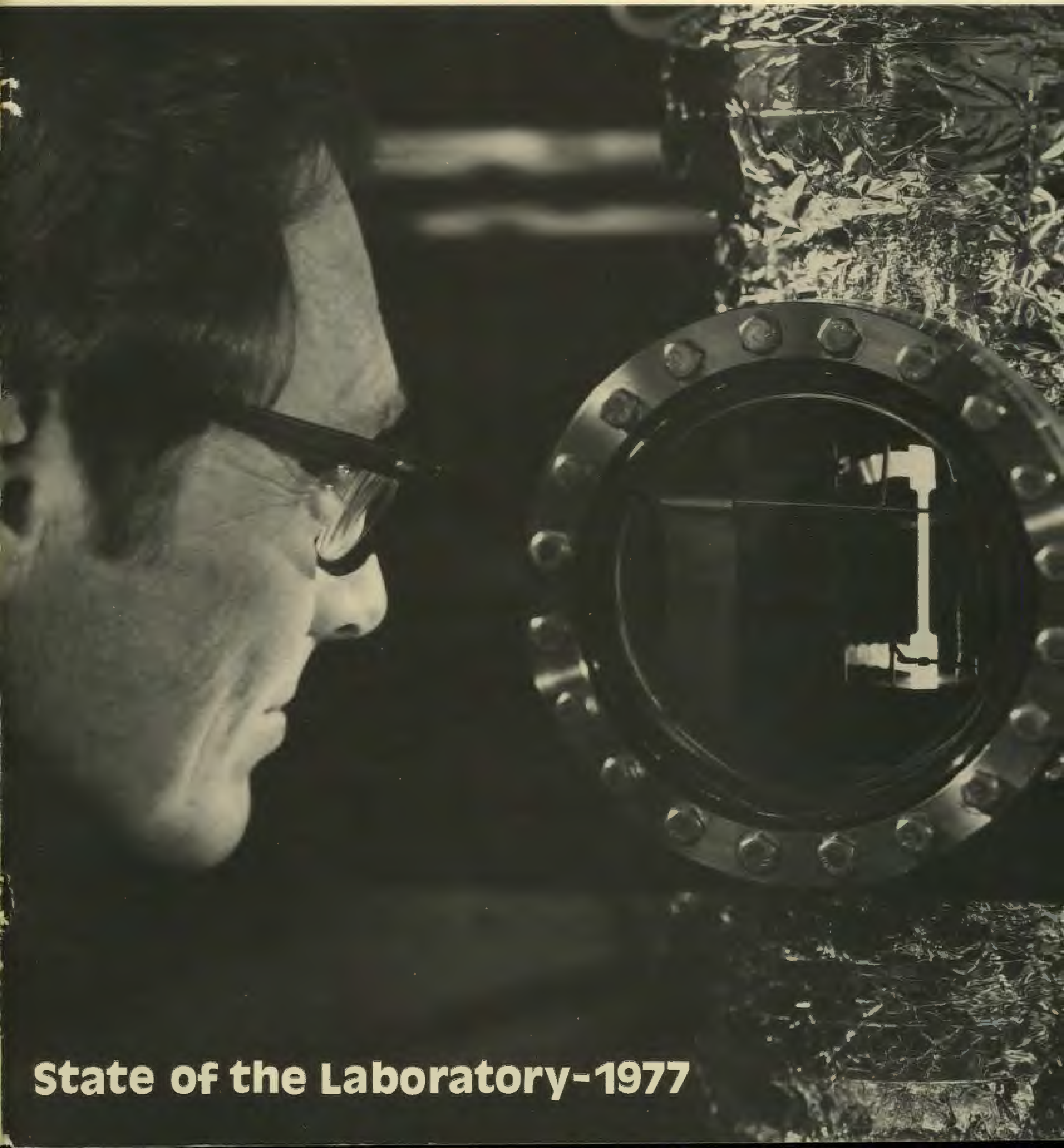
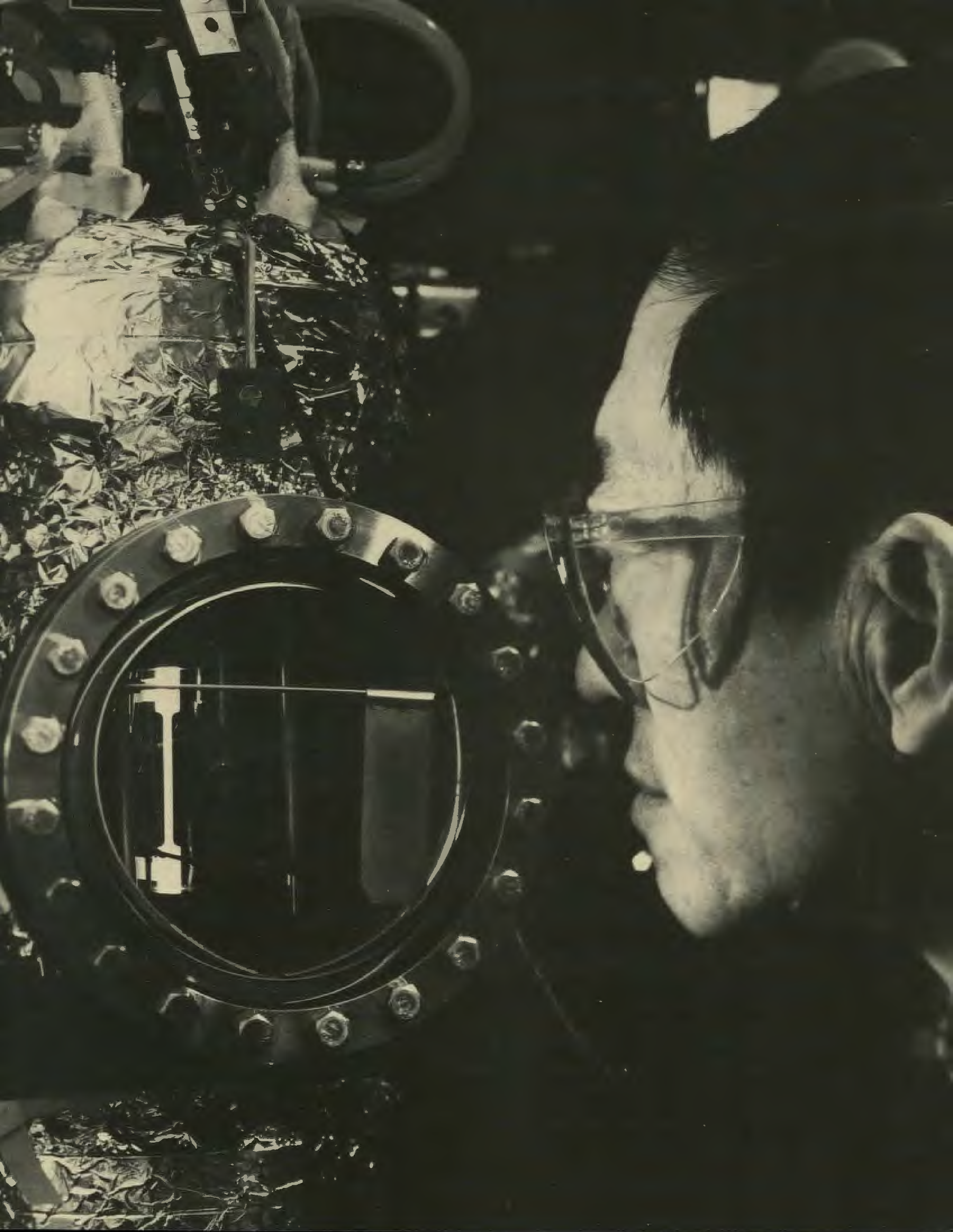
Oak Ridge National Laboratory

Spring 1978

review



State of the Laboratory-1977



JON THOMPSON

THE COVER PHOTOS: Director Herman Postma, on the cover, and Henry Inouye, opposite page, take turns peering into an environmental test chamber in which new Long Range Ordered Alloys will be tested later this year. The tests will demonstrate the alloys' increased strength with maintenance of ductility at temperatures up to 950°C. This is one of the metallurgical achievements at the Laboratory in 1977 described by Postma in the State of the Laboratory address he delivered early this year.

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Oak Ridge National Laboratory

review

VOLUME 11, NUMBER 2 SPRING 1978

DEPARTMENTS

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE DEPARTMENT OF ENERGY

State of the Laboratory-1977
—*A Longer-Range View*

By Herman Postma

While the State of the Laboratory address itself is a tradition at ORNL, there is little in the past year (or in previous years) that can be characterized as being traditional. Externally, important changes in government energy policy and in its organization, as well as internal changes in an institution dedicated to creating change, make the word "transition" more appropriate than "tradition" in describing ORNL activities.

This year I not only will review what has characterized ORNL in 1977, but also will place it in the context of occurrences since the Arab oil crisis of 1973 prompted a new look at energy policy and government action. Since then, the Laboratory has passed through several phases. We've had replacements in rapid succession of our sponsoring agency, from the AEC, to ERDA, and now DOE. There have also been important changes in government policy with respect to energy—particularly during this year with respect to nuclear energy.

That evolving energy policy, along with environmental and economic constraints, is affecting the Laboratory. I will highlight those turns, twists, and opportunities in the perspective of the last four years with particular examples of what culminated during 1977.

Most of my talk will be concerned with the science and technologies and the innovations that are the core of the Laboratory and constitute its most important and essential function. Finally, I will conclude with a view of the future that may characterize the way our programs will move in response to national needs and to the new energy look.

Indicators of Change

There are many numerical indicators of change at the Laboratory. I will restrict myself to three areas—the growth in people, in facilities, and in dollars of R&D support. The past four years have seen a recognition that solutions to energy problems throughout the country will require an extensive commitment to research and development. The result has been a growth in the number of people that work at the Laboratory, almost a 30% increase over the 1974 level—although really only bringing us back up to the level of 1968. We have found it easy to recruit and attract some of the finest people throughout the United States and the world with strong motivation to solve crucial energy problems of the country, and to contribute to a vibrant R&D atmosphere.

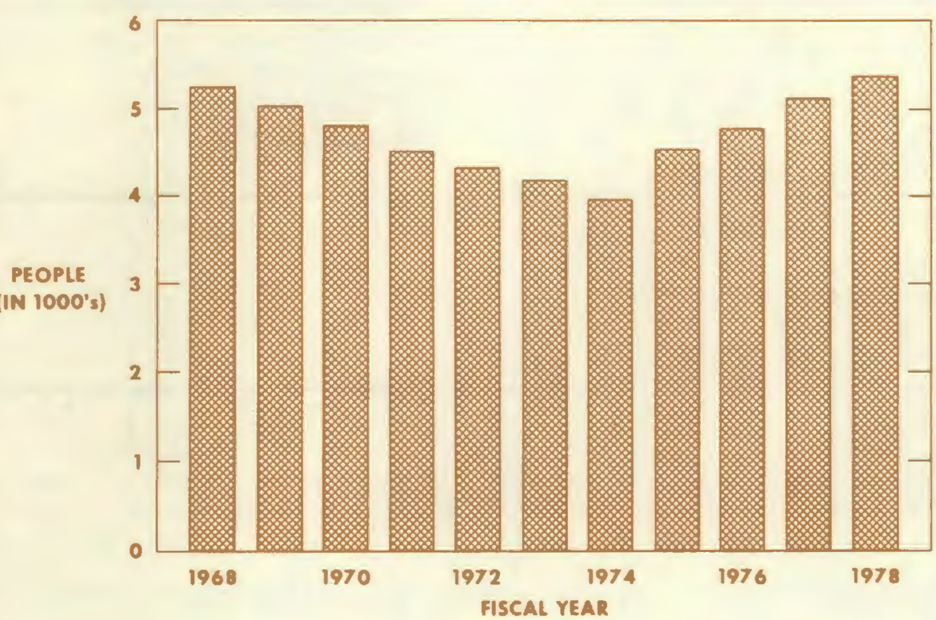
However, that growth in people at the Laboratory has itself brought problems. New programs and the changes in old programs require different laboratory and office utilization. There has been too little money to relieve overcrowding, to bring crucial laboratory space up to date, and to allow grouping of disciplines for the best interaction among the people. The money to relieve those constraints is not here, and to all those who are putting up with inadequate facilities and surroundings, I apologize.

Yet there have been important changes in facilities during the last four years. Soon we will be occupying the Environmental Sciences Division building. Construction of the Holifield Heavy Ion Research Facility is progressing, and some much needed additions to buildings, offices, and labs have been made. We are also converting the steam plant to burn coal instead of oil and natural gas. This should allow us once again to maintain temperatures that are comfortable and to provide a productive work environment during the heating season. We also hope in another few years to get approval for a sizeable addition to the Laboratory.

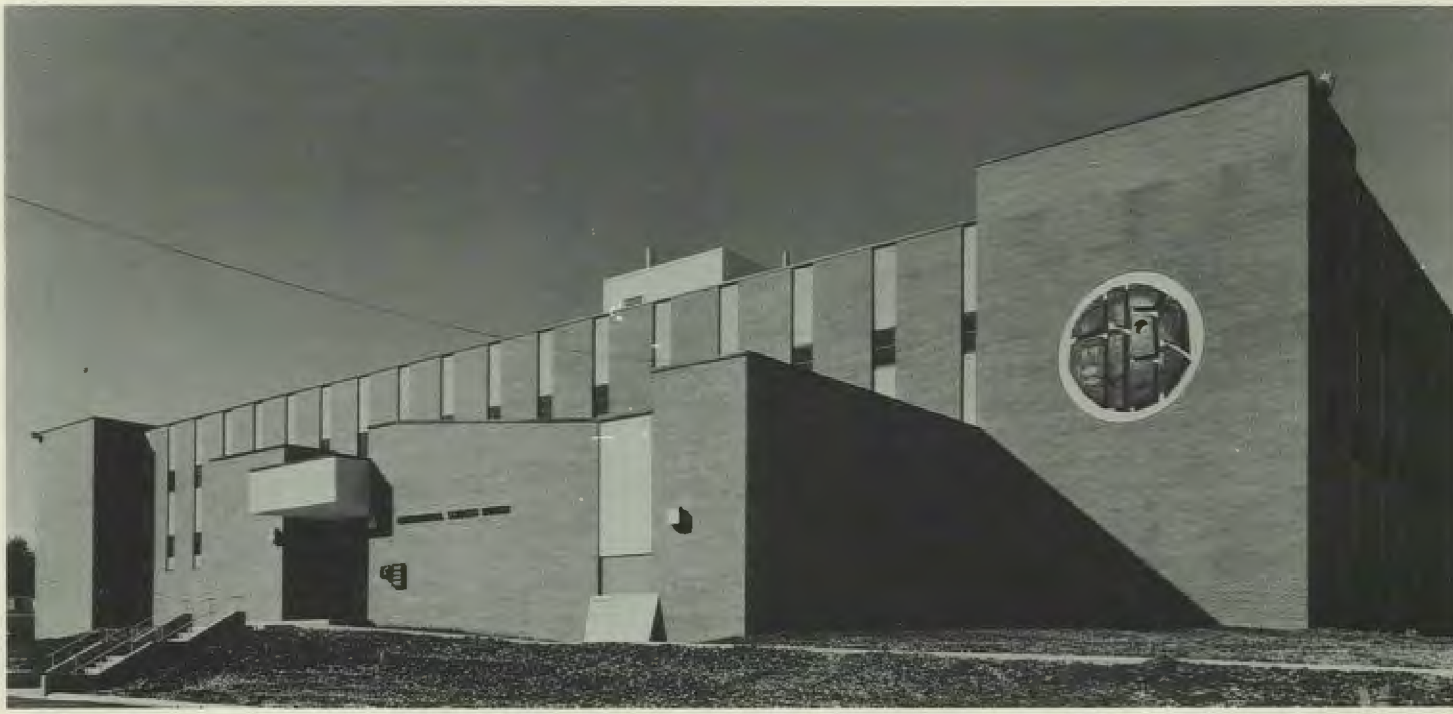
A crucial indicator of what's happened at the Laboratory is the growth in R&D support in dollars. The Laboratory budget has doubled over the last four years, far exceeding the cost of living during that period, as well as outpacing the growth in people.

Responsible for that difference is the fact that we have money, along with program management responsibilities, and this in turn means that we now are subcontracting more research and development. On the one hand, spending more extramurally allows us to utilize other national resources—universities and industries—and enlarge our capability; on the other hand, it gives us more flexibility in responding to changing program directions at the Laboratory. In four years, our R&D subcontracting has grown sixfold. This is in addition to the monies that we normally spend for equipment and capital construction and for buying material to carry on the intramural R&D of the Laboratory.

We cannot expect the recent rapid growth of the Laboratory to continue at the same rate. Obviously, it will slow down and perhaps plateau until a consolidation of direction and policies is reached.



There has been substantial growth in the numbers of ORNL employees.



If all goes as expected, the new Environmental Sciences Building will be occupied before the end of spring.

Evolutions in R&D Approach

Many factors contribute to the uniqueness of this institution and its ability to innovate and solve crucial problems. Changes in those factors have been evolutionary and not revolutionary over these four years. We expanded greatly our multiprogram nature that began during the AEC, that was broadened during the formation of ERDA, and that has endured with the formulation of DOE. Since the Laboratory remains an institution that is national in scope, we continue to work for many agencies in those areas where we can effectively put together the resources needed to solve national problems. ORNL cherishes its ability to mobilize many disciplines to attack complex problems. During the last four years, growth has occurred in the number and mix of disciplines used, since the problems themselves have become more complex. In particular, we've seen an increasing number of economists, social scientists, and information specialists.

Another evolution at the Laboratory, and the theme of my address last year, has been the broadening of our work with other institutions and users' groups.

CHANGING PROGRAMS

The trends in dollar level over these years indicate obvious changes in what we do, but I need to provide some insight into the fundamental changes taking place within the trends and programs themselves. I will divide it into two broad areas: the sciences and the technologies.

The Sciences

While we have seen growth in the sciences during the last few years, the amount of money spent in the sciences has not increased dramatically as in the technologies. The drama lies in the shifts that have occurred within research areas. Perhaps the most pervasive change has been in the basic studies related to nuclear and radiation effects, both in the physical sciences and in the biomedical and environmental sciences. The shift to studies of chemicals is most notable. In contrast with the insults caused by radiation, the biological and environmental impacts of chemicals are more numerous, more complex, and less well understood.

Our research concerns the carcinogenic, mutagenic, teratogenic, and toxic effects of these chemicals. From lessons we learned in the nuclear business, we carry over studies on the movement of trace contaminants through the terrestrial and aquatic food chains where they may be concentrated and passed on to humans. We have now evolved to a point where our research on environmental and biological effects for various non-

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Late in 1976, the pressure vessel was installed and welded in place at the Holifield Heavy Ion Research Facility. It is scheduled for completion in late 1979.

nuclear fuel cycles exceeds our involvement with nuclear. That same characteristic shift holds for the changes in physical sciences where our programs have moved from nuclear to the catalysis of coal, the cleanup of waste, and materials for conservation.

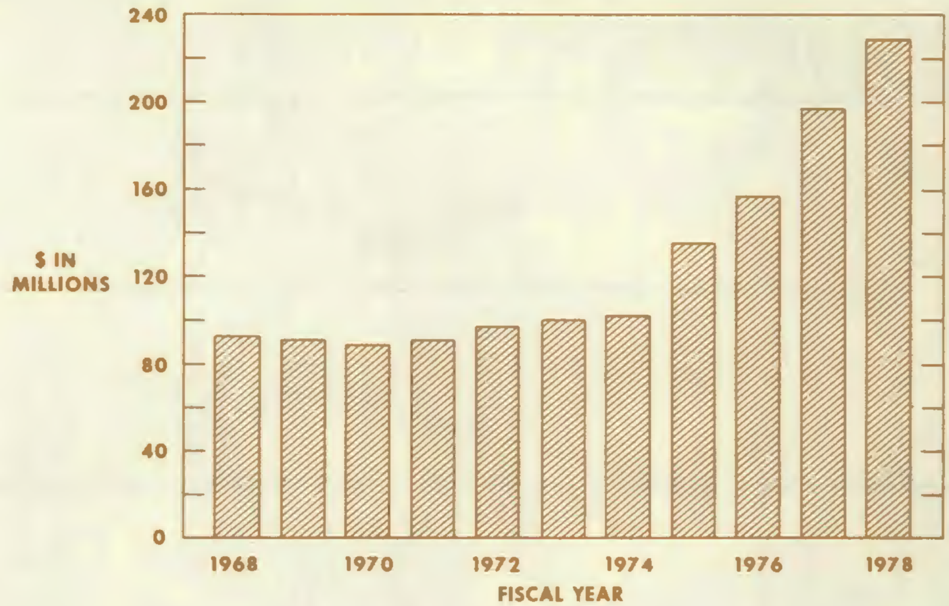
Another emerging shift is from being the primary investigator to being the custodian of a national user facility as well. This is best exemplified in the preparation of the Holifield Heavy Ion Research Facility for operation next year. This facility will be used by more than 500 people in the national and international physics and chemistry community. Another event this year reinforced that role when a recent NSF grant came for the utilization of small-angle neutron scattering capability along with the related small-angle x-ray scattering facility.

The Technologies

The largest areas at ORNL are the applied sciences, our large engineering tasks, and the early demonstrations and pilot plants. These stages are necessary to show engineering practicability and economic competitiveness of many processes and techniques discovered in the more basic areas.

During the last few years, the technologies have grown more rapidly than the sciences. But growth here, too, hasn't been the dominant change. We've seen basic shifts in the nuclear technology area, which now accounts for 35% of our work. Because of the outside pressures, changes in government policies, and new initiatives, the nuclear technologies have changed substantially during the last four years. We have become far more involved in nuclear fuel reprocessing, a revival of an area that was turned over to industry for commercialization in the 1950s. During the last four years, we've seen the passing, the return, and the passing again of the Molten Salt Reactor; a revived interest, waning, and renewed interest in the HTGR; a strong push on the LMFBR, and now an eleventh hour waning of interest; and a new concern for nonproliferating

There has been substantial growth in R&D support.



fuel cycles which has been an especially important undertaking this past year. And the yo-yoing in the nuclear technologies seems destined to continue for the next few years.

The technologies associated with proving and perfecting the fusion process have progressed dramatically during these past four years. Budgets have increased more than four times during that period. Large and very productive experimental devices have been built, have yielded important data, and have closed down.

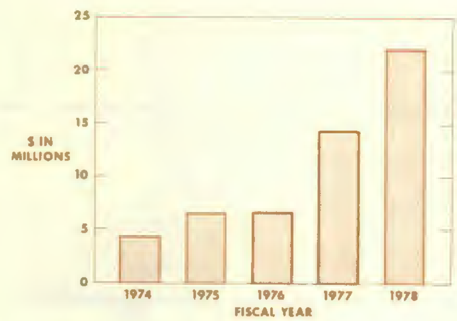
The Laboratory has been assigned increased responsibilities for development of beams and superconducting magnets, both very large technological undertakings. Impressive contributions have been made throughout the fusion community—and particularly in Oak Ridge—during this period.

Major new growth has occurred in the nonnuclear technologies at ORNL. In two cases, coal and conservation, efforts that four years ago were mere fledglings are now thriving and are major programs. We are contributing in important ways to the technology, to studies and evaluations, to process development and refinement.

But these four years have been particularly difficult for those involved in leading us into nonnuclear areas. The Laboratory was aggressive in declaring its desires, its capabilities, its background, and its record of accomplishment as it sought to become involved with crucial areas in the national energy program where the unique capabilities of the Laboratory would be of particular importance. There was, for some time, an initial reluctance in Washington to have any national laboratories move into these nontraditional areas. But gradually, based on performance, we've become involved in new and major ways in coal and conservation research. In the industrial community, there were, and still are, doubts about having a national laboratory involved. But as our scientists and technologists make discoveries that improve the processes, we are accepted increasingly within those communities. A greater receptiveness on the part of program managers in Washington now is becoming apparent, and we can remain cautiously optimistic about being even further involved.

Our involvement in geothermal and solar energy technologies has been more restrained. Although our activities have remained small, we have directed our efforts and entered into those areas where we felt we could make a specific contribution. We now envision a fairly constant level of involvement with geothermal resources. The waiting for and establishment of the Solar Energy Research Institute (a new national laboratory) has, of course, precluded much involvement of any national laboratory in the solar programs. Those relationships with SERI over the next few years will determine whether we can undertake much solar research.

There have been less publicized changes. We all are conscious—in part as a result of the reorganizations of energy agencies and programs—of a heavy increase in the administrative detail associated with our work. Unfortunately, many of these new administrative requirements have an adverse effect upon the precious scientific and technological capabilities of the Laboratory, and it is difficult to remain optimistic about the reversal of this trend.



Flexibility is enhanced through subcontracting research and development.

On the more positive side, however, we have seen that many of the services and support activities supplied by our machine shops, medical groups, industrial hygienists, and safety groups during the last four years have adapted creatively to new undertakings. They have been remarkably adroit in their ability to anticipate, and to come up with, timely solutions to very difficult practical problems. To these many unsung heroes, I offer special thanks for their outstanding contributions, not only in 1977, but over the preceding three years.

Balances

A number of balances must be maintained if the Laboratory is to function at maximum effectiveness. One of those, of course, is the interrelations among all disciplines important to our primary mission—that of energy production, conservation, and related environmental concerns. We need a diversity and strength across disciplines that matches the complexity of the problems we're called upon to solve. We need also to maintain the strength in the sciences necessary to support the technologies. We recognize the problem not only of slower growth in the sciences, but also of the fact that the shifts from nuclear to nonnuclear in these areas have taken place basically within nearly constant budgets. The emphasis on technologies is necessary at this time. What is of concern, however, is that if the growth in technologies is at the expense of the sciences, it erodes the very base that supplies the essential ingredients for future success. That imbalance has been articulated by the Presidential Science Advisor and by the President himself. Our greatest local concern is in the basic biological sciences, where we must take steps to ensure support for this research, which provides the underpinnings essential for discoveries about the effects of carcinogens, mutagens, and other energy-related insults to biological systems.

During these last four years, the seriousness of our near-term energy situation has led to a current emphasis on short-term research payoffs. As a result, the long-term technologies—whether breeders, fusion, or central-station-solar electric—are all being slowed in order to supply more money for technologies that could yield more rapid returns. This cannot long continue for this would eventually preempt the range of alternatives open to future decision makers. There is not at present a serious imbalance at the Laboratory, for ORNL has contributed strongly in the short-term areas to problems of considerable importance. My concern at this point, however, is that we remain strong and active in long-term, high-risk technologies that the private sector cannot afford to finance or be involved with.

EXAMPLES

I turn now to examples of technical accomplishments in 1977 that are indicative of the kinds of changes, nuclear and nonnuclear, that have taken place at the Laboratory during the past four years. Such a selection is always very difficult. Out of more than 600 separate projects at the Laboratory, and out of several thousand employees, a selection of any one example automatically precludes equally valid examples of equally high quality work throughout the organization.

Life Sciences

In the biomedical and environmental sciences, perhaps the single most striking example of a large, new, integrated, multidisciplinary activity is the synthetic fuels program. Eight different ORNL divisions now participate actively in life sciences research on synthetic fuels.

Our work in this area, particularly in relation to coal conversion, reflects the philosophy that attention to health and environmental impacts of energy production and utilization must go hand in hand with the development of new energy technologies.

The major activities include (1) chemical and physical characterization and monitoring of coal-derived products and effluents, (2) biological characterization and health effects of these substances, (3) environmental transport and effects, (4) environmental control technology, and (5) assessment.

This new program, I believe, is an outstanding example of the Laboratory's ability to deal comprehensively and imaginatively with an emerging technology—in this case, the projected use of coal as a source of synthetic crude oil and substitute natural gas. Already there have been important accomplishments.

Using many of the same protocols designed for their work on

In the Biology Division, Bobbie Brewen and Donna Moore (left to right) study the biological effects of coal conversion byproducts.

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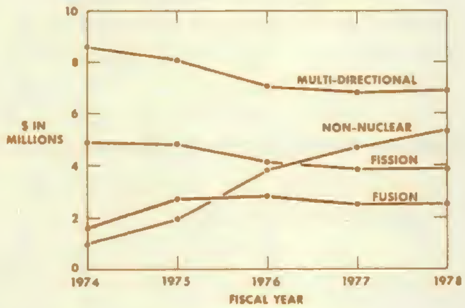


Support has shifted from nuclear to nonnuclear in the physical sciences.

tobacco smoke and carcinogenesis, teams led by Jim Epler in Biology and Mike Guerin in Analytical Chemistry are now collaborating in tests of the biological activity of coal-derived products. They have identified agents responsible for this activity using a microbial mutagenesis system and a variety of analytical techniques. Among their conclusions, based on the data shown here, are that

- coal-derived oils generally are more biologically active than shale oil or petroleum crude oils;
- biological activity is concentrated primarily in neutral and basic fractions; and
- biological activity in individual fractions can be added together to calculate the activity of the original material.

These results on bioactive components are also being extrapolated to higher organisms using a variety of experimental systems, including yeast (Frank Larimer), *Drosophila* (Carroll Nix and Bobbie Brewen), and mammalian cells (Abe Hsie). Comparative studies in the mouse are being conducted by the Russells and Walderico Generoso.

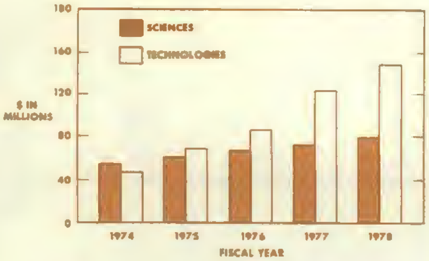
The carcinogenic potential of synthetic materials derived from coal is being tested in mammalian systems by Mike Holland and coworkers in Biology. Collaborating with chemists, they have looked at the production of tumors in a model skin-carcinogenesis system in the rodent.

In Environmental Sciences, the chemical characteristics of an aqueous effluent from the Solvent Refined Coal process are being studied. The finding that there are similar levels of toxicity in the unfractionated and reconstituted effluents means that the whole effluent and its fractions can be studied rather than identifying all the chemicals and studying each separately.

Solid wastes from coal conversion facilities pose problems of disposal. In Environmental Sciences, the leaching characteristics of ash from U.S. coals gasified in a Westfield, Scotland, facility have been defined, and the toxicity of the leachate has been examined. The data are important not only to be able to use landfill techniques successfully for disposal of ash from coal conversion processes, but also to meet new requirements of the Resource Conservation and Recovery Act.

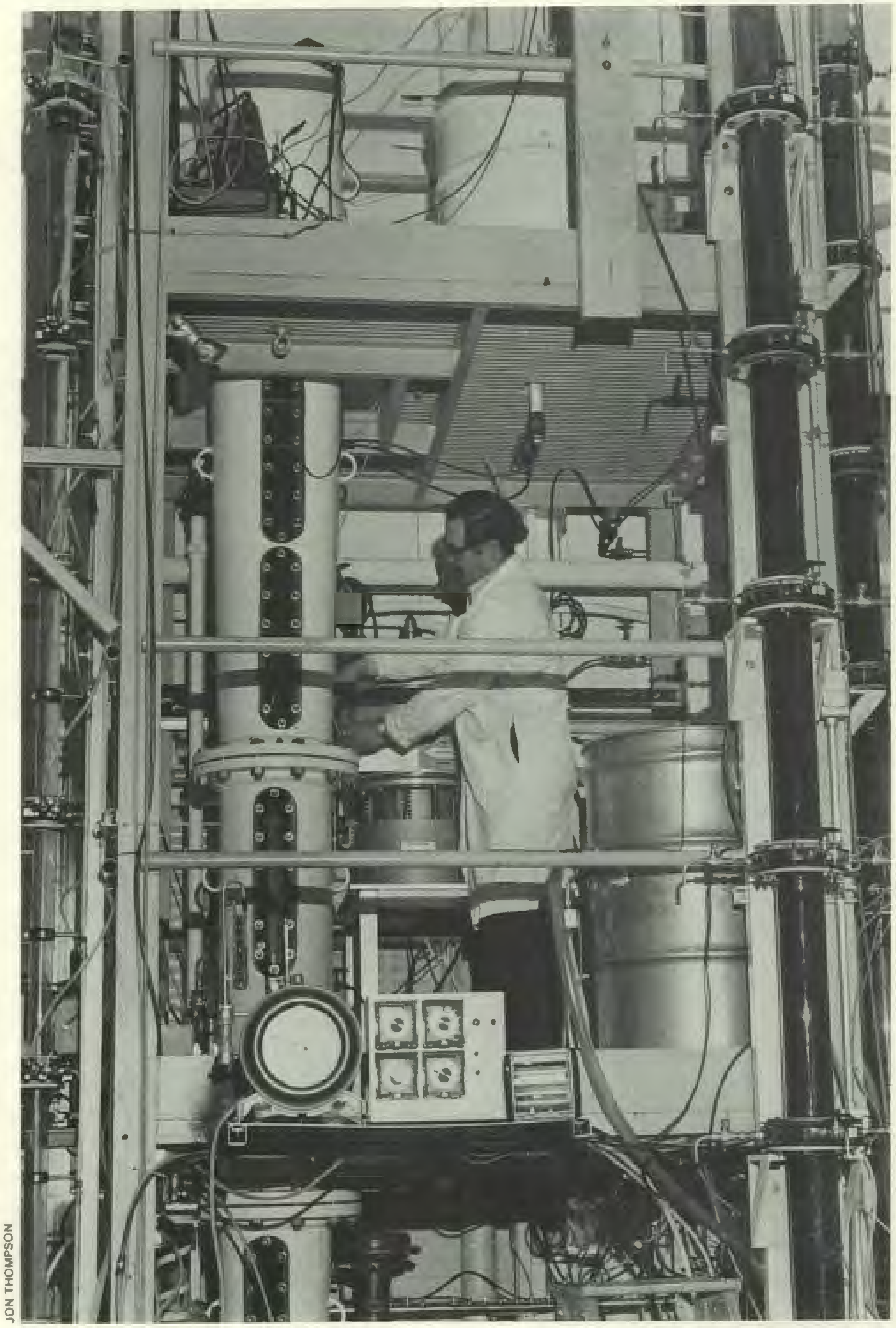
Ultimately, the effectiveness of environmental control systems will determine the acceptability of coal conversion processes. In Chem Tech, we have completed an assessment of aqueous wastes from the hydrocarbonization process at a considerable scale-up from our own 10 lb/hr process-development unit. The data have shown that a tapered, fluidized-bed "bioreactor" can reduce contaminant levels in waste streams some 40 times as fast as conventional biological systems.

Current coal conversion processes may subject plant workers to various chemical and physical stresses, including polynuclear



Technologies have grown faster than the sciences.

Chuck Hancher works at the scaled-up bioreactor that is now cleaning up aqueous wastes from coal conversion processes.



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aromatic hydrocarbons, phenols and creosols, sulfur compounds, toxic trace elements, coal dust, and noise and heat. The Health Division, under Tom Lincoln, Newell Bolton, and coworkers, developed an industrial hygiene and medical surveillance program for ORNL workers involved in coal conversion R&D. These methods led to two ORNL conferences involving interested industrial and other groups, for which proceedings have now been published.

Dick Gammage and coworkers in the Health and Safety Research Division are looking at ways to increase the sensitivity of monitoring measurements in coal conversion workers. Prototype devices based on second-derivative ultraviolet-absorption spectrometry and on phosphorescence are being built to detect aromatic compounds in work areas and to measure surface contamination.

Under a new program, Gasifiers in Industry, DOE is sponsoring development of six low-Btu gasification demonstration projects. One of them, at the University of Minnesota at Duluth, is providing the setting for ORNL to develop an integrated comprehensive health and environmental plan for an operating coal conversion facility. Sampling and monitoring requirements have been specified by a team from the Chemical Technology Division to evaluate the efficiency of environmental control devices and to characterize the process.

These various efforts reflect the multidisciplinary nature and the breadth and cohesiveness of the synthetic fuels activity. Their goal is early identification and control of potential problems so that coal conversion

At the hydrocarbonization plant, D. J. Christian "sniffs" for vapor emissions of aromatic compounds, which can be identified by a second-derivative UV-absorption spectrometer.

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technologies can be implemented safely, with minimum impact on human health and environmental quality.

Physical Sciences

In our physical research programs—now called "basic energy sciences"—a very substantial effort is directed toward acquiring the fundamental knowledge needed for development of nonnuclear energy technologies. The physical research effort also reflects a dimension which, if not unique to multidisciplinary installations such as our own, is certainly an outstanding characteristic—and one difficult to duplicate elsewhere. This is the synergism that exists between pure and applied science, between fundamental research and our technological mission as an energy laboratory. Examples are many; I will mention a few.

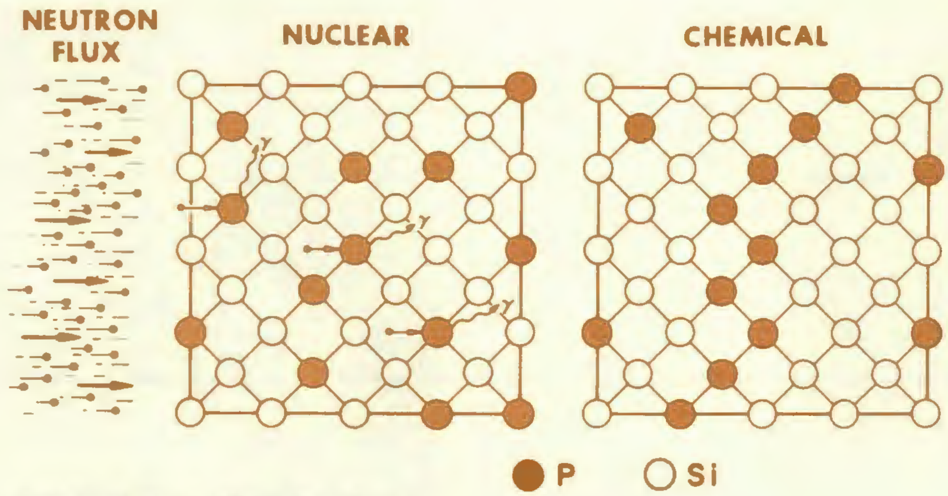
Physicists in the Solid State Division have been exploring methods to improve the efficiency and fabrication economy of solar cells made from silicon—which is expected to be the most commonly used photovoltaic material until at least the end of this century.

In one extensive study, neutron transmutation doping of silicon has been used to introduce an extremely uniform distribution of phosphorus dopant in the silicon. This method almost completely eliminates the nonuniform distribution which is characteristic of doping done by chemical means. A lack of homogeneity, in turn, may explain why the maximum efficiencies attained in these devices are lower than theoretically expected. The irradiations are performed at the Bulk Shielding Reactor, where the thermal neutron spectrum is soft, and the neutrons produce little radiation damage.

A key achievement this year, related to solar cell fabrication, has been the use of high-energy ruby laser pulses to anneal the lattice damage created by ion implantation of boron in silicon. This work shows that it is possible to remove virtually all damage due to the ion implantation. The result is a p-n junction with excellent response in both the red and blue parts of the solar spectrum. Ion implantation followed by laser annealing holds promise as a relatively inexpensive method for producing high-efficiency solar cells.

Two recent Physics Division developments illustrate basic-science support for the fusion energy program. One involves measurements of plasma ion temperatures for the next generation of tokamak-type fusion experiments which would not be possible with present diagnostic methods. To make this measurement, Don Hutchinson, Percy Staats, and Ken Vander Sluis of the plasma diagnostics group have developed the world's most powerful submillimeter laser. One megawatt of deuterium oxide laser radiation with a wavelength of 0.385 mm is generated by the oscillator-amplifier system. Scattering of this radiation by the plasma will result in a nanowatt spectrally broadened signal. Its frequency profile provides a measure of the plasma ion temperature.

Also in the Physics Division, theoretical and experimental studies have been made on impurity-atom cross sections that contribute to the cooling and heating of fusion-type plasmas. The data indicate that the heavy-atom impurity level in plasmas must be extremely low to achieve



Dick Wood, Woody White, Rosa Young, and Jagdish Narayan (left to right) stand at the laser of the ISX where they developed the process of annealing the silicon to repair it after the damage of boron-ion implantation to make solar cells.

Nuclear doping achieves more uniform distribution of phosphorous in silicon for solar cells.

fusion. Experiments also confirm theory to a degree that allows many hundreds of cross sections or reaction rates important in plasma physics to be computed to a high level of confidence.

A fourth example from the physical-research area involves contributions to the understanding of coal chemistry by the organic chemistry group under Clair Collins in the Chemistry Division. This group was established in 1946 to prepare carbon-14 labeled compounds and stimulate the use of radioisotopes in organic research. As the Laboratory's mandate has broadened beyond nuclear energy, most of this group's effort has shifted to coal.

Perhaps the most significant result has been the identification of the cleavage of carbon-carbon bonds as an important structural change in coal liquefaction. Easily cleavable bonds have been identified through model studies and isotopic tracer techniques. This knowledge of chemical bonding in coal compounds, itself an important discovery, leads toward the ability to break linkages at low pressure and temperature. Vernon Raaen and Howard Roark have shown that carbon-carbon bonds can be broken at 400°C with vitrinite as the hydrogen donor. Many coals, in fact, are better hydrogen donors than such classic donors as tetralin. The total percentage of hydrogen which can be removed from the coals when they are used as donors (for the reaction benzophenone → diphenylmethane) has been measured. It is highest (up to 34%) for bituminous coals, less (22%) for the subbituminous coals, and becomes minimal (4%), as expected, for anthracite, which is more aromatic in nature.

The conclusions we may derive from these observations are (1) added catalysts are not necessary for the dehydrogenation of coal; and (2) it should now be possible, by a simple test, to classify coals according to their hydrogen donor ability.

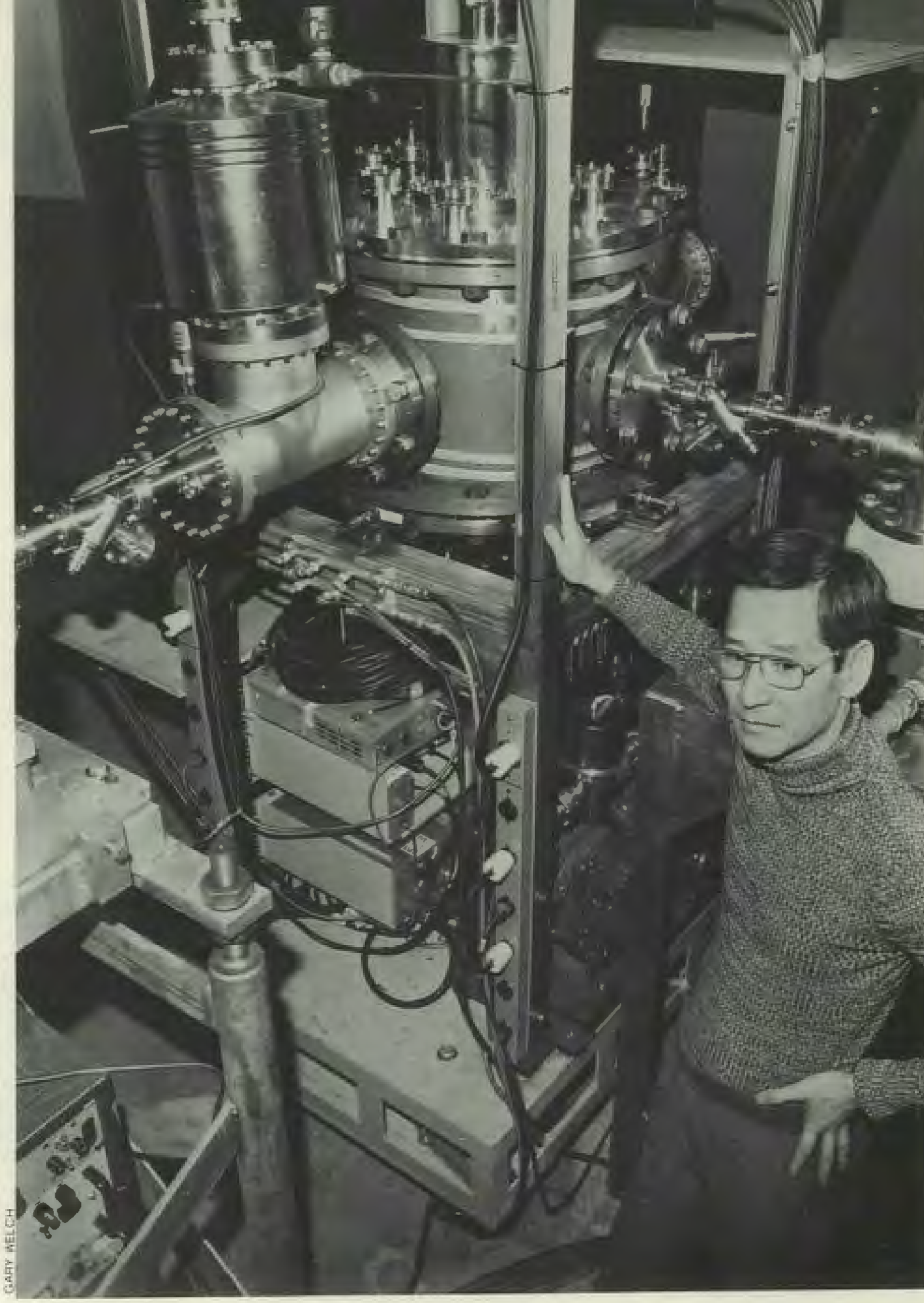
Advanced Energy Systems

In the Laboratory's Regional Studies, the tools of the social sciences and economics have been successfully integrated with our more traditional "hardware" disciplines. The result has been to greatly strengthen and expand the capability for assessment of energy systems. The fact that environmental impact statements for energy facilities now routinely include analysis of socioeconomic effects on the communities in which the facilities are to be located is due in no small measure to pioneering contributions at ORNL during these past four years.

These techniques have been modified and refined with the aid of a very sophisticated computer-based graphic analysis capability developed by Bob Honea of the Energy Division and Dick Durfee of Computer Sciences.

Such tools are being extended to deal with other facets of regional energy demands, economic growth, and environmental effects and to incorporate a greater

Cross-section studies are contributing to the understanding of the role of impurities in the cooling and heating of fusion-type plasmas. Here a beam of neutral hydrogen crosses a beam of O^{5+} at kilo-electron volt energies to determine the probability that such a collision will ionize the hydrogen. This result is important to the understanding of the injection heating of the plasma. Hee Kim monitors the experiment.



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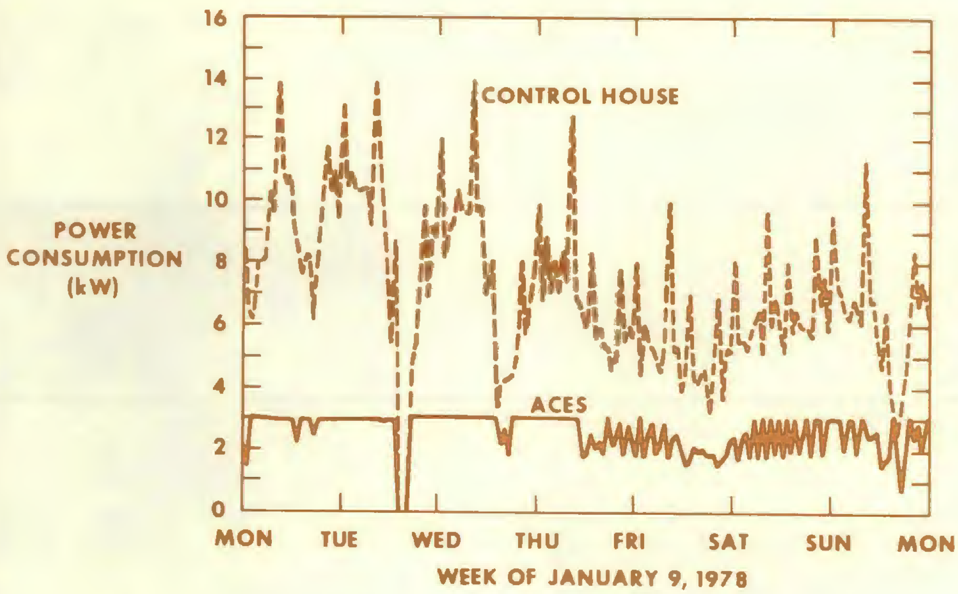
variety of data bases, including earth satellite imagery, transportation systems, and basic geological and land-use data.

This year, as part of the National Coal Utilization Assessment, we have also looked broadly at the social, economic, and environmental effects of coal development and use in the South. The analyses cover effects anticipated over a 40- to 50-year period from development of coal-fired power plants, synfuel plants, and strip and underground mining of coal. Another contribution of Regional Studies related to national energy policies had been the analysis of the impacts of President Carter's National Energy Plan on nationwide water availability.

In summary, it is fair to say that these regional-analysis tools, themselves the product of a major new direction in the Laboratory's programs, already have provided an important regional and national benefit in terms of increased power to predict and to adjust to the consequences of various energy futures.

Because of our expertise developed in nuclear work, we have been called upon more recently by ERDA and DOE to assist in preparation of impact statements and assessments for coal gasification demonstration plants and for a wide variety of geothermal projects. These activities last year led to several important results. One was the decision by DOE to move the location of a geopressure test-flow well to avoid impacts on a nearby resort community in Texas. Chuck Boston of the Energy Division has completed a monitoring handbook to help DOE contractors fulfill their environmental obligations, and this is being used in work on two pipeline gas demonstration plants.

Our work on environmental statements has also identified needs for additional research. Examples of this work include the extensive work done on the effects of thermal discharges on fish and on entrainment and impingement; models of striped bass populations, developed for the Indian Point licensing case; and a variety of environmental



The ACES House uses less power than the control house and eliminates load "peaking," thanks to better insulation and an efficient heat pump which extracts energy from an insulated tank of water.

transport models, including the Unified Transport Approach developed by Arsev Eraslan. In a related area, our electricity-demand models on the state level now are being adopted by the Nuclear Regulatory Commission as the standard methodology in the "need for power" sections of impact statements.

Closely allied with energy impacts is energy demand. Our role as an energy laboratory involves not only energy development, but also analytical and experimental efforts to reduce demand through conservation.

Some of the main characteristics and results of our conservation work were elaborated at some length in last year's address, including the Annual Cycle Energy System (ACES) development, our applicance-efficiency studies, and energy-demand models for the residential and commercial sectors. These achievements continue to influence program development within DOE as well as policy formation by the Executive Branch and the Congress. There are now, for example, 13 DOE and privately sponsored applications of ACES under way throughout the country.

Very significant new data on the conservation performance of our own ACES house derives from a comparison of its energy use during the extreme cold last winter with that of the conventionally heated control house. Not only did ACES show a much lower level of average power consumption—3 kW vs 8 to 10 kW—but also the twice-a-day peaking of that load was eliminated.

We also have assumed responsibility for the management of a DOE effort to determine the thermal efficiency of insulating materials used in the residential and commercial sectors. Our inhouse R&D seriously questions present testing methods.

Nuclear and Engineering Technologies

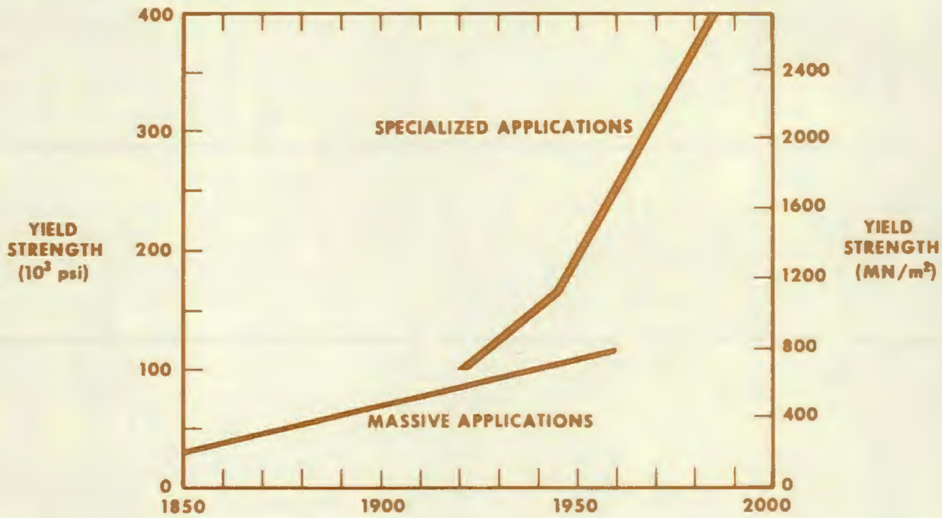
The important policy changes this year on fuel-cycle matters, and the resulting substantial changes in our own programs, truly make it proper to discuss the fuel cycle in the context of new directions at ORNL. That change, I hasten to add, can best be described as a resurgence in the level of our fuel-cycle work, even though at the same time it represents a departure from many traditional assumptions. In the late 1960s, this work had gone from the stage of being the major effort of several divisions to a rather small fraction of the work of one division.

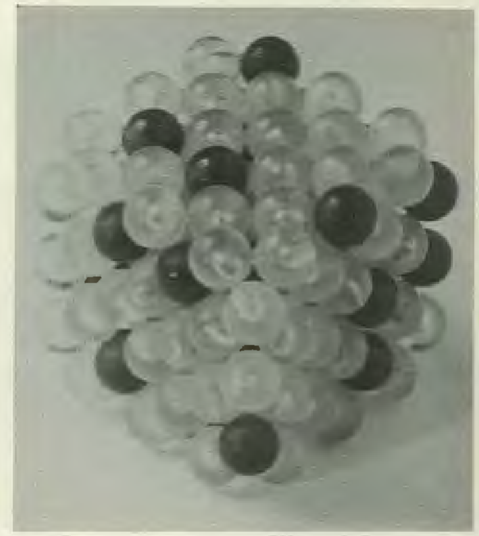
The last two years, however, have seen increased emphasis on the Advanced Fuel Recycle and the HTGR Fuel Recycle programs and the advent of the Alternate Fuel Cycle Technology Program for the LWRs, carried out in support of work at Savannah River. With the expansion of these efforts, about 12% of the Laboratory staff is now engaged in fuel cycle R&D.

In the Advanced Fuel Recycle Program, a notable accomplishment this year has been the procurement and installation of a half-ton per day rotary dissolver and the development of shears for cutting fuel assemblies into acceptable discrete fragments. In the HTGR program, continuous loading of ion-exchange resin microspheres with uranium at 1 kg/hr has been demonstrated, together with an automated pneumatic system for transport of loose coated fuel particles without damage to coatings.

Both of these recycle programs now are focusing on fuel types that may evolve from current studies of alternative, more proliferation-resistant fuel cycles. These studies are part of the Nonproliferation Alternative Systems Assessment Program (NASAP), in which ORNL has a leading

Energy and aerospace needs have accelerated the increase in yield strength of structural steels.





role. Irv Spiewak and Andy Frankel of the Engineering Technology Division are responsible for technical oversight and integration of results from these studies, which in turn contribute to the International Nuclear Fuel Cycle Evaluation effort that was initiated in May 1977 by President Carter.

Results from NASAP indicate there may be definite advantages in the thorium cycle. Preliminary conclusions suggest a high level of optimism about the long-term future of the nuclear option, including, of course, the fuel cycle. The principal issues are (1) whether breeder reactors and advanced converters operating on the denatured thorium cycle can be economically viable, although less attractive than U/Pu-cycle reactors; (2) whether the thorium cycle can be incorporated without extensive new reactor development programs, such as PWRs with spectrum-shift control modifications and fast breeders; and (3) the possibility of moving the fuel cycle from the present stowaway cycle to a symbiotic denatured thorium cycle involving fast U-233 producers and denatured U-233-fuel advanced converters.

TRADITIONAL AREAS

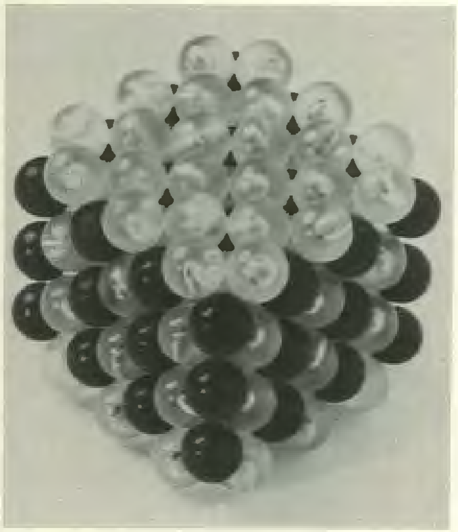
What is new and exciting in ORNL programs is, of course, not limited to what happens in the new and rapidly evolving areas of our activity. You have heard me mention frequently in the past that one of the Laboratory's great strengths is the continuity it represents in what sometimes seems to be a sea of turbulence represented by the changing political and programmatic winds in Washington.

I would like now, therefore, to document some outstanding technical accomplishments this year in our more traditional areas, although time again imposes a severe limit.

Materials

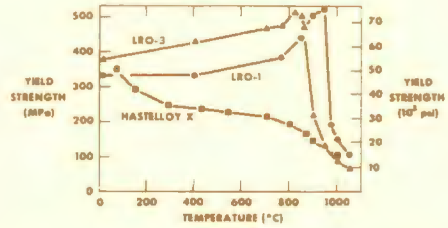
ORNL's development of new alloys for special structural service has justifiably gained wide recognition in the past. Recent developments indicate, I believe, that this will continue to be an area of some of the Laboratory's most significant technical accomplishments. This year we developed irridium spheres that contain the isotope fuel for the thermoelectric generators used in the space program, including the two Voyager planetary probes launched this fall; the development of a radiation-resistant stainless steel, or low-swelling alloy, for the fast breeder reactor program (incidentally, fuel-pin wrapper cans have been fabricated from the modified alloy for test in the Fast Flux Test Facility at Hanford); and a ferritic steel, being developed jointly by ORNL and Combustion Engineering, for potential use in piping liquid metal in breeder reactors instead of the more expensive and difficult to fabricate conventional stainless steel.

These activities reflect the tremendous world-wide importance given over the past 30 years to developing high-strength alloys for specialized structural applications—many of them involving advanced energy systems. Much of the progress in achieving greater yield strength has been made possible by advances in the basic theory of alloys.



LROs differ from conventional superalloys in regular ordering of atoms.

I want to mention the most recent and very promising materials development in the Metals and Ceramics Division. This is a series of alloys, based on an iron-nickel-cobalt-vanadium system, which exhibit long-range order and increasing strength at elevated temperatures up to 950°C and yet which can be fabricated by the usual commercial techniques. The difference between the Long-Range-Ordered (LRO) materials and conventional alloys is significant. In the normal alloy, atoms of one element replace atoms of another element in a more or less random manner. Contrasted with this is the LRO structure, in which the elemental identity of atoms on lattice sites is regular, and the atomic binding is much stronger, giving the material high strength and greater resistance to radiation damage and corrosion. Historically, however, one of the main disadvantages of LRO alloys has been their tendency to be brittle. But now, by applying theoretical understanding of alloys to this particular compositional system,



New LRO alloy gets stronger at higher temperatures.

Hank Inouye and Chain Liu have been able to develop LRO alloys that maintain ductility—a major breakthrough! Control of the ordered structure by adjusting electron/atom ratios and heat treatment produces an alloy with these enhanced properties—increased strength and corrosion resistance, better thermal conductivity, and improved ductility and radiation resistance.

Tensile tests of the LRO alloys at elevated temperatures indicate an unusually attractive mechanical behavior. Their strength, instead of decreasing as with conventional alloys, actually increases with temperature because of ordering effects. Moreover, the LRO alloys exhibit superior resistance to creep and reduce evaporation loss, and they are expected to have improved high-temperature stability.

Because of inadequate strength and high-temperature stability in existing superalloys, the energy-system components, such as heat exchangers, steam generators, and turbine blades, which employ them have had to operate at reduced temperatures and efficiencies. We expect, therefore, that this new development should contribute significantly, in the years ahead, to advanced energy conversion technology.

Fusion Development

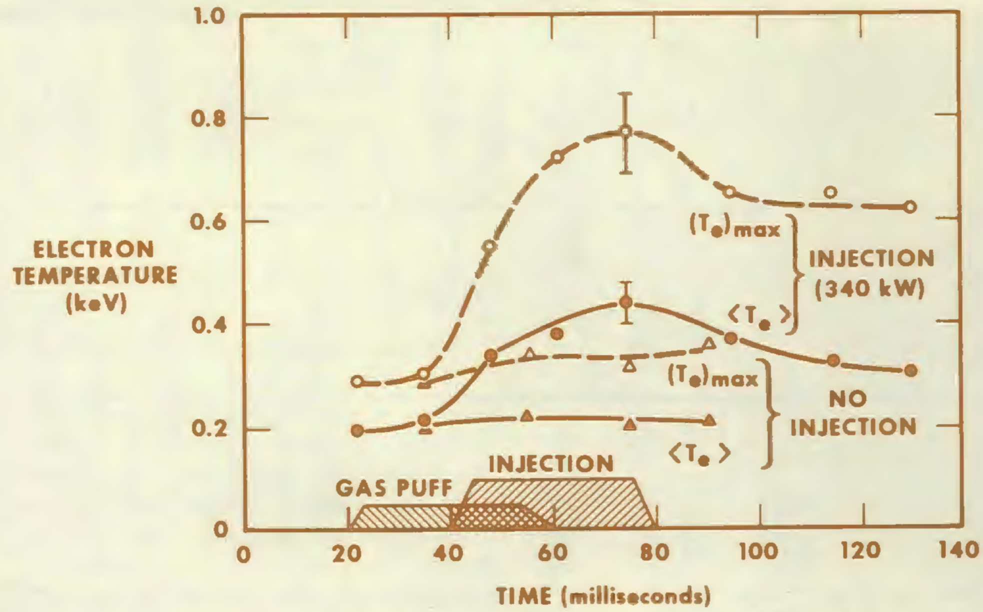
As a result of its rapid and dynamic growth over the last four years, fusion energy development now is the largest single program area at the Laboratory—funded at a level of more than $30 million annually. The strength and uniqueness of the ORNL program, I believe, lies in the degree to which it brings together and keeps in constant interaction at the working level every significant area of the magnetic fusion energy effort—from plasma theory and experiments, through development of beams and magnets, to reactor technology and advanced design studies. This year, I want to focus particularly on physics results in the tokamak program and in our principal backup effort, the ELMO bumpy torus.

Oak Ridge National Laboratory's pioneering role in the physics and technology of neutral injection heating of tokamak plasmas has made this proven supplemental heating technique a major element in most of the world's fusion programs. Before ORMAK was shut down in January, it was possible to develop key new understandings of plasma confinement in the important areas of electron heating and macroscopic stability. Simultaneously, neutral heating technology was increased by a factor of approximately 5, to the 750-kW level required by the next generation experiments.

Increased injection power made possible the first demonstration of electron heating by injection. In contrast to ion heating, which had been demonstrated previously, the apparent lack of electron heating by neutral beams had been an experimental puzzle in tokamak plasma physics. The ORNL experiment showed, however, that approximately half of the 340 kW of injection power was delivered to the electrons.

Increased injection power also increased macroscopic stability.

Increased injection power produced first heating of electrons in tokamak plasmas.



The maximum density attained with injection was higher than without injection, and thermal isolation of the plasma improved with rising density. This resulted in attainment of a peak Beta—the ratio of particle kinetic energy to toroidal field energy—of approximately 3% with injection.

Theory predicts that this Beta is close to the limit for the circular cross-section tokamak, and that the limit can be increased by elongating the plasma cross section. The second generation of work with our new Impurity Study Experiment, to be called ISX-B, will be able to address the limit of Beta—a key to prospects for an economical fusion reactor—since this device is expected to have a higher confinement efficiency than any other tokamaks in the world. The dedication of the ISX in November was, of course, an important program milestone. The machine iteself has operated more quickly and reliably than any previous tokamak device.

In neutral beam heating, an immediate target met this year was the development of injector systems for the Princeton Large Torus. The design goal was to deliver 750 kW of neutral power for 300 msec from a 60-Å, 40-keV ion beam. The systems have already reached this goal and are being modified to deliver 1.5 MW of power for ISX-B.

The Elmo bumpy torus, under the guidance of Ray Dandl, has, in the last two years, gained an increasing acceptance that is based on a series of physics results that confirm predicted performance related to confinement, transport, and impurity behavior.

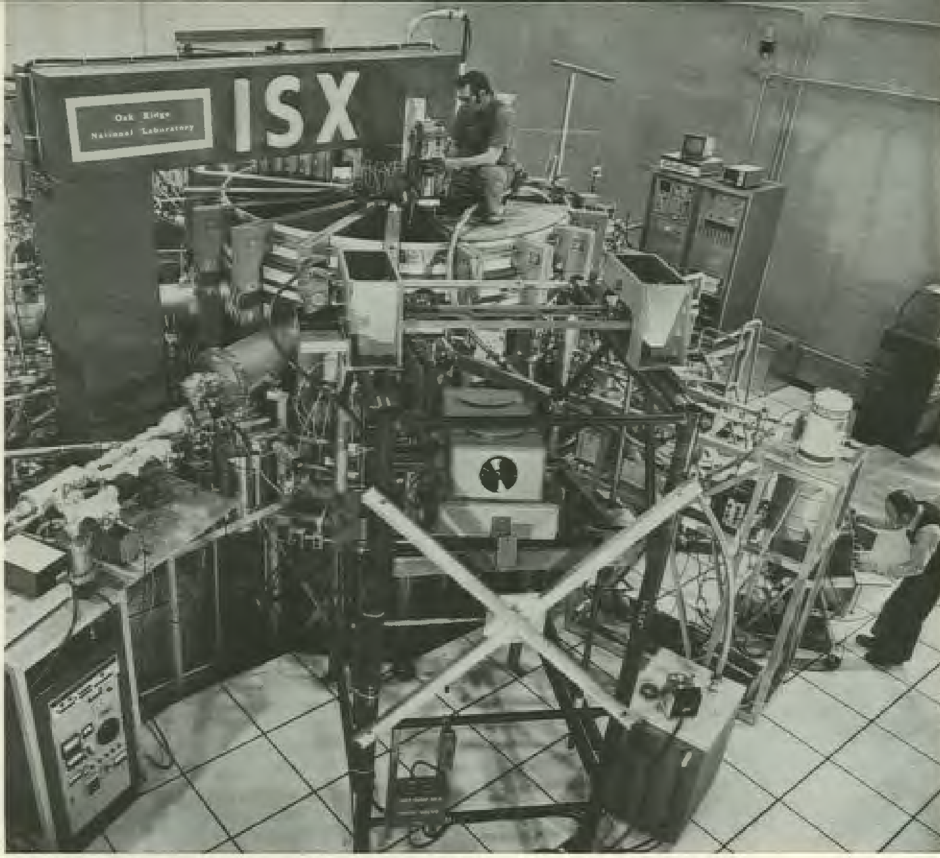
The EBT now is being modified to permit operation at the higher magnetic field and increased electron cyclotron heating that can be achieved with the higher frequencies and power provided by the new "gyrotron" microwave sources. Experiments in the upgraded facility, called EBT-S (for Scale), will have a higher density plasma and will operate at higher plasma temperatures.

Reactor Safety Research

The nuclear safety research conducted by ORNL for the Nuclear Regulatory Commission has shown that criteria used for current LWRs are either correct or conservative. Results now are sufficiently extensive, so there is little probability for additional data to indicate that current operating reactors should be derated. In fact, some uprating of reactors might be justified.

Two examples illuminate these continuing interactions on regulatory matters. One is a study by John Cathcart and Dick Pawel of Metals and Ceramics on zirconium-metal–water-oxidation kinetics, completed last October. It has provided a highly reliable set of isothermal oxidation-rate data in the range of 900 to 1500°C and has demonstrated that the Baker-Just correlation is conservative by as much as 40%. This correlation is used in LWR licensing to limit design and operation so that negligible metal-water reactions would occur during a loss-of-coolant accident, and so that the core would remain in coolable geometry. Apart from other restrictions, these new data would allow higher operating temperatures.

The Blowdown Heat Transfer Program, led by Dave Thomas, Jim White, and Bob Hedrick in Engineering Technology, is the largest NRC research program at ORNL. This nonnuclear core simulator has the important mission of verifying analyses of in-core heat transfer during the first 20 sec following a major rupture in the primary coolant system of a PWR. Results show that the time to critical heat flux (CHF) is approximately 0.7 sec, with a range from 0.2 to several seconds, and that power level significantly influences the peak temperature



FRANK HOFFMAN

November marked the dedication of the Impurity Study Experiment in fusion research, a device of high confinement capacity.

after blowdown, while initial temperature does not. Present design criteria assume an immediate CHF. Thus, the range of data obtained indicates that these criteria are quite conservative, although the data are still uncertain enough so that one cannot presently justify relaxing the criteria.

An interesting development in a DOE-sponsored program relates to the surveillance of operating power stations. This work by Ken Piety of I&C involves the use of neutron noise analysis to increase the safety, availability, and reliability of nuclear power stations. The goal is to develop a surveillance system that would automatically "learn" and store the normal signals and signatures (such as the frequency spectrum of the fluctuating components of neutron detector signals) from the standard instrumentation of each power station. After learning and defining "normal" signals, the system would examine the incoming signals and detect abnormal signatures in a timely manner.

Significant this year has been the development and testing of an automatic pattern recognition algorithm. Now the goal is to demonstrate long-term unattended operation and the ability to predict an imminent failure of any component or system from trends in the sensor signals. This would permit a power-plant operator to take corrective action before shutdown becomes necessary.

Mammalian Genetics

Virtually all estimates of the genetic risk of radiation to man are based on results from ORNL's mammalian genetics facility, as are both national and international population dose limits. In the past few years, however, a major portion of this effort has been switched from radiation effects to chemical mutagenesis, particularly investigation of compounds of importance to coal-related technologies. This broad effort is concerned with genetic effects at different germ cell stages and in both sexes. It may involve chromosome losses that can result in early death or in sexual anomalies in the offspring; chromosome abberations that can result in partial sterility of the progeny or in a variety of clinical syndromes; and gene mutations, some of which can have effects in the first generation and others which may be obscure for a number of generations. Relatively quick whole-animal prescreens, such as the dominant lethal test and the spot-test, are generally used before a decision is made to proceed with more long-term protocols that require large investments of time and money. The genetic testing of coal-related chemicals obviously benefits greatly from systems developed earlier for use with radiation.

Scattering Research

Finally, let me point to two impressive new pieces of equipment—one in operation and one shortly to be built—for scattering research. A major addition to our capability has been the 10-m small-angle x-ray scattering facility developed by Bob Hendricks of the Metals and Ceramics Division. In routine operation for about 18 months, this device has been applied to a wide variety of structural problems in materials science, solid state physics, chemistry, and the biological sciences. J. S. Lin is working with Hendricks in the utilization of this unique facility, which in September received an IR-100 award as one of the 100 most

Micrograph of a cross section of a Zircaloy-4 PWR fuel tube after being oxidized in flowing steam under transient temperature reaching a maximum of 1400°C. Its mechanical properties change with the thickness of the Zircaloy oxide and alpha layers, but also with the extent and distribution of oxygen in the potentially ductile beta phase.

important technological developments of 1977 (one of five such awards in which ORNL scientists shared this year).

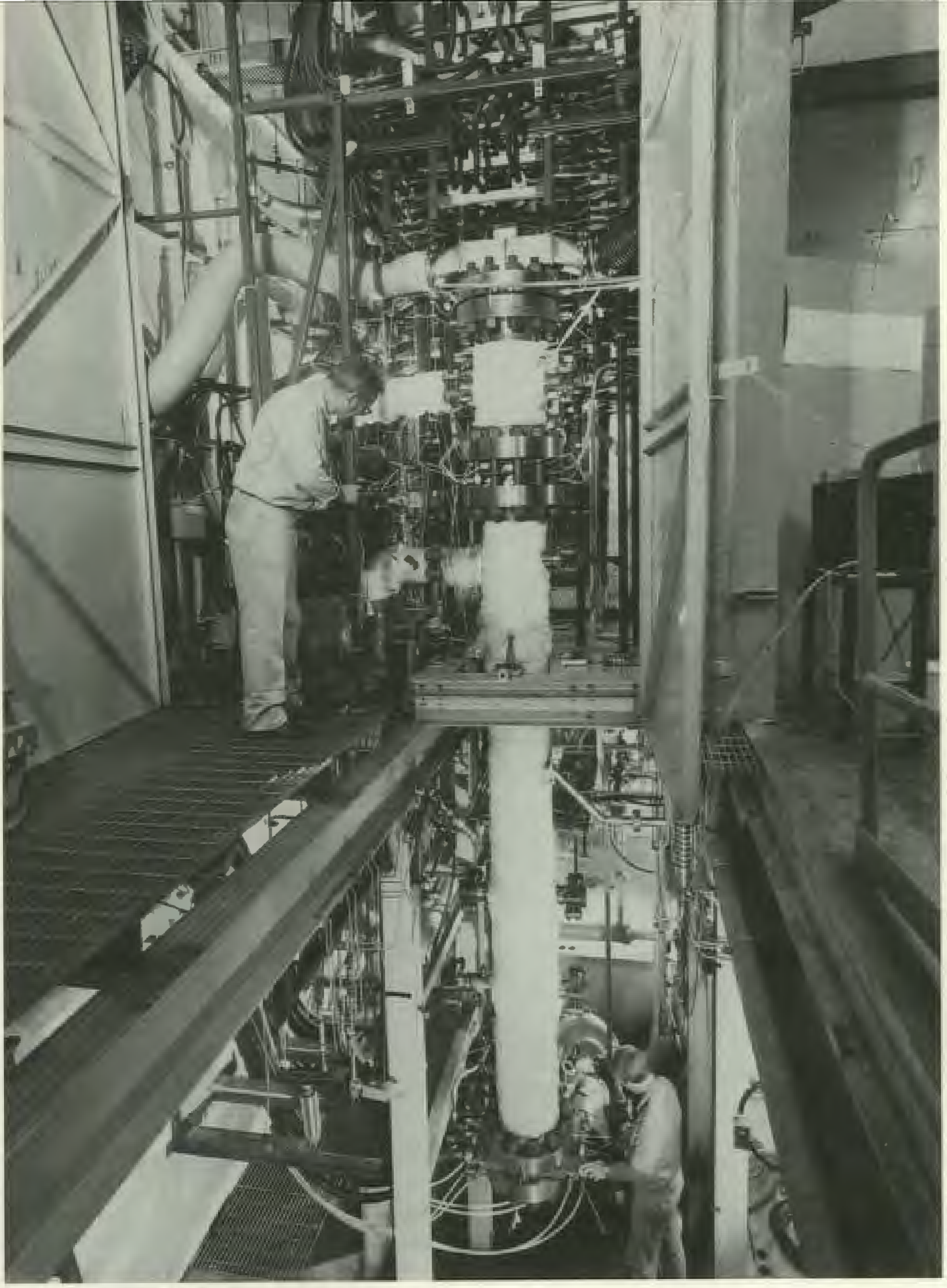
As the year closed, the National Science Foundation announced support for establishment at ORNL of a National Small-Angle Scattering Center, to be directed by Wally Koehler, of Solid State, and Hendricks. Some 30% of the beam time of four existing devices (two x-ray, two neutron) will be utilized by university scientists under sponsorship of the NSF. In addition, a new small-angle scattering facility, costing an estimated $600,000, will be constructed at HFIR. It will be competitive with the best facilities in Europe, and the combination here of state-of-the-art x-ray and neutron machines will make the Laboratory a truly important international center for small-angle-scattering research.

New Directions

Earlier, I mentioned that the character of the Laboratory is evolutionary rather than revolutionary. With the constant change in the kinds of work we do, and the ways we do it, it is important that we not lose sight of those things which make ORNL an essential institution and a leader among national laboratories. Within those, we have seen three important characteristics evolving. One is in the area of program management. For many years, the Laboratory has worked with the federal agencies in giving technical advice in many areas. But in the last few years we've seen our sponsors also depend on the Laboratory to take a more active role in the definition of programs, in letting subcontracts, and in monitoring results. This is a positive step, I believe, because those close to the technologies can make the best decisions about their technical needs and direction. We've had that role, under Pete Lotts, in program management for HTGR Fuel Recycle throughout the country; and with Bill Burch, in managing Advanced Fuel Reprocessing. We've also undertaken technical management responsibility for a number of conservation areas—and others are in the offing. A few of those we are already involved with include home appliances, heat pumps, and energy storage. In all cases where we have accepted such roles, we insist that the Laboratory have expertise in that area and continue to be active in the research. The majority of the work may be done by others, however, through subcontracts with both universities and industries.

A second growing area has been our broadening interaction with the southeastern region of the United States. We've seen growing involvement with the Tennessee Valley Authority, with the universities of the Southeast, and with outreach programs whose purpose is to take the technologies that we and others develop to the architect-engineers, consulting engineers, state energy directors, consumers, and so on, who can see that they are applied.

A third major area, also increasing in the last few years, is an emphasis on transferring the technology that is created in the Laboratory to those that might use it. This involves, of course, our working with other institutions, particularly with industry. The discoveries that we make at the Laboratory can have profound effects—there's much evidence of that. But we must make strong efforts to take those technologies and place them in the hands of those who can create the products.



CURTIS BOLES

John Wolfe looks down at Delmar Fraysier at the huge nonnuclear heat-transfer blowdown experiment in Engineering Technology Division.

These three directions are not new, for we have done them before, but they are areas which I feel will become more ingrained as part of the character of the Laboratory in the next few years.

Omens

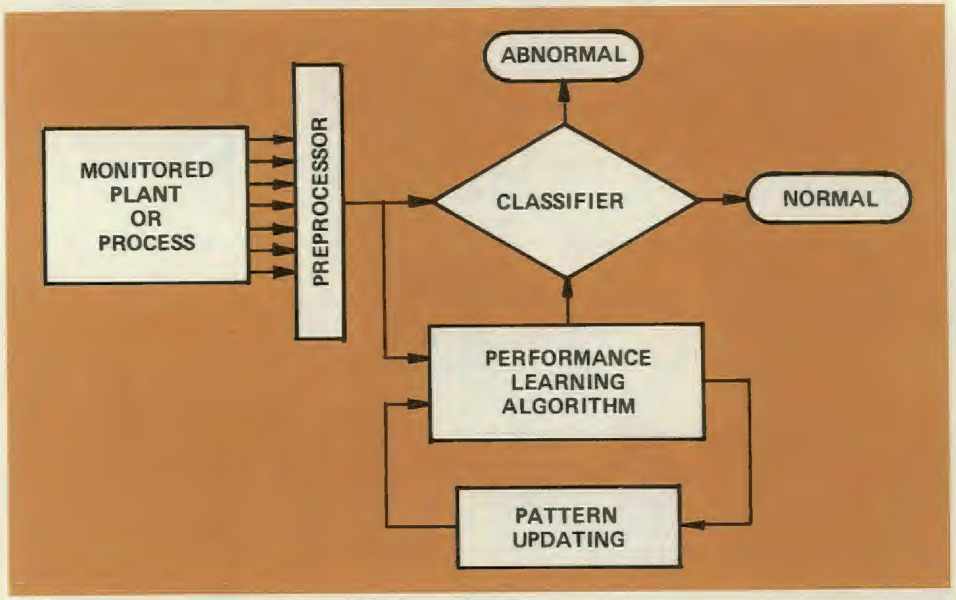
Other things that are happening on a broader scale may have longer-term consequences for the laboratory—although not necessarily predictable ones. A continuing example is the attack on nuclear energy. Some of the policies of the past now are being reversed. These changes present opportunities as the Laboratory is asked to look at new kinds of fuel cycles, new reactor choices, better ways of creating nonproliferating cycles, ways of reducing environmental impact, and ways of increasing margins of safety in reactors. Whether we are seeing a flurry of activity that will subside as the crucial role of nuclear energy becomes apparent in the next few years, or whether we are witnessing the death throes of a technology that is under attack by a few articulate, powerful people, remains to be seen.

Coupled with that attack is an impressive and more subtle new attack being leveled by a combination of environmentalists and consumers'-rights advocates. It is represented best in the newest spokesman, Amory Lovins. The attack is not just upon nuclear but upon technology as a whole. The idea of going toward the soft path, toward decentralization of the supply and use of energy, and away from big institutions sounds very appealing. This articulate attack upon technology and upon our present basic social and economic structure in the United States, if successful, will undoubtedly influence the Laboratory's character in the future.

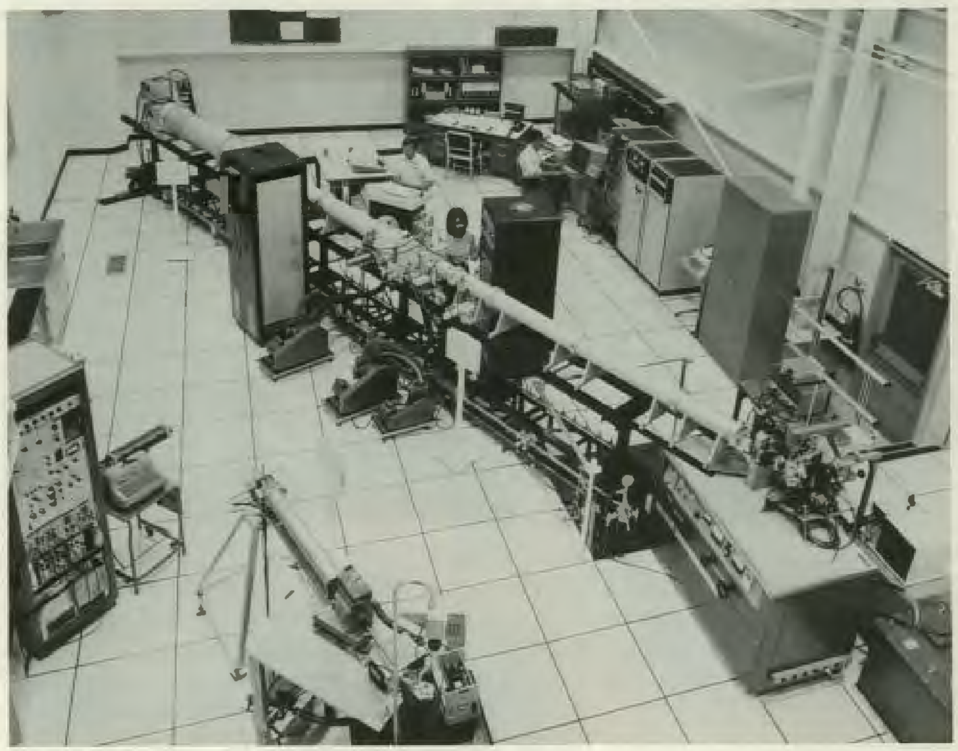
There again are those who question the role of national laboratories. This year, I testified on this subject before the Committee on Science and Technology of the House of Representatives. There are, in particular, questions from industry, from universities, from not-for-profits about what the national laboratories are doing and why. Such questioning is always healthy. We look forward to honest debate and to opportunities to sharpen our contribution. But the questioning within ERDA, the Department of Energy, GAO, OMB, OTA, and others in Washington means that the national laboratory must indeed be involved in more active discussion of roles.

There are also some good signs—a willingness by DOE to discuss placing more responsibility in particular areas at the labs and to create technical

The algorithm shows how complex nuclear power plants can be monitored automatically. Signals from the plant process are translated by a preprocessor into neutron power density spectra, are compared with the learning period spectra (presumed to be normal), and then are classified accordingly as to normality.



Panoramic view of Bob Hendricks's small-angle x-ray scattering facility described in the Winter 1978 issue of this journal. Its outstanding success has led to support by the National Science Foundation for a National Small-Angle Scattering Facility to be established at ORNL, embodying the construction of a similar neutron-scattering machine at HFIR.



centers with sufficient breadth to attack significant problems. There is increasing attention in DOE to areas of research that have in the past been a no-man's land—falling in the cracks between the too well defined responsibilities. There is an awareness of the coming plight of basic sciences and a pledge to do something.

Summary

This year, like every year, has been an exciting one for the Oak Ridge National Laboratory. I hope I have indicated a number of the changes in direction, as well as examples of our continuing contributions, which keep ORNL at the forefront of science and technology. The future obviously will have many other changes and challenges, enough to demand the best from all of us.

The obvious and continuing source of the Laboratory's strength is its people. All of you whose creativity, hard work, and dedication have solved some of the knottiest technical problems any civilization has faced, who have the desire for participation and involvement, and who have achieved remarkable track records in discoveries, make the Oak Ridge National Laboratory a great institution. The real emphasis of any State of the Laboratory address at any time must be the quality of the people of the Oak Ridge National Laboratory and the excellence of their technical contributions. It's been my biggest pleasure again this year to be involved with this community of scientists, technologists, administrators, and support personnel. I have no doubt that 1978 will continue to be an exciting period for all of us as we work together.

take a number

By V. R. R. Uppuluri

Can Squares Be Negative?

We all know the square of a number is always positive. For instance, $(2)^2 = 4$ and $(-3)^2 = 9$. When we speak of a number we mean a real number.

But mathematicians have introduced complex numbers and defined the multiplication of two complex numbers; the product of an imaginary number by itself is, in fact, negative, as the complex number *i* represents the square root of -1.

Matrices are another class of objects created by mathematicians. Multiplication of matrices is defined in a technical manner. Because of the special method of multiplication of matrices, very unusual things can happen. For instance, the square of a matrix (which is different from the zero matrix) can equal the zero matrix.

If $A = \begin{pmatrix} 1 & -1 \\ 1 & -1 \end{pmatrix}$

then $A^2 = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$

Matrices B, such that $B^2 = B$, are studied in literature. While working on Stochastic Compartments Analysis, I encountered matrices C such that $C^2 = -C$.

For example, if

$$C = \begin{pmatrix} 1 & -2 \\ 1 & -2 \end{pmatrix}$$

then

$$C^2 = \begin{pmatrix} -1 & 2 \\ -1 & 2 \end{pmatrix} = -C .$$

These thoughts show that it is not always healthy to combine traditional functions like multiplication with newly defined classes of objects. Such a criticism is leveled more strongly in connection with Catastrophe Theory in recent times.

Ron Goans holds forth in the Whole Body Counter Facility in Building 2008, back of the cafeteria. His three degrees in engineering physics, physics, and health physics were earned at The University of Tennessee, after which he joined the Health Physics Division in 1974. His interest and expertise in instrumentation led to his being asked to investigate the sonar principle for use in diagnostic testing of burned tissue. Today, a patent is pending on a device developed by Dr. H. D. Stambaugh of the Norton Children's Hospital Burn Unit in Louisville, Kentucky; John Cantrell of NASA's Langley Research Center in Virginia; Brad Meyers, a student at Vanderbilt University; and Ron Goans. The device is now ready for testing at the Louisville clinic, and Goans will be working there with Dr. Stambaugh this year.

JON THOMPSON

How Deep is the Burn?

By JEFF McKENNA

The principle behind finding submarines in the Pacific Ocean and bass in Melton Hill Lake has been applied by an ORNL scientist to a stubborn medical problem. Using ultrasonics, and operating on the same principle as sonar, health physicist Ronald Goans has developed a device that could give doctors a quick, accurate way to diagnose burns. The technique not only can determine how deep a burn goes, but can also distinguish among the various types of tissue damage associated with the burn.

"Knowing the depth of the burn is crucial," Goans said, "because it determines how severe the injury is and, consequently, the method of treatment."

Goans' research is significant because until now there has been no sensitive, quantitative way to measure the depth of thermal damage in burns—information of primary importance to the physician treating a burn patient. That's not to say, however, that the search for such a tool hasn't been under way. Sophisticated techniques

JON THOMPSON

Application of the ultrasonic transducer to human skin is simple and painless.

such as dye differentiation, use of radioactive tracers, thermography, and infrared spectral methods have been tried, but none has been entirely satisfactory and none has come into widespread clinical use.

As a result, most of the 70,000 Americans burned severely enough each year to require hospitalization have been under the care of a physician who has had little to work with besides his imperfect eye, experience, and a scalpel.

"Ultrasonics has had many other diagnostic applications in medicine, but this is the first time it's been used for burns," Goans explained. "It's really a simple idea related to an old problem. I'm kind of surprised no one has thought of it before."

Types of Burns

To understand this "simple idea," something should first be said about the nature of burns, which traditionally are divided into three classes of severity. A first-degree burn involves only the epidermis—the outermost layer of skin—and is characterized by a slight reddening and a sensitivity to touch. These burns are superficial and generally heal readily.

A second-degree burn, also called a partial-thickness burn, is a deeper injury and involves all of the epidermis and part of the dermis, the thick layer of fibrous connective tissue underlying the epidermis and containing many blood vessels. In addition to reddening and touch sensitivity, these burns produce blisters, but can, with time, repair themselves. The rate of healing depends on the depth of skin destruction and the likelihood of infection.

Deep dermal burns are difficult to diagnose and, if they become infected, can easily turn into third-degree injuries. Third-degree, or full-thickness, burns are very severe, injuring the fat tissue beneath the dermis and being characterized by a dry insensitive surface. Unless extremely small in area, these burns usually require skin grafting; self-repair is impossible.

In cases of third-degree burns, the patient must first be treated for symptoms such as shock and loss of body fluids and blood plasma. "During this time," Goans explained, "you're inviting every kind of bacteria in the world. A variety of complications could occur—blood poisoning, massive infection, nerve problems, cardiac arrhythmias. The greatest danger is in the first few weeks following the burn, especially the first two days."

Treatment by Surgery

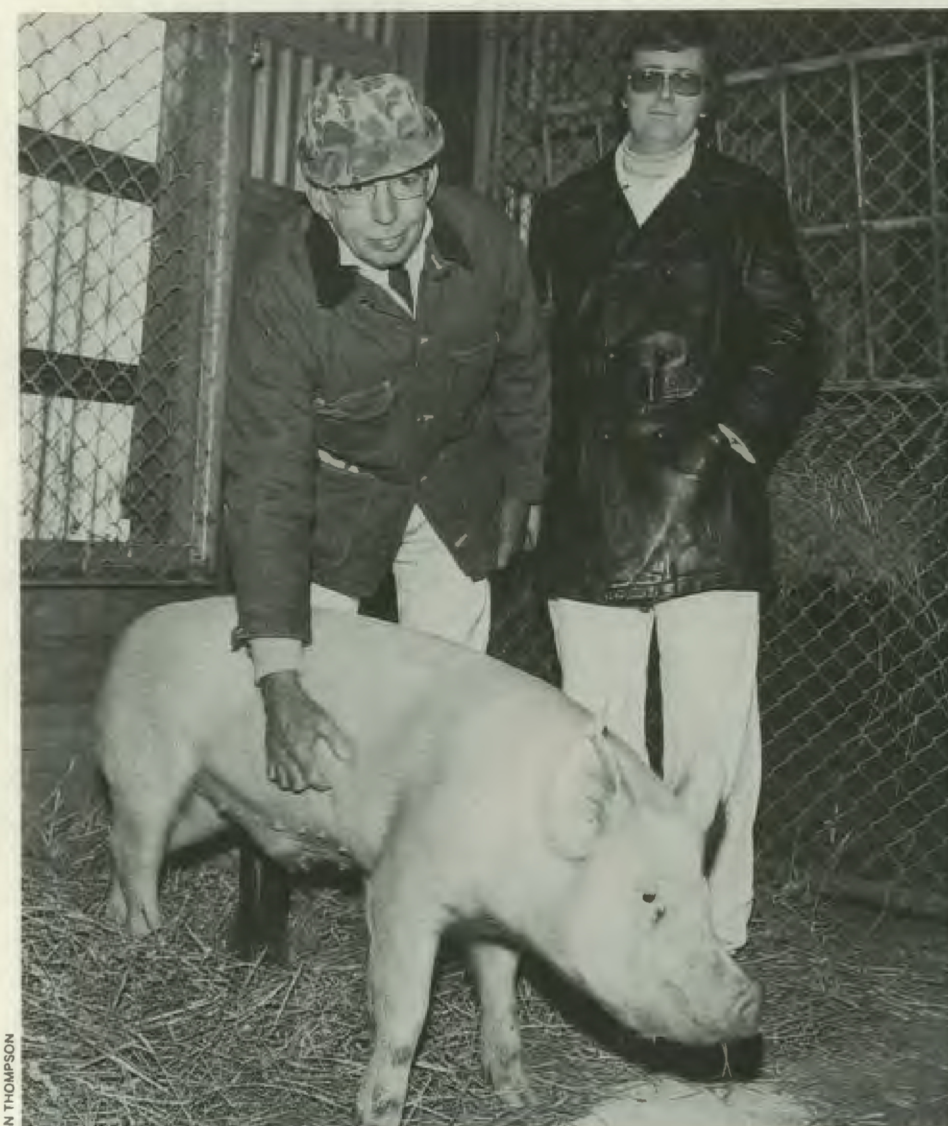
In conventional burn treatment, this long and hazardous period of time was used to allow the dead tissue to separate itself from the less severely burned tissue (viable tissue) under and around the burn. Only after this spontaneous separation had occurred, a process that takes three to four weeks, was the dead tissue removed and skin grafting started—in many cases not in time to evade serious infection or death.

"But several years ago," Goans said, "surgeons started attacking the burn problem vigorously and excising (cutting away) the destroyed tissue early. The tissue is cut away until bleeding occurs, at which point the surgeon can be sure he's reached viable tissue."

Recognizing the value of early excision of the burn wound, many major burn treatment centers are now using this method. However, there remains the knotty problem of determining how much tissue has been destroyed by the burn and cannot be expected to regenerate and how much tissue is likely to survive and regenerate. So although many surgeons agree that early excision is desirable because it removes all dead tissue, they also point out that the procedure offers disadvantages since it is often several days before the extent of injury is known.

The benefits of early excision and immediate grafting were shown in a recent study of the death rates of two groups of patients sustaining similar third-degree burns but receiving different treatments. Compared to the conservative method of allowing spontaneous separation of dead and viable tissues, early excision and grafting reduced mortality from 11 to 4% and required much less time for wound closure.

Other techniques of burn treatment—excision in stages and the use of chemicals to



JON THOMPSON

Pigs have responses oddly similar to humans. This pig, at the Comparative Animal Research Facility, paced nervously when his sty was invaded by strangers, but eventually slowed down and permitted W. J. Kopp, director of animal services at CARL, to reassure him with a few calming strokes. "The only way you can work with a pig," says Dr. Kopp, "is to have more time than he does." Ron Goans stands by, as he has many times in this study, waiting for the pig to gain his composure enough to submit to the preliminary anesthetic, administered by precise injection in the ear.

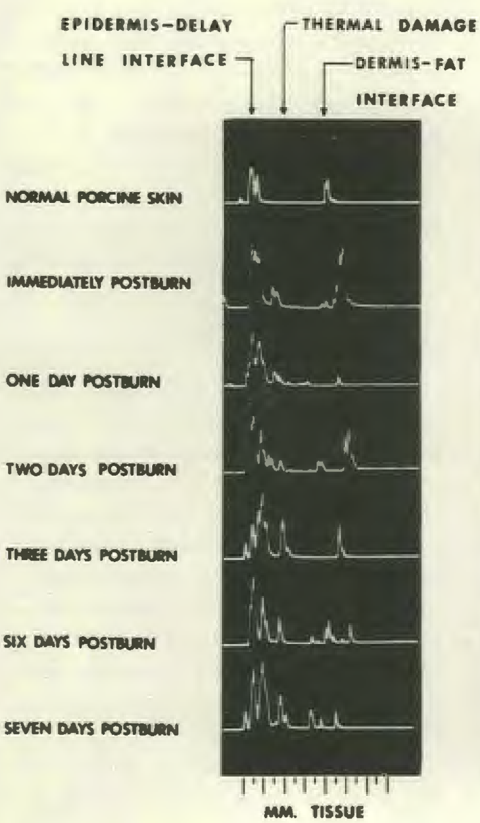
remove dead tissue—also have merit, but again, the extent of damage and the level of separation must be determined subjectively by the surgeon at the time of surgery. Therefore, the patient would be better off if the surgeon could distinguish self-repairing, second-degree burns from nonrepairing, third-degree burns. Using an ultrasonic pulse-echo device such as that developed by Goans, the physician can make that fine distinction, remove the dead tissue surgically, and perform immediate grafting while applying topical agents to the skin.

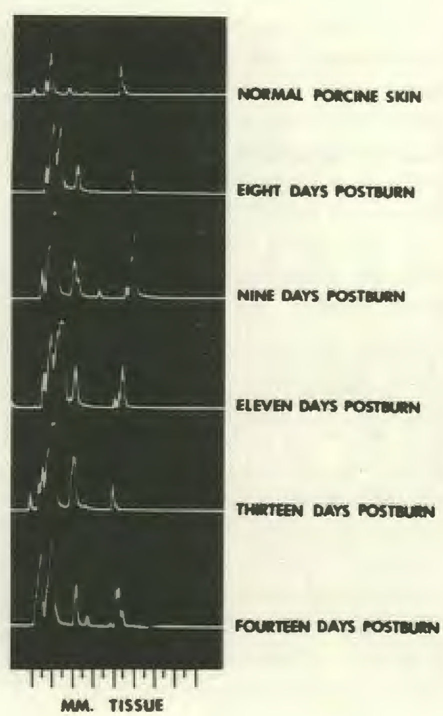
The New Technology

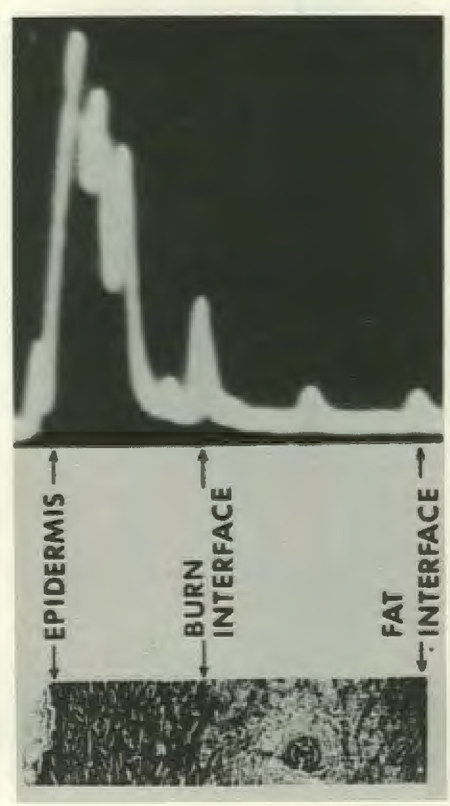
The "magic" of Goans' machine, ultrasonics (sometimes called silent sound), is the science of sound waves having frequencies too high for the human ear to hear—that is, higher than 20,000 cycles/sec. These waves are directional and can be more easily focused than audible waves. Due to their shorter wavelengths, they can be used for examining small variations in structure. In ORNL's nondestructive testing program, for example, ultrasonics is used to detect hairline flaws in metals. Its use in recent years has been applied to other disciplines as diverse as dentistry and gynecology.

In fact, the Industrial Safety and Applied Health Physics Dosimetry Laboratory (Building 2008), where the radioactivity level in ORNL employees is monitored, had been using a standard ultrasonics machine—an echoencephaloscope—for several years. It was used to measure the amount of tissue covering the ribcage in humans, and thus the amount of internal radiation that is absorbed before reaching the detectors. About two years ago, Dr. Harry D. Stambaugh, a plastic surgeon at the Norton Children's Hospital Burn Unit in Louisville, Kentucky, through his association with John Auxier, then director of the Health Physics Division, suggested that the machine be tried out on burns. Goans, whose major duties are still in the dosimetry lab, headed the project due to his background in engineering physics and because, as he said, "I've always been interested in any kind of medical research."

Early devices for producing ultrasonic waves, such as the whistle and tuning fork, have given way to modern transducers. These are crystals which







A cross section of skin, showing the sonar response to the layers from epidermis to the beginning of the fat tissue. By comparing normal skin readings with the burned skin, the depth of the burn can be ascertained.

change electrical energy into mechanical vibrations (sound waves) and vice versa. In Goans' device, a pulse of voltage is applied across the transducer to produce ultrasonic waves at the rate of 500 times per second. Sound frequencies can be varied to suit different purposes (the smaller the details being studied, the narrower the sound pulse must be) by varying the size of the transducer and the voltage.

"As the waves pass through the material being studied," Goans explained, "any kind of discontinuity (such as the boundary between burned and viable tissue) in the material will cause a reflection (echo) of the sound pulse." The transducer receives these echoes, converts them back into electrical energy, and the electronics of the machine translate the time lapse between echoes into distances—hence the label "ultrasonic pulse echo" to describe the device.

Because of the small distances involved in measuring burn depth (human skin is roughly 1 mm thick), the echoencephaloscope was modified electronically to give a finer time resolution. Otherwise, the received echoes from different layers of the skin would blur together. Goans has been able to bring the resolution down to the remarkable range of 0.1 to 0.2 mm. "According to burn surgeons," Goans said, "knowledge of the burned tissue thickness to within 10 to 15% is adequate for all surgical procedures. We certainly feel that our technique can give answers within this precision."

Volunteered Piglets

After the machine was checked and calibrated by measuring materials of known thickness, its accuracy in burn applications was tested on pig skin, which is very similar to human skin. Young (5 to 8 months old) Yorkshire pigs at UT's Comparative Animal Research Laboratory (CARL) served as the experimental subjects. Burned portions of the pigs' skin were analyzed ultrasonically to determine the burn depth and type of tissue damage. These measurements were then compared with those from slides of tissue samples taken from the burns.

All the burnings were done, of course, under deep anesthesia. And, at first, the measurements on these burns were attempted on the wide-awake pigs. As Goans tells it, the fact that an alert pig does not sit still while a tender spot on its back is being probed caused some problems for him, for the vet, and for all that finely tuned hardware. "I've been bitten, stepped on, and squealed at," he says with a smile. "We used anesthetic when we could, but giving the pigs too many injections would kill them." The solution turned out to be a simple one. Fed a large meal about a half an hour before the experiment, the pigs fell into a deep, contented slumber, oblivious to any untoward manipulations.

When the experimental results were in, they confirmed the usefulness of the ultrasonic technique. Not only were reflections measured from both the near and far sides of the epidermis and from the boundary between the dermis and fat layer, but a distinct reflection was also noted at the boundary between burned and viable tissue.

Using these reflections to diagnose whether a burn is partial- or full-thickness basically involves examining changes in the reflection spectrum relative to a known reference pattern. If the burn is partial-thickness, the ultrasound pattern will contain multiple near-surface reflections from the burned epidermal tissue as well as a strong peak at the burn boundary (somewhere in the dermis). The area in the ultrasound spectrum from the peak of the burn boundary down to the reflection at the dermis-fat boundary will be relatively free of reflected signals. Thus, the absence of signals in some portion of the dermis below the signal from the boundary indicates that viable tissue is present and that the burn is second-degree.

For full-thickness burns, there will be virtually no echo-free areas between the initial epidermal reflection and the dermis-fat reflection. The reflection at the boundary between the dermis and fat thereby serves as a natural anatomic landmark—important because dermal thicknesses vary considerably over the surface of an animal—and the presence or absence of echoes relative to this reflection indicates the degree of burn.

Greater Precision

Besides determining the depth of burns and the degree of tissue damage, Goans' research also sought to explain what caused the definite sound reflection—or "impedance mismatch"—at the boundary between burned and viable tissue. This reflection is visible immediately after the skin is burned and becomes very distinct by the third day following the burn.

What was known is that impedance is dependent on the velocity of the sound wave, the density of the medium through which the wave passes, and the attenuation (weakening of intensity) of the wave in the medium. Previous work had shown that the velocities of sound in both normal and burned tissue are approximately equal. And density measurements of burned and viable tissue showed that the densities were not different enough to produce the observed impedance mismatch between the two layers.

Using a spectrum analysis technique, Goans then found that the difference in ultrasound attenuation between the burned and viable tissue layers was "quite noticeable." The spectral shape for each layer (from burned to viable) changes, and the calculated attenuations are significantly different in going from the first layer to the deeper tissue below. Though not positive, Goans attributed this finding to differing absorptive properties of the two kinds of tissues, a complicated determination which will require the assistance of a computer to be verified.

Goans also discovered that the spectra for normal tissue and viable tissue differ from each other significantly, evidencing that the unburned skin layer below the burn, while still viable, is not left undamaged by thermal injury to the skin.

Refinements Anticipated

Although some testing of the ultrasonic device has been done on human burns, Goans has only recently been given the green light to experiment with the machine at the Norton Children's Hospital.

"All our research protocols have been approved for clinical testing," he said, following a rigorous review by members of a human use committee. "Now we'll be able to get involved with humans in a major way." Goans should also be able to devote more time to the project, which he described as "almost a sideline" to his demands at the Internal Dosimetry Laboratory.

Despite the success of the ultrasonic device till now, Goans doesn't consider it to be in its final stage. "After we started using it in the pig experiments, a lot of modifications from the original design were made. When we start examining human burns, we'll probably make many more."

One of the major improvements will be to convert the current one-dimensional display—which provides an oscilloscope trace of the depth and extent of the burn for any one point on the skin—into a two-dimensional scanner, allowing the user to see the actual cross-sectional geometry of the burn. With the addition of a minicomputer, the machine will be able to give physicians real-time readouts of entire burn areas for use at the patient's bedside—a capability that has several instrument companies looking on with interest.

"That's the really exciting possibility," Goans said. "I think all the technology is available. It's just a matter of coming up with the right interface."

Among the people who have assisted Goans in this work are John Cantrell of the National Aeronautics and Space Administration at Langley Research Center in Virginia; Roberta Roswell, Rensselaer Polytechnic Institute; Brad Meyers, Vanderbilt University; M. D. Schneider, chief of pathological services at The University of Tennessee Comparative Animal Research Laboratory (CARL); W. J. Kopp, veterinarian at CARL; and H. E. Walburg, CARL director.

Further Applications

With this increased diagnostic power, ultrasonic techniques might very well be useful in other areas where such methods as x rays are now used. For example, the standard echoencephaloscope described here is useful in ostetrics for assessing the stage of pregnancy, where a resolution of centimeters is sufficient. But with the submillimeter resolution of Goans' device, it could also be applied to screening for breast cancer. Goans thinks tumors on the order of one-half centimeter or less could be detected without the problems connected with x-ray mammography.

Even when the ultrasonic device is perfected, Goans pointed out, the proper treatment of a burn victim "will eventually rely on the skill of the doctor. But the scanner should give him much information he never had access to before." Dr. H. D. Stambaugh, a plastic surgeon who specializes in burns, agrees. Quoted in *Business Week* (June 13, 1977), he said, "The surgeon's eye is not very accurate except in clear-cut cases, and there is no way you can look at any given case and be sure." The ultrasonic machine, Stambaugh added, would change all that. "There is no question of its effectiveness. Once surgeons learn to interpret its data, I see no barriers to its use at all."

awards and appointments

David G. Thomas has been named a Fellow of the American Institute of Chemical Engineers.

Dan Robbins has been named director of the Information Division, replacing Fritz McDuffie, who has returned to research in the Chemistry Division.

Theodore Odell has been named associate director of the Biology Division, succeeding Stan Carson, who retired in late 1977.

L. E. McNeese, formerly associate director of the Chemical Technology Division, has been appointed director of the Coal Technology Program, replacing Jere P. Nichols, who has returned to the Chemical Technology Division to become manager of Engineering Analysis.

Stanley I. Auerbach, director of the Environmental Sciences Division, has been named to President Carter's Committee on Health and Ecological Effects of Increased Coal Utilization. The committee will make recommendations to the President and the Secretary of Health, Education, and Welfare concerning the health and environmental effects of increasing the production and use of coal as an energy source.

Dorothy M. Skinner has been elected to a four-year term as one of four members-at-large of the Biological Sciences Section Committee of the American Association for the Advancement of Science.

Terry Bott won the ANS Nuclear Reactor Safety Division's 1977 Best Student Paper Award for "Experimental Comparison Studies with the VENUS-II Disassembly Code," written while attending Brigham Young University.

Mitchell Conner and **John Slaten** have been certified by the National Registry of Radiation Protection Technologists.

The Greater Knoxille Advertising Club, in its 1978 Annual Addy Competition, awarded First Place in the category of house organs to **Bill Clark** for his design of the Winter 1978 issue of the ORNL *Review.*

Chet Richmond has been appointed to Committee 2 on Internal Exposure, of the International Commission on Radiological Protection.

The Carolina chapter of the Printing Industries of America, in their 1978 annual competition, have awarded second place to **J. W. Gollehon** and **Bill Clark** for "Oak Ridge" in the category of four-color brochures.

Hugh C. Long was awarded the Ben S. Gilmer Award for Engineering Excellence by Auburn University's School of Engineering. Established in 1977 in the name of an outstanding alumnus, the award is given, not necessarily annually, to honor a distinguished alumnus of the school.

J. P. Blakely has been appointed by the Board of Directors for the Society for Technical Communication to be program chairman for the 27th International Technical Communication Conference to be held in Minneapolis in the spring of 1980.

Elected Fellows of the American Physical Society have been **Yok Chen, Robert N. Compton,** and **L. A. Boatner.**

David Reichle has been appointed to the National Research Council's Board on Toxicology and Environmental Health Hazards.

Jim Weir was elected to a three-year term on the board of trustees of the American Society for Metals.

At the joint competition held by the East Tennessee chapters of the Society for Technical Communication and Industrial Graphics International, the following ORNL entries received awards: Best-of-Show trophy: "Oak Ridge," by **J. W. Gollehon**, which also won first prize in the brochure category; *Energy Division Annual Progress Report*, fourth prize, annual reports; *Ichiban: Radiation Dosimetry for the Survirors of Hiroshima and Nagasaki* by **John Auxier,** first prize, books; *Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations* by **Webb Van Winkle,** second prize, books category; ORNL *Review* (**Barbara Lyon,** editor, **Carolyn Krause,** staff writer, **Bill Clark,** art director), first prize, house organs category; *Lab Newsletter* edited by **Jeff McKenna,** second prize, house organs category; *14th ERDA Air Cleaning Conference*

Effects of Explosion-Generated Shock Waves in Ducts, by **J. E. Kahn** and **J. P. Belk**, first prize, conference materials category; *The Maryland Power Plant Siting Project: An Application of the ORNL Land-Use Screening Procedure* by **J. E. Dobson**, third prize, technical reports category; *Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview,* Vols. 1 and 2, by **Helen Braunstein, Emily Copenhaver,** and **Helen Pfuderer,** third prize, technical reports; *Career Opportunities at Oak Ridge, Tennessee, and Paducah, Kentucky, with Union Carbide Corporation, Nuclear Division,* by **J. W. Gollehon,** second prize, brochures; *Mathematics and Statistics Research Department of the Computer Sciences Division at Oak Ridge, Tennessee,* by **J. W. Gollehon,** fourth prize, brochures; *Technology Assessment of Modular Integrated Utility Systems, Vol. 1, Summary Report,* edited by **Wm. R. Mixon** and contributed to by 17 authors in the Chemistry, Energy, Chemical Technology, Engineering Technology, and Environmental Sciences Divisions, fourth prize, brochures.

Design Data and Safety Features of Community Nuclear Power Plants by **Fred Heddleson,** first prize, literature compilation; *Nuclear Safety,* edited by **Bill Cottrell,** first prize, technical journals; *Time-dependent Fatigue of Structural Alloys: A General Assessment* by **L. F. Coffin, A. E. Carden** et al., first prize, technical reports; *NRC Water-Reactor Safety-Research Program* by **Bill Cottrell,** second prize, technical journal article; *Metallurgical Examination of LMFBR-FEM Bundle 50 Following Failure During Boiling Tests* by **P. A. Gnadt, R. W. Ludwig,** and **J. W. Koger,** second prize, technical reports; *Test of 6-inch-thick Pressure Vessels, Series 4: Intermediate Test Vessels V-5 and V-9 with Inside Nozzle Corner Cracks* by **J. G. Merkle, G. C. Robinson** et al., third prize, technical reports; *Prestressed Concrete Reactor Vessel Thermal Cylinder Model Study* by **J. P. Callaghan, D. A. Canonico** et al., fourth prize, technical reports; *Stress Analysis of Cylindrical Pressure Vessels with Closely Spaced Nozzles by the Finite-Element Method* by **J. D. W. Tso, J. W. Bryson** et al., fourth prize, technical reports.

In the technical art categories, ORNL winners were **Bill Clark,** for "Oak Ridge," first place, booklets, and second and third place for line illustration; **Alice Richardson,** second place, brochures; and **John Waggoner,** third place, displays and signs.

Henry Inouye, Donald E. Harasyn, Karen H. Galloway, Anthony Schaffhauser, Chain T. Liu, Richard L. Heestand, and **William O. Graves** have received DOE citations in recognition of their "substantial and invaluable contributions to the nation's program of scientific outer-planetary studies." The Department of Energy commended ORNL for its role in the development of the multi-hundred-watt radioisotope thermoelectric generators to supply power aboard the Voyager 1 and 2 spacecrafts.

At the International Metallographic Society meeting in Houston last year, **C. K. H. DuBose**, chairman of the metallographic exhibit since its inception in 1968, received the President's Award, given for the first time in acknowledgment of special services to the Society. **J. B. Davidson** received second prize in this exhibit's Novel and Unusual Techniques Class for his "Neutron Diffraction Tomography: A Technique for 3D Nondestructive Crystal Inspection."

Robert W. McClung and **K. Kawashima** received the 1977 Achievement Award from the American Society for Nondestructive Testing for the most outstanding contribution to *Materials Evaluation* in 1976. Their paper, "Electromagnetic Ultrasonic Transducer for Generating and Detecting Longitudinal Waves," was submitted when Kawashima was a Laboratory guest from Nippon Steel Corporation, Japan.

Domenic Canonico has been appointed to serve a three-year term on the editorial committee of *Metal Progress,* a monthly publication of the American Society for Metals.

Carl McHargue was named Fellow of the Metallurgical Society of the American Institute of Mining, Metal, and Petroleum Engineers.

Phillip Maziasz received the American Nuclear Society's award for the best booth display during the Materials Science and Technology Division's poster session at the ANS winter meeting in San Francisco.

The National Research Council has appointed **Bob Jolley** to membership on the Committee on Chemistry of Disinfectants and Products, a subcommittee of the NRC's Safe Drinking Water Committee.

CHARLES TUCKER

MAZUR

Peter Mazur and Stanley Leibo have collaborated for 12 years on cryobiology projects, including the famous mouse embryo freezing experiment, the dramatic results of which were depicted in 1972 on a *Science* magazine cover. Mazur, a native of New York City, is a Harvard graduate who earned his Ph.D. in biology from Harvard in 1953. After a four-year stint in the Air Force, he was awarded a National Science Foundation fellowship allowing him to pursue post-doctoral research in biology at Princeton University. Since 1959, when he joined ORNL's Biology Division, Mazur has held various posts, including group leader in cell physiology, professor of biomedical sciences at the UT-Oak Ridge Graduate School of Biomedical Sciences, scientific director for biophysics and cell physiology, and, currently, unit leader of theoretical and applied cryobiology. In 1973–74, he was

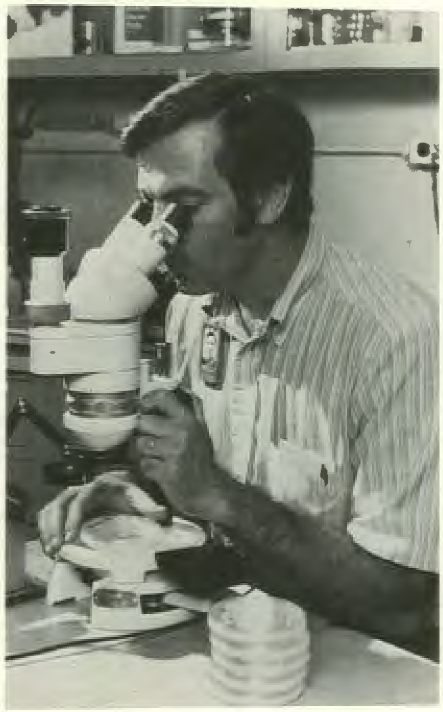
Stopping Biological Time

By CAROLYN KRAUSE

In 1949 Audrey Smith, C. Polge, and A. S. Parkes of England were trying to preserve specimens of turkey sperm by freezing them in sugar solution. The experiments were not working: the freezing killed the sperm. But then one day they had a piece of extraordinary luck. They froze sperm suspended in solution and, to their surprise, observed fantastic survival rates. They decided to repeat the experiment in a fresh sugar solution, but they were not successful. So Audrey Smith asked an analytical chemist to examine the solution they had used in which they obtained high survival rates. He determined that the solution was glycerol, not sugar. What had happened, it was later learned, was that the labels on the jars of glucose and glycerol in the refrigerator had fallen off and a lab assistant had inadvertently switched the labels as he put them back on.

This serendipitous discovery that glycerol would protect fowl sperm against freezing damage launched the field of cryobiology, the study of the effects of subzero temperatures on living systems. The discovery also had immensely practical implications, as it led to further experimental work which demonstrated that glycerol could protect against freezing damage in bovine sperm, human sperm, and human blood. Applications of these results were not long coming: two were improved cattle breeding and life-saving transfusions of clean, disease-free blood from hospital blood banks throughout the world.

The emerging discipline of cryobiology is largely concerned with understanding the factors required to stop biological time—that is, to freeze clusters of cells, hold them in frozen storage for days or months or years, and to thaw them out without killing them. Choosing the right concentration of the right additive (such as glycerol) to protect against freezing damage is only one critical factor; other factors that must president of the Society for Cryobiology. He is author or coauthor of more than 60 scientific papers. Last year, as a member of the Space Science Board of the National Academy of Sciences, he was the first author (with six coauthors) of a report produced for the Academy entitled *Post-Viking Biological Investigations of Mars.* Leibo, a native of Pawtucket, Rhode Island, earned his Ph.D. in biology from Princeton in 1963 and became a staff biologist at ORNL two years later. As the chief investigator continuing mouse embryo research, Leibo has been involved in several international meetings and has led workshops on freezing mouse strains in the Netherlands, Poland, Hungary, and Denmark. Currently, he is on leave to conduct research in immunology and cryobiology at the Basel Institute for Immunology in Switzerland.



W N SHIPLEY

LEIBO

be understood are the right rates of freezing and thawing for each type of cell.

Among the cryobiologists making significant fundamental and applied contributions in the area of the freezing of a variety of cell types have been Peter Mazur and Stanley Leibo of Oak Ridge National Laboratory's Biology Division. Since the 1960s they have studied the response to freezing of various types of simple cells, including microorganisms, red blood cells, bone marrow, and tissue culture cells. For each type of cell they found that the factors critical to cell survival include cooling rate, thawing rate, and a concentration of the additive solution that is high enough to protect against freezing damage without being toxic. During the 1970s they applied their understanding of the fundamental aspects of cellular response to freezing to the preservation of more complex cellular systems. In 1972, in collaboration with British scientist David Whittingham, Mazur and Leibo successfully froze mouse embryos, stored them, thawed them, and implanted them into foster mothers, which three weeks later gave birth to healthy, fully-developed animals.

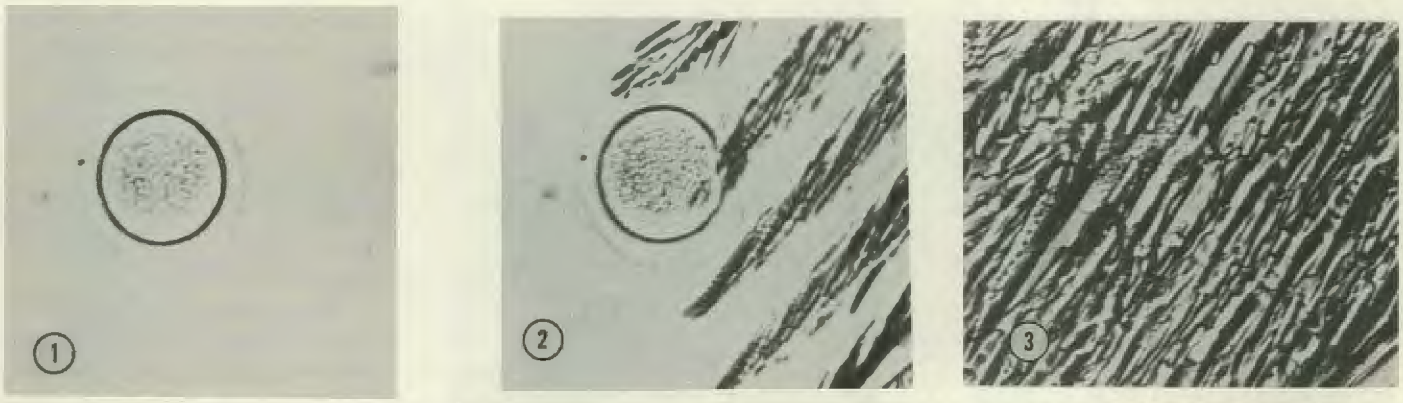
Their fundamental observation that a cellular system as large and as complex as a mammalian embryo can be successfully preserved by freezing has stimulated similar research in more than two dozen laboratories around the world, resulting in several international conferences specifically devoted to the subject of embryo freezing. It has now been demonstrated that embryos of rats, rabbits, sheep, goats, and cattle can also be successfully frozen so as to develop into living young following transfer into suitable foster mothers. In 1976, Mazur and his colleagues again achieved a dramatic experimental success. They demonstrated that intact pancreases of fetal rats can be frozen to -196°C and yet retain full function, producing insulin to reverse diabetes when transplanted into adult rats suffering from this disease.

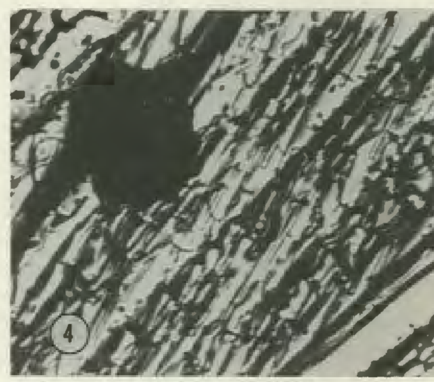
These advances at ORNL have helped cryobiology move forward in its quest for successful methods to freeze human organs for storage in organ banks. Such an achievement would be a medical tour de force because it might enable patients in need of a functioning organ to receive a genetically compatible one without delay. (A close genetic match is essential to minimize the possibility of immunological rejection of the transplant.) The formidable difficulty of human organ preservation, however, can be explained by the findings of Mazur and Leibo, who have shown that each type of cell is limited in the range of cooling and thawing rates it can withstand. Complex organs such as kidneys are composed of many different types of cells; hence, it may be difficult to find ideal cooling and warming rates that will permit the survival of the majority of such organs' constituents. Another problem is the potential toxic effect on some cells of the protective additive.

The Problems

In his article in the 1976 *McGraw-Hill Yearbook of Science and Technology,* Leibo

The four photomicrographs show intracellular freezing in mouse ova in dimethyl sulfoxide as a function of cooling rate. Intracellular freezing is indicated by the sudden darkening at –40° of the ova cooled at 32°C/min (No. 4).





sets forth the questions that cryobiology attempts to answer: "Why do some cells, but not others, withstand exposure to subzero temperatures? How does a cell survive the conversion from the liquid to the solid state under one set of freezing conditions but not under another? Does 'freezing damage' result from exposure to subzero temperatures alone, from events that occur only during freezing, during storage in the frozen state, or during thawing? Can freezing of biological systems be used practically to achieve a state of suspended animation, thus staying the otherwise inevitable passage of time?"

Cryobiologists have been zeroing in on what happens when a cell freezes. To begin with, a cell's contents and surrounding liquid consist of a dilute salt solution (mostly sodium chloride, some potassium chloride). When the temperature of the cell is lowered below 0°C, water begins to crystallize out of solution as ice, causing the salt concentration in the remaining liquid to increase. Eventually, all the liquid water is removed either by intracellular ice formation or by diffusion through cellular membranes, and the entire cell is converted into the solid state.

J. Lovelock of England has offered the widely accepted hypothesis that one cause of freezing damage is exposure to high salt concentrations. He suggested that compounds such as glycerol and dimethyl sulfoxide may serve to protect cells against freezing damage by acting as a "salt buffer" to reduce electrolyte concentration during freezing. From this hypothesis has sprung a corollary long accepted by cryobiologists: if damage results from exposure to high salt concentrations during freezing, then the rate of freezing should be fast to reduce exposure time and thus minimize damage. But experiments at ORNL in the 1960s persuaded Mazur to throw cold water on the idea that fast cooling rates assured high survival rates.

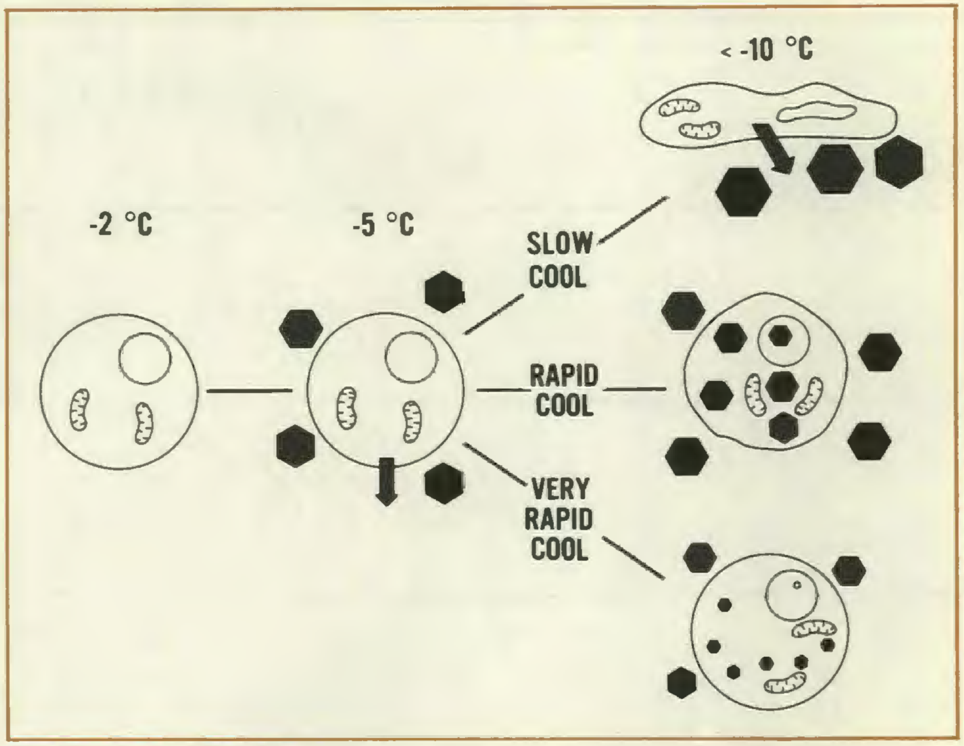
According to Leibo in the McGraw-Hill article: "Mazur was the first to offer a rational explanation of the fact that the probability of survival of a cell decreases if the cooling rate exceeds a certain value. Moreover, his explanation can adequately account for the fact that different cell types exhibit different optimum cooling rates. Assuming that cell cytoplasm is an ideal solution and that the cell will achieve equilibrium only by the movement of water, Maxur derived mathematical expressions to describe the response of a hypothetical cell to freezing."

According to Mazur, this is what happens. As a cell's temperature plummets below the freezing point, the water in the

interior of the cell remains supercooled (i.e., unfrozen), and the ice crystals that begin to form remain outside the cell. This upsets the cell's equilibrium. As Mazur puts it: "The unfrozen, supercooled water has a higher chemical potential than that of the ice outside. Like water at the top of a waterfall, water with a higher potential will tend to leave the cell—diffuse through the cellular membrane by osmosis—resulting in a higher concentration of salts in the remaining liquid and in a lower potential. If we cool the cells slowly down to liquid nitrogen temperature (-196°C), each cell has time to dehydrate, and the water leaving the cells forms ice outside. If we cool at a fast rate, then there isn't time enough for the water to leave, and eventually ice forms internally because cell water does not remain supercooled below about -10 to -15°C."

Mazur's hypothesis predicts that the probability of intracellular ice formation increases with increasing cooling rate. The experimental evidence confirming this prediction for several types of cells is now persuasive. Light and electron micrographs, taken in Mazur's as well as several others' laboratories, clearly show that slowly cooled cells appear shrunken with no evidence of intracellular ice, whereas rapidly cooled cells are not shrunken but contain large amounts of intracellular ice. Mazur and Leibo believe that intracellular ice formation is usually, but not inevitably, lethal. At a minimum, its presence renders a cell highly susceptible to lethal events that may occur during warming and thawing. Furthermore, circumventing these potentially lethal

These brown mouse pups are tended to by their albino foster mother into whose womb they were implanted as embryos. The mouse embryos had been removed from pregnant mice, held in frozen storage for eight days, thawed by slow warming, and transferred to the reproductive tract of the foster mother mouse. Another photograph of these mice appeared on a Science *magazine cover in 1972.*



This schematic depicts the physical events in cells during freezing. If the cell is cooled slowly (upper right), there is enough time for the cell to lose its water, resulting in some shrinkage but in no formation of intracellular ice. If the cell is cooled too rapidly (bottom and center right), it is not able to lose water fast enough to maintain equilibrium; it becomes increasingly supercooled and eventually freezes intracellularly. The cooling rate can be controlled by regulating the rate of flow of liquid nitrogen through special chambers containing the sample or by suitably insulating the sample tubes from the refrigerant.

events under practical conditions may be difficult if not impossible. Therefore, Mazur's analysis together with results of his and Leibo's experiments demonstrate that freezing damage is most easily avoided by cooling cells under conditions in which ice does not form intracellularly—that is, by cooling them slowly.

The common thread running through Mazur's equations—which relate the volume of water in a cell to temperature, cooling rate, and permeability to water—is that cells seek to remain in equilibrium with their surroundings. Mazur mathematically described this biological principle as well as the physicochemical principle that lowering the temperature produces two conditions believed to be potentially damaging to cells—increased salt concentration and intracellular ice. "With these equations," Leibo said recently, "one can predict theoretically how a cell ought to respond to freezing. What is now quite clear is that the theoretical description does in fact match the experimental observations quite closely."

The work of Mazur and Leibo established that many cells could be preserved by freezing if one selects a slow enough cooling rate to avoid intracellular ice formation, coupled with a sufficient concentration of an additive such as glycerol to protect against damaging salt concentrations. Then they considered the possibility that slower warming might be necessary to assure the survival of cells coming out of frozen storage. Mazur hypothesized that cells cannot remain in osmotic equilibrium unless excess protective additive in the cell diffuses out during thawing to keep the concentration of salt solution both inside and outside the cell the same.

Hence, slow warming of cells previously cooled slowly might be important, since it permits time for cells to remain close to osmotic equilibrium during thawing. Some modeling experiments by Leibo to simulate some aspects of freezing and thawing had also suggested that slow warming might be superior to rapid warming, at least for slowly cooled cells. This suggestion was verified in the first embryo freezing experiments, since Whittingham, Leibo, and Mazur found that slowly frozen embryos also had to be warmed slowly if they were to survive.

Embryo Freezing

Something of a milestone in cryobiology was achieved in 1949 with the successful freezing of fowl and human sperm. But cryobiology had to wait until 1972 for the freezing of ova (unfertilized eggs) and embryos (fertilized eggs). As Mazur recalls it: "First, we made a decision, based on theoretical considerations, to cool the embryo cells slowly to avoid formation of intracellular ice. To thaw the cells, we had been warming rapidly because most people assumed that that was the best procedure since it would shorten exposure to high salt concentrations. But work by Leibo indicated that too rapid a warming might be damaging. The guess that slow warming might be more protective than fast warming was correct, and it helped lead to successful freezing of mouse embryos."

Says Leibo: "We had observed some surviving cells when we warmed them at 450°C per minute. So we thought, if a little is good, a lot has to be better. Hence, we slowed the rate of warming to 215°C/min. Once we came to that realization of the importance of warming rate, we went from zero survival to 80% survival over the course of a week's experiments. It was a very exciting time."

In their initial experiments, Whittingham, Leibo, and Mazur surgically removed three-day-old brown mouse embryos (up to 120 cells in size) from pregnant mice, cooled them with liquid nitrogen to -196°C, left them in frozen storage for eight days, thawed them by slow warming (so that the protective additive dimethyl sulfoxide could diffuse out), and then transferred them to reproductive tracts of albino foster mothers. A large number of the frozen-thawed embryos developed normally into living mouse pups. Later experiments indicated that three-day-old embryos could be frozen for at least a year and survive just as well as those held at -196°C for only a few days.

This technique has now been successfully applied elsewhere to the embryos of several other animal species, including rats, rabbits, sheep, goats, cattle, guinea pigs, and hamsters (the latter two species have been frozen in embryonic form, but unlike the others, live animals have not been produced from them).

Jackson Laboratory in Bar Harbor, Maine, and Carshalton Medical Research Council Laboratory in England are currently applying the procedure to preserve mutant stocks of inbred experimental mice. Because diverse forms of mouse germ plasm (egg fertilized by sperm) are so valuable for genetic research and because maintaining mutants by breeding colonies is so expensive, these laboratories subscribe to the view that it is worth the expense to freeze certain strains of mouse embryos which can be developed into live animals in the event that they are needed or in the event that a highly selected strain is eliminated by disease.

Mazur and Leibo believe that cattle embryo freezing, which has been achieved in England, may soon be used to increase the production of superior cows. Says Leibo: "The ability to freeze such embryos, coupled with techniques to superovulate cows so as to increase the total number of eggs produced by a superior animal, may have as far-reaching an effect on cattle production as sperm freezing has already had."

Other possible applications of embryo freezing might be:

- Importing into the United States new or improved animal breeds in the form of embryos that could be implanted into the oviducts of foster mothers on domestic farms. This approach could circumvent the economic problems of shipping live animals from abroad as well as the U.S. Department of Agriculture's quarantine restrictions on imported animals to minimize the possibility of bringing foot-and-mouth disease into the country.
- Preservation of embryos of endangered species and of wild animals maintained in zoos. Says Leibo: "It has been suggested that embryo freezing might be used to prevent absolute extinction of an animal species. The hope is that these wild animal embryos could be reared by transferring them into similar common species, e.g., a zebra embryo in a foster horse. This formidable question of cross-species transfer remains wholly unanswered, however. On the other hand, present techniques would permit the improvement of the genetic stock of wild animals currently bred in captivity, e.g., lions and tigers. The constant inbreeding of animals maintained in zoos is leading to growing deterioration of the fitness and vigor of these animals. Freezing of embryos from animals still living in the wild, and transfer of these embryos into captive foster mothers almost certainly would revitalize the genetic pool of animals in zoos, without the necessity of reducing the size of the wild animal population."
- Preserving human embryos so as to permit previously infertile women to bear children. Freezing might help physicians to circumvent tubal blockages causing infertility in an estimated 5% of the female population of child-bearing age. The steps in the procedure would consist of inducing a woman to superovulate by hormonal stimulation and surgically removing her ova, which are then fertilized in vitro, cultured, placed in frozen storage, and transferred back into her uterus several months after her body has reverted to a normal state. If she aborts, the physician can

draw upon her other fertilized ova in frozen storage and implant an ovum each month until a successful pregnancy results. Mazur and Leibo emphasize, however, that this is a speculative and untested notion.

The investigation of embryo freezing provided Mazur and Leibo with a fundamental understanding of cellular response to freezing and warming which, they pointed out, could have application to the preservation of mammalian organs. Even so, they recognized in 1972 that it would not be easy to adapt a procedure used on three-day-old embryos (which are in a relatively undifferentiated state) to the freezing of mammalian organs (which are larger and contain many different types of cells). But in 1976, the hope that organ preservation is feasible was revived when the ORNL group was successful in freezing and thawing pancreases from rat fetuses. Unlike the mouse embryo, the fetal rat pancreas is in a differentiated state closely resembling that of mammalian organs in general. The pancreas is a gland made up of specialized cells, some of which secrete digestive enzymes while others secrete the hormone insulin that is essential for metabolizing carbohydrates.

The story began at the University of California at Los Angeles, where researchers had demonstrated in 1975 that rats could be made diabetic chemically by destroying the insulin-producing cells in their pancreases. The chemically-induced diabetes could then be reversed in many cases by transplanting pancreases from rat fetuses. (Diabetes is a partly inherited disorder of carbohydrate metabolism characterized by inadequate secretion or utilization of insulin and by excessive amounts of sugar in the blood and urine.)

Because the first UCLA experiments involved inbred rats, the implanted pancreases came from rats of the same genetic background as the recipients. So the UCLA researchers sought to do a followup study in which fetal pancreases could be frozen and genetically classified for later implantation in non-inbred rats of varying genetic backgrounds. When the UCLA researchers failed to preserve the pancreases by freezing, they turned to the Oak Ridge group for help.

Relying on his analysis of the causes of cell injury during freezing and thawing, Mazur selected the conditions for the experiment. Working with John A. Kemp of UCLA and Robert H. Miller of ORNL, Mazur immersed the fetal pancreases in a high concentration of dimethyl sulfoxide solution to protect them against freezing injury, cooled them very slowly to either -78°C or -196°C, held them in frozen storage for days or weeks, and then thawed them by slow warming. To measure the success of the procedure, they used protein synthesis as their criterion. They found that frozen-thawed pancreases were able to synthesize 80 to 100% as much protein as is synthesized by unfrozen organs.

Additional work by the UCLA team of Yoko Mullen, William Clark, and Josiah Brown demonstrated that the thawed pancreases, after being transplanted into adult rats, were able to produce insulin that reversed experimentally induced diabetes. Mazur, Ray Rajotte (a visiting postdoctoral investigator from the University of Alberta, Canada), and Lucia Cacheiro at ORNL have also done transplantations of frozen-thawed pancreases in 20 diabetic rats here. They have found that 50% of the adult rats were cured or greatly improved as a result of the transplantations. Mazur says that it is possible that the cure rate would be increased by improvements in their transplant technique.

The ORNL study also demonstrated the feasibility of long-term low-temperature storage of organs. Temperatures below -120°C are required to keep organs indefinitely because no chemical reactions can occur in such a range. (The only damage that can take place is that caused by ionizing radiation; Mazur calculates that most cells are preservable at liquid nitrogen temperatures for up to 2000 years before sufficient damage would accumulate to kill them.) Previous attempts to freeze mammalian organs resulted in irreversible damage below -20°C, but the ORNL experiments successfully preserved the organs first by lowering the temperature to -78°C and then to -196°C.

What is next on the horizon for mammalian organ freezing? Leibo believes that David Pegg of Harrow, England, may successfully freeze rabbit kidneys in the next three years. Pegg has succeeded in getting 40% glycerol solution in and out of a kidney that has been surgically removed from a rabbit. The next step will be to cool a kidney while injecting it with glycerol, then to hold it in frozen storage until the rabbit has recovered from the trauma of surgery, thaw that kidney, remove the glycerol from it, and implant it into the rabbit while removing the other kidney. The rabbit will then be observed to determine if the thawed kidney can maintain the rabbit's life.

Current State and Prospects

Although a fledgling science, cryobiology has already achieved some dramatic results. Its first application was sperm preservation, which has had an important impact on the beef and dairy industry. It is estimated that as many as 50% of the cattle born each year all over the world are produced from frozen bull sperm used for artificial insemination. Freezing of human sperm has also been achieved, but as Leibo points out, "It now appears that human sperm banks will have only very limited appeal in conjunction with vasectomies as a measure for family planning."

Blood cell preservation is another important application of cryobiology. Banks of frozen blood have been established in hospitals all over the world, including a half dozen in the United States. Unlike fresh blood, frozen blood does not have to be discarded because of outdating; furthermore, due to the necessity of washing thawed blood to remove glycerol, the incidence of serum hepatitis following transfusion with frozen-thawed blood is substantially lower than that following transfusion with fresh but unwashed whole blood.

Freezing of mammalian embryos is already being applied to preserve valuable strains of laboratory animals. Due to the potential the technique offers for improving the economics of animal husbandry, vigorous research in cattle embryo freezing is now being conducted in laboratories in Australia, Great Britain, Canada, Denmark, France, The Netherlands, and Poland. It appears human embryo freezing may have important clinical applications in the treatment of human infertility.

Cryobiology has also been applied in the treatment of cancer. Cryosurgery is now in use for killing by freezing (rather than preserving) diseased cells of a tissue. Tumor cells are killed by applying a temperature-monitored probe through which liquid nitrogen circulates. Alan Solomon, a visiting applied mathematician from Israel in the Computer Sciences Division, is currently devising computer methods to simulate the events that occur during cryosurgical freezing with the idea of enhancing the surgeon's control and manipulation of the procedure.

One prospect for the future in cryobiology might be preservation of bone marrow extracted from healthy, young clients; the thawed bone marrow could then be reinjected into these people several decades later when their immune systems are in need of rejuvenation to combat the diseases of old age. Other prospects include aging studies involving frozen-thawed cells to permit researchers to examine changes in plant and animal cells over time, preservation of normal and diseased blood cells to aid in studies of how to treat hematological disorders, and, perhaps most important of all, human organ preservation.

"The potential applications of cryobiology in the future may be staggering indeed," Leibo writes in the *McGraw-Hill Yearbook* article. "They may range from the purely practical for medical treatment and food production to the almost philosophical. That is, it is already possible to freeze mammalian embryos to within a few degrees of absolute zero. It is conceivable, therefore, that an embryo that would otherwise develop into an adult in the 20th century could be frozen and stored close to 0 K for a millenium, to begin its life in the 30th century. The freezing of biological systems, then, offers the potential for the human being to control time, rather than the reverse."

Staff Quote

"I am most impressed by the research program led by Dr. T. Kada who is well known for his DNA-repair studies in E. coli. *His recent finding that the mutagenicity of smoked meats and fish can be neutralized by vegetable extract has deep implications in human evolution as well as our everyday living."— Abraham Hsie, discussing a recent visit to Japan.*

letters

Hard Path, Soft Path

I am responding to the editor's invitation to comment on "Hard Paths and Soft Paths: A Dialogue," published in the Winter 1978 issue of the *Review,* because I believe that we need to consider the possibility of a "middle path."

So far, the reaction to Lovins' 1976 paper in *Foreign Affairs* seems to bear out his argument that there is "a deep conceptual dichotomy" between the two paths. As Allen Hammond has pointed out, both sides agree that either hard or soft technologies could probably be made to work. But each side vigorously rejects the other path, often on grounds that are "not mainly technical or economic but rather social and ethical" (Lovins).

My personal response is to be skeptical about the proposition that we are limited to two mutually exclusive long-term energy policy alternatives—and that we must place our bets on one or the other right now. One reason is that if I choose either of the paths, I am apparently expected to stop considering some scientifically interesting and socially attractive ideas.

For example, we can examine Lovins' ideas without necessarily agreeing that a total national commitment should be made to a soft path. Consider these notions:

(a) Our energy supply system is more reliable and stable if it includes considerable technological and geographical diversity;

(b) an energy supply system needs some geographical fine tuning because resources, needs, and preferences vary from place to place;

(c) when thermal or mechanical energy is needed and can be supplied directly, it is energy-inefficient to meet the needs with electricity;

(d) because a highly centralized energy supply system incurs relatively high costs for energy transmission and distribution, a less centralized system may be preferable; and

(e) many people in the United States want to be assured of continuing participation in decisions about energy alternatives for their communities, neighborhoods, and homes; but such participation is harder to bring about for systems that rely predominantly on large, high-technology facilities.

These are ideas that can be incorporated into a national energy policy—and an energy RD&D policy—without foreclosing future options. In the same way, I believe that we can continue to examine a lot of possibilities that Lovins considers part of a hard path, without necessarily agreeing that a national commitment should be made to supply all of our energy from very large central stations.

Unless and until we are faced with a "guns or butter" decision, because our fiscal resources no longer allow us to learn more about a range of alternatives, we can choose to follow a "middle path": a strategy that gives "soft," small-scale technologies equal access to R&D support, utilization incentives, and management emphasis. Such a path helps us to expand and clarify our options without predetermining the choices that society will make several decades from now. And I believe that this kind of objective is not only politically efficacious but socially, ethically, and scientifically appropriate.

Thomas J. Wilbanks
Energy Division

One of the really important factors in the "hard" versus "soft" technologies (*Review*, Winter 1978) is reliability. Most people do not suffer the loss of energy (electricity) more than a couple of hours in one year (or one day in 10 years by utility system design standards.) Unfortunately, this is not automatically true of the smaller, single home, or local, soft technology, energy converters. A good analogy is the heat pump. This is a hybrid soft-hard technology application in which "hard technology" electricity is used to extract "soft technology" solar energy from the atmosphere. Consider how often the heat pump fails compared to how often electricity is not available. Almost any "soft" technology approach I know of is susceptible to failure during operation whether by corrosion, mechanical failures, or simple cloud cover.

The obvious answer is redundancy in the stand-alone systems. Cost factors then lead to the realization that it may be just as effective, yet considerably less expensive, to back up two or more homes with one standby system; and soon one develops the legal notion of a public utility to handle the ownership problem.

Conservation and efficient system operation are our most reasonable answers to the energy problem. Call it "soft" or "hard" if you will. More insulation helps either approach; waste heat recovery helps either approach; designing for passive energy sources helps either approach. Unfortunately, Lovins' "soft" approach presupposes the availability of hard technology energy to function, and the hard technologies need the soft technology energy savings to work. It's too bad that only people who must turn a profit have known this and practiced it long before there was an energy crisis. It was called "cost savings."

Harry G. Arnold
Energy Division

I really enjoyed reading the dialogue between Helen Braunstein and Dick Roop in the winter issue of the *Review*. They did a superb job of discussing both sides of the controversy in an interesting, informative, and informal style.

Would it be possible to conduct similar dialogues in future issues? I think this would be a great way to stimulate more thinking and discussion at ORNL about key substantive issues related to energy.

Eric Hirst
Energy Division

Lab in Flux

The article "A Laboratory in Flux" by A. H. Teich and W. Henry Lambright, excerpts of which were contained in the Winter 1978 *ORNL Review,* deals in part with the establishment of "a large Environmental Research Program" at ORNL in 1970. Unfortunately, the article does not distinguish between this Environmental Program and ongoing environmental research being carried out by the (then) Ecological Sciences Division for the National Science Foundation. Clarification should be made that there is no connection between the "Environmental Program" mentioned in this article and the present Environmental Sciences Division. The latter is an outgrowth of the earlier large-scale work in ecosystem analysis and radiation ecology carried out by the aforementioned Ecological Sciences Division.

S. I. Auerbach
Environmental Sciences Division

information meeting highlights

Metals and Ceramics, September 27–28

For years the Metals and Ceramics Division has conducted research projects on materials related to nuclear fission reactors. But in recent years the Division has also distinguished itself with work on other energy sources (in keeping with ORNL's broadened mission), such as coal. Some examples are reported here, as based on two poster sessions at M&C's tent-covered information meeting held September 27 and 28, 1977.

Studies of coal constituents. Larry Harris and Charlie Yust have developed a technique combining optical microscopy with electron microprobe analysis that not only determines the total amount of sulfur in a sample lump of coal, but also maps for the first time the relative densities of sulfur among the sample's minerals and macerals (organic constituents). After inspecting polished sections of various samples of coal under the optical microscope, Harris and Yust pinpointed the relative locations of the macerals of exinite, vitrinite, and inertinite as well as minerals such as pyrite, which tie up sulfur (e.g., FeS_2). Then Harris and Yust subjected the samples to electron microprobe analysis, which provides data on the relative amount of sulfur at each location by bombarding the coal with electrons and detecting and counting the characteristic x rays emitted from the excited atoms of sulfur. From the data they inferred that there is relatively more sulfur in exinite than in vitrinite, and that sulfur content is lowest in inertinite.

This analytical technique, which is quick and relatively low in cost, offers the potential of determining the relative content and distribution of sulfur in various coals, thus allowing the user to select the coal that is least likely to pollute the air in violation of federal standards. Since the distribution of sulfur among the pyrite and organic constituents governs how well coals can be cleaned, the technique could be useful in selecting the coals that can be effectively cleansed of their sulfur by conventional "sink and float" processes which separate out heavy minerals. The technique could also aid in developing new methods for removing sulfur from macerals in the coal.

These recent findings are a direct outgrowth of earlier work performed by the investigators using ORNL's high-voltage electron microscope and a scanning-transmission electron microscope interfaced with an x-ray dispersion unit. These instruments have revealed the distribution and size of pores as well as the location and identity of submicron-size minerals in coal.

Two years ago, in collaboration with Pedro Smith (now with the Chemistry Division), Harris and Yust found that exinites have channel-like pores—many shaped like golf tees—which frequently contain a microscopic spherical particle. At the time, the investigators theorized that the unidentified particles acted as catalysts to form the pores, which branch out from filler material. More recently, Harris and Yust have observed that the inertinite region of coal has much smaller pores than are seen in exinite, and that these pores are widely distributed and highly interconnected. The character of porosity in vitrinite is now being studied.

Using electron microscopy to extend the knowledge obtained by optical petrography studies, Yust says that he and Harris have observed mineral bands in coal that are on a finer scale and that are much more finely distributed than has been generally appreciated. Typically, mineral particles in these bands range in size from 50 to 150 Å in diameter. Understanding the mineralogy of aggregate coal is critically important to the conversion of coal to clean-burning liquid and gaseous fuels because some minerals act as poisons to external catalysts, whereas other minerals serve as catalysts to promote conversion (primarily to get hydrogen from donors into the heated coal). Yust and Harris have found in coal such minerals as titanium silicate, which renders the cobalt moly catalyst ineffective, as well as iron and aluminum silicates, which tend to catalyze coal conversion reactions.—*CK*

Physics, October 3–4

A new giant resonance in nuclei. Nuclei of atoms are normally thought to be more or less spherical and to have a roughly spherical distribution of charge. In the 1940s, experimental physicists found that irradiating atoms with photons (gamma rays) of certain energies caused the atomic nuclei to oscillate strongly, creating an excited state of the nucleus. This excited state, called a giant dipole resonance, is thought to consist of a nuclear motion in which the neutrons and protons within a nucleus move collectively against one another, so that their center of mass and charge separate, thus creating an electric dipole moment.

In the early 1970s, ORNL pioneered the investigation of other giant resonances in nuclei with the discovery of the giant quadrupole resonance, an excited state of the nucleus which can be characterized by the spherical nuclear shape oscillating back and forth between a prolate (football) shape and an oblate (pancake) shape. Led by Fred Bertrand, several members of the ORNL Physics Division have continued the experimental study of the giant quadrupole resonance and initiated searches for other new giant resonances.

The first direct evidence of the quadrupole resonance came in 1971, based on measurements in which numerous nuclei were bombarded with 60-MeV protons from the Oak Ridge Isochronous Cyclotron, and angular distributions of the inelastically scattered protons were obtained. (Inelastic scattering means that the particles bounce off the nucleus with less energy than they had as incident particles because some of the initial energy is deposited in the nucleus where it appears as the oscillation energy of the giant resonance.) The shapes of the angular distributions and strengths of the inelastic scattering observed in these experiments were compared with theoretical predictions by ORNL's Ray Satchler. These comparisons helped confirm that a giant quadrupole resonance had been found. (These observations were reported in 1971 by Bertrand and M. B. Lewis in *Nuclear Physics* and separately by Satchler in the same journal.)

At about the same time, these new excitations were also being produced in Darmstadt, West Germany, and Sendi, Japan, by inelastically scattering electrons from nuclei. Later, measurements were also made using the inelastic scattering of alpha particles. (These particles, unlike protons and electrons, do not excite the previously known giant dipole resonance, which is fairly close in excitation energy to the newly discovered quadrupole resonance. This makes experiments with alpha particles easier to interpret.) In order to obtain alpha-particle beams at high enough energies to assure a high probability of their exciting new resonances, Bertrand spent five months in 1976 (followed by seven weeks in 1977) doing giant-resonance research at the Kernfysisch Versneller Instituut in Groningen, The Netherlands. The cyclotron there produces a beam of 120-MeV alpha particles, which Bertand and his KVI collaborators used to irradiate lead-208 nuclei. They carefully measured spectra of the inelastically scattered alpha particles. Each spectrum showed the peak corresponding to the quadrupole resonance, but in each case an additional resonance could be seen with a slightly higher excitation energy.

Comparison of the measured angular distribution of inelastically scattered alphas corresponding to the new peak with theoretical predictions by Satchler showed that this new resonance has the characteristics of a giant monopole resonance. The monopole mode of nuclear excitation, which had not been previously observed, can be visualized as a breathing, or compressional, mode in which the nuclear sphere expands and contracts, changing in density but not in shape.

Similar results were also obtained when the experiment was repeated for lead-206, gold-197, bismuth-209, and thorium-232. The results on lead-208 have since been confirmed by further measurements by a group at the Texas A&M cyclotron. The results obtained at the Groningen cyclotron were reported March 28, 1977, in *Physical Review Letters* by Bertrand and KVI staff members M. N. Harakeh, K. van der Borg, T. Ishimatsu, H. P. Morsch, and Adriaan van der Woude (formerly at ORNL).

The discovery of the giant monopole resonance, reported at the Physics Division's annual information meeting this past fall, is of considerable importance for the physicist's understanding of the properties of nuclear matter. As Satchler explains it: "Many nuclear phenomena, such as fission or the fusion and scattering of two heavy nuclei, can be understood in terms of a picture of nuclei as drops of liquid, or nuclear fluid. The simplest approach to this nuclear model treats the fluid as incompressible; however, this is known to be only an approximation and the fluid really is compressible. Unfortunately, heretofore there has been no way to experimentally measure this compressibility. The new observation of a compressional oscillation in nuclei gives us the first opportunity to obtain information on this important and fundamental characteristic of the nuclear fluid.

"For example, one important question for which this information is vital is whether shock waves can be excited in nuclei in which the density of the nuclear matter may be many times that of normal density. If such shock waves can be excited, it is possible that new phenomena, such as the existence of a super-dense form of nuclear matter as predicted by some theorists, may be revealed. These shock waves might be induced by the collisions of two heavy nuclei, using heavy ion accelerators such as the one under construction at ORNL. Even if shock waves do not exist, knowledge of the compressibility (or the bulk modulus of elasticity) of nuclear matter is vital for our understanding of the behavior of heavy ion collisions, as well as being a fundamental characteristic which any theoretical description of nuclei must be able to reproduce."—*CK*

Chemical Technology October 27–28

ORNL's increasing involvement in research on the nuclear fuel cycle and on coal conversion is heavily reflected in the projects of the Chemical Technology Division, as reported at the Division's annual information meeting held on October 27 and 28, 1977. The Division's work also includes stable isotope separation, the uses of microbes to remove pollutants, and the development of sophisticated instruments for biomedical and environmental measurements. Several of these projects are described here. Others (such as the tapered, fluidized-bed bioreactor for removing phenols from coal waste streams, the Anflow pilot plant, and fission product release from reactor fuel) have been covered in previous issues of the *Review*.

Nuclear fuel reprocessing. Owing to shifts of emphasis in national policy, research at ORNL on reprocessing spent nuclear fuel has been broadened to include extraction of uranium-233 from thorium-based fuels in addition to the recovery of usable uranium-235 and plutonium-239 from spent fuel from light-water reactors and fission breeders.

Dave Campbell and his colleagues have successfully extracted and stripped plutonium from irradiated light-water reactor fuel after dissolving it in nitric acid. They found that plutonium losses could be maintained below 0.01% as long as acid concentrations during stripping were not too low. A small fraction of irradiated fuel is insoluble in nitric acid, and this "dissolver residue" was analyzed by a variety of methods, which showed it to consist of fission products (molybdenum, technetium, ruthenium, rhodium, and palladium) with negligible amounts of uranium and plutonium. Under certain conditions, process solutions are unstable to precipitation of zirconium molybdate, which will carry some of the plutonium present in solution, but this does not occur if high temperatures and low acidities are avoided.

The process of nuclear fuel recovery requires the use of holding reductants to prevent nitrous acid from oxidizing the recovered trivalent plutonium. After testing a variety of compounds in fast reactions in the new ORNL-developed Portable Centrifugal Fast Analyzer (described at the end of this article), Don Kelmers and Diane Valentine of the Chemistry Division found that the conventionally used compounds of hydrazine and sulfamic acid are still the most effective holding reductants.

Special equipment, which will be used to aid in the design of future chemical reprocessing plants, is being installed at Building 7603 to test processes for recovering usable nuclear materials from spent reactor fuel. The shearing system, the voloxidizer (in part), and the rotary dissolver have been installed so far. The shearing system severs the top and lower sections of fuel assemblies, compacts them, and cuts them into small pieces. The shear product then enters the voloxidizer, which converts the UO_2 to U_3O_8 and drives off most of the gaseous fission products to a collector system. The fuel material is subsequently fed into the rotary dissolver, where it is rotated in a drum and mixed with nitric acid, which dissolves the uranium, plutonium, and some fission products.

Fixation of wastes in concrete. One of the most promising methods for disposing of low-level wastes from nuclear fission is the fixation of these wastes in concrete. ORNL has pioneered the incorporation of radioactive wastes in cementitious grouts. These grouts are pumped into deep-lying, geologically suitable shale deposits (hydrofracture); in fact, ORNL is the only nuclear installation in the United States currently employing underground rather than surface storage of low-level nuclear wastes.

Recently, John Moore and Gene Devaney reported their work on a process developed by Walter Clark and Clarence Thompson for solidifying radioactive iodine-129 in a cement mixture. Their tests have shown that barium iodate (mixed in concrete) is the most suitable iodine compound. The suitability stems from the fact that it produces a waste form with very low leachability over a long period of time. Other tests have indicated that the addition of fly ash to the cement reduces the leachability even further, and that the leachability of iodine is about 10,000 times less in seawater than in fresh water.

Stable isotope separation. Iodine-123, a valuable isotope in medical diagnosis, is used in radioactive scans and uptake studies of the thyroid gland. Iodine-123 is preferred over the commonly used iodine-121 because of its shorter half-life and correspondingly lower body burden. One source of this isotope is isotopically enriched tellurium-122, which is transmuted to iodine-123 in an accelerator. To reduce the body burden even further, it is desirable that the enriched tellurium contain a minimal amount of tellurium-123.

Last year, a research and development group in the Isotope Separations Section, including Bill Bell, Al Veach, and George Howell, developed methods to overcome problems besetting the calutron separation of the tellurium isotopes. As a result of this study, they collected samples which show an isotopic assay greater than 97% tellurium-122 with less than 0.3% tellurium-123. Since these samples meet current medical requirements, steps are now being taken to adapt the developmental equipment and procedures for a forthcoming tellurium separation.

Hydrocarbonization research. ORNL has completed the first phase of its investigation of the hydrocarbonization process for coal conversion with Wyodak coal, a western subbituminous coal. In the bench-scale hydrocarbonization experiment, pulverized coal is pyrolyzed under hydrogen pressure in a fluidized bed to produce liquid hydrocarbon fuels, gaseous fuels, and low-sulfur solid fuel. The relative yields and the quality of these products may be controlled by adjustment of the operating conditions, such as temperature (up to 1200°F) and pressure (up to 20 atm). More than a dozen experiments have been completed with Wyodak coal, providing data for optimizing the hydrocarbonization process.

Hank Cochran, of the Chemical Technology Division, has concluded that useful products can be extracted at modest prices by mild hydrocarbonization of western coal based on the following attributes:

- Significant quantities of oil and gas can be obtained without the need for a gasifier and oxygen plant to produce hydrogen.
- The residual solid char is a low-sulfur efficient boiler fuel which does not require stack-gas scrubbing or limestone for sulfur sorption.
- The quality of the oil produced is such that only light hydrotreating is required.
- The substitute natural gas is a direct product of hydrocarbonization, and methanation is not required.
- Subbituminous coals are noncaking and do not agglomerate in the reactor.

Lloyd Youngblood, who operates the hydrocarbonization experiment, indicates that tests are under way to apply this technology to the bituminous coals of the East and Midwest. Chemical pretreatment has been found to render the bituminous coal noncaking and to facilitate the production of clean-burning char from these high-sulfur coals.

Biomedical technology. In 1968, ORNL researchers invented the centrifugal fast analyzer (dubbed GeMSAEC), which revolutionized the speed, accuracy, and sensitivity with which medical diagnostic tests and other analyses can be performed. Three commercial versions of the GeMSAEC have been used in clinical laboratories to measure certain constituents in blood, such as various enzymes, total protein, glucose, and triglycerides, in order to identify malfunctions of the liver, kidney, and heart. GeMSAEC was followed, in 1973, by a miniaturized analytical module coupled to a computer; this prototype, weighing over 350 lb, has recently been made available commercially. This past year, ORNL researchers led by Chuck Scott, John Mrochek, Martin Bauer, and Richard Genung developed a third-generation machine which, in combination with its integral microcomputer, weighs only 55 lb. Like the initial prototype GeMSAEC, the new portable Centrifugal Fast Analyzer received an IR-100 Award in 1977 (bestowed by *Industrial Research Journal* to the top 100 technical innovations of the year).

The new machine is superior to its predecessors in two respects: (1) it has a revolutionary centrifuge drive system which mixes the samples to be analyzed with their reagents so rapidly that up to 99 separate measurements can be taken on each of 16 different solutions in less than 2 sec; and (2) the integral microcomputer not only acquires, processes, and prints out the data, but also controls the analyzer and checks its performance to diagnose potential malfunctions. The compact size of the microcomputer and its output device contribute greatly to the portability of the machine (dimensions of 18 by 11 by 12 in.), which enables it to be carried into remote or rural areas by mobile vans and to be operated from a battery pack. This new analyzer can measure light transmission, light scattering, or fluorescence on up to 16 different samples to follow changes in the concentrations of products.

Potential applications include field assessments of environmental pollutants such as phosphate, ammonia, sulfates, and silica; clinical monitoring of astronauts in space; and typing of blood at a patient's bedside. Of course, these applications are possible in addition to the machine's already proven capabilities to perform routine analyses of minute quantities of serum or urine in the clinical chemistry laboratory.—*CK*

Solid State Physics, November 2–3

The Solid State Division has been reorienting its studies of the structure and physical behavior of solid materials to provide basic information to the Department of Energy as an aid in the development of new energy technologies. Some of the experiments described at the November 2 and 3, 1977, information meeting have yielded results that could lead to a method for the economic production of efficient solar cells, improved experimental techniques for better understanding of catalysts, improved superconducting magnets for confining plasmas in fusion reactors, and a more precise quantification of the simulation of neutron-radiation damage by ion beams from an accelerator.

Solar cells from ion-implanted laser-annealed silicon. One way to make a solar cell is to dope the thin upper layer of a silicon wafer with boron by ion implantation— that is, by accelerating boron ions enough to force them into the crystalline solid. The problem with ion implantation is that it knocks silicon atoms out of their lattice positions, thereby degrading the crystalline structure. In the past, this problem has been partially solved by placing the doped silicon wafer in a conventional furnace for heat treatment. Called thermal annealing, this technique restores the boron-doped silicon layer to its crystalline structure and incorporates the boron atoms substitutionally into the lattice; however, substantial lattice irregularity remains. There is also another problem: the phosphorus-doped base region of the silicon wafer is adversely affected by the heat treatment. After the base region is heated, an undesirable recombination of electrons and "positive holes" in the photovoltaic device occurs, thus destroying the potential for a voltage difference necessary to produce an electric current through an external circuit.

Last summer, after exploring the Russian literature, Rosa Young came up with the idea of trying laser annealing instead of thermal annealing to fabricate solar cells. Working with Woody White, Greg Clark, Jagdish Narayan, and others, she found that pulses of coherent light from a Q-switched ruby laser (at ORNL's Fusion Energy Division) effectively annealed radiation damage and completely removed crystal imperfections in the ion-implanted region. Even better, the localized heating effect of the laser light inflicted no harm on the electron-hole recombination properties of the phosphorus-doped base region. According to the ORNL evidence, laser annealing, unlike thermal annealing, almost completely preserves the lifetime of the electrical carriers in the base region. Tests here showed that the ion-implanted, laser-annealed solar cells possess an efficiency of about 12 to 14% (output power divided by input power from the sun), and that the cells are improved in in their response to light in all wavelengths. Because ion implantation combined with laser annealing offers a potentially less expensive way to make quality solar cells, there is growing industrial interest in the ORNL process.

LEED studies of copper surfaces. X-ray diffraction studies done early in the century on such crystalline solids as copper revealed both the orderly array and lattice positions of the atoms in the bulk of the material. These early x-ray studies and neutron diffraction studies gave solid-state physicists considerable insight into the structure of matter. But only in recent years have sophisticated techniques been available to permit an understanding of how the structure of surfaces compares with the bulk of a given material. One such technique is low-energy electron diffraction (LEED), which is being successfully used at ORNL due to the Lab's experimental capability, together with the availability of theorists and large computers to perform the complicated quantum mechanical analyses required to interpret LEED data. The experimental technique involves striking a single crystalline target material like copper with a well-collimated beam of electrons from an electron gun; some of the electrons hitting the surface atoms are elastically backscattered and can be observed on a phosphorescent screen where the electrons trigger the emission of a symmetrical pattern of light when diffraction has occurred. Using other methods to measure the intensities of the reflected electron beams as a function of the energy of the incident electron beams, the experimentalists and theorists can develop computer models that build a picture of the electronic structure and geometrical arrangement of atoms in the surface layer of the material in question.

Using LEED, Harold Davis, John Noonan, and Les Jenkins have studied ultraclean surfaces of copper and have found that there is 10% less space between the surface layer and the next layer of atoms for one surface arrangement of copper, when compared with known distances between the layers of atoms in the bulk. They have also inferred, on the basis of what they call weak evidence, a contraction of some 2% between the second and third layers relative to the bulk interlayer spacing. Such experiments are expected to lay the basis for future studies of how reactive substances interact with surface atoms of catalytic materials.

Positive ion crystallography of surfaces. A newer technique for studying solid surfaces is positive ion crystallography of surfaces (PICS), which is evolving as a powerful new surface analysis tool for determining the species, quantity, geometrical arrangement, and dynamic properties of atoms on both clean and contaminated surfaces. About five research groups in the world are using the technique now, but the ORNL Ion Bombardment Group under Bill Appleton was the first to publish results utilizing PICS.

PICS is based on the observation that ions from an accelerator bombarding surfaces of crystalline solids are either backscattered by the surface atoms or can penetrate the solid by entering open regions, or channels, between the rows of atoms. (This phenomenon, known as channeling, was discovered at ORNL in the early 1960s.) The surface sensitivity of the PICS technique is a direct consequence of channeling. By measuring the yields of positive ions (e.g., helium) scattered from the surface atoms of a single crystal (e.g., gold) as a function of angle of incidence to a channeling direction, Appleton, O. E. Schow, and John Barrett have been able to make quantitative determinations of the geometrical arrangement of surface atoms. Their PICS measurements can distinguish between surface layers which are relaxed inward or outward by distances less than 1×10^{-9} cm. Furthermore, it is possible to detect relaxation of interface layers between the bulk and adsorbed contaminants; this is particularly promising for future studies in catalysis.

Appleton and his colleagues can also detect the dynamics of surface atom vibrations and determine the nature of reordered surfaces (changes in geometrical arrangements and the number of surface atoms) which can result, in the case of gold, when the surface is made perfectly clean. Appleton is optimistic that the data derived from both PICS and LEED will contribute to improved understanding of the physical mechanisms responsible for surface reordering.

Peculiar properties of a rare earth. It has been established that, when the rare earth compound samarium sulfide is under high pressure, the valence of the samarium ions appears to fluctuate between +2 and +3 within a very short time, with the best estimates ranging from 10^{-9} to 10^{-15} sec. To pin this time down better, Herb Mook performed an inelastic neutron scattering experiment on $Sm_{.75}Y_{.25}S$ and determined that the lifetime of the +2 configuration is about 4×10^{-13} sec.

To understand better the behavior of the samarium ions, Ralph Moon studied samarium sulfide under pressure in the presence of a strong magnetic field to induce a magnetic moment on the samarium ions (the reason: samarium ions have the peculiar property among rare earths of being unable to line up in a specific orientation, that is, to order magnetically). Using elastic scattering with polarized neutrons from the High Flux Isotope Reactor, Moon observed that samarium sulfide enters the mixed-valence state when the pressure exceeds 6 kilobars, and, at this point, the compound's lattice contracts, bringing the atoms in the bulk closer together. Although it was expected that one could measure a change in the distribution of the induced magnetic moment around the samarium ions corresponding to a shift in valence, Moon was surprised to find that the observed distribution was identical to that calculated for the +2 ion, and that there was no evidence of a distribution typical of a +3 ion. This presents another puzzle for the theorists, who are still grappling with the problem of explaining the peculiar magnetic properties of rare earths in mixed-valence states.

Fluxoids in superconductors. When certain metals (or metallic alloys) such as niobium are cooled to liquid-helium temperatures, they exhibit superconductivity—the property of having no resistance, so that an electric current can flow continuously through the material without loss of strength. At low current in a superconducting wire, the wire excludes the lines of force of the magnetic field—the so-called Meissner effect. Increasing the current and accompanying magnetic field beyond a certain point designated as H_{c1} (lower critical field) forces the field into the wire in the form of quantized lines of magnetic flux called fluxoids. These fluxoids are filaments of nonsuperconducting material in which the magnetic field is concentrated. In equilibrium, they are parallel straight lines arranged in a two-dimensional lattice. It is the motion of fluxoids under the force of a transport current which gives rise to resistive losses. Fluxoids can be kept from moving in superconductors (thereby eliminating losses) if there are a sufficient number of crystal defects to serve as flux-pinning sites.

Dave Christen has used small-angle neutron scattering on a defect-free single-crystal sphere of pure niobium to measure the magnetic-field level at which the interaction between fluxoids shifts from being repulsive to being attractive, thus determining H_{c1} for this element as a function of temperature and crystal orientation with respect to the applied field. He has also measured the equilibrium fluxoid-lattice symmetry and found that the fluxoids adopt an orientation-dependent configuration inside the cubic lattice of niobium.

By measuring the bulk magnetization, Rich Kerchner verified Christen's findings for the mixed state of the same sample. Kerchner has also studied the effect of neutron irradiation on niobium by irradiating niobium samples with high-energy neutrons produced by stopping deuterons in a beryllium target at the Oak Ridge Isochronous Cyclotron. Each collision between a high-energy neutron and a niobium atom produces a cascade of atoms displaced from their regular crystalline lattice sites. This kind of radiation damage is of interest because it is similar to the damage that is expected to occur in the superconducting magnet in a fusion reactor. He found that the "displacement cascades" pin fluxoids. This combination of small-angle neutron scattering and bulk magnetization measurements provides a unique method for understanding fluxoid pinning, which can lead to the development of better superconductors for a variety of applications.

Measuring radiation damage by accelerators. The neutron-induced damage that would occur in fission and fusion reactor components over their expected life spans can be simulated in a few days by bombarding reactor materials with energetic heavy ions from an accelerator. Consequently, irradiation tests can be rapidly performed to aid the development and ultimate selection of structural materials that are most resistant to radiation damage. However, the quantitative comparison of ion damage to neutron damage has rested on theoretical calculations which were largely untested by experiment.

To determine the extent to which ion-produced damage agrees with neutron-produced damage as calculated by theory, Tom Noggle has studied damage production rates of 5-MeV aluminum ions in aluminum and 17-MeV nickel ions in nickel as a function of the depth of ion penetration into the target material. The damage is measured by inserting a thin-film electrical-resistivity specimen, which serves as the damage sensor, behind thin foils of aluminum or nickel to simulate different depths in the bulk that can be penetrated by the bombarding ions from the ORNL tandem accelerator. The increase in the electrical resistivity in the damage sensor varies directly with the number of defects formed in the material as the ions displace atoms from their lattice positions. Because the irradiations and electrical resistance measurements were carried out at low temperatures (below 10 K), the displacement damage observed was frozen in to eliminate the possibility that some of it would anneal, as ordinarily happens at higher temperatures.

Comparisons of Noggle's experimental ion damage rates in aluminum and nickel with experimental fast-neutron damage rates in these metals agree within 20% of that expected from theory. In fact, these experimental results show that the theory is better than had been anticipated; they also provide a sound basis for using ion-damage experiments to simulate the damage expected from neutrons.—*CK*

Staff Quote:

"My Czech hosts were very cordial and looked after my needs to extremes. I was even able to learn one sentence in Czech: 'Strc prst skrz krk!' which means, 'Stick (your) finger down (your) throat!' And every letter is pronounced. Unfortunately, I found no occasion to use this phrase."— **Gary Howland,** *recounting his attendance at the Second Symposium on DNA, held at Liblice Castle near Prague last year.*

BOOKS

Environment and Society: An Introductory Analysis *by Brian Harvey and John D. Hallett, The MIT Press, Cambridge (1977). 150 pp. + appendices, $6.95. Reviewed by Virginia Cone.*

This analysis is a concise, thought-provoking compilation of environmental problems, both their scientific bases as well as their social, political and economic aspects. The book is intended to cover the issues of the environmental debate, particularly for nonspecialist readers. A historical framework is offered in which the effects of man's intervention in normal environmental cycles are clearly demonstrated. These cycles, involving materials and energy in the biosphere, are discussed in a chapter which summarizes fundamental principles of ecology. Natural-energy-material systems are complex and easily restored to their normal balance after disturbance, whereas systems generated by man are generally less complex and less stable. Such a generalization is important in considerations of resources, particularly their finite nature.

The impact of man on his environment is related largely to the growth of the world population. The growth, geographic distribution, and principles of population dynamics are discussed. Requirements for food will increase in the future—indeed, famine and malnutrition are seen as future realities, calling for agricultural developments and improved distribution of food supplies.

The origins and development of the environmental debate are discussed. Resolution of problems will likely involve changes in individual attitudes and behavior, a cultural revolution, control of science and technology, changes in decision-making processes, and political and economic changes.

The social framework in which the environmental problems occur is dealt with in detail. Environmental problems are discussed as being intricately related to political and economic processes. The authors present an applicable model and discuss market theory and approaches to the solution of environmental problems. These approaches include taxes, subsidies, governmental and legal roles, and technological development. The authors accept the possibility that fundamental changes in social, economic, and political systems may be required.


JIM RICHMOND

Dick Davis (left) and Jerome Dobson study the computer-generated map that assesses the water sources for the United States by county. It is one of the resources used in the National Coal Utilization Assessment (NCUA) that is being undertaken for DOE by the national laboratories. Some of the work of Davis's Regional Urban Studies Section in the Energy Division, along with a bit of its background, is recounted here.

Regional Impacts of the Energy Plan

One of the first actions taken by President Carter upon assuming office was to address himself to the nation's energy crisis by drawing up his now famous National Energy Plan. A salient feature of this plan includes conservation of natural gas and oil, with attendant concentration upon coal as an energy source. This would include not only the increased extraction and burning of coal, but gasification and liquefaction operations as well. An unknown quantity in such a change of activities was the impact they would have on several aspects of the national environment, specifically their effect on water availability, water quality, and the amount of solid waste generated thereby.

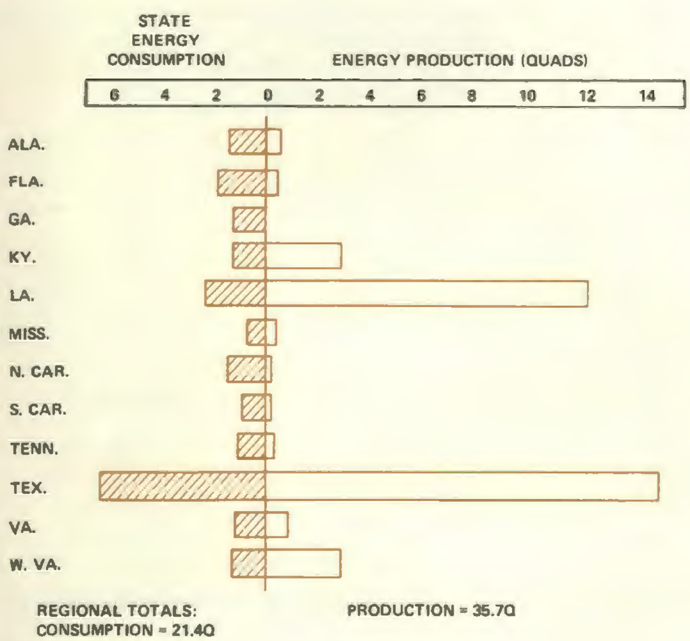
So when the President asked ERDA for a quantitative assessment of these projected impacts last year, the Assistant Administrator for Environment, former ORNL Associate Director James Liverman, turned to Argonne, Brookhaven, Los Alamos, and Oak Ridge National Laboratory with the request that they bend their joint efforts in such a determination. To ORNL went the task of siting all the facilities; in addition, we assessed the extent of water consumption under the new scenario. Argonne studied water quality, and Brookhaven the solid waste question; LASL provided assistance on water quantity assessment in the West. The deadline given for this inquiry was eight weeks.

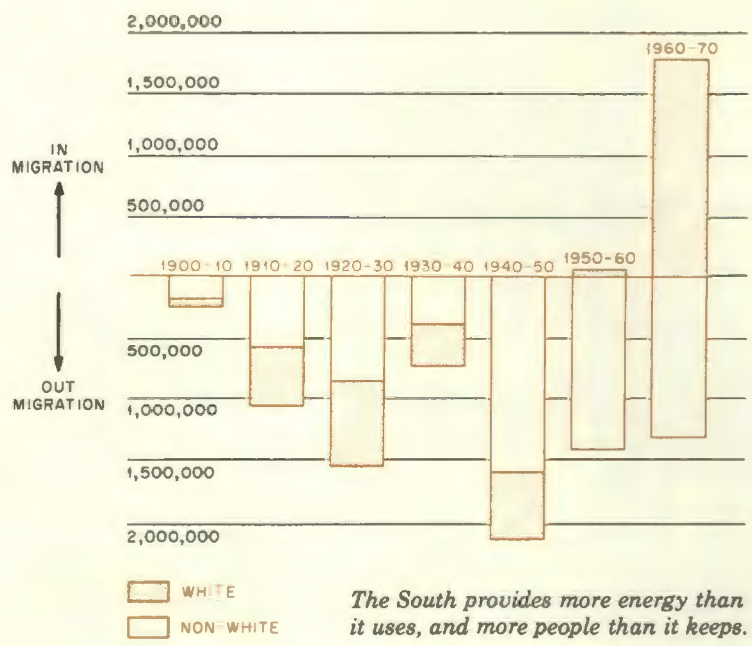
By August, ORNL TM-6098, *A Nationwide Assessment of Water Quantity Impacts of the National Energy Plan*, was in draft form. This analysis, which with the siting study was headed by Jerry Dobson, shows that the NEP differs from the "base case" for 1985 by less than 1%, with the exception of the Trinity River Basin in Texas, which is projected to differ by about 4%. Dobson's group was able to accomplish this study within the time allotted because the Regional and Urban Studies Section in the Energy Division has worked for the past several years in the perfection of just such analyses.

Program's Roots

The program has a very respectable history. Its roots go back to early 1969, when a memorandum went to Alvin Weinberg, H. G. MacPherson, Liverman, and Floyd Culler, the quartet who represented the leadership in administration of the Laboratory at the time, proposing a study of urban decentralization, to be funded by the Department of Housing and Urban Development. National concern at that time was directed toward the potential congestion of the cities by the massive migrations there from rapidly diminishing rural areas. The memorandum that reached the executive office of ORNL was signed by James C. Bresee, at the time director of ORNL's Civil Defense Project. In June of that year, an interagency agreement had been perfected, within which a task force of 15 social scientists and 9 physical scientists were put to work under HUD sponsorship to summarize the current state of knowledge regarding decentralization of population and industry, and then to initiate research into the determinants and consequences of such redistribution. This HUD program subsequently made possible rare access to details of the 1970 U.S. Census figures, an advantage available to very few such groups in the country.

The Regional Studies Program, which is now directed by Dick Davis in the Regional and Urban Studies Section of the Energy Division, has expanded and involves staff from the Environmental Sciences and Computer Sciences Divisions as well. Before the President's latest query, Liverman had already asked for an evaluation of the impact on the South of increased mining and use of





The South provides more energy than it uses, and more people than it keeps.

coal over the principal alternative energy sources. The region customarily assigned to the ORNL group is the 14-state area that extends from Texas to the Atlantic coast, and as far north as West Virginia and Virginia. However, for some analyses the program covers the entire East and sometimes even the whole United States. Thus, ORNL covers the major historic coal mining as well as oil and gas producing states. In response to this request, ORNL and the other five big national laboratories have undertaken a nationwide network of regional studies called the National Coal Utilization Assessment. Its purpose is to identify the potential major environmental, social, and economic effects of coal development and use in order to ensure that these effects are adequately considered in DOE's R&D planning. This program is developing an entire series of assessment reports, the first of which was ORNL-TM 5900, *Coal and Energy: A Southern Perspective*, and carries the names of F. D. Boercker, Davis, F. G. Goff, J. S. Olson, and D. C. Parzyck.

Energy and the South

Some interesting insights were revealed in TM-5900. For one thing, the southern region is the most complex of any of those studied: it includes those states that are among the highest in the United States in energy production—by coal (Kentucky and West Virginia) and by oil and gas (Texas and Louisiana). Approximate figures derived from state publications show that in 1974, the region produced 35.7 quads of energy from all sources, while consuming 21.4 quads. Besides the four states mentioned, which produced much more energy than they consumed, another four states produced an extremely small fraction of the energy they consumed (Georgia, Florida, North Carolina, and South Carolina). The remaining states, Alabama, Mississippi, Tennessee, and Virginia, used only slightly more energy than they produced. The report showed other characteristics in which the states within this region varied widely from one another, the kind of information that is frequently concealed in national and regional generalizations. It offers useful material for national, regional, and local energy planners.

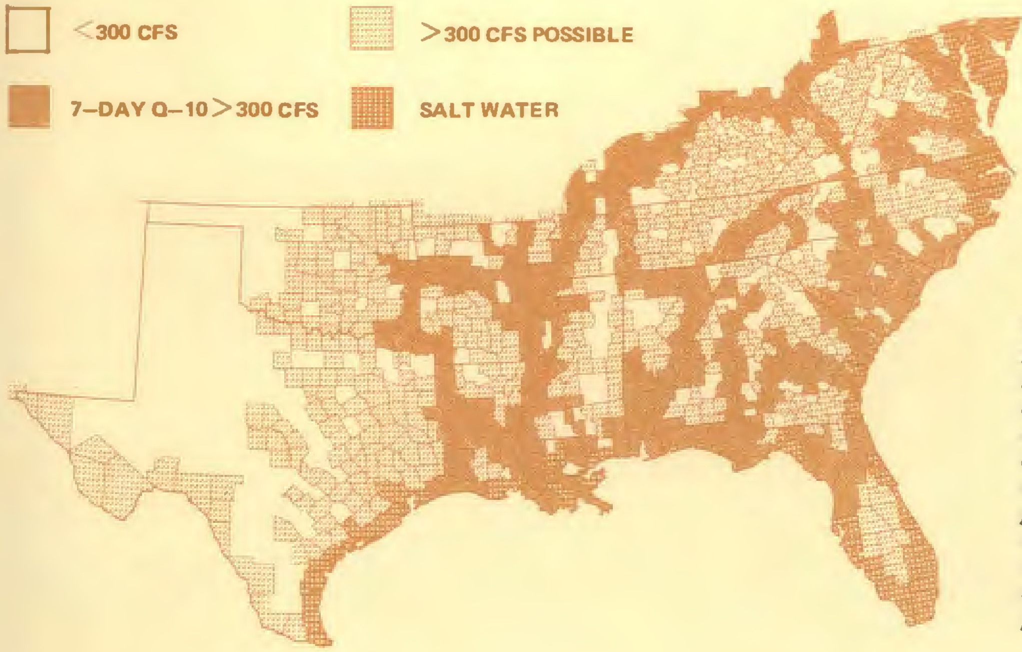
This report however, is only the precursor to the principal assessment reports, the first of which was released in draft form in January. Volume I of *Preliminary Regional Assessment of Coal Use in the South* forecasts the energy supply-demand conditions in the region over the next 45 years, assuming a moderate rate of coal use and a relatively high rate of nuclear use. Based on this energy future, the report describes the plausible location for future coal-fired power plants, synfuel plants, and coal mining activity, and the probable impact of these patterns on air quality and water availability, as well as socioeconomic impacts in the region.

Davis anticipates that this study group will be given the responsibility for performing additional energy-fuel-cycle impact assessments for the region in the future. All of these subsequent assessments, although smaller and more limited in scope, will follow the form pioneered by the coal study, which was an entirely new structure, involving an interdisciplinary team from ORNL with their counterparts at the other laboratories.

NCUA Study

Whereas the National Energy Plan postulated a reduced annual rate of growth in energy demand (2%), the NCUA base-case scenario assumed an annual growth rate of approximately 2.7% over the forecast period. This higher rate results in a net increase in energy use in the Southeast of 32% by 2020. The air-quality study has shown that most areas in the South that are up to 50 km distant from large generating facilities should be well below National Ambient Air Quality Standards for SO_2 in 1985 (80 $\mu g/m^3$ annual average concentration) although incremental insults may crowd EPA's regulation for prevention of significant deterioration as a result of the additional pollution from utilities.

In addition to sulfur, ground-level concentrations of nitrogen oxides (which form ozone in sunlight and contribute to the acid rain problem), and total suspended particulates (TSP) were predicted. Calculations for oxides of nitrogen show a common prediction of around 10 $\mu g/m^3$, although one location showed as high as 20 $\mu g/m^3$. The National Ambient Air Quality Standard for NO_2 is 100 $\mu g/m^3$. Dispersion of particulates, also, is anticipated to be well within the air quality standards of 75 $\mu g/m^3$. Even though these pollutant levels from utilities do not appear to exceed national standards, the full impact of coal use will not be known until we assess the added pollutant contribution from industrial coal use. This assessment is currently under way.



The region of interest to the ORNL National Coal Utilization Assessment study, showing the accessibility by county to cooling water. The dark areas show a dependable stream flow of over 300 ft^3/sec; light areas show an equal amount possible with storage; perforated dark areas have only salt water for cooling; and the blank areas represent counties that have insufficient water flow, that is, less than 300 ft^3/sec.

Impacts on Water

The assessed impact on water availability showed significant variations across the region. If the continued use of water-cooling technologies is assumed, significant impacts on water resource availability are predictable, according to the NCUA analysis. Four conclusions are cited in the report:

1. Water consumption problems for all competing uses already exist in certain drainage basins in Texas, Oklahoma, Arkansas, and Florida. These will be aggravated by the projected growth in energy production.

2. Potential problems exist in West Virginia and Pennsylvania along tributaries to the upper Ohio River Basin.

3. Several states, notably Florida, Delaware, and Maryland, will have to use brackish water for cooling if they want to avoid major efforts toward water conservation or toward limiting energy growth.

4. Heavy conservation measures in electricity use, or shifts to dry-cooling technology will be necessary if the most significant water consumption impacts predicted by the assessment are to be avoided.

With these findings in mind, then, the authors of the report assess the possible power-production sites in each of the 12 states in the ORNL region. In seeking plausible hypothetical energy-facility sites, they emphasize that the patterns that emerge should not be considered final, but rather that these are a basis for further analysis. Because of the constraints assumed, it is unlikely that the patterns would vary significantly for different levels of total energy demand, except in terms of the size of facilities placed in specific counties. The report does not identify specific siting locations, only totals by county.

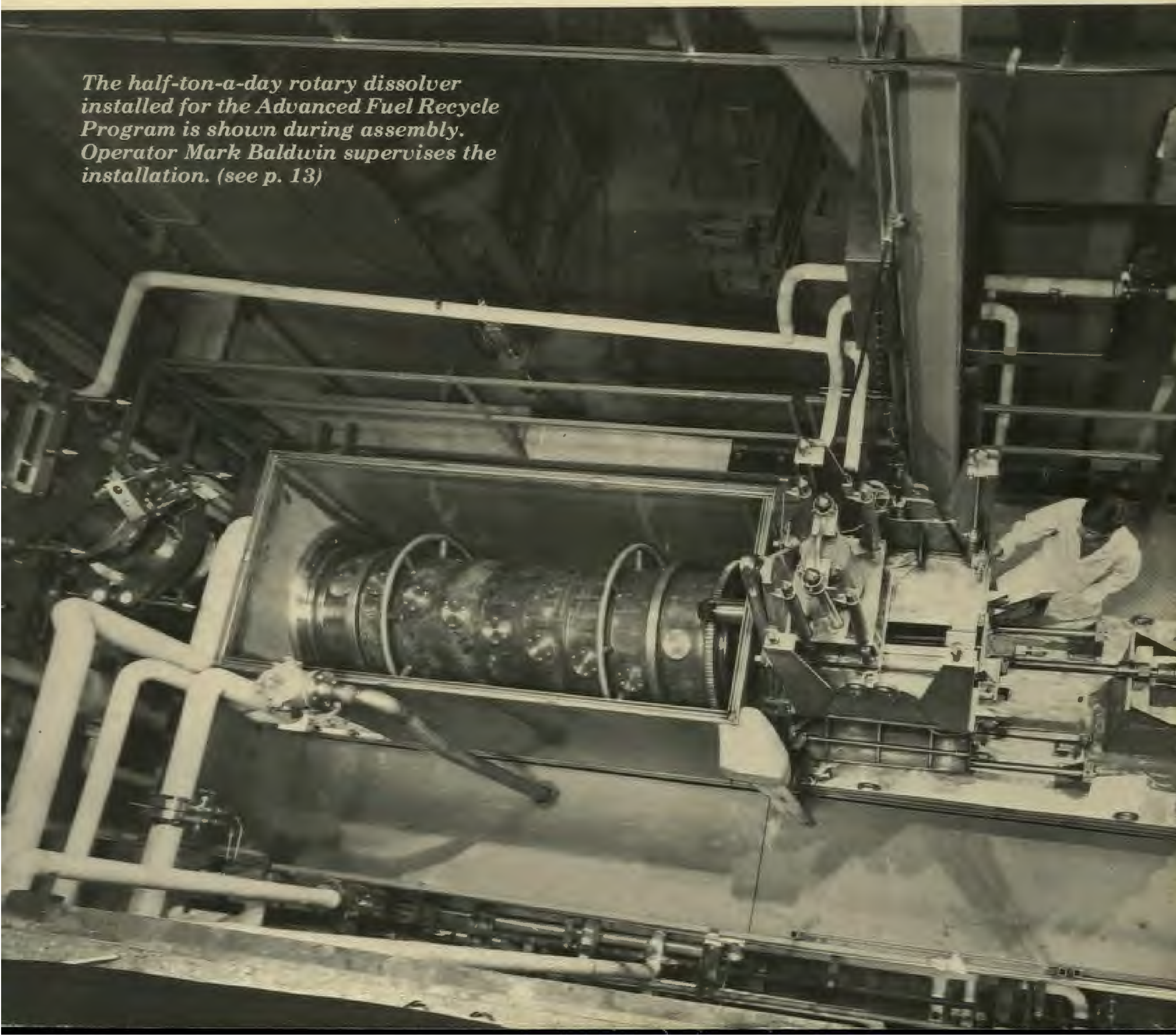
Outreach

The techniques used in performing assessment studies, as well as the information developed in these programs, is now being made available by the Laboratory throughout the southern region in a program called Regional Outreach, under the direction of Fred Boercker's group. Boercker makes a point of keeping in close communication with many of the state and local agency representatives in the region by means of newsletters, forums, seminars, and direct contact. The Regional Outreach Program is designed to facilitate future planning efforts between the federal and local governments.

"Our explorations into regional energy analysis have allowed us to develop an important capability for extending our work to include the investigation of a wide range of alternative energy futures for the nation," says Davis. "More importantly, we have demonstrated that ORNL can analyze the potential regional effects of national energy policy."

OAK RIDGE NATIONAL LABORATORY REVIEW

P. O. BOX X: OAK RIDGE, TENNESSEE 37830



The half-ton-a-day rotary dissolver installed for the Advanced Fuel Recycle Program is shown during assembly. Operator Mark Baldwin supervises the installation. *(see p. 13)*