examine NO and NO_2 adsorption and dissociation on Cu surfaces and found that NO dissociates on the surface when the temperature is raised above 113 K or when the



Top. The Pt(332) surface has a series of steps six atoms wide and one atom high. Bottom. A high-frequency vibrational peak localized at the steps is observed by electron-loss spectroscopy. When the forces at the step edges are increased by 35%, the calculated spectrum for an edge atom has a sharp peak in the center of the experimental peak; most of the latter's width is instrumental.



In silicon, germanium, and other tetrahedrally bonded semiconductors, each atom has four nearest neighbors with which it shares electrons.

surface is exposed to more than a critical amount of NO.

The energy resolution of electron-loss spectroscopy has improved dramatically in the past five years or so, from about 25 meV down to the order of 2 meV. This has made it possible to begin looking at surface vibrations in metals, whose *maximum* vibrational frequencies are typically around 25 meV, at the lower limits of the old resolution. In late 1978, Ibach and Bruchmann observed an electron-loss peak arising from vibrations that were localized at the steps of a clean platinum surface having a regular sequence of steps just like a microscopic flight of stairs. What was surprising was that the frequency of this surface vibrational peak was higher than the maximum frequency in bulk platinum, even though an atom at the surface has many fewer neighbors than it does in the bulk. In a simple ball-and-spring model, surface vibrations always have lower frequencies than in the bulk unless the surface springs are much stronger.

Ibach and Bruchmann's results were the first (and so far, the only) observation of anomalously high-frequency vibrations at a clean metal surface. Using one-dimensional arguments, they estimated that the forces (springs) at the steps must be about 70% larger than in bulk platinum. Mark Mostoller was skeptical that such very large changes in forces were required, particularly since three-dimensional conclusions were reached on the basis of a one-dimensional model. By doing large-cluster (~4000 atoms) calculations for the actual stepped surface observed, he was able to show that the forces at the steps need increase by only 30 to 40% to explain the data.

Let There Be Si(111):(1 × 1)

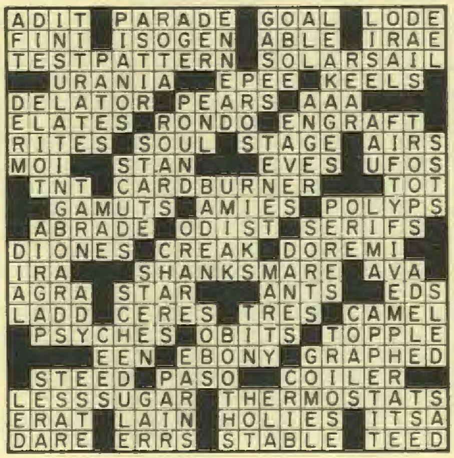
Most metal surfaces terminate as you would expect them to from a stick-and-ball model. Parallel to the surface, the planes of atoms preserve the same atomic arrangement as in the bulk crystal, and the interplanar spacings change by modest amounts in the surface region. Most semiconductors do not behave in this expected fashion, and as a consequence, their surfaces are much more difficult to understand.

Silicon, germanium, gallium

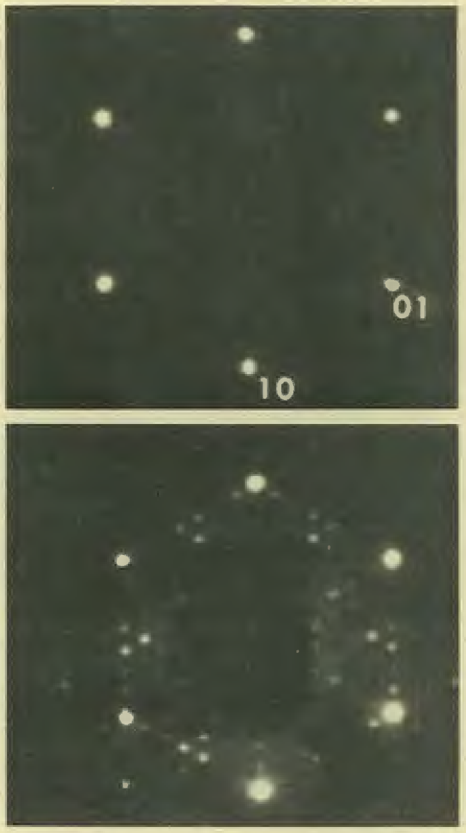
arsenide, and many other semiconductors are covalently bonded materials that crystallize in the diamond or the essentially identical zinc-blende structure. Each atom can be viewed as sitting at the center of a pyramid, with directional bonds of shared electrons to four nearest neighbors at the corners. This covalent, tetrahedral bonding is the source of the great hardness of diamond (carbon in the diamond structure) itself. The tetrahedrally bonded semiconductors are the material heart of the revolution in electronics and related technologies that began after World War II: transistors, integrated circuits on silicon chips, solar cells, light-emitting diodes, and random access computer memories are just a very few examples of devices based on these materials. To emphasize their importance on a prosaic level, it may be fair to say that without semiconductor devices, calculators would still be as big as breadboxes, and about as fast.

Virtually all semiconductor surfaces reconstruct: the atoms at the surface do not have the same two-dimensional arrangement as corresponding planes in the bulk. Instead, the surface atoms shift around to form some new ordered structure called a superlattice. In a 2 × 1 superlattice, for example, the periodic repeat distance is doubled along one direction in the surface. There are many ways to do this: remove every other row of atoms perpendicular to this direction; ripple the surface by raising and lowering alternate rows; dimerize by moving pairs of rows closer together to produce a repeating sequence of short-long-short-long distances between rows; or combine the ripple and dimer models. Further complicating the problem, the reconstruction may extend several layers deep, rather than being confined just to the outermost layer. Because there is such a proliferation of possibilities when reconstruction occurs, the detailed atomic arrangements and electronic structure of many semiconductor surfaces remain to be elucidated.

Answer to crossword puzzle, p. 16.

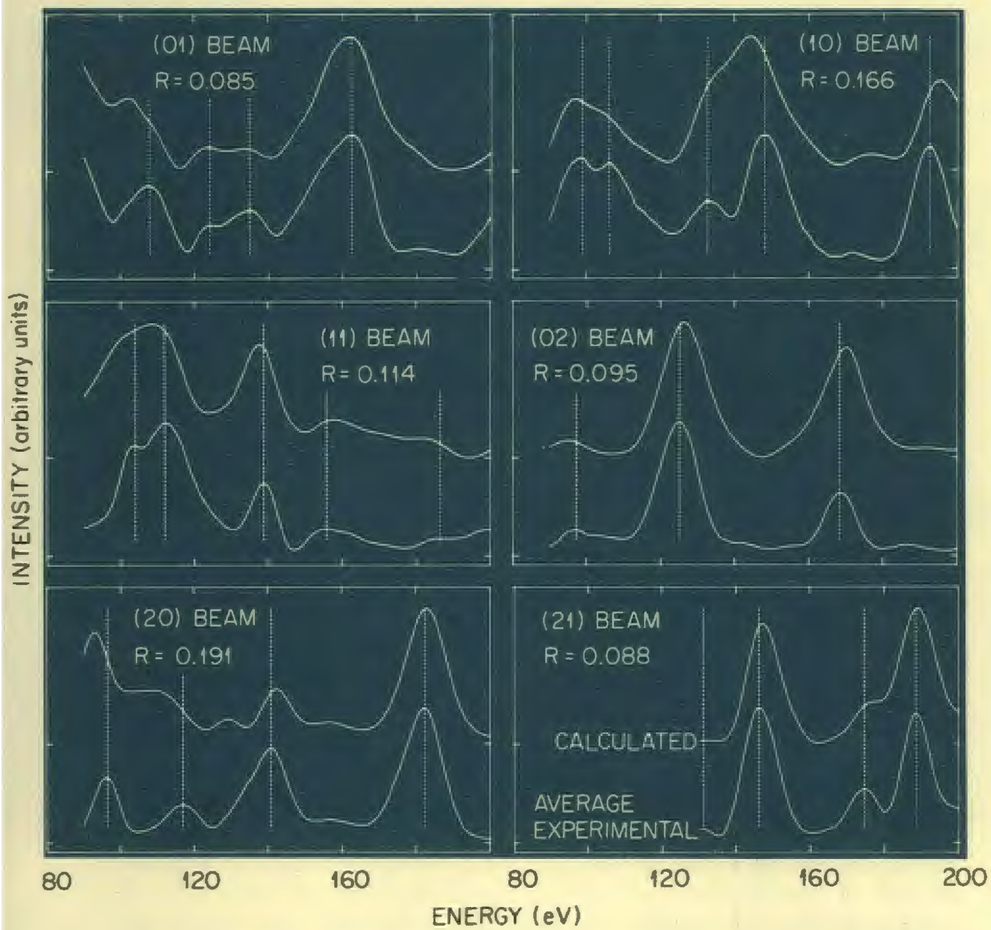


LEED patterns from clean Si(111) surfaces show the difference between an unreconstructed, 1 × 1 surface prepared by laser annealing (top) and the reconstructed, 7 × 7 surface obtained with conventional thermal annealing (bottom).



Si(111)—the (111) surface of silicon—is normally a reconstructed surface with a structure that is unknown save for the new periodic repeat distances. A 7 × 7 LEED spot pattern is observed when the surface is prepared in the conventional way by bombarding it with argon ions and then thermally annealing it at a temperature of ~1100 K. An unreconstructed, or 1 × 1, spot pattern has been seen only, for example, when a rather sizeable concentration of tellurium impurities (about 5%) is used to stabilize the surface against reconstruction. How the tellurium impurities do this, or even where they sit, is not known, and doing LEED calculations for a random alloy surface would require some questionable assumptions.

In the past few years, members of the Solid State Division have been among the pioneers of a new method of materials processing called laser annealing, which typically works in the following way. A semiconductor sample is irradiated with a short pulse (say, 10 ns, or 10^{-8} s) of light from a ruby laser, of sufficiently high intensity 1 to 2 J/cm^2 or so) to melt the surface region. The melt front penetrates to a depth of several hundred nanometers and then sweeps back to the surface at very high velocities on the order of 3 m/s (7 mph) as the molten silicon recrystallizes in registry with the unmelted substrate. At the end of this cycle, the annealed region is usually crystallographically perfect, whether the starting material was crystalline, damaged, or even amorphous. High, uniform concentrations of electrically active impurities such as boron and arsenic can be incorporated at substitutional sites by the laser-



Calculated and experimental I-V profiles for the unreconstructed Si(111):(1 × 1) surface.

annealing technique. This capability, the high degree of perfection obtained, and the technique's great simplicity make laser annealing a potentially very attractive way to fabricate devices such as solar cells.

Sensing the possibility that laser annealing might produce new surface structures, Dave Zehner tried for some time to obtain the laser to do exploratory LEED experiments. He finally achieved that objective in the spring of 1979, when he, Woody White, and Gary Ownby laser-annealed a number of samples in vacuum and looked at the resulting surfaces with LEED. To their delight, it appeared that laser annealing produced an atomically clean, *unreconstructed* (or 1 × 1) Si(111):(1 × 1) surface. This offered the chance to study the atomic and electronic structure of the (111) surface without the complications introduced by reconstruction. There might then be more hope of understanding the structure of the reconstructed surface and the forces driving the reordering.

With Noonan's help, more LEED measurements were subsequently done on Si(111):(1 × 1) to collect I-V profiles for several sets of equivalent beams. Presented with this opportunity in the spring of 1980, Davis then very quickly but carefully performed a series of calculations to analyze the data. He found that the spacing between the first and second layers contracts by (25.5 ± 2.5)%, while that between the second and third layers expands by (3.2 ± 1.5)%. These correspond to bond-length changes of -5.8×10^{-12} and $+7.5 \times 10^{-12}$ m (−0.058 Å and +0.075 Å), respectively; the first-second layer spacing is one-third that of the second-third layer spacing before relaxation occurs, and the bonds between the first and second layers are at an angle to the surface normal, so the larger percentage change in interplanar spacing produces the smaller change in bond length.

Davis's final results were in better agreement with experiment than any previous LEED analysis of any semiconductor surface. It was, furthermore, the first LEED analysis of a clean semiconductor surface in which the surface atoms exhibited no ordered lateral displacements.

More experiments on the unique Si(111):(1 × 1) surface and others produced by laser annealing are planned. In fact, as this article was being written, Zehner, White, Ownby, silicon samples, and the laser were all at the synchrotron at the University of Wisconsin for photoemission measurements of the electronic states at the surface. Step by step, using LEED, electron loss, photoemission, and other spectroscopies, and carrying out the requisite calculations in parallel, we will eventually understand the structure of semiconductor surfaces. ornl

lab anecdote

Red, White, and U

Human blood has always been looked at as a mirror of the human condition. The mirror is often cloudy.

In 1944 two chemists here at the Lab were given leave with pay because of low white blood cell counts and because they worked with uranium fission products. Was there really a correlation? Two weeks later the counts had not increased, so they were invited back to work. Glen Jenks and John Boyle, the two chemists, are still working at ORNL thirty-six years later. The norm for white blood cells today is from 4,800 to 10,800 cells per cubic millimeter; with such a range how does one know what is a significantly low count—anyway, there are many ways to drive the count down, such as staying out late every night for a week. Needless to say, no one has been given a free vacation since then for no bigger a reason than a low blood count, including Glen Jenks and John Boyle.

Interest in the white blood cells soon changed. Several years later Jean Felton, M.D., the director of Health Services at the Lab, spoke at a seminar about the declining red blood cell count. Since he had monthly blood analyses of every employee, he had a wealth of data and the data disturbed him. He compared old employees (in 1948 that meant those with more than three years of service) with new employees, and both groups showed the same decline. He advertised for employees who had grown up within 50 miles of ORNL, and they too showed the decline. "Perhaps," he told us at the seminar, "the great hematologists at Johns Hopkins who established the norms did not use a representative population but only used nurses and interns in their studies, and the hematologists' value for a normal red blood count was not really a good number." Dr. Felton never published his findings because the red blood cell count turned upward and reached the old level. Was the whole thing a matter of the changes in wartime and postwar nutrition, of "more steaks in the diet"?

When I phoned Dr. Felton last year he said that he had forgotten the episode. But the statement about the great hematologists was in character. Henri Levy, still working in a chemistry lab here, corroborated the story for me. Along with many written reports, we still carry forward our oral traditions.—Herbert Pomerance

Trends in Scientific and Technical Information

By CAROLYN KRAUSE

Take a look at the exciting new advances prophesied for information science by the late 1980s. They may well keep pace with the anticipated advances in science information.

At the press of a button, the scientist in the late 1980s has instant access to information; just months before, he had to wait for a librarian or a professional documentalist to seek out the source material that might answer his questions.

With his intelligent computer terminal and cathode-ray tube screen, the scientist has face-to-face conferences with his colleagues who are all over the nation, receives color pictures and text on his split CRT screen, talks to a colleague while both look at the same data, and transmits a journal article he has written and edited on his CRT screen to the CRT screens of the journal editor and peer review committee as part of a new electronic refereeing process. The scientist particularly likes this last feature because it means that his article will appear in print in a few weeks instead of six months to a year later.

The scientist now conducts rapid searches for information on his terminal. He calls up documents in the electronic library for perusal on his CRT screen and prints them out in his office at the rate of one page every 4 s. It used to be that he would ask an information specialist to get a list of books and journal articles that pertained to the subject of interest, and then the scientist had to ask the librarian to find the journal in which the article appeared. All of this consumed more time than the scientist wanted to take.

Now, in the late 1980s, the scientist can access the appropriate data base almost instantly, thanks to computer programs (software), called transparency aids, that match the user's needs with the appropriate class of data bases. These aids perform such services as translating information from a foreign language to the user's native language. Intelligent terminals, CRT screens, transparency aids, and other wonders give the scientist information at his fingertips, with a speed he has never known or dreamed of before.

This future-shock scenario was suggested by Joseph Becker, president of Becker and Hayes, Inc., in a keynote address delivered during the symposium called "Perspectives on Scientific and Technical Information," which took place September 9 through 10, 1980, at ORNL. The symposium was sponsored by the Information Center Complex of ORNL's Information Division. Becker made the following observations:

- **We are seeing a shift in emphasis away from bibliographic systems and towards the development of information systems for individuals. STI (scientific and technical information) in the 1980s, I believe, will be much more the responsibility of individual scientists and other end users, and no longer the sole domain of the professional documentalist. . . .**
- **[Computerized] devices are forever getting smaller and cheaper, and this trend is making the dream of intelligent terminals, home computers, and hand-held information displays a reality. Eventually, this development means that the computer will invade the office and home, particularly those of the scientist, not only for numerical use but also for nonnumerical information processing.**

Becker added that scientists will be able to call up whole documents on their CRT screens (and have them printed out at the press of a button), thanks to improvements in direct access magnetic disk memories and optical devices that use laser light beams both to "write" and "read" binary data electronically.

Becker has a word processor on which he writes and edits letters and manuscripts. It consists of an intelligent terminal, which is programmed to carry out simple functions itself. "All of the information I generate as an author is immediately available in machine-readable form; this allows me to be a publisher as well. I can choose a particular type font and style,

Carol Oen, chairman of the ICC committee that organized the September symposium on "Perspectives on Scientific and Technical Information," discusses information access advances with Helga Gerstner, ICC director.

determine the pitch of my lines, specify column height and width, and request right-hand margin justification. On command, my intelligent terminal faithfully executes my instructions for hyphenation when required and will even check the text for spelling errors against a dictionary stored in its memory."

With this word-processing machine, Becker can go on-line with the aid of a special computer network. "I am then able to send my text to one or more associates for comment, or send them a message with a report number so that they can call up the text later, at their convenience. I can also direct a copying machine to accept laser-produced images from the computer, and to print copies and collate them—as many as I wish....

"With information display terminals in every home, we can expect basic changes to occur in the social structure of scientific communication. STI will no longer be equated with library research, or data base lookup, or document delivery. It will mean 'teleconferencing' with voice, pictures, and text; performing analytical information work on intelligent terminals; publishing research results electronically; and allowing scientists to be in almost constant communication with their colleagues and peers."

In the 1990s, according to Becker, we can expect the signals from information machines to be transmitted along broad-bandwidth channels, which are much more efficient than narrow-band telephone cables. Computers will be "talking" to each other over fiber optics cables, whose broad bandwidth permits them to carry 8000 times as much information as copper wires.

From Copper to Fiber Optics

"Fiber optics," explains Becker, "employ thin strands of glass no wider than a human hair. They can bend and twist without breaking. The glass fibers carry coherent light in the form of electromagnetic energy called photons. Because more photons can pass down a coherent light path per unit of time than electrons can pass down a telephone wire, they provide greater bandwidth. Moreover, photons carried by glass fibers do not dissipate the way electrons do when traveling over copper wires. Therefore, photon signals remain stronger longer."

Although electronic journals, electronic mail, and paperless record centers may be the wave of the future, Becker does not forecast the end of paper and books as did Octave Uzanne in 1894 when he wrote in *Scribner's* that books would be replaced by phonograph records. Says Becker, "Let us not forget paper's essential advantages: it is cheap, portable, and personal. We can hold it in our hands."

In the meantime, we have to find the best ways to use technological brain-childs such as video disks, picture phones, and high-speed printers that reel off 30,000 lines a minute. "What has become clear in recent years," says Becker, "is that technology leads rather than follows. As never before, we must decide not only which technology is to be used, but how it is to be used before it even arrives."

Transparency Aids

Research is under way on the development of transparency aids to help scientists and other users locate the information they need more rapidly. Martha Williams of the University of Illinois, speaking on "Research Toward a Transparent Information System" at the ICC symposium, said that specialists now have to take eight steps to find the information sought by users. They must (1) identify and search a directory, (2) identify and locate the secondary system (such as a computerized data base), (3) query the secondary system, (4) identify and locate the primary source (such as a journal article or book), (5) order or access the primary source (print out an abstract or find a book in the library), (6) search the primary source, (7) locate the facts, and (8) assimilate the information for their own use.

Because of the proliferation of information and data bases, finding a fact has become as difficult as locating a needle in a fast-growing haystack. Williams pointed out at the ICC symposium that the growth of computer-readable data bases in the second half of the past decade has been phenomenal. From 1975 to 1979, the number of data bases nearly doubled, the number of records tripled, and the number of on-line searches multiplied fourfold. In addition, the number of technical journals has increased from 20,000 to nearly 30,000 in the last decade.

The problem that the scientist faces is the number and variety of data bases in a given subject area. He faces the same problem that a small newspaper's food editor might have in searching the recipe files of many homemakers in hopes of finding a particular recipe requested by a reader. Frequently, the scientist needs an intermediate—a group of people such as those in ORNL's ICC who have the expertise in the technical subject and who know how to search the appropriate data bases.

To expedite the scientist's retrieval of information, special computer programs called transparency aids are being developed as an alternative to the costly standardization of data bases. These aids, described by Williams, include automatic selectors, converters, routers, evaluators, and analyzers. The University of Illinois, Lockheed Corporation, and Systems Development Corporation have developed data base selectors, which match the class of data bases with the class of user. The National Bureau of Standards and Lawrence Livermore National Laboratory have developed converters that convert the language of one system to that of another. Evaluators and analyzers determine the user level—that is, the program asks the user to describe himself ("I'm in junior high," or "I'm a grade school science teacher," or "I'm a nuclear engineer"). The evaluator then decides what level of difficulty the output should be for the individual user. The advantage of this software is that it will eliminate the need for personal assistance on easy searches and will provide rapid answers to user questions at the press of a button.

Unifying Data Bases

Research is being done at the University of California at Berkeley on ways of unifying data bases to achieve a total collection of related data in a given subject area, and, in the process, to eliminate duplication and resolve inconsistencies between the same subject data bases. This work was described at the ICC symposium by Eugene Wong, a Berkeley professor. Success in unifying and integrating data bases would make it easier for scientists to access distributed information systems.

Homer Hall of Rutgers University asserts that scientists and other users of information in data bases should be aware of the biases that are operating when information analysts compress data for the use of others. When a scientist obtains data from an experiment, he is selective about which data he will record and which information he will publish. His published articles are then abstracted and indexed by others. The selection-and-rejection process used on the original information is governed by the personal viewpoints and values of the people who have handled the information on its way from laboratory bench to data base. These biases are normal, Hall said at the ICC symposium, but information users should be aware of their existence.

The National Library of Medicine has demonstrated success in unifying data bases—or subsets of data bases—on toxic chemicals in one subject-specific on-line file called TOXLINE. This file can be accessed through the NLM Medical Literature Analysis Retrieval System. At the ICC symposium, Henry Kissman, associate director for Specialized Information Services of NLM, described the Chemical Substances Information Network project—a more far-reaching networking concept that will eventually combine all available files on potentially hazardous chemicals so that the files can be accessed simultaneously. If a user has a question about toluene, for instance, CSIN can provide such data as chemical composition, properties, commerce, products

Dana Ellingen, at an INTEXT terminal in the Information Center Complex, searches RECON's Energy Data Base.

and uses, exposure, health effects, regulations and controls of the chemical, and results of research and studies. Under the sponsorship of NLM, the Laboratory is currently building a toxicology data bank which contains numerical and factual data on chemicals. The toxicology data bank is incorporated into the NLM Medical Literature Analysis Retrieval System and is available on-line to the scientific community at large. The toxicology data bank will become a major contributor to CSIN.

Marketing STI

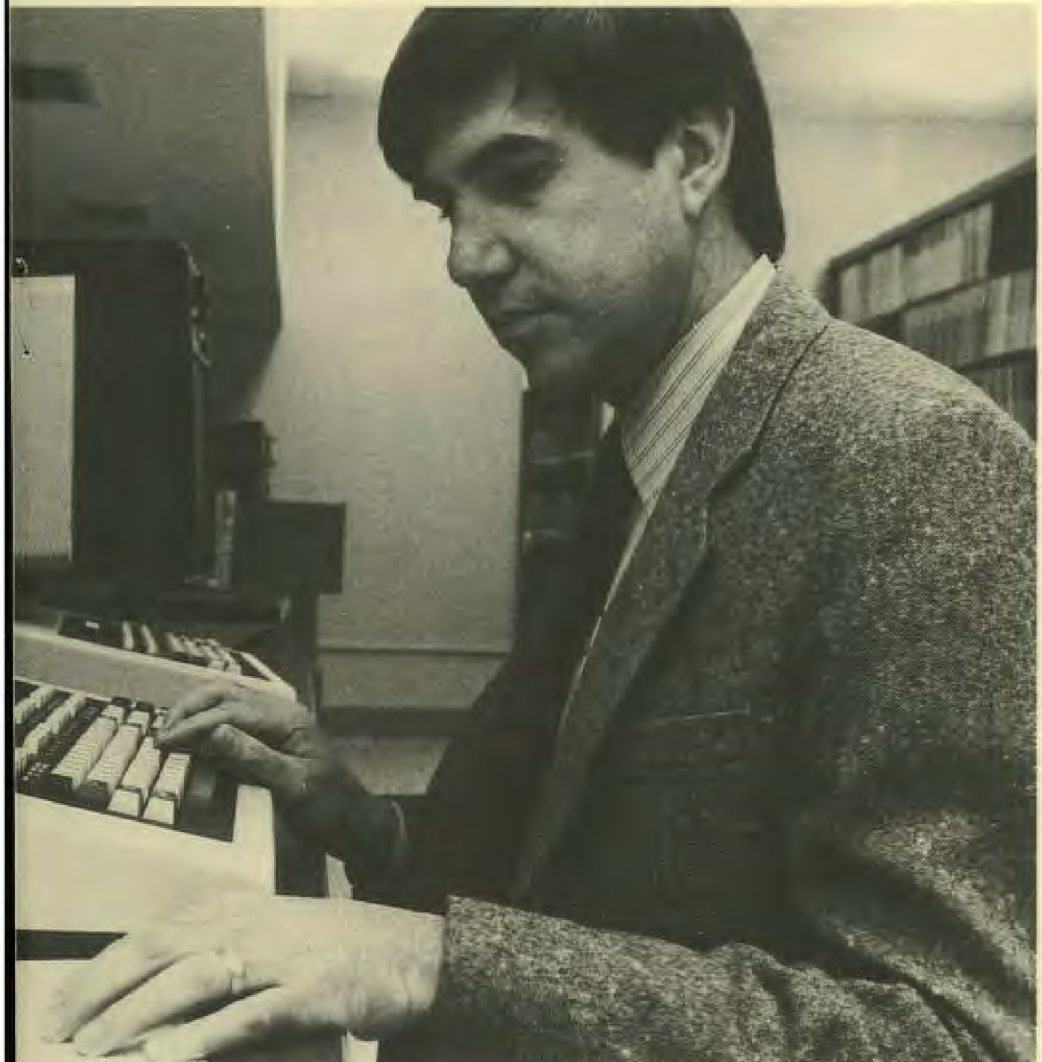
Although the price of information access to computerized data bases is gradually declining as technology improves and demand increases, it has a long way to go to match the low price of information products such as books and brochures. Joseph Coyne, manager of DOE's Technical Information Center, says that information products tend to be priced low because of the presence of the federal government in the information business. "This in effect leads information users to believe that all information should be priced low and, as a result, limits the flexibility the private sector has in developing products of quality," Coyne told participants at the ICC symposium.

Coyne says that there are several reasons why the government is in the information marketplace: to handle information products and services that the private sector is either not interested in or finds unprofitable; to provide free information to those unable to pay for it; and to serve government objectives by providing useful advice to the public, as in the case of energy conservation.

TIC is interested in what the market is for STI. Pertinent data on the information needs of scientists and engineers is provided in *Managing the Flow of Technology*, a book by Thomas Allen that Coyne cites. "In his book," Coyne says, "Allen maintains that technology information is transferred primarily through personal contact. He sees a difference, however, between scientists and engineers. Scientists keep track of one another's work through visits, seminars, meetings, and conferences, supplemented by an informal exchange of written material long before it reaches archival publication. Technologists, on the other hand, keep abreast of their field by close association with coworkers in their own organization." Allen found that three times as many engineers as scientists felt it was important to gain knowledge of their company's management, policies, and practices. Such information on the work habits of various groups of scientific and technical personnel is useful in understanding the potential market for technical information products and services, Coyne suggests.

Information as a Commodity

Like food, STI is an American product in great demand around the world. Questions are now being raised as to whether the United States should impose controls on the information it exports, whether it should learn how to import information from computer networks such as Euronet, what international competition can be expected, and what policies should be developed concerning international information exchange. These questions were mentioned at the ICC symposium in an address on information trends given by



Andrew Aines, director of STI at DOE.

"My first observation," says Aines, "deals with the geopolitics of information, the heightened awareness on the world scene of the importance of information as a major constituent of power.... The major countries of Europe and Japan have taken many actions singly and in combination to cope with the lead of the United States in information technology. The developing countries of the world have united in demands on the advanced countries for assistance in developing their information processes and for provision of the technical and other kinds of information they need to achieve progress in manufacturing, agriculture, and services."

Because of various happenings on the international scene, Aines foresees the formulation of policies that impose some controls on information export. "Most foreign countries in which STI is generated take a less liberal view of making it available to the world than we do," Aines says. "We are beginning to hear expression of concern in the United States about our so-called 'giveaway' of U.S. know-how, including technical information. We have not heard the last of this, I am sure. I expect that congressional and White House leaders will ask us to establish controls to make sure that there is a reasonable quid pro quo received for U.S.-generated technical information made available to other countries."

Aines noted that Congress is "rapidly becoming a modern information-generating, information-using, and information policy-formulating institution.... It is a huge information operation using increasingly sophisticated technology and techniques.... Congress will expect, possibly demand, that the federal agency data bases be open to them at all times.... There were about 1500 bills dealing with information matters of all kinds introduced in the last Congress, of which about 150 became laws."

The courts, Aines says, will be increasingly pulled into information issues as commercial firms seek settlements involving their right to obtain federal information, including data bases. He believes that universities may soon offer courses in information law.

Both Aines and Carol Alexander, head of the Environmental Protection Agency's Office of Library Systems and Services, mentioned the importance of a directive on information about to be issued by the Office of Management and Budget. Says Aines of the OMB directive: "It will require a top-level information executive in OMB, who will ride herd on a number of similar information executives or directors in each of the federal agencies. It also sets up the information locator system that the Paperwork Commission recommended a couple of years ago. We can presume that the directive will result in more openness and better management of all information systems."

The National Technical Information Service, says Aines, has two new missions: to improve the productivity of U.S. industry by packaging useful technical information and to gather foreign technical information for possible exploitation in the United States.

Also, the White House Office of Science and Technology Policy has the task of implementing a law passed in 1976 that gives the federal government the responsibility of promoting the prompt, effective, reliable, and systematic transfer of STI. The law calls upon the government to "coordinate and unify its own STI systems and facilitate the close coupling of institutional scientific research and commercial application of the useful findings of science."

Aines is currently organizing DOE's STI program, which has given priority to strengthening TIC in Oak Ridge. DOE has set up a panel on international STI to examine the DOE interchange program and to see what steps DOE might take to help developing countries, especially in research information on renewable energy resources. Another panel, the ad hoc DOE National Laboratory Scientific and Technical Information task group, is chaired by Dan Robbins, director of ORNL's Information Division. It brings together members of Aines's program and information managers from all the national laboratories to examine information-sharing programs and networks.

Information access for increasing numbers of people will be a trend in the 1980s. As Carol Alexander put it, "We have shifted from traditional libraries that house collections of books and journals to switchboards that get information quickly to the customer at low cost." Another trend is the continued growth of the information industry. Edward Kolb of the U.S. Army observed that, in 1980, more than 70% of the U.S. work force was involved in the service industry and that this industry was predominantly information dependent.

The long-range future for science information and information science is perhaps best summarized by Becker: "The twenty-first century has the task of bringing STI more directly to the people. The wider need for STI to solve social problems means that more people will qualify as potential users. The policymaker, the administrator, the problem solver, and the public must all be taken into account in the processing and distribution of STI and the serving of information needs." ornl

ORNL Celebrates STI's Coming of Age

During the week of September 8 through 12, 1980, the Information Center Complex of ORNL's Information Division held an open house in Building 2001, hosted the first meeting of ICC's new advisory committee, and sponsored a national symposium called "Perspectives on Scientific and Technical Information." As Chet Richmond, ORNL's associate director for biomedical and environmental sciences, put it, "We are celebrating the coming of age for scientific and technical information activities at ORNL."

One of the earliest information centers set up at ORNL was the Nuclear Data Project (1946). But information analysis centers did not really begin to sprout at ORNL until after the first seed was planted by a panel of the President's Science Advisory Committee. The panel's mandate was to determine the most efficient methods for systematically dealing with the explosion of scientific information. Headed by Alvin Weinberg, then ORNL director, the panel recommended in 1963 that information analysis centers be created to bring some semblance of order to information entropy.

Today, ORNL has a large contingent of information centers and programs. Some of these are imbedded in ORNL divisions, such as the Engineering Physics Information Center and the Information Center for Energy Safety (Engineering Technology Division). The Information Division's ICC, however, houses and maintains the bulk of ORNL's information centers. ICC provides information support to ORNL researchers, program managers, and administrators, as well as to private industry, consumers, and government agencies, including DOE, the Environmental Protection Agency, the National Toxicology Program, the National Library of Medicine, and the National Institutes of Health. In concert with nationally important issues, ICC generates and disseminates information relating to the health and environmental impact of various energy and related chemical technologies, and it develops new data bases and other information services and products as the need arises.

take a number

BY V. R. R. UPPULURI

Second Guessers

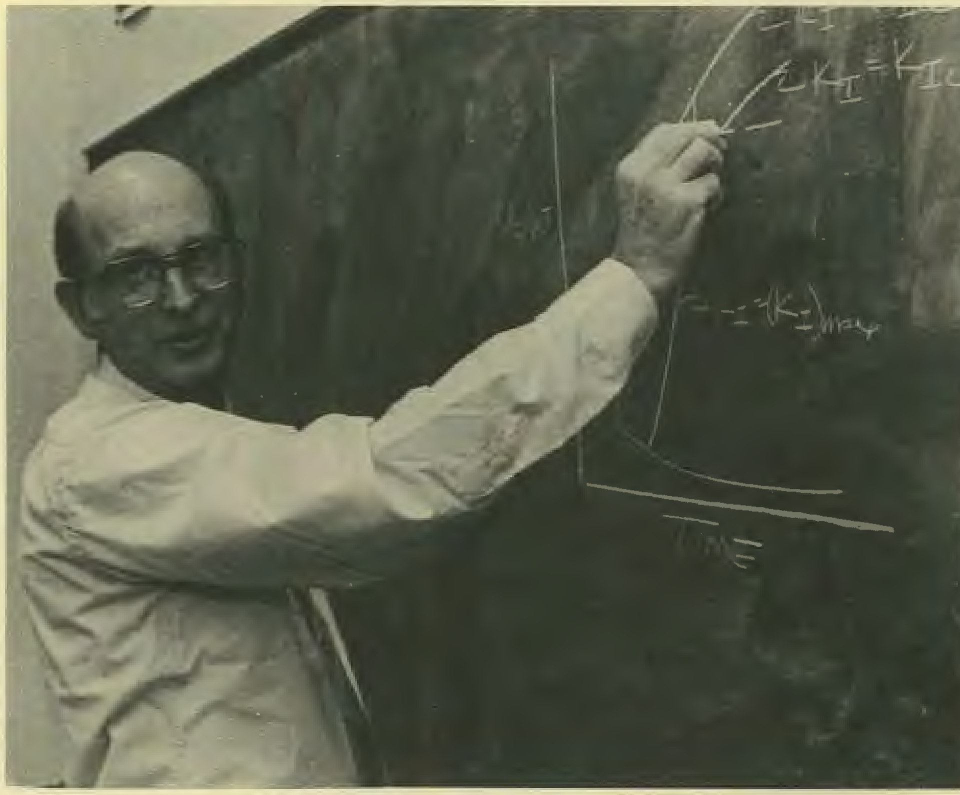
Suppose Alan and Betty are equally good at guessing the weights of people. At a party where there are several people, Alan, guessing first, says that the weight of Charles is 70 kg. Then Betty says that the weight of Charles is 70.1 kg. Charles declares Betty to be the winner because she is closer to the correct weight. This game is played several times, with Alan always going first. The question is, who wins this game more often?

It is clear that, so long as she always goes second, Betty has better than a 50% chance of winning this game. In fact, the advantage to Betty is typically as large as 75%. The statistical framework in which this result can be established is discussed in a recent paper by J. M. Steele (Stanford University) and J. Zidek (University of British Columbia).

Alternating Binary Sequences and Primes

Consider numbers of the form 101010...101, where the zeros and ones alternate. It can be seen that $10101 = 3 \times 7 \times 13 \times 37$, which makes 10101 a composite number. But 101 is a prime number, since its only factors are 1 and 101. The question arises whether there are any prime numbers of the type 101010...101.

Interestingly enough, it can be shown that there are no other prime numbers of the type 101010...101. Thus except for 101, all numbers of the type 101010...101 are composite. (This result is true in any base system.)



Dick Cheverton joined the Laboratory in 1953 directly from Georgia Tech, where he earned his bachelor's and master's degrees in mechanical engineering. At ORNL, he completed the ORSORT course in 1956, and he has been with the Engineering Technology Division's predecessors and the division ever since. His principal interest has been the analysis, design, and development of reactor components, and he has the principle responsibility for the nuclear design of the High Flux Isotope Reactor. He is currently responsible for the Laboratory's thermal shock program, in Grady Whitman's heavy-section steel technology program, sponsored by the Nuclear Regulatory Commission. His colleagues in this investigation, with their areas of responsibility, are Sam Bolt, operation of test facilities; Shafik Iskander, fracture mechanics analysis; Domenic Canonico and Walt Stelzman, material-characterization studies and fracture-surface analysis in the Metals and Ceramics Division; and Pete Holz, flaw preparation.

Pressure Vessel Integrity

How will reactor vessels respond to sudden cooling?

By R. D. CHEVERTON

As a matter of necessity, reactor pressure vessels (RPVs) have been designed to be virtually indestructible because the vessel must contain the coolant that prevents meltdown of the core. During emergencies, relief valves and safety valves prevent the primary-system pressure from going much above normal, and emergency core-cooling systems provide coolant for the core, if necessary. Thus, all seems well. However, injecting emergency core coolant (ECC) and/or introducing the normal coolant at an abnormally low temperature (the result of an overcooling accident) can subject the pressure vessel to a thermal shock (rapid cooling) that results in high thermal stresses and low fracture toughness. In the absence of cracklike flaws on the inner surface of the vessel wall, the thermal stress and low temperature would be of little concern. On the other hand, if inner-surface flaws do exist, it is possible that under some circumstances the flaws will propagate deep into the wall, introducing the possibility of a breach in the primary-system-coolant containment. Because of concern over this possibility, a program was established at ORNL for investigating the behavior of inner-surface flaws in RPVs during severe thermal-shock loading conditions. These studies have included thermal-shock experiments with large, thick-walled steel cylinders and an extensive analysis of pressurized water reactor (PWR) vessels during a loss-of-coolant accident.

The predicted behavior of surface flaws falls into the realm of fracture mechanics, and linear elastic fracture mechanics (LEFM) is the usual analytic tool. LEFM is based on the notion that when the change in potential energy within a structure, resulting from a small extension of a sharp flaw, is equal to or greater than the surface energy corresponding to the crack extension, then the crack will propagate in a brittle fashion. Through a stress analysis of the crack tip, this change in potential energy can be related to a quantity referred to as the stress intensity factor, K_I, and the surface energy per unit of new surface area can be thought of as a critical value of the change in potential energy in the structure. Thus, there is a critical value of K_I for fracture, referred to as K_{Ic}, which is regarded as a material property for certain specified conditions.

Once fast fracture takes place, the crack will run at high speed (several hundred meters per second) until K_I falls below another critical value, K_{Ia}, the crack arrest toughness, which is less than K_{Ic} and which also is regarded as a material property. Although K_{Ic} and K_{Ia} are generally measured in the lab with small specimens, they can also be deduced in some cases from experiments with large structures. One of the prevailing questions is whether the two values so derived agree. In other words, does a large flaw in a large structure behave in accordance with the lab toughness values?

In addition to having different values for different materials, K_{Ic} and K_{Ia} increase with temperature and decrease with fast-neutron fluence. Thus, when a thermal shock is applied to a PWR vessel, inner-surface flaws are particularly vulnerable because the inner surface has the highest fluence and is subjected to the lowest temperature.

The Copper Problem

Another factor influencing the material toughness is the concentration of impurities, particularly copper. The higher the concentration of copper, the greater the radiation-damage effect. This is an important consideration because a number of the early PWR pressure vessels contain a rather high concentration of copper in welds and/or in the base material.

When K_{Ic} is measured in the lab, care is taken to make the initial flaw very sharp to result in a minimum value of K_I at fracture. In a real structure such as a pressure vessel, the flaw may not be so sharp, and the K_I values for fracture will be greater than K_{Ic}. This may prevent fracture, but if fracture does occur, the relatively large amount of potential energy at the time of fracture will cause the crack jump to be substantially greater. There is some concern that long crack jumps will introduce dynamic effects (ringing of the wall) that immensely complicate the analysis of crack behavior.

During all standard K_{Ic} testing, the load on the specimen is increased continuously, and the specimen is maintained at a constant temperature. For actual structures this may not be the case, and as a result the effective value of K_{Ic} may vary. For instance, in the case of thermal-shock loading, K_I for a given flaw first increases with time and then decreases as the thermal stresses subside, while at the same time K_{Ic} decreases continuously since the temperature does so. It is possible that during such a transient, K_I will not become equal to K_{Ic} until after K_I begins to decrease with time. It has been postulated and demonstrated as a part of our program that under these conditions the flaw will not propagate, even if K_I becomes much greater than K_{Ic}. This inability of the flaw to propagate under these conditions is referred to as warm prestressing (WPS) and may be an important phenomenon in limiting crack growth in PWR vessels during thermal-shock loading.

LOCA and Flawed Vessels

A reactor thermal-shock problem of particular interest to us is the PWR double-ended-pipe-break loss-of-coolant accident, generally referred to as simply PWR-LOCA. The PWR-LOCA results in a sudden loss of primary-system pressure, triggering injection of the emergency core coolant. The ECC, which normally is at room temperature (~20°C), enters the pressure vessel through a main coolant line and passes over the inner surface of the vessel on the way to cooling the core. The temperature of the vessel at the outset of the accident is the vessel's normal operating temperature of ~290°C. The large temperature difference (~270°C) between coolant and wall, in combination with a substantial coolant-film heat-transfer coefficient, results in a severe thermal shock to the vessel wall, producing inner-surface stresses close to the initial yield strength of the material.

The probability of cracklike flaws existing on the inner surface of the vessel wall is remote because of the application of extensive inspection procedures. However, one must not ignore the possibility that a flaw will go undetected or that a flaw may develop as a result of corrosion or fatigue during reactor operation.

The length and orientation of the flaw are important also. For the purpose of most of our analyses, the flaw is assumed to be quite long and oriented in an axial direction; such a flaw is more amenable to accurate analysis, and there are indications that the more probable short flaw would become a long flaw anyway. But aside from this, a long flaw has a greater potential for propagating deep into the wall, so the conservative approach is to consider the long flaw.

Our analysis of the PWR-LOCA, using LEFM, indicates that present-generation and future PWR vessels, which have or will have low concentrations of copper, will not experience significant crack propagation. However, about twenty-five of the early PWR vessels have high enough concentrations of copper to create a potential problem, unless it can be demonstrated that arrest will take place in a rising K_I field and that WPS will in fact limit crack propagation. The analysis of these high-copper vessels indicates that crack propagation will proceed in a series of initiation-arrest events, with at least the first arrest event taking place in a rising K_I field. If WPS is not effective, the final crack depth will be in excess of 80% of the wall thickness. However, if WPS is effective, the final depth will be less than 50%, which is acceptable for a severe accident such as a PWR-LOCA. The range of flaw depths for which $K_I \geqslant K_{Ic}$ is from ~1% to over 80% of the wall thickness.

Thermal Shock Experiments

Because of the many unique features associated with the fracture-mechanics aspects of the PWR-LOCA, an extensive experimental program was undertaken. The scope of the program included initiation and arrest of shallow and deep flaws, a series of initiation-arrest events, long crack jumps, arrest in a rising K_I field, and WPS; that is, all of the features identified in the PWR-LOCA analysis were included.

Our thermal-shock experiments are being conducted with thick-walled steel cylinders that are subjected to thermal shock on the inner surface. With the exception of one of the first four experiments, the intentional initial flaws have been shallow axial flaws that extend the full length of the test cylinder. For the first four experiments (TSE-1, 2, 3, and 4), the test cylinder material was a typical PWR-vessel material except that a special heat treatment was used to obtain properties similar to those for the same steel after years of intense fast-neutron exposure. The degradation of the material was not quite sufficient to permit actual PWR-LOCA thermal-shock conditions, however, so a more severe thermal shock was required. The initial temperature of the test cylinder was the same (288°C), but the coolant temperature was less (-24°C) and the heat-transfer coefficient greater. The thermal shock was achieved by suddenly pumping a prechilled mixture of alcohol and water through the inner cavity of the preheated test cylinder at high velocity.

The dimensions of the test cylinders for TSE-1, 2, 3, and 4 (533 mm OD × 152 mm wall thickness × 914 mm length) were such that only a single shallow initiation-arrest event could take place, and neither arrest in a rising K_I field nor WPS could be demonstrated. However, the results of these experiments did indicate that initiation and arrest of shallow flaws would take place in accordance with LEFM.

The two most recent experiments, TSE-5 and TSE-5A, were conducted with large enough test cylinders (991 × 152 × 1220 mm) to result in a series of initiation-arrest events with deep penetration of the wall (greater than 50%), arrest in a rising K_I field, and WPS, provided that the desired material properties could be obtained through heat treating. For these experiments, toughness properties similar to those specified for unirradiated reactor-grade material were desired. Since this material's toughness would be much greater than that for the previous four experiments, a more severe thermal shock was required.

The desired thermal shock for TSE-5 and -5A was achieved by initially heating the test cylinder to 100°C and then quickly submerging it in liquid nitrogen (-197°C). The ends and outer surface of the cylinder were heavily insulated, while the inner surface was coated with a thin layer (~0.8 mm) of a material similar to rubber cement. This coating suppresses film boiling, which tends to insulate the surface, and promotes nucleate boiling, which provides a relatively high heat-transfer coefficient. This method of conducting our thermal-shock experiments has proved to be quite economical, and furthermore the thermal shock is severe enough and the temperature low enough to compensate for the absence of radiation damage in the test cylinder.

The coating method for suppressing film boiling was suggested to us by our French counterparts, and we have spent nearly four years developing the technique to the point where it can be used dependably. There are many factors that influence the performance of the coating, and at this point in its development the technique closely resembles a black art. Fortunately, we have been successful in achieving the desired thermal shocks.

3900 kg test cylinder for TSE-5A being inspected by Sam Bolt prior to installation of instrumentation.

Crack Behavior Studied

TSE-5 resulted in three initiation-arrest events as predicted, but the final crack depth (~80% of the wall) was substantially greater than expected. This indicated that the fracture toughness of the material was less than had been expected on the basis of our pretest material-characterization studies. Because of this apparent discrepancy, additional material-characterization studies were conducted, and the results indicated a large scatter in the data (±50%) that we had not obtained in the previous study. Furthermore, the results confirmed a growing suspicion among fracture mechanicians that the long axial flaw had behaved in accordance with the lower bound rather than the average of these data, and that the lower-bound toughness is the material property that governs flaw behavior.

When a running crack arrests, there is a possibility that the crack tip will be blunted, thus requiring a K_I value greater than K_{Ic} if there is a subsequent initiation event. Such a situation developed during TSE-5, and as a result a long crack jump (43%) took place. This provided the opportunity for investigating possible dynamic effects at arrest. As it turned out, dynamic effects were negligible, which tends to confirm the latest crack-arrest theories.

Another important result of TSE-5 was the extension of a very short and shallow flaw that was not known to exist. This flaw extended in length to become in effect a long flaw and then behaved accordingly, confirming our previous analyses and to some extent justifying our selection of long flaws for analysis.

TSE-5 produced a number of firsts as well as other important information, but because of the unexpected low toughness of the material, demonstrations of arrest in a rising K_I field and of WPS eluded us.

Warm Prestressing Limits Crack Growth

A more extensive pretest material-characterization study was conducted for TSE-5A in an attempt to define an appropriate heat treatment and lower-bound toughness curve (K_{Ic} vs temperature). Application of this information resulted in all objectives of TSE-5A being met. These objectives were the same as those intended for TSE-5A and thus included demonstrations of arrest in a rising K_I field and of WPS.

Based on the results of these studies, it appears that LEFM can be accurately applied to the analysis of severe thermal-shock loading conditions and that the PWR vessels containing high concentrations of copper will not experience excessive crack propagation during a PWR-LOCA, because of the effectiveness of WPS in limiting crack growth. ornl

awards and appointments

This year's Fermi Award was shared by two winners, one of whom is former ORNL director **Alvin Weinberg.**

W. S. Lyon received the Radiation Industry Award of the American Nuclear Society for his work in applying nuclear analytical methods to studies of fossil energy production.

Alex Zucker has been appointed to a two-year term on the editorial board of *Science.*

This past November **R. A. Weeks** was awarded a Fulbright-Hays short-term lectureship for the Near East and South Asia.

On the occasion of its silver anniversary, the American Nuclear Society singled out a relatively small number of its members who have made outstanding contributions to the society during its first 25 years. Present or past ORNL staff members receiving this one-time ANS Exceptional Service Award include **A. Dixon Callihan, William B. Cottrell, Jack Cunningham, Don Ferguson, Warren Grimes, Walter Jordan, Betty Maskewitz, Arthur Rupp, Floyd Culler, James L. Scott, Ann Savolainen, John Swartout, Alain Colomb, Milton Levenson, Larry Meem, E. P. Blizard, Bill Breazeale,** and **James A. Lane.**

Martin S. Lubell has been elected president of the board of the Applied Superconductivity Conference, Inc., a new nonprofit organization.

Davis Reed, David Cook, and **Randy Hobbs** won the 1980 National Graduate Student Design Competition sponsored by the American Nuclear Society. The winning entry was entitled "Design of Liquid Level Detection System for a Pressurized Water Reactor."

The Environmental Sciences Division has established an annual Scientific Achievement Award. The first recipient of this award is **Samuel B. McLaughlin,** who has pioneered field, laboratory, and modeling studies of air pollution effects upon forest trees and ecosystems. The Environmental Sciences Division recently received the Award of Distinction from the Miami University Institute of Environmental Sciences in recognition of the valuable relationship between the ORNL division and Miami University.

ORNL's Technical Management Center of the Consolidated Fuel Reprocessing Program has announced the appointments of **William S. Groenier** as program manager for process and engineering research and development and **Orlan O. Yarbro** as program manager for integrated equipment test facility operations. **Melvin J. Feldman,** program manager for engineering systems, has been given added responsibility for technical support activities related to the Hot Experimental Facility.

Tom Wilbanks has been appointed a member of the National Research Council's Committee on Behavioral and Social Aspects of Energy Consumption and Production.

Tom Cole has been named manager of the light water reactor technology program.

O. L. Keller is chairman-elect of the East Tennessee Section of the American Chemical Society.

Pete Patriarca was appointed chairman of the Joining Division of the American Society for Metals.

Jack Cunningham, past chairman of the Engineering Materials Achievement Award Selection Committee of the American Society for Metals, was named chairman of the Planning

Cycle Subcommittee of the American Nuclear Society. He was also appointed to the ANS Books, Monographs and Handbooks Committee.

Gerald M. Slaughter has been appointed a member of the Technical Divisions Board of the American Society for Metals. He was also named second vice-chairman of the American Society for Testing and Materials-American Society of Mechanical Engineers-Metal Properties Council Joint Committee on the Effect of Temperature on the Properties of Metal. He was also appointed a member of the ASME Research Committee on the Effect of Temperature on the Properties of Metals.

Jack Lackey was appointed to the 1980-81 program committee of the Nuclear Division of the American Ceramic Society.

Nick H. Packan was appointed chairman of the Procedures for Neutron Radiation Damage Simulation Subcommittee of the American Society for Testing and Materials.

Richard J. Beaver was appointed chairman of Committee E-46 of the American Society for Testing and Materials.

James L. Scott has been appointed to the Publications Steering Committee of the American Nuclear Society. He was also elected a fellow of the American Society for Metals.

Gene M. Goodwin has been selected to serve as a member of the Welding Academy Committee of the American Welding Society.

Dewey S. Easton, Don M. Kroeger, and **Carl Koch** were cowinners of DOE's 1980 Metallurgy and Ceramics Award for their research paper "A Prediction of the Stress State in Nb_3Sn Superconducting Composites."

The Oak Ridge Section of the American Society for Nondestructive Testing won the 1979-80 President's Award. **Jim Smith** is chairman of the Oak Ridge Section.

Barbara Ashdown has been appointed affirmative action coordinator at ORNL. She succeeds Lynda Lewis, who has a new assignment in the Employee Relations Division.

At the Ninth International Exhibition of Inventions and New Techniques last December in Geneva's Palais des Expositions, **Edward Slade** was awarded a silver medal for his invention of a cylindrical pressure valve, for use in high-technology piping systems, that has no hand wheels or operators.

readers' comments

To the editor:

I read with great interest, as always, the Summer ORNL *Review*. I was somewhat surprised to see in the article by Carolyn Krause, "The Promise of Energy Efficient Buildings," on page 5, some units that are not metric. It is urgent that as prominent an area as energy conservation, with its paramount application in the future, adhere to metric units. Specifically the R value on page 5—the R value there is adequately defined without any reference to units; however, the example, for no apparent reason, uses customary units. It is not clear why a (rather high?) Fahrenheit reference temperature is chosen when 20°C seems adequate. The examples of thickness given would be perfectly adequate if given as 9 (or 10?) and 15 cm respectively. While the numerical values of R, as currently used, are derived based on customary units, they are essentially nominal values and their actual value can be just as well stated in metric units. The R value range for fiberglass seems to be from 1 to 3 per centimeter. This translates to 5 to 15 $m^2 \cdot K/W$ for this range of fiberglass. Better yet, a nominal "C value" (conductance) can be defined in units of $W/M^2 \cdot K$. The C value has the advantage that it is more readily understood; it yields the energy consumption by multiplication rather than by division. For the fiberglass described, this would result in C values of 0.2 to 0.07—the smaller the value the less energy is used.

Let's make applied engineering as simple and as available as possible.

Uri Gat
Building 9102-2
Phone 4-0559

Dave McElroy, who provided much of the information used in the article in question, replies:

I thank Uri Gat for his interest and his letter. Our example is given in the only units that communicate marketplace terms to potential customers. Reporting R values for materials in customary units at 75°F is a useful practice within the insulation industry to allow valid intercomparisons among available materials. Nominal "C values" are used for envelope systems, such as walls, containing a host of materials which may lead to heat shunting effects that reduce the effectiveness of an insulating material. The insulation community and this measurer welcome and endorse S.I., if it enhances communication and individual productivity.

To the editor:

I beat on *Business Week* when they tell about Bausch and Lomb making contact lenses out of silicon (sic), when they mean silicone. They are not basically a technical journal and, yet, should not make that kind of mistake.

Now, what about the prestigious Oak Ridge National Laboratory *Review*, which from its affiliation must be knowledgeable technically, as well as accurate, which says (page 4, Fall 1980):

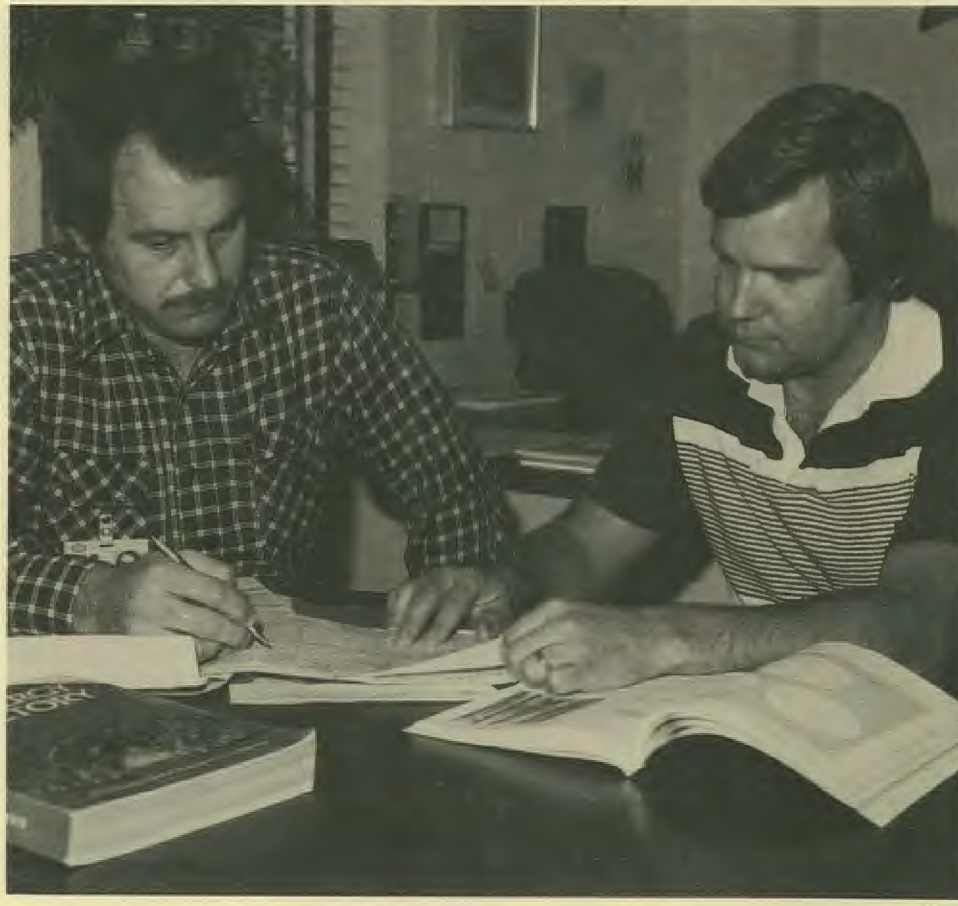
> "...to several large, unused buildings that had been hastily constructed at Y-12 for chemical extraction of uranium-235."

Oh, come now!

A. E. Cameron
114 W. Malta Road
Oak Ridge, TN 37830

Carolyn Krause replies:

Thank you for calling the *Review* a prestigious journal. We try to keep our publication technically knowledgeable by using reliable sources. The statement you question is based on a sentence from *A History of the Atomic Energy Commission, Vol. 2: Atomic Shield (1947-52)*, by Richard G. Hewlett and Francis Duncan. The sentence reads as follows: "In the old Y-12 area, where the racetracks for the electromagnetic process now stood silent, there were several large buildings which the Manhattan District had hastily constructed in 1945 for chemical extraction of uranium-235 but had never used." It should also be noted that the statement in question was not disputed by the several ORNL staff members who reviewed the manuscript before its publication.



Bob Van Hook, left, confers with Jack Ranney about biomass research. Both are members of ORNL's Environmental Sciences Division and of the Biomass Working Group of the International Energy Agency. Van Hook is section head of the division's terrestrial ecology section, and Ranney is technical advisor to the national Woody Biomass Program.

Biomass into Energy

What are the environmental effects?

By CAROLYN KRAUSE

As world oil prices continue to climb, we are turning back to the sun for the energy it stores in the green plants around us. Thousands of Americans are now heating their homes with wood-burning stoves. Farmers are fermenting surplus corn into ethanol that can be mixed with gasoline to make gasohol for powering tractors. Citizens are finding that they can reduce their private energy costs and assume some control of energy production by using biomass as an alternative to oil.

The federal government is showing an increasing interest in squeezing energy from the biomass resource, which includes trees, crops, seaweed, algae, manure, and urban waste. The United States is not alone in this endeavor; nations such as Brazil, China, and Sweden have even more ambitious programs of biomass energy development.

A potentially major source of biomass energy in the United States is wood, which is usually burned but which could be converted by various processes to crude oil, fuel gas, methanol (wood alcohol), and possibly even ethanol (ethyl alcohol). Wood, manure, grain, and other biomass now supply about 20×10^{17} J (2 quads) of energy per year, or about 2.5% of the energy consumed in the United States. It is estimated that by the year 2000 biomass use could quadruple and contribute the equivalent of 150 million m^3 (930 million bbl) of oil per year. If utilized on a large

Virginia Polytechnic Institute researchers in Blacksburg, Virginia, are testing a machine to bale wood slash from the forest floor.

scale, biomass from American forests and farms could—according to one government estimate—yield 13×10^{18} J (12 quads) per year, or 15% of the total energy used today in the United States.

To increase our wood resources, the federal government is examining the possibilities of intensively harvesting the waste wood lying around in forests and of planting "energy forests" of fast-growing trees such as willow, birch, sycamore, and sweet gum. Oak Ridge National Laboratory is managing a national program for the Department of Energy to increase the production of wood for fuels.

In addition to plantations of hardwoods that resprout quickly after harvesting, the government is counting on our most abundant grains—corn and wheat—to supply energy. Surplus corn and wheat can be fermented to make ethanol, and their crop residues (stalks, corn cobs, and wheat straw) can be burned for heat, fermented to produce fuel alcohol, or converted by microbes to methane.

Besides the common grains and their residues, other "energy crops" on the government's list are plants that grow in the arid Southwest. These plants—candelilla, dogbane, euphorbia, guayule, jojoba, milkweed, and certain sunflower species—contain saps rich in hydrocarbons. As yet unexplored but still under consideration as an energy source is aquatic biomass, which offers enormous energy potential.

ORNL's Role

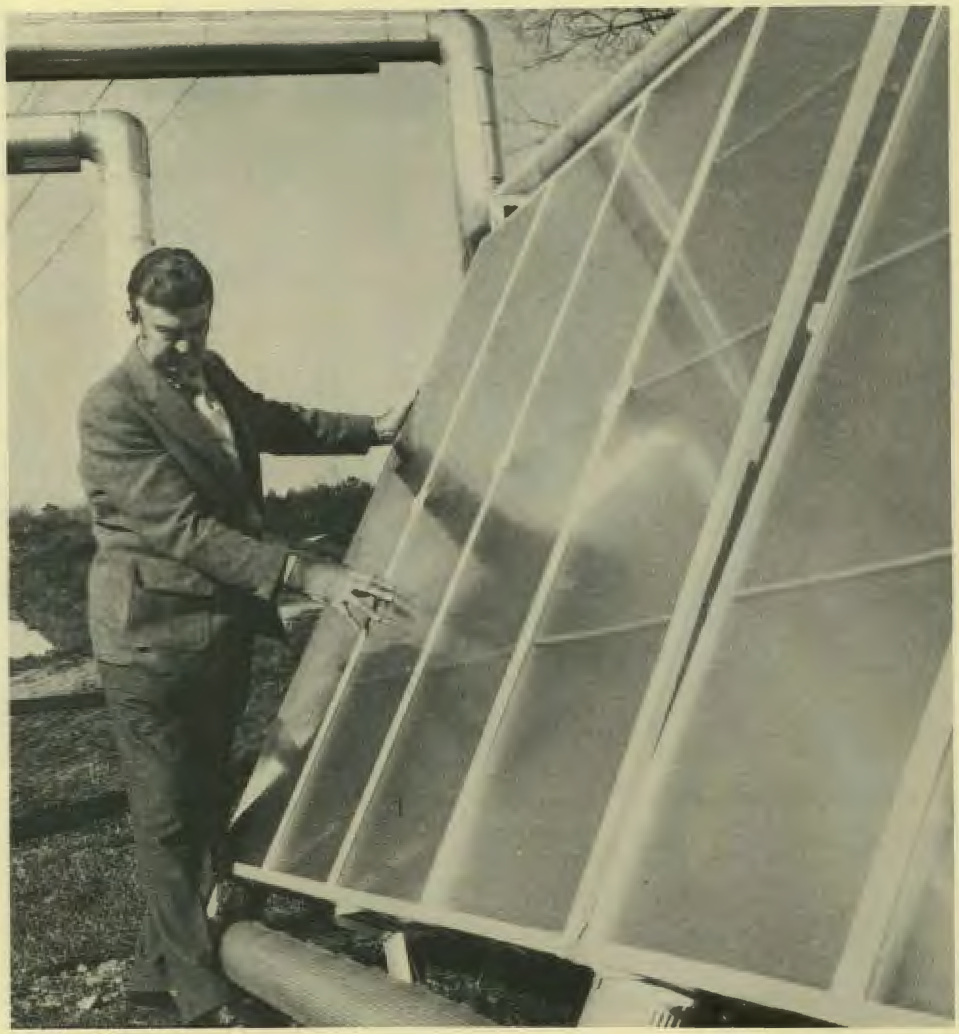
At ORNL, programs are under way to increase the productivity of forests, to guide field research for determining the environmental effects of whole-tree harvesting and crop residue removal, to find energy-efficient methods for converting wood cellulose to glucose sugar and for fermenting glucose into pure ethanol, to guide the development of wood-burning stoves that are safer and more efficient, and to assess the environmental and economic impacts of producing fuels and chemicals from biomass.

Biomass is perceived as a renewable resource whose use is environmentally benign. But its renewability could be limited and its use could be harmful to the environment unless proper steps are taken. And serious land-use conflicts could occur because biomass energy farms would be competing for land that might be needed for food and fiber crops or for trees used by the building and paper-products industries. These are messages of *Biomass Energy Systems and the Environment*, a book written at ORNL (to be published by Pergamon Press) that is an outgrowth of an environmental assessment done here for DOE. Its authors are Helen Braunstein of the Energy Division; Dick Roop, Fran Sharples, Paul Kanciruk, and Kathy Oakes of the Environmental Sciences Division; and Jesse Tatum, formerly of ORNL and now at the University of California at Berkeley.

The ORNL document identifies the kind of research needed to determine how best to reduce potential environmental impacts as biomass energy systems are established. Already, research in some of these areas is being done

(continued on page 46)

Jim Schreyer shows visitors the solar collectors which serve as the heat source for separating out 90% pure ethanol, makes an adjustment on the solar still, and descends the ladder from the still platform.

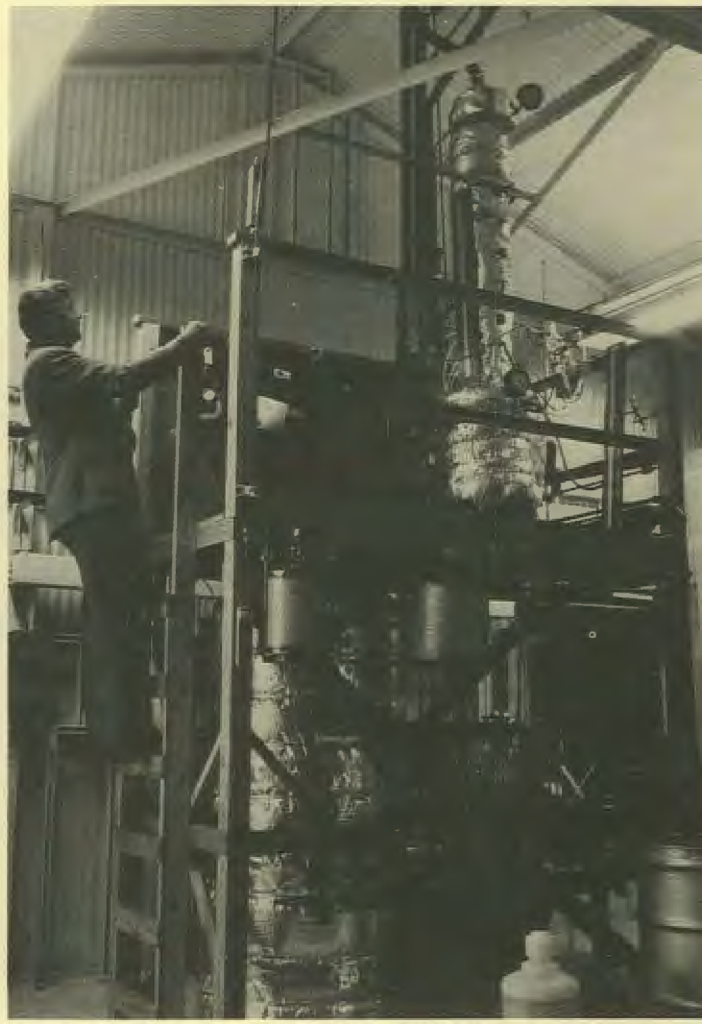


Moonshine from Sunshine?

An inexpensive, automated still that could produce fuel alcohol from fermented surplus crops to power farm machinery is a farmer's dream. Jim Schreyer of ORNL's Energy Division is working on making that dream come true. Schreyer has built an experimental solar still that is remarkably energy efficient. His goal is to develop a $5000 automated plastic device that would be a cost-effective fuel source for farmers.

The ORNL still is heated by the refrigerant Freon, which is circulated through solar collectors. The collectors are coated with Microsorb, a carbon coating that absorbs 20% more energy than conventional black paint. (Schreyer shared an *I·R 100* award in 1978 for his work in developing Microsorb for solar applications.) At atmospheric pressure Freon boils at 23.8°C (75°F), but in the collectors under a vacuum, the Freon boils at a lower temperature and turns into a gas that expands and heats up to 82.2°C (180°F) as it is piped to the still.

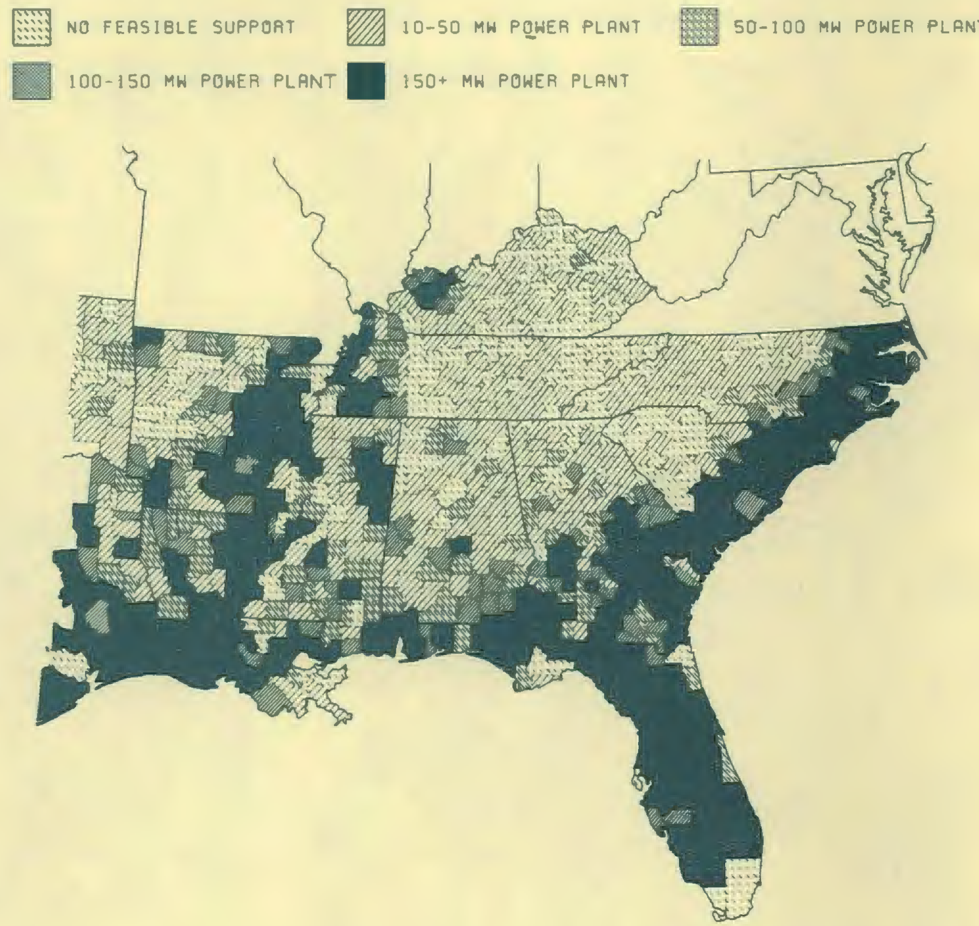
Using a small electric motor, Schreyer creates a partial vacuum in the still so that the alcohol and water composing the "beer" will boil at lower temperatures. The distillation unit therefore requires less heat energy from

the Freon to separate the water from the alcohol, which has a lower boiling point than water and thus rises to the top of the 1.98-m column. Because the system is heated by solar energy, the only electrical energy required is 30 W for the electric motor that produces the vacuum. Besides 90% pure alcohol, the still yields the by-product stillage, a protein-rich solid residue that can be fed to cattle.

Schreyer makes the beer by fermenting ground corn. The farmer could also use sugar cane or sugar beets for the feedstock. Schreyer uses one enzyme (alpha-amylase) to convert the cornstarch to dextrose and another enzyme (glucoamylase) to convert the dextrose to glucose sugar. Yeast is added to convert the glucose to alcohol. While it is fermenting, the beer emits carbon dioxide, which the farmer can use to enrich the atmosphere of his greenhouse.

With Mark Williams, a University of Tennessee engineering student, Schreyer is also working on developing a distillation unit that uses waste heat. And the feedstock proposed for fermentation into glucose is wastepaper. With all these developments, we may soon need some new proverbs: One person's waste is another person's alcohol. Or, make moonshine while the sun shines.



This map, developed by ORNL's Jack Ranney and Janet Cushman, shows where biomass could potentially be grown on wood energy plantations in the Southeast for electric energy production.

through DOE's program studying fuels and chemicals from woody biomass (managed by Jack Ranney and Janet Cushman), as well as through the DOE programs examining the environmental effects of whole-tree harvesting (managed by Darrell West) and of crop residue removal (managed by Jim McBrayer); all these are under the management of Bob Van Hook of Environmental Sciences Division and are supported by DOE's Biomass Energy Systems Division. Other biomass research at ORNL is conducted in the Chemical Technology, Energy, Engineering Technology, and Health and Safety Research divisions.

Forests and Energy Plantations

If 2% of the U.S. forests and grasslands were available, 12 million ha (30 million acres) could be used for wood energy farms. The energy produced by these plantations would be 10 to 15 times as much as the energy consumed, depending on the level of productivity.

Maximizing and optimizing the productivity of woody biomass are the chief goals of the Fuels and Chemicals from Woody Biomass Program. The two-year-old program, which is largely devoted to wood-energy-plantation research, is already showing some positive results. For example, hardwood productivity rates of 23,000 kg/ha per year have been attained or exceeded in several regions, with the highest productivity reaching 32,000 to 36,000 kg/ha annually. (An average, unmanaged forest might produce only 4000 kg/ha per year.) Superior species are being genetically screened and selected to improve productivity, but the initial results will not be apparent for several years because selected stock is only now being propagated and grown. The theoretical maximum production of woody plants is believed to be 40,000 kg/ha per year.

Ranney and Cushman are working with 23 contractors (mostly universities, in 19 states from coast to coast) in four research areas: (1) species screening and genetic selection are done to determine tree species that are fast growing, resistant to pests and disease, and capable of rapid resprouting and growth for repeated harvesting in three- to ten-year cycles; plantations are then established with seeds or cuttings from only the hardiest, fastest-growing species; (2) the establishment of stands of those trees found to grow best on a specific type of land; (3) advanced management practices such as close spacing that makes the best use of soil, precise short cutting cycles to take advantage of the fast early growth of trees, and determination of the optimum frequency of fertilizer and herbicide application; and (4) the development and testing of improved equipment or methods for efficiently harvesting, collecting, transporting, and storing woody biomass.

The program has examined more than 75 tree species, including nitrogen-fixing hardwoods such as the European

The Home Fires

Home wood burning in fireplaces and wood stoves is becoming increasingly popular and widespread. It saves money and permits consumers to participate in energy production for home heating. Fireplaces offer the aesthetic pleasure of dancing flames and glowing coals, but they also have the drawbacks of low efficiency and emissions of carbon monoxide and potentially hazardous particulates. These problems also plague wood stoves.

Airtight wood stoves are more efficient, transfer more heat, and may control some emissions better, but efficient stoves can pose a safety problem, as pointed out in the ORNL environmental assessment:"A noteworthy aspect of home wood burning is the potential hazard from creosote formation. The black tarlike substances that condense in flue pipes are the products of pyrolysis and combustion. Stoves with high energy efficiencies are more likely to have chimney creosote problems because they do such a good job of extracting heat from the flue gases. In addition to creating hazards from chimney fires (if flue pipes are not cleaned regularly), creosote formation allows potentially hazardous exposure to some possibly toxic or carcinogenic compounds produced in pyrolysis."

Curtis Travis, Bob Meyer, and Elizabeth Etnier of the Health and Safety Research Division have found that the main safety hazards of home wood burning are home fires and chain saw accidents. It is estimated that in 1979 there were 4300 injuries and 80 deaths caused by fires associated with wood-burning equipment. Chain saw accidents accounted for an additional 10,300 injuries and three deaths.

The chief health hazards from small-scale, uncontrolled combustion appear to be emissions of particulates, polynuclear aromatic hydrocarbons, and carbon monoxide, according to a study done by Helen Braunstein and Frank Kornegay of the Energy Division. Particulates are irritating to the lungs, PAHs may be carcinogens, and CO is lethal in high doses and can cause structural damage to the heart in low doses.

Assuming a worst-case scenario, Braunstein and Kornegay also surmised that a community of about 250 houses using wood heat for four months under adverse meteorological conditions would emit a greater load of particulates into the atmosphere than a 1000-MW coal-fired power plant. The community would discharge 16,000 kg (18 tons) of particulates, versus 12,000 kg (13 tons) from the power plant having a state-of-the-art particulate-removal system and serving the energy needs of a half million people. The message here is that existing, uncontrolled, small-scale biomass energy systems when considered as a whole may have more adverse health

effects than large, centralized power systems.

Fortunately, technology may come to the rescue of biomass combustion. That is the aim of DOE's program on Residential and Commercial Space Conditioning using Wood and Coal Energy, now being managed by Fred Creswick of the Energy Division. Creswick, who will be working with Fang Chen, says that program goals include "developing technology to improve efficiency, fire safety, reliability, and emission control for wood-burning equipment." Other goals are to ensure that wood supplies are adequate and to educate consumers on the safe and effective use of wood stoves. Creswick is working with ORNL's Analytical Chemistry and Health and Safety Research divisions in devising methods for measuring and identifying the components of wood-stove emissions. There are currently 400 manufacturers of wood stoves in the United States who could benefit from new information on how to overcome such problems as inefficiency, air pollution, and fire hazards.

Linda Mann removes a leaf from the coshocton sampler, a wheel that turns with water flow. The rate of water flow on this portion of the Oak Ridge reservation is shown on the flow recorder, which is housed in the elevated instrument shelter. Linda and her colleagues are studying the effect of tree harvesting on water flow, soil erosion, and nutrient losses in the forest site.

black alder and the black locust, that could be planted with other high-yield trees to reduce the use of energy-expensive nitrogen fertilizer. About 25 species have scored high in productivity so far; they include hybrid poplars in the Northeast, sweet gum in the Southeast, mesquite in the Southwest, and eucalyptus in the tropical climates of Florida and Hawaii. Other good trees are black cottonwoods, sycamores, and willows.

DOE and the U.S. Department of Agriculture are examining energy-efficient harvesting equipment that can cut trees without preventing regrowth and can collect the branches and other residue efficiently. The incentive for developing efficient equipment for collecting waste wood arises from studies estimating that there are 540 billion kg (600 million tons) of unused wood biomass—enough to supply 2% of the nation's energy needs. Says Cushman, "Industrial forest operations in the South and Southeast are beginning to collect logging residues for energy uses, and it appears it will be worth the effort to pick up residues in Douglas fir stands in the Northwest."

Partially through field research at ORNL, the Environmental Sciences Division is examining the environmental impacts of whole-tree harvesting and of planting wood energy farms. Darrell West's group (Dale Johnson, Linda Mann, Mac Stubbs, Don Todd, and Jack Waide) is comparing the environmental effects of whole-tree harvesting to the effects of contemporary harvesting techniques. Whole-tree harvesting involves removing all the aboveground woody biomass and leaving only the tree stumps. Contemporary harvesting techniques include such methods as removing only trees of a certain size or logs of commercial value and leaving branches, culls (trees having crooked trunks), and other residue.

Harvesting technique comparisons are being made at selected sites in northern hardwood, oak-hickory, northwestern coniferous, and southern pine forests. The sites are at the ORNL reservation and in North Carolina, South Carolina, Georgia, Florida, Maine, New Hampshire, Connecticut, and Washington. The effects being studied are differences the techniques produce in mineral cycling, direct nutrient removal, nutrient leaching, erosion, runoff, the addition of nitrogen to the soil by bacteria, and productivity. Several projects are particularly looking at the long-term effects on productivity that result from biomass and nutrient removal through repeated forest harvesting.

It will probably take five to ten years for the ORNL study to gather sufficient information to decide which areas of the United States can remove large amounts of aboveground woody biomass without inflicting unacceptable environmental damage. Early results, however, indicate that the direct effect of nutrient removal may be more significant than expected. For example, ORNL researchers have found that 25% of the soil's total calcium may be removed by harvesting the aboveground woody vegetation from the Oak Ridge reservation, thus affecting the subsequent productivity of this deciduous forest site.

Johnson, Waide, and West will

Planting spruce in Michigan by machine.

be studying a 30-ha site on the Oak Ridge reservation that is now being cleared for conversion into an intensively managed wood energy plantation in the spring of 1981. They will evaluate the environmental consequences of several specific forest-management practices that may be applied to wood plantations. Also, they will investigate the effects that fertilization, the use of seedlings deliberately infected with fungi that help transfer soil nutrients to plants, and mulching have on the leaching of soil nutrients, as well as the total effect that intensive management has on soil nutrient capital and on subsequent productivity over successive harvests.

Forest Biomass Impacts

According to Dick Roop, there are four categories of wood which could be used for energy: sawmill wastes, such as wood chips and shavings; logging-forest residues, such as branches and culled trees abandoned or burned by loggers; biomass from forests not ordinarily cut because of their low quality or because of other problems, such as bark-beetle infestation; and wood from energy plantations.

What are the potential environmental impacts of biomass production, as seen in the ORNL assessment to which Roop contributed? Burning sawmill wastes in wood boilers could have a beneficial impact, but removing forest residues such as slash and culled trees could produce adverse environmental effects, such as nutrient depletion and soil erosion. The erosion problem is aggravated by compaction of the soil by heavy collection equipment: because compacted soil loses its porosity, it cannot hold much water and so is loosened by heavy rainfall. Thus, residue collection for biomass energy production could backfire if sufficient losses of nutrients and organic matter in soil reduce productivity of the site. The impacts of harvesting biomass from forests not ordinarily cut include erosion associated with new logging roads, soil disturbance caused by whole-tree removal, and the destruction of wildlife habitat.

The potential environmental effects of establishing wood energy plantations include accelerated erosion due to site preparation, water pollution from fertilizer and herbicide runoff, and the loss of habitat for wildlife. The major impact of wood energy plantations, however, may be land-use changes. Says Cushman, "These plantations will probably be sited on marginal agricultural land flat enough for mechanized planting and harvest, but not high-quality farmland. If they replace forests, there may be a loss of wildlife, although some animals such as deer may return to a managed forest monoculture. If energy plantations replace pastures, they will remove a source of livestock feed.

"Energy is required for making and using fertilizer, herbicides, and irrigation equipment, so the use of these on wood energy farms would affect the net energy gain. Preliminary studies of proposed demonstration plantations indicate that the return from fertilizer will justify its use, but that the economics of using irrigation are questionable. There is still uncertainty about whether productivity is greater for closely spaced trees harvested every three years or for trees spaced rather widely and left to grow for eight to ten years. The cost of land will clearly be a major factor in

Plots of corn in Madison, South Dakota. The plot at left has half as much residue as was calculated to be needed to control erosion, whereas the other plot has twice the amount calculated to be needed.

making spacing and harvesting decisions at a specific site."

Agricultural Crops

Corn and wheat are the two most abundant grains in the United States. These crops can be fermented to fuel alcohols and their residue can be burned or converted to liquid or gaseous fuels. After corn and wheat are harvested, the residue is usually plowed under as the soil is turned. This is conventional tillage without residue removal. It has long been believed that conventional tillage techniques return nutrients to the soil, maintain tilth, and prevent erosion. Studies now indicate that leaving the residue on top of the soil instead of plowing it under permits better erosion control.

Conservation tillage methods, such as the chisel plow technique, prepare a seed bed without turning the soil and leave up to 80% of the residue on the surface. The U.S. Department of Agriculture is examining conservation tillage with residue removal to determine how much residue should be left to control erosion and how much can be removed to produce energy. The objective is to formulate a tool for county agents to use in advising farmers on the minimum residue required for erosion control.

Jim McBrayer of the Environmental Sciences Division is technical manager of the DOE–Department of Agriculture program to examine the environmental effects of crop residue removal. The program includes studies of how to optimize conservation tillage and residue removal for biomass energy production. DOE has interagency agreements to study wheat residue production at Pullman, Washington; corn residue production at Morris, Minnesota; nitrogen-cycle effects at Lincoln, Nebraska; and double cropping and water management at Florence, South Carolina.

Early results from the Nebraska study, which is examining the effects of nitrogen fertilizer on crop biomass production, indicate that crop residue removal can cause a deficiency of micronutrients that is manifested in an altered growth form of corn.

First-year results from Florence, South Carolina, indicate that residue removal increases yields of corn that is under irrigation and minimum tillage. Grain yields for maximum residue removal were 10% greater than the yield for minimum residue removal. But conventional tillage produced 10% more grain in every case. Residue removal reduced crop yields in the nonirrigated plots. The significance of results of these studies will not be known for five to ten years.

The ORNL environmental assessment suggests that biomass crops, such as corn and wheat, are a renewable energy resource only if land and water are available and if the productivity of these resources is protected from damage due to excessive or abusive exploitation. This is a big "if" given the poor precedent set by food and fiber agriculture in its failure to control soil erosion and non-point-source water pollution. A major question for biomass is whether energy crop farming will exacerbate the adverse impacts that agriculture already has on land, soil, water, air, and wildlife. Some examples of these:

- Agriculture makes heavy demands on the nation's water resources. Although only 10% of our cropland is irrigated, water for irrigation accounts for 80% of the total annual water consumption.
- Because of water erosion of soil and the runoff of soil, pesticides, and fertilizers, agriculture is the major source of non-point-source water pollution.
- Agriculture is a significant source of particulate air pollution, because of wind erosion of soils. This impact could be intensified by energy farming if marginal land, which is highly susceptible to wind erosion, becomes the focus of intensive biomass cropping.
- More than one-third of all American cropland is not adequately protected against wind and water erosion. Nutrient depletion and soil degradation increase the amount of energy which must be expended in the form of fertilizers and fuels in order to maintain productivity.
- Converting wilderness to cropland and pasture has displaced wildlife, and huge crop monocultures have favored the proliferation of pests such as the grasshopper.

About 20% of the nation's land is suitable for the cultivation of crops, but shifting land-use patterns are consuming some of this valuable farmland. Each year three million acres of American farmland, including one million acres of prime land used for raising food and fiber crops, are diverted to nonagricultural uses such as real estate tracts, highways, factories, amusement parks, and shopping centers. Some farmers cannot resist trading productive land for a large capital gain. This land thus becomes forever unavailable for energy crops as well as for food and fiber crops.

The land available for biomass crops is reserve cropland not now in production or marginal land now in pasture and range. While reserve cropland would support biomass crop production, its use for energy crops could cause conflicts in the future, as competition for this land for the production of food crops intensifies with the increasing demand for food. If marginal, less productive land is used for biomass crops, the energy required to compensate for lower productivity could endanger the net gain for which the biomass is produced. Biomass production on large tracts of land now in pasture and range could also interfere with livestock production needs. Thus, it is clear that diverting large tracts of land for raising corn for conversion to fuel alcohol could cause problems. S. David Freeman, chairman of the Tennessee Valley Authority, recently was quoted in *Science* magazine as saying, "Corn-based alcohol may be good business for the farm lobby, but it can be very expensive for the rest of us. Breaking the OPEC habit by digging into our bread basket poses the grave risk of driving up the price of food in a hungry world."

Much of the land available for biomass production is in the West, where water is in short supply. The competition for this scarce water resource is expected to intensify because of the heavy water demands of shale-oil and coal-conversion plants.

Fran Sharples of ORNL suggests that mitigation measures to avoid environmental damage from biomass production and harvesting be incorporated into the energy plantation design at the start. She favors conservation tillage with some residue left on the land to control erosion, networks of diverse vegetation to attract wildlife, and the use of both proved and innovative techniques to manage the soil, water, and nutrient resources in order to protect and sustain productivity over the long term.

Aquatic Biomass

Freshwater biomass includes water hyacinths, algae, and duckweed that are found in lakes and ponds. According to Roop, the economics of raising and harvesting these freshwater plants for energy production are poor unless the plants are also used to treat wastewater. One proposal believed to be economical is to plant lagoons of industrial wastewater with water hyacinths, which could provide surface area for microbes that remove heavy metals from contaminated water. The microbe-covered hyacinths could then be harvested and put through presses, with the extracted fluids run through an anaerobic digestion system like ORNL's ANFLOW device to produce methane. The nontoxic metals in the digested hyacinths could be deposited on land to help fertilize the soil.

Ocean biomass farming has enormous energy-producing potential, but it also has technological, economic, and environmental problems that may prevent it from becoming a commercial venture for 15 to 20 years, according to ORNL's Paul Kanciruk.

Consider the present scheme of deploying kelp farms off the southern California coast. A 25-km diameter farm—on which kelp could grow at a rate of more than 0.5 m per day on a nylon rope grid suspended 30 m beneath the surface by buoys—might produce enough biomass for conversion to methane to equal the energy potential of a 1000-MW power plant. The energy from 75 such kelp farms, for example, could supply 3% of the energy requirements of the United States.

For kelp to grow on the ocean surface, however, the seaweed must be fertilized with nutrients. Relatively high concentrations of nitrates and phosphates exist in oceanic waters 300 m deep. This nutrient-rich water, if pumped to the surface by an upwelling system, would fertilize the kelp plants. The rising cost of oil would probably make diesel-fueled upwelling in kelp farming uneconomical, so DOE and the Gas Research Institute's jointly funded kelp project plans to develop an energy-efficient upwelling system that would transfer the energy from waves to the pumping system.

Large-scale kelp farming may have environmental impacts. Says Kanciruk: "Many offshore kelp farms may intercept wave energy which otherwise would wash ashore and give beaches and littoral areas their shape. Changing the pattern of wave energy might cause beaches to erode away or build up at different rates. With so much more kelp in the ocean than is naturally found there, there may be a problem with kelp fronds breaking loose from these massive kelp farms during severe storms or during normal harvesting, resulting in littering of the shoreline.

"Dense kelp farms might also interfere with the migration of large mammals such as whales and dolphins, and upwelling pipes could suck in large numbers of deep-water invertebrates and fish, which could be killed by rapid temperature and pressure changes in their 300-m ride to the surface. Drawing up large amounts of cold water from the ocean depths might have climatic effects, perhaps reducing coastal rainfall and releasing large amounts of carbon dioxide, which could alter global climate."

One positive impact could be that kelp farms might create a favorable habitat for species of food fish, making these farms sources of food as well as of energy. On the other hand, a kelp monoculture might attract pests, requiring the use of chemicals to control the problem and thus raising the question of the legality or desirability of ocean dumping of chemicals.

"All these impacts associated with proposed offshore kelp farming are so far speculative," emphasizes Kanciruk. "Research in concert with technological progress must begin to identify and quantify the environmental effects, with the goal of protecting the environment."

These before and after photographs show how much this newly established Georgia plantation of sycamores can grow in two years. At the center is a European black alder, a nitrogen-fixing tree which lessens the need for energy-expensive chemical fertilizer.

Biomass Conversion

"We are hooked on hydrocarbons," says Helen Braunstein, "so we use brute force in the form of high temperatures and pressures to transform oxygen-rich carbohydrates in biomass into energy-rich hydrocarbons that can substitute for natural gas, oil, and gasoline."

Biomass can be converted to energy or fuel by combustion, thermochemical conversion, methane fermentation (anaerobic digestion), and alcohol fermentation. The Chemical Technology Division is conducting research aimed at developing a variety of energy-efficient biotechnologies for alcohol fermentation and methane fermentation, including modifications of the ANFLOW system previously developed for municipal wastewater treatment. This division is also interested in studying the thermochemical conversion process used to produce methanol from wood and may be able to apply the expertise it has gained in coal conversion research to improving the process. Methanol could be used as a motor and power-generation fuel, although it is more corrosive than ethanol and provides less energy per liter. The Energy Division is

also looking at more efficient ways of fermenting fuel alcohol and is managing a DOE program that aims at improving the safety and efficiency of burning wood for space heat.

These conversion processes may have adverse impacts on human health and the environment. The combustion of wood, crop residues, bagasse, and other biomass materials could increase air pollution, but the emissions would differ from those of fossil fuel combustion. The ORNL environmental assessment of biomass energy systems states it this way:

Although combustion of biomass instead of coal would reduce the amount of sulfur dioxide emitted, particulate and carbon monoxide emissions may increase.The change in nitrogen oxide (NO_x) emissions is uncertain and requires further study. In most cases substitution of biomass for a clean fuel such as natural gas or low-sulfur fuel oil would increase air emissions of all pollutants except SO_2. The high emissions from biomass combustion are caused by factors such as the moisture content of the feedstock material and the lack of emission controls on small combustion units such as wood stoves and fireplaces.

DOE is sponsoring a number of projects that use gasification, liquefaction, pyrolysis, and other thermochemical conversion technologies to convert wood and other biomass to oil or a fuel gas. The most significant environmental hazard of thermochemical processing of woody biomass is expected to be the formation of chemicals that might cause cancer. According to the ORNL assessment, "In one study, the carbonization of wood produced at least 22 chemicals or groups of chemicals that are known or suspected carcinogens or tumor-producing agents." The assessment concludes that the environmental impact of air emissions and aqueous effluents can be minimized through proper controls and treatment.

Anaerobic digestion, or methane fermentation, produces a gaseous product, a liquid effluent, and a solid sludge from wet biomass material such as manure, kelp, water hyacinth, and some agricultural crop residues. The gases are largely methane and carbon dioxide, but there may also be traces of hydrogen sulfide, which should be removed to prevent corrosion and odor. Because of its high sulfur content, kelp is the only feedstock for methane production that could require mitigation measures to reduce SO_2 emissions. Liquid wastes from digesters will require secondary treatment, and the solid sludge has potential as fertilizer or animal feed.

The chief environmental impacts of large-scale alcohol fermentation—producing ethanol for fuel from sugar, grain, or cellulosic materials—are expected to result from the voluminous solid sludge (stillage) and an

(continued on page 56)

Ed Arcuri, left, does sampling at the fixed-bed bioreactor in which he has converted glucose to a mixture containing ethanol by using the bacterium Zymomonas mobilis. *This system produces 10 to 30 times as much ethanol as do the typical industrial systems using yeast.*

To increase the stability of the enzyme cellulase (which converts cellulose to glucose), Katherine Whaley, a University of Tennessee student, center, first reacts the enzyme with an agent that chemically modifies it. Then she removes the excess, unreacted agent by a chromatographic separation method.

Converting Wood to Ethanol

If cellulose could be converted to ethanol more efficiently, we could turn to wood for a motor fuel that is superior to wood alcohol, or methanol. ORNL's Chemical Technology Division is trying innovative approaches to increasing the efficiency of the three-step process of deriving ethanol from wood: (1) converting cellulose to glucose via enzyme action; (2) converting glucose to a fermentation brew containing ethanol, using a bacterium instead of the fungus yeast; and (3) utilizing solvent extraction or molecular sieves rather than conventional distillation units to separate ethanol from water in the brew.

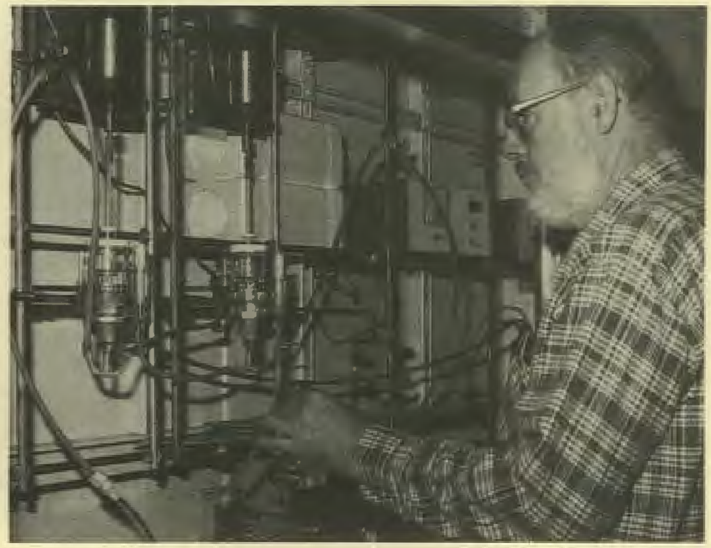
The enzyme cellulase breaks down cellulose into glucose as an energy source for microorganisms such as fungi living on cellulosic materials such as trees, but this enzyme is inactivated once it has produced the amount of glucose required for the microorganism. ORNL enzymologist Jonathan Woodward has found that the enzyme cellulase is not inhibited by fructose, another type of sugar that can also be fermented into fuels. Because glucose can be converted to fructose by another enzyme called glucose isomerase, Woodward is now studying whether the addition of this enzyme to the reaction mixture can increase the efficiency of the cellulase enzyme by preventing the inhibitory effect of glucose.

In another basic research project funded by seed money, Woodward is looking at an additional factor that appears to inactivate the cellulase in glucose production—namely, the warm temperatures needed to speed up this glucose-producing reaction. Because experiments have shown that temperatures above 50°C cause cellulase to become unstable, Woodward will try to stabilize the enzyme by chemical modification or by immobilizing it on a support medium such as glass beads.

"Our goal," says Woodward, "is a stable and immobilized cellulase enzyme that can be used repeatedly and for a longer time at higher temperatures. Because this will allow high rates of glucose production and will require less enzyme, this method could significantly lower the cost of converting woody biomass into glucose enzymatically for fermentation into alcohol fuels."

Cellulose—a product of photosynthesis, during which solar energy is converted to stored chemical energy—is the principal component of wood, paper, agricultural residues, and municipal wastes. If efficient methods for converting cellulose to glucose can be found, biomass may replace fossil fuels as an important feedstock for long-term production of fuels and chemicals.

A bacterium more effective than yeast in converting glucose to ethyl alcohol has been tested for the first time in a fixed-bed bioreactor at ORNL. First



Dave McWhirter adjusts a solvent extraction technique that uses much less energy than a conventional distillation process in separating ethanol from water in the fermentation brew.

studied in the early 1900s, *Zymomonas mobilis*, a microorganism used to make tropical beverages, produces 10 to 30 times as much ethanol in the ORNL bioreactor as do typical industrial systems that use yeast, says Ed Arcuri of the Chemical Technology Division. In Arcuri's system, the glucose stream enters the bottom of the bioreactor column and flows upward through a bed of stationary glass-fiber pads to which the bacteria are attached. A fermentation brew containing ethanol is taken from the column top.

An Australian group is using the same bacterium to produce ethanol in a continuous cell-recycle system. Arcuri says that the fixed-bed bioreactor is superior to the Australian system in that "comparable productivities are achieved in the fixed-bed system without the expense of including a cell-recycle step." In the meantime, ORNL's Chuck Scott (who recently received the E. O. Lawrence Award for contributions to the field of nuclear science) is testing *Zymomonas* in a fluidized-bed bioreactor with cation-exchange resins. There are other bacteria that can ferment glucose into alcohol, but they also yield acidic compounds. The advantage of *Zymomonas* is that it converts glucose into only two main products: carbon dioxide and

Solvent extraction and sorption-desorption processes may be more energy efficient than conventional distillation for separating ethanol from water in the fermentation brew. Zane Egan and Doug Lee recently tested a solvent extraction technique that requires considerably less energy than a conventional still. The energy-efficient process uses a solvent that is immiscible in water to extract ethanol selectively from the watery mixture. Ethanol that is 98% pure is easily distilled from the solvent because of ethanol's lower boiling point.

Wilson Pitt and Doug Lee have recently evaluated the use of solid sorbents (which employ a hydrophobic molecular sieve and high-surface-area polystyrene beads) in the selective removal of ethanol from fermentation broths; the removal is followed by stripping through the use of a warm gas. Preliminary results indicate that this two-step process is at least as energy efficient as the most efficient distillation processes.

A new energy-efficient method of directly separating ethanol and other neutral solvents from the fermentation broth has been developed by Alicia Compere and Bill Griffith of the Chemistry Division. The other chemicals include ketones and low-molecular-weight alcohols such as isopropanol, 1-butanol, and acetone. The separation process can be done concurrently with fermentation or on the finished broth, and the resulting product may be used directly or purified further. Called Fualex, this process was first described to representatives of industry at a conference held December 2, 1980, at ORNL.

Wealth from Wastes

ANFLOW—ORNL's prizewinning, energy-efficient bioreactor for treating liquid wastes by using anaerobic (oxygen-shunning) bacteria that produce methane—has distinguished itself in the wastewater treatment field. An ANFLOW system at Oak Ridge's East Waste Treatment Plant has shown its main virtue to be in saving energy. Because the system produces little sludge to be hauled away and requires no energy-hungry aerators for its anaerobic bacteria, it saves up to 40% of the energy used by conventional sewage treatment plants. While municipal ANFLOW systems do not produce large quantities of methane, they have demonstrated the ability to produce enough to supply most of the power required for their own operation.

Now, however, there is an indication that ANFLOW may be dedicated to the production of significantly larger quantities of methane from animal wastes. Much of the biomass-derived energy now produced in the United States comes from animal manure that is obtained from cattle feedlots and converted to methane for the drying and processing of feed. Richard Genung of the Chemical Technology Division, who is currently overseeing a study of the feasibility of a demonstration ANFLOW plant for treating meat-packing wastes in Knoxville, is also proposing the design of another ANFLOW system to treat animal manure. Because manure has a higher carbon content than most sewage, ANFLOW and animal wastes could team up as a productive source of methane, making ANFLOW important as an energy-producing as well as an energy-conserving device.

aqueous effluent. While stillage may be usable as fertilizer or cattle feed, excessive amounts of it may pose odor problems, clog sewage treatment plants, and make streams uninhabitable because of its high biological oxygen demand. Wastewater from the fermentation process also has a high BOD that needs to be reduced through secondary treatment.

The stillage problem is being considered by ORNL, which has the task of preparing for DOE's Office of Alcohol Fuels a generic environmental assessment of conventional alcohol fuel production by units supplying 58 million to 570 million L/year (15 million to 150 million gal/year).

Social and Economic Impacts

Large-scale biomass energy production schemes have been proposed to replace nonrenewable fossil fuels in producing process heat, space heat, electricity, and transportation fuels. But such schemes if implemented could have large social and economic impacts, some of which may be positive. Former ORNL engineer Jesse Tatum has identified impacts and issues that will affect society as biomass energy systems proliferate. Some scenes from Tatum's crystal ball:

• Direct impacts will be experienced by farmers, ranchers, forest-products operators, fuel producers, and utilities. Also affected will be the food, construction, transportation, farm machinery, and fertilizer industries.

• Land requirements for biomass energy production are orders of magnitude larger than for other energy technologies. This raises aesthetic and land-availability questions and suggests that we can expect severe conflicts among competing land-use interests.

Fuels and Chemicals From Biomass

Farmers could produce vegetable oils to fuel diesel engines and thus reduce their purchases of increasingly expensive diesel fuel. Steam boilers could be heated with combustible fuel pellets made from municipal wastes, agricultural crop residues, or wood residue. Wood production is likely to be the most important object of long-term biomass research.

These are some of the preliminary conclusions of an assessment of biomass energy technologies that is being conducted for DOE's Office of Energy Research by members of ORNL's Engineering Technology and Environmental Sciences divisions. The analysis includes characterization of biomass feedstocks such as wood, grass, and urban wastes and of conversion processes such as combustion, gasification, and alcohol and methane fermentation; an assessment of the economics of biomass fuels compared to alternative fuel sources; and consideration of the social issues surrounding the use of biomass. The assessment investigators are Sherman Reed, Otto Klepper, and Irv Spiewak of the Engineering Technology Division and John Krummel of the Environmental Sciences Division.

Terry Donaldson of the Chemical Technology Division is leading an effort to assess chemical production from biomass. He will examine biomass resources, conversion processes, and market demand for chemicals to determine which biomass-derived chemicals might contribute to the chemical industry in the future. The processes being studied include microbial conversion and acid hydrolysis, which decomposes cellulose into fermentable glucose. An interesting source of chemicals is the woody arid plants, whose hydrocarbon-rich latexes could be used in lubricants and paint thinners. Another goal of the study is to identify specific areas in which R&D work is needed to improve economics and thus make production of chemicals from biomass more attractive. Donaldson plans to complete this assessment this year.

- Competition between food and energy from biomass could affect domestic and international food supplies and prices.
- Rural employment could increase as a result of the location of biomass facilities in rural areas. Regional demographic shifts may also occur because of variations in biomass availability.
- Biomass transportation may significantly increase road upgrading and maintenance requirements and cause traffic pattern changes.
- New political and institutional issues will crop up to deal with such problems as ensuring markets for biomass fuel producers and subsidizing farmers and industries to guarantee sufficient biomass availability and conversion capacity to shore up the nation's energy supplies.

Helen Braunstein looks at biomass energy production from the point of view of humanistic values. In an interview she observed that clearing forests for energy production would cause hardship for people as well as for wildlife. "Human beings require some access to wilderness areas," she says. "They need an unspoiled natural environment for their spiritual enrichment. We want to avoid the mistakes that turned the Cedars of Lebanon into a Middle East desert."

Biomass is renewable only to the extent that land, fertile soil, and water are available. If not properly used, it can cause environmental and health problems. But it is a valid regional technology that allows people some control of their energy production. A gift from the sun, biomass poses a challenge to our sense of values as we try to decide how to apportion it for food, energy, and spiritual enrichment. ornl

CO_2 and Acid Rain

Assistant Secretary Clusen's briefing at ORNL

The environmental effects of carbon dioxide and acid rain are the front burner issues that Department of Energy officials are being asked about at congressional hearings. So spoke Ruth Clusen, DOE Assistant Secretary for Environment, at the DOE/ASEV Field and Laboratory Representatives Meeting held at ORNL in early October.

The meeting began on October 2 when Secretary Clusen spoke at the dedication of the 5500 ha (13,000 acres) of the Oak Ridge reservation that became DOE's fifth National Environmental Research Park. On that first morning of the meeting, organized by the staffs of Secretary Clusen and ORNL Associate Director Chet Richmond, the program was an exchange of information between ORNL, DOE headquarters, and other national laboratory officials. ORNL division directors provided an overview of programs in biology, health and safety research, information sciences, and environmental research. Following the ORNL presentations, DOE officials gave the news from Washington, including a description of the impacts of the new Energy Security Act. This act created the Synthetic Fuels Corporation and authorized $20 billion to sponsor projects that produce synthetic liquid and gaseous fuels from chemical feedstocks such as coal, peat, lignite, shale, tar sands, biomass, and urban wastes. Title VII of the Energy Security Act deals with CO_2 and acid rain, the environmental issues that were focused on during the second day of the meeting. Secretary Clusen said that this was the first program review meeting she has organized that focused on issues of public concern.

Carbon Dioxide and Climate

One of two serious environmental problems posed by an escalation in fossil fuel combustion and conversion is carbon dioxide. Increasing atmospheric concentrations of CO_2, which pose both a worldwide and a long-range problem, could induce changes in our global climate. It could also have positive as well as negative impacts: plants may grow better with increased concentrations of CO_2, and climatic shifts could lengthen the growing season, especially at high latitudes, or increased CO_2 could create some deserts even as it makes others bloom.

Representatives of Oak Ridge Associated Universities, Lawrence Livermore National Laboratory, DOE, and ORNL (Bill Emanual, T. J. Blasing, and Bill Fulkerson) addressed the CO_2 question. Some of the information that surfaced in this session is noted here.

• The prevailing view is that a doubling of atmospheric CO_2 concentrations, which would cause the atmosphere's increased absorption of infrared radiation (heat) emitted from the earth's surface, will raise the average global temperature by 1.5 to 3°C. This greenhouse effect could have a dramatic impact on climate.

• The National Academy of Sciences is conducting a three-year study of the CO_2 problem, but DOE is not expected to play a role in this study because the Academy has the task of independently reviewing DOE-sponsored research.

• An ORAU-ORNL assessment of the CO_2 problem will review the available physical, biological, and social science facts and prepare an integrated evaluation of the likely direction and consequences of fossil fuel combustion. Our state of knowledge and the sizable uncertainties about future rates of international energy use, where the industrial CO_2 goes, and how much climate change could result limit the information from which to make clear policy decisions.

• One controversial question is whether forested regions are a new sink for CO_2 or a net source

Secretary Clusen shows interest in the head section of an Alderson Rando phantom used in the Health and Safety Research Division for dosimetry studies. Guven Yalcintas explains the device.

due to the trend toward clearing forests and burning the felled trees. ORNL's study of the Southeast indicates increased carbon storage in terrestrial ecosystems over the last 30 years, suggesting that this region is now a CO_2 sink.

• Livermore and Argonne researchers are planning to use CO_2 sensors mounted on aircraft and towers to measure CO_2 fluxes over tropical rain forests and oceans in order to determine their ability to absorb atmospheric CO_2.

• Temperature changes in the stratosphere, resulting from increased CO_2 content, may build up the ozone layer, which is threatened by fluorocarbons. Because warmer air holds more moisture, increased cloudiness with a greenhouse effect of its own could result, but it is unclear whether the overall effect of clouds will be to warm or cool the climate.

• Global average temperatures about 1°C higher than the present ones occurred about 5000 years ago. Fossil pollen evidence from that period indicates a northward displacement of the Boreal forest and an eastward extension of prairie vegetation, indicating that there was a warmer, drier climate in much of the central United States. A reoccurrence of that climate could cause regional shifts. Forest species now growing in southern latitudes would move northward, and farmers in the western corn belt would have to switch from growing corn to raising wheat or else increase their energy and water demands for irrigation.

There are many more questions than answers in the CO_2 puzzle. The overall conclusions were that we need to know much more about CO_2 pathways and about the effect of increased CO_2 on the climate, and that we have time to learn. This sentiment is contained in an energy policy analysis, conducted by staff members of ORNL, the Massachusetts Institute of Technology, and the Institute for Energy Analysis of ORAU, that examines the question of when action may be needed to curtail fossil fuel combustion in order to avoid unacceptable atmospheric CO_2 levels. Some conclusions reported at the DOE meeting are as follows: (1) the world may not need to take actions to curtail fossil fuel use for two or three decades if development of nonfossil energy sources is rapid, (2) the world needs to maintain a viable nuclear industry option, (3) energy must be used more efficiently to ease the problem, and (4) an international energy strategy is required to ensure cooperation among nations in their use of energy sources that have a global impact.

Acid Rain

The national laboratories' role in acid rain research has not yet been spelled out, as government agencies await research plans of the White House's Council on Environmental Quality and the 20-member (including Herman Postma) interagency Acid Rain Task Force. Acid rain occurs when oxides of sulfur and nitrogen, from industrial and automotive emissions, are transformed in the atmosphere to dilute acids that are transported long distances before they fall as rain. There is growing national concern about acid rain because it is believed to cause reduced crop yields, structural damage to buildings and statues, such pollution of lakes and streams that they can no longer support fish, and possible health effects such as eye, skin, and lung irritation.

The results of DOE's initial activities in acid rain research were reported at the DOE/ASEV meeting by representatives of the Pacific Northwest, Argonne, and Brookhaven national laboratories as well as by ORNL. Dave Shriner of ORNL's Environmental Sciences Division listed the following results.

• Threshold growth responses are seen in some crop species exposed under laboratory conditions to rain that is 10 to 40 times as acidic as normal rain—that is, rain that has a pH between 3.5 and 4.0 rather than the normal pH of 5.6. In other words, some crops exposed to rain in this acidic range have the potential to undergo growth reductions. However, field studies have yet to confirm the significance of this threshold to regional crop production. Rain in Oak Ridge has been found to have a pH of 4.

• At the Walker Branch Watershed, a much greater accumulation of sulfur is found in the soil than in vegetation. Sulfate ions from acid rain do not leach out nutrients from soils on the watershed in proportion to the inputs because the sulfate ions tend to bind to the iron and aluminum oxides in the soil.

• There is evidence that plants are suffering damage from acid rain even if there is no visible injury, which is the sole criterion for acid rain damage in some research efforts. Microscopic studies of soybean leaves at Argonne uncovered evidence of stress responses in leaves that appeared to be undamaged. However, this stress response was not accompanied by any negative effects on crop productivity.

Secretary Clusen said that she was pleased with the issues-oriented format of the DOE representatives meeting and planned to try it again. The experiment in the auditoriums of ORNL's Environmental Sciences and Biology divisions was a success.


Chet Holifield at HHIRF

The impressive facility we dedicate today will stand as a monument to one who was among the first to see and to help define a proper relationship between our federal government and the promotion of science.

For those who will labor in this facility to advance the cause of science, the important point to realize in this relationship is that science is not an isolated phenomenon. Science is one of the pieces in the mosaic of human experience. It can flourish only in those places where the political system is sufficiently mature to allow unfettered freedom of inquiry. It can develop only in those places where economic strength is sufficient to support it. Science can be undertaken only by those who are able to see its value and are willing to make a commitment of faith and hope that its pursuit is worthwhile.

The methods of science, its modes of inquiry and its criteria for validity, are not revealed on stone tablets but are hammered out in the forge of human experience. The decision of what facilities to build and what experiments to perform, the creation of the concepts and structures through which scientific data are interpreted are largely products of the human imagination, of the human intellect reflecting on all that human history has suggested as pertinent to the issues at hand.

And while its applications have transformed our world, science is judged not alone on what it can do but on its simplicity, its beauty, and its power to impart a coherent and comprehensive understanding.

As we stand in the shadow of the technological marvel that constitutes the Holifield Heavy Ion Facility, let us remember that its significance and meaning come not alone from its tangible form, but as well from these unseen but very real political, economic, historical, intellectual, ethical, and aesthetic values that must be called on to justify it.

It is in that spirit—of science as an essential element in the complete pattern of human experience—that, I believe, this facility should be dedicated.—

Wendell G. Holladay, Provost, Vanderbilt University, in his remarks at the dedication ceremonies for the Holifield Heavy Ion Research Facility at ORNL on December 8, 1980.

4/1/81

OAK RIDGE NATIONAL LABORATORY *REVIEW*

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A tree is being weighed on the Oak Ridge reservation during forest-clearing operations as part of a study of the environmental effects of whole-tree harvesting. See article page 42.