Spring 1982

Oak Ridge National Laboratory review

State of the Laboratory—1981

"User Facilities"

ORAU photograph by John Richards.

COVER: A technician makes an adjustment at the laser optical-spectroscopy system of the University Isotope Separator (UNISOR), an ORNL user facility. User facilities are the theme of Laboratory Director Herman Postma's State of the Laboratory address, page 1.

Oak Ridge National Laboratory

review

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Editor
BARBARA LYON

Staff Writer
CAROLYN KRAUSE

Consulting Editor
ALEX ZUCKER

Design
BILL CLARK

Publication Staff: Technical Editing/Lydia Corrill, Deborah Barnes; Typography/Betty Littleton, Linda Jeffers; Makeup/Betty Jo Williams; ORNL Photography and Reproduction Departments.

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Relaxing in the lobby of the Joint Institute for Heavy Ion Research are, from left, visiting scientists Karl-Omtjes Groeneveld of the University of Frankfurt's Nuclear Institute, R. Soundranayaham of Ceylon, Dieter Hofmann, also of Frankfurt, and Rodney Piercey of Vanderbilt University.

State of the Laboratory-1981

ORNL's User Facilities

By HERMAN POSTMA

The purpose of this address has always been to highlight the Laboratory's outstanding research accomplishments of the previous year. The space available permits me to discuss only a modest fraction, at best, of the year's outstanding work. I trust, therefore, that you will view these selected examples as representative of a much larger body of high-quality research and development performed at ORNL.

My theme gives me the opportunity not only to highlight significant R&D projects but also to comment more generally on our institutional health and direction at the end of one year and the beginning of another. Discussions of new missions, new programs, new facilities, and, increasingly in recent years, new institutional roles and types of interactions have provided the themes for past addresses—and will again tonight. I will also comment more specifically on the outlook for the next year and the effects of actions in Washington on our programs.

Because the purposes and roles of national laboratories in general, and of ORNL specifically, have again this year been the subject of considerable scrutiny—by Congress, the Administration, and within DOE itself—it may be well first to review those multiple and varied roles that are characteristic of ORNL and the other multiprogram laboratories as they have evolved under DOE.

Then I want to discuss in greater detail the particular role I have selected as the theme for this talk—ORNL's increasingly important part in the development and operation of what we have come to describe as user-oriented facilities. These are the national centers or capabilities that exist here not only to support our own programs but also as a resource for use by the outside technical community, represented by universities, industry, and other laboratories and research centers.

Recently, for a study being conducted by DOE's Energy Research Advisory Board, I had the opportunity to identify what turned out to be 13 distinct roles that we and the other laboratories play. Better understanding of the nature and diversity of these roles and their relevance to current needs and circumstances is absolutely essential, I believe, to any consideration of what may be appropriate for the future. Let me highlight each of them briefly before returning to one as tonight's theme:

1. Performers of R&D. This is a primary role of the Laboratory, to be sure, but one that is by no means exclusive to ORNL.
2. System Engineers/Technical Consultants. This role has been of particular importance to DOE and other sponsors in fields where industry has an economic or proprietary interest and might be perceived as being biased, such as in coal conversion processes requiring government funding or in nuclear safety questions.
3. Public Health and Safety/Environmental Impacts Experts. Here again, objectivity, a detailed technical knowledge of complex systems, and an analytical capability are key factors.
4. Management of Brushfires. ORNL has been called upon as a source of expertise in emergencies, such as the Three Mile Island incident or the Strategic Petroleum Reserve fire in Louisiana.
5. Stewardship. We hold the responsibility for the maintenance and safeguarding of special facilities that are considered nationally or internationally unique or at least very rare. These include our accelerators, reactors, scattering facilities, and large animal populations, among others. Our stewardship in this regard is the theme to which I will return.
6. Service. ORNL has performed non-R&D functions important to DOE in areas where knowledgeable personnel were required for a mandated rapid action (e.g., implementing the Residential Conservation Service program nationally through the states and utilities).
7. Agents. As DOE has decentralized, laboratories have been assigned broad technical management responsibilities, or "lead" roles. Subcontracting to universities and industry is one result. In FY 1981, 25% of the ORNL budget went for R&D projects outside the Laboratory ($20 million to universities and $60 million to industry).

Ron Mlekodaj (front) of Oak Ridge Associated Universities, Jerry Cole of Louisiana State University, and Ken Carter of ORAU work at the beam line of UNISOR (University Isotope Separator), the user facility that operates online with the Oak Ridge Isochronous Cyclotron for studies of rare, extremely short-lived heavy nuclei.

Ken Carter of ORAU tests UNISOR's laser optical-spectroscopy system.

8. Production. Where the capabilities exist, the Laboratory stands ready to produce items of commercial value for which no private industrial source exists, for instance, radioactive and stable isotopes, having an annual sales of $15 million.
9. Regional Consultants. ORNL consults with state and local governments on unique energy-related problems or engages in cooperative programs with neighboring universities.
10. Training and Education. The Laboratory continues its long tradition of providing doctoral research, postdoctoral training, and undergraduate summer assignments and science semesters. It houses the degree-granting educational branch of the University of Tennessee-Oak Ridge Graduate School of Biomedical Sciences in the Biology Division.
11. Local Support. ORNL has provided technical support to Nuclear Division production areas, to the CRBR Project Office, and to DOE's Oak Ridge Operations in large project-management responsibilities like its synfuels demonstrations.
12. Work for Other Federal Agencies. The Laboratory has cooperated with NRC, EPA, NSF, NIH, in cases where sharing of resources minimizes expensive duplication of capabilities.
13. Technology Transfer. For a mission-oriented laboratory, the ultimate measure of our R&D performance is often the practical extension of these results through, for example, the Technology Push/Market Pull types of interaction discussed last year.

I will turn now to a more detailed discussion of our role as steward and the theme of "User Facilities at ORNL," first giving some background and then some examples.

User Facilities at ORNL

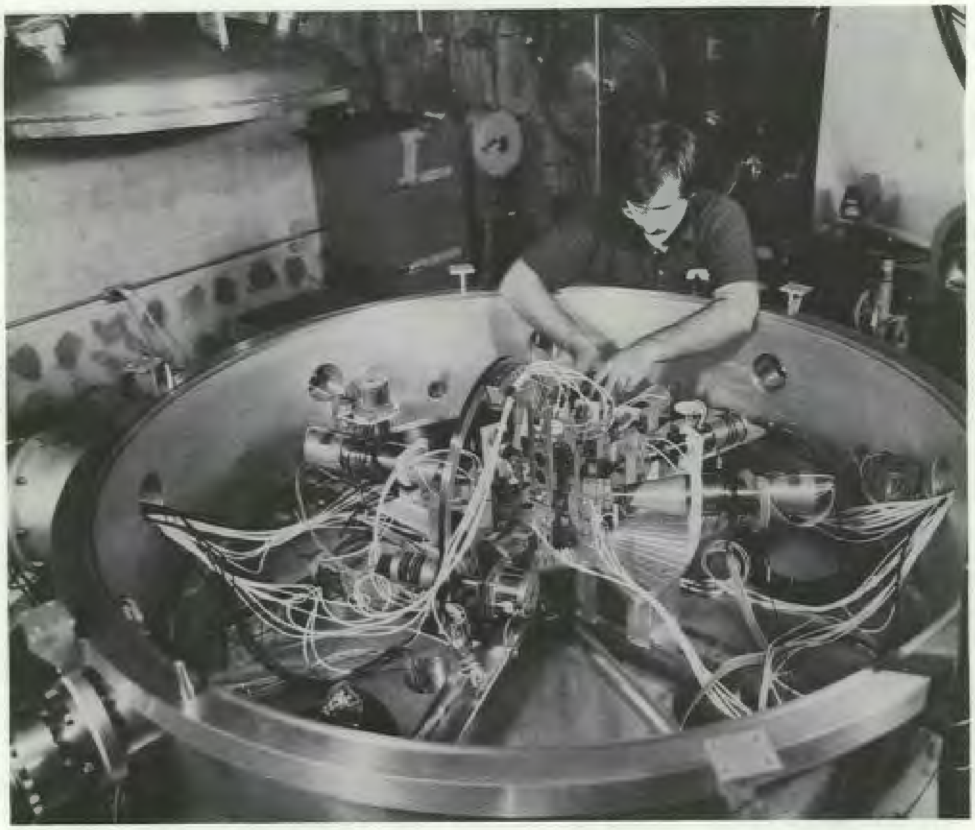
Historically, the national laboratories have been stewards of what is a national trust—facilities built with public funds to carry out advanced scientific and technological research and development deemed to be in the public interest.

Minimizing duplication, promoting beneficial interactions, and making the most efficient use of large, costly, often one-of-a-kind or state-of-the-art facilities are among the goals we have as a national laboratory in making these facilities more widely available to qualified users.

It is important at the outset of this discussion that we make clear that the existence of user facilities at ORNL is not an altogether new, unusual, or unprecedented direction. Since our early years, reactors, accelerators, and other specialized equipment have been open to use by research participants and guests under a variety of cooperative arrangements. To a large degree, the nuclear industry grew up out of the use of ORNL facilities and training (ORSORT) in the 1950s.

What is quite new and noteworthy at ORNL in recent years is, first, the existence of large, structured user groups, such as those

Glenn Young of the Physics Division makes adjustments in the scattering chamber at the Holifield Heavy Ion Research Facility.



associated with the Holifield Heavy Ion Research Facility or the National Center for Small-Angle Scattering Research, which are truly national or international in scope; second, the commitment of a significant fraction of operating time or the establishment of user-dedicated facilities to serve the needs of identified users; and third, the increasing variety of ways in which we facilitate large- and small-scale user arrangements and interactions—and the range of disciplines and activities involved.

Here, our history is somewhat different from the major high-energy physics laboratories, where a user mode of operation is the predominant activity and the principal justification for the facility's existence, as with the Fermi National Accelerator Laboratory or the Stanford Linear Accelerator Center.

Since the early postwar period, when Oak Ridge Associated Universities (then the Oak Ridge Institute of Nuclear Studies) came into being, the contribution that outstanding Oak Ridge (and particularly ORNL) facilities could make toward strengthening nuclear-related science and technology on a regional and national basis was clearly recognized. In fact, ORAU's founding purpose was to administer programs that would make the specialized facilities and research-participation opportunities here available to college and university faculty and students throughout the region. Looking back, one certainly can see that the increasing stature of graduate education and research in neighboring institutions in the Southeast today is in no small part a result of this initiative and its effects over a 35-year period.

A decade ago, in its 25th year, ORAU helped provide another important impetus toward fuller realization of the potential for user-oriented facilities here. This was the establishment, cooperatively with ORNL, of the University Isotope Separator—Oak Ridge (or UNISOR) organization to build a facility operating on-line with the Oak Ridge Isochronous Cyclotron for studies of rare, extremely short-lived heavy nuclei. At the time, this may have appeared to be "the impossible dream," not so much technically as organizationally. The facility was acquired and installed by the UNISOR members—12 state and private universities and ORAU, with a major boost from the State of Tennessee; housed in an annex to the cyclotron building that was financed by Federal funds through an ORNL General Plant Project; and operated jointly with state and private funds from UNISOR member institutions and our own programmatic monies. That an arrangement having this financial complexity and so many bureaucratic pitfalls was even discussed, much less completed, is a singular achievement.

Perhaps most important of all, this project demonstrated the community of interest in heavy-ion physics and chemistry among the UNISOR group which, ultimately, gave the necessary strength to the successful proposal to build the Holifield Facility's 25-million-volt tandem machine as a national user center.

Thus, UNISOR quite properly can be credited as the "granddaddy" to the present generation of user-oriented facilities at ORNL—some 16 at last count, with more in the offing. It also presents an outstanding example of continuing cooperation among institutions having related interests, as evidenced a year or two ago by the development

The Joint Institute for Heavy Ion Research.

of a laser optical-spectroscopy system at UNISOR to which more than half of the consortium members contributed technical expertise. (A welcome footnote is that this system, which was severely damaged by last October's flooding of Building 6000 as a result of a waterline break, is once again fully operational.)

User-Facility Criteria

This year, recognizing the important mutual benefits to us and the users of this type of activity, criteria were established for formally designating user facilities at ORNL, some of which are obvious from the preceding discussion. The criteria are:

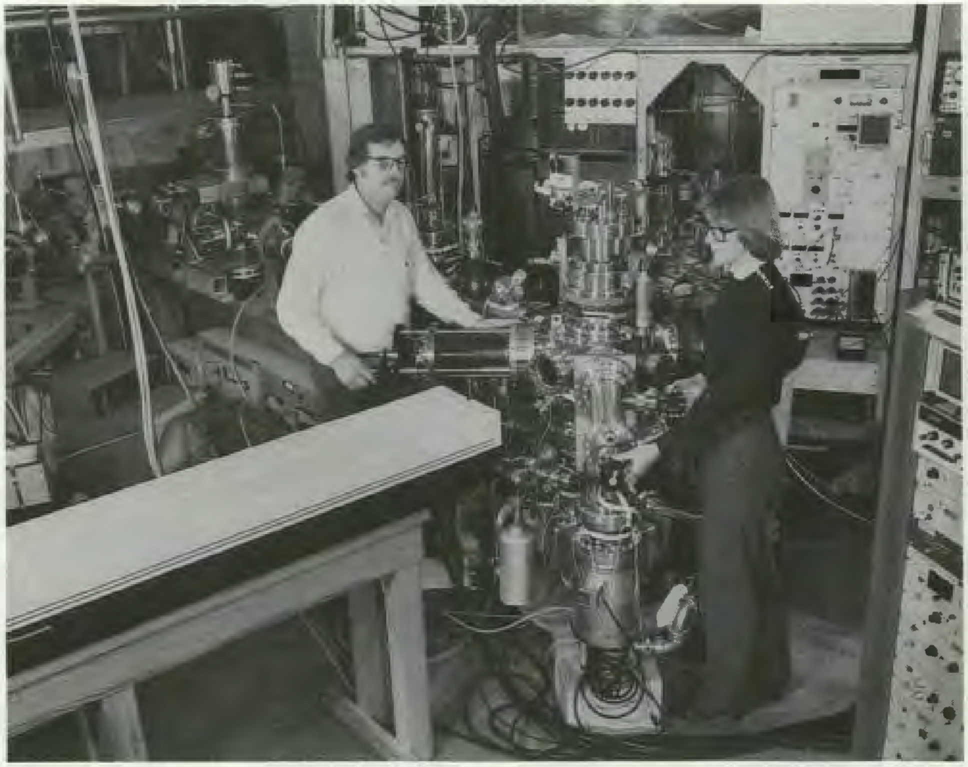
1. It is a facility or collection of related facilities which can be used for conducting scientific or technical research.
2. The research capabilities of the facility are unique or relatively rare in the United States.
3. Outside groups (e.g., universities, industry, or other national laboratories) have evidenced their desire to use the facility.
4. The facility is of sufficient monetary value or sophistication that wide-scale duplication is unlikely.
5. At the site of the facility, adequate supporting services exist to allow an outside experimenter to complete all essential elements of an experiment.
6. A source of funding, independent of the user, is available to provide for routine maintenance and repair.
7. The facility is unclassified and located in an unclassified area.
8. The sponsoring agency ensures that sufficient time, space, and other resources are made available to users without compromising the objectives of either the Laboratory's or the sponsoring agency's own research programs.
9. The facility is of such design that users can conduct experiments without health and safety risks and without risk of damage to the facility.

Once these criteria are met, a formal request for approval is made to DOE. What has emerged is designation of seven existing user facilities at ORNL, nine others that meet the criteria and await only formal designation, and suggestions for others to be considered in the future.

Existing user facilities are:

- Holifield Heavy Ion Research Facility
- EN-Tandem Van de Graaff Accelerator

Bill Appleton, left, tells Susan Thomas about his project on the ion implantation accelerator and laser in the Ion-Solid Interactions Laboratory in the Solid State Division. The facility is used for laser annealing and modifying surfaces to tailor materials to specific needs.



- Oak Ridge Electron Linear Accelerator
- Neutron Scattering Facility
- National Center for Small-Angle Scattering Research
- Ion-Solid Interactions Laboratory
- Shared Equipment Research Program—Oak Ridge
- University Isotope Separator

Facilities awaiting formal designation are:

- Atomic Physics Laboratory
- High-Temperature Materials Laboratory
- High-Pressure Geochemistry Facility
- University Isotope Separator—Oak Ridge
- National Synchrotron Light Source X-Ray Research Group
- National Environmental Research Park
- Magnetic Separation Laboratory
- Tower Shielding Facility
- Heating, Ventilation, and Air-Conditioning Testing Facility

The examples that follow illustrate the functions and the contributions of some of the user facilities at ORNL.

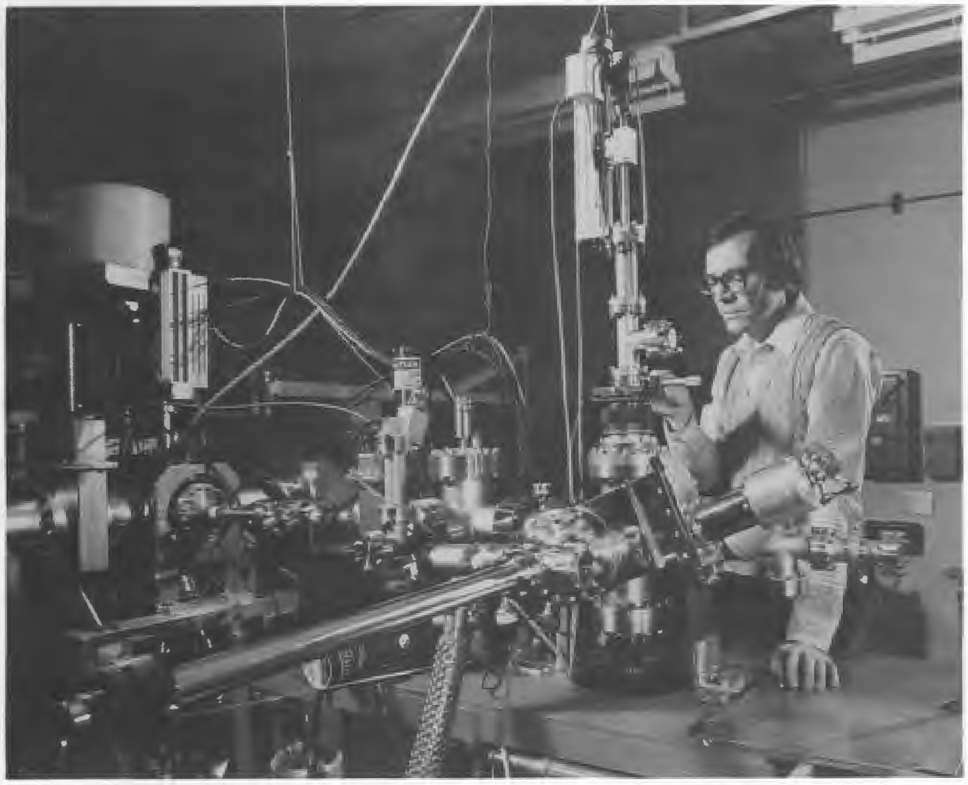
Holifield Heavy Ion Research Facility

Beginning with the largest of our user facilities, at least in number of users, the Holifield Heavy Ion Research Facility incorporates two accelerators: the new 25-million-volt tandem electrostatic accelerator, whose tower is now an ORNL landmark, and the Oak Ridge Isochronous Cyclotron. The two accelerators operate either independently or in a combined mode in which the cyclotron serves as an energy booster for particle beams from the tandem. A number of unique state-of-the-art experimental devices, such as the spin spectrometer for gamma-ray detection, provide additional services, as does a powerful data-acquisition computer system.

Use of the facility is open to all scientists associated with an approved research program, and approval is obtained through formal submission of proposals to a Program Advisory Committee comprising knowledgeable scientists representing the user community. In the initial rounds, this committee has reviewed 88 proposals requesting 10,000 hours of accelerator time; 41, for a total of 3400 hours, have been approved.

A formal users organization was chartered in 1975 when the project began, and its members have participated in planning the experimental program and development of specialized instrumentation and data-handling equipment. The group elects an executive committee and chairman with which it interacts with HHIRF facility management through a staff liaison scientist. Of the more than 400 members, 215 are from universities, 130 from government labs (including 60 from ORNL), 11 from industry, and 60 from foreign institutions and research centers. Geographically, ORNL and the Southeast account for about 40% of the membership, and the balance is divided evenly among users in the Northeast, the Central United States, the West, and abroad.

A necessary component of HHIRF, besides the accelerators, is a home away from home for the users. The Joint Institute for Heavy Ion Research, a 380-m^2 structure, provides offices, sleeping rooms, kitchen, and commons area for use



Monty Lewis of the Metals and Ceramics Division prepares to operate the Van de Graaff nuclear back-scattering equipment used by ORNL researchers and outside collaborators as part of Project SHaRE (Shared Research Equipment Program).

by nonresident researchers. Since May, when it opened, some 70 visitors have been accommodated. About half of the capital cost of this innovative, earth-protected structure was generously contributed by The University of Tennessee and Vanderbilt University. The State of Tennessee has since authorized $350,000 for a second building of comparable size to provide offices and laboratories for personnel of Tennessee institutions and visitors assigned to the Joint Institute.

The Joint Institute building is an experiment in energy-conserving architectural principles and passive-solar design, conceived by architect Hanna Shapira of the Energy Division. It features earth cover for the roof and an earth berm for added insulation on three sides, indirect space heating via an unvented mass-storage (Trombe) wall behind glass, direct-gain space heating via large south-facing windows with reflective insulating blinds, and an economizer-cycle heat pump to use ambient air for cooling when temperature and humidity are suitable.

While the use of HHIRF is still too new to report major results, two experiments during the initial cycle are instructive concerning the user mode of operation. One was an in-beam gamma spectroscopy experiment in which 13 participants, half from Vanderbilt and ORNL and the balance from universities in West Germany, Portugal, India, Sri Lanka, and the People's Republic of China, took part. The other, a survey of entry states and gamma decay, involved participants from ORNL, Washington University, and institutions in Denmark, Sweden, and the United Kingdom.

Scattering Research Facilities

Scattering research has been another pioneering area for user-oriented activities. For many years ORNL has had informal programs in both the Solid State and Chemistry Divisions for outside use of the neutron scattering equipment at HFIR. These programs now have been formalized and publicized. More than 200 scientists in the solid state and crystallographic communities have indicated a desire to become regular users. Over the past 18 months, these facilities—including three triple-axis spectrometers and one polarized-beam spectrometer—were used by 44 outside scientists: 24 from universities, 11 from other labs, and 9 from abroad. Heavier future use is anticipated.

A totally user-dedicated scattering facility also now exists at ORNL. Last January, we dedicated a new 30-m small-angle neutron scattering instrument at HFIR as a key facility of the NSF-supported National Center for Small-Angle Scattering Research, established in 1978, under the directorship of Wally Koehler. This instrument, with a sophisticated data acquisition and processing system and two-dimensional position-sensitive detector, meets a long-felt need for such a state-of-the-art facility in the United States. Routine user-mode operation began in August 1980, and since then more than 80 proposals have been submitted for research in the areas of biology, chemistry, materials science, and polymer science. The proposals come primarily from university scientists but also from industrial, DOE, and other government laboratories. It is noteworthy that we have been able to instigate special procedures for proprietary research, and such contracts are in place with the DuPont Company and with Firestone Tire and Rubber Corporation. Our 10-m small-angle x-ray scattering instrument, unique in the world, also has been made available to the user community through this national center, and more than 70 users have performed experiments on it.

So far, the majority of problems examined with the neutron scattering instrument fall into the polymer-science area, where the powerful technique of isotopic (hydrogen-deuterium) substitution can be used to make individual molecules "visible" in the solid. In the near future, biologists are expected to make use of the technique of contrast variation to study the structure of biological systems on a scale of 1 to 100 nm. Users of the x-ray machine are primarily metallurgists and chemists, but with the addition of a computer-controlled dynamic deformation device, which makes this instrument even more powerful, a growing number of polymer scientists are applying for beam time.

Ion-Solid Interactions Laboratory

Still another user pattern, also in the Solid State Division, is represented by collaborative research with other national laboratories, universities, and industry in the Ion-Solid Interactions Laboratory. The facility includes a 2.5-million-volt positive-ion Van de Graaff accelerator used for ion-beam analysis; a high-current, multi-ion 200-kilovolt accelerator for ion implantation doping; several pulsed and continuous-wave lasers for laser annealing; and a variety of ultrahigh vacuum surface analysis chambers for in situ materials modification and analysis experiments.

In addition to being ideal fundamental research tools, these processing techniques lead increasingly to a wide range of practical applications. For example, controlled near-surface modifications have been used to fabricate semiconductor devices, enhance the friction wear and lubrication characteristics of surfaces, reduce corrosion, identify catalysis mechanisms, fabricate high transition-temperature superconductors, and alter the mechanical properties of ceramics. Among the industrial collaborators in this work have been Exxon, Motorola, Westinghouse, Bell Labs, Union Carbide, Mobile Tyco, Texas Instruments, and IBM. An equal number of university and U.S. and foreign laboratory groups could be cited. The kind and quality of interactions here suggest that a fully user-dedicated ion beam and laser facility not only would be used by outside groups but also would lead to even more rapid and direct transfer of commercially important technologies. To meet this demand, we are building a second beam line in the recently expanded Solid State accelerator facility.

Shared Equipment Research Program

The focus of project SHaRE (Shared Research Equipment Program) is also in the materials-science area. Specifically, it is the user component of the advanced microanalytical techniques and capabilities centered in the Metals and Ceramics Division. SHaRE draws on state-of-the-art capabilities in transmission electron microscopy, surface analysis, and nuclear microanalysis, including analytical electron microscopes, the high-voltage electron microscope facility, the Auger electron spectrometry/surface microanalytical apparatus, the Van de Graaff nuclear back-scattering equipment, and computer facilities. The research is collaborative, with one ORNL staff member and one senior researcher from the outside institution having joint responsibility for each project and publication of the results. One outstanding example of the power of the collaborative approach has been work on a problem in structural ceramics with Rockwell International. It involved the elevated-temperature properties of silicon-nitride-based ceramics, which are seriously degraded by the presence of noncrystalline phases at the grain boundaries. Our analytical electron microscopy was employed to characterize the phases in several ceramics in terms of microstructure, crystallography, and composition. The electron energy-loss spectroscopy capability developed here also played a critical role in this project, allowing light element quantitative analysis at the 10^{-18} level. Besides Rockwell, several other industrial laboratories and more than a dozen universities in this country and Canada are currently participating in SHaRE projects, which are administered through ORAU.

High-Temperature Materials Laboratory

One of our highest priority user facilities in the materials sciences remains the proposed High-Temperature Materials Laboratory, discussed last year in the State of the Laboratory Address. Although deferred in the current budget, it represents another area in which user interest by the industrial as well as academic research community has been strongly indicated. HTML will be the site for collaborative research to help solve materials-related problems associated with both nuclear and nonnuclear energy generation and conversion technologies. About $3 million of the $17-million cost for this line-item project will be for specialized equipment needed for high-temperature materials synthesis, preparation, and characterization.

X-Ray Facility at National Synchrotron Light Source

Finally, from the materials area, an ORNL user facility with a

Jim Wilson works at the portable viscometer, which measures the physical properties of the black gummy product of a vacuum distillation column in one of DOE's coal conversion pilot plants. The unique capability of the device is that it measures the viscosity of residues containing a high loading of solids. It can be transported for use at pilot plants.

twist—it is located at another laboratory! This is the X-Ray Research Group facility to be managed by the Metals and Ceramics Division at Brookhaven National Laboratory's new National Synchrotron Light Source, scheduled to come on-line in July. In this instance, in fact, we are both tenant and host, because a minimum of 25% of the time at the ORNL station is to be made available to other users. Synchrotron radiation, because it can be precisely tuned to specific electron energy levels, is providing a powerful tool to gain detailed knowledge of the spatial arrangement and electronic structure of atoms in solids. Because these parameters determine the basic chemical and physical behavior of materials, these experiments constitute an important step toward being able to calculate materials properties entirely from first principles. X rays from synchrotron radiation are being used to see biological material at great magnification, even in the presence of water; to study the atomic structure of catalytic surfaces while the catalyst is in action; to observe the transient behavior of crystal growth or plastic deformation at millisecond intervals; and to determine atomic arrangements and bonding distances from less than a monolayer of material. ORNL's installation is on schedule, and set up will begin in March or April to be ready for initial use when the source begins 72-hour-a-week operation in July.

Magnetic Separation Laboratory

The Magnetic Separation Laboratory in the Engineering Technology Division is dedicated to research and industrial applications of the magnetic separation of particulate materials having very weak magnetic susceptibilities. Last year I discussed the application of the newly developed open-gradient technique to magnetic beneficiation of coal. However, as noted, because of the unique capability to separate materials having negative susceptibility, the potential applications of this method also extend to ores, minerals, and industrial materials and wastes which have both positive and negative components. The intent of this facility is to make our laboratory equipment and analytical and design capabilities available to industry for the assay of the magnetic separability of ores, minerals, and industrial process materials; to develop pilot-scale processes; and to design open-gradient magnetic separators for industrial use. So far, separations of oil shales, natural graphite, phosphate tailings, and industrial process materials have been performed. Customers and commercial contacts have included TVA, U.S. Steel, and FMC (coal); Breckinridge Minerals and Exxon (oil shales); Y-12 Plant Development Division (lithium hydride); and Phillips Petroleum and Lukens Steel (industrial process materials).

Coal Liquids Flow System

The Coal Liquids Flow System in the Chemical Technology Division has attracted the interest of industrial organizations developing and designing direct coal-liquefaction processes. It is capable of measuring the physical properties of the process streams—liquids and slurries—under operating conditions. Such measurements are essential for reliable design and operation of synfuels plants because coal-derived fluids behave differently (i.e., are not predictable from experience with more common petroleum-derived liquids). Our facilities currently are capable of measuring viscosity and density of slurries and liquids from the near ambient conditions at the front end of the plant through the most severe operations at temperatures to 733 K (860°F) and pressures to 21 MPa (3000 psi). Capabilities are being extended to measure the extremely viscous residues of vacuum distillation, which have a very high loading of solids; the thermal conductivity of process streams; and heat capacity and enthalpy. Development of all four major direct coal-liquefaction processes—SRC I and II, H-Coal, and Exxon Donor Solvent—has benefited from the ORNL capability.

Synfuels Research Materials Facility

The Synfuels Research Materials Facility in the Analytical Chemistry Division is a user resource of experimental materials rather than experiments themselves. Samples of products and wastes from coal- and shale-conversion plants have been collected here along with related products for comparison from petroleum processing and coal combustion. Samples, many in barrel quantities, are stored at 4°C and protected from light. Approximately 100 investigators from national laboratories, energy technology centers, universities, and industry make use of this joint DOE/EPA facility. ORNL has used the samples to identify biologically active constituents and to develop and compare chemical and biological analysis methods. The National Bureau of Standards has generated certified reference materials. These common samples greatly facilitate intercomparisons in synfuels life-sciences research.

Oak Ridge National Environmental Research Park

The Oak Ridge National Environmental Research Park, established in 1980, consists of about one-third, or 5500 ha, of the protected land area on the Oak Ridge Reservation available as a user resource. Two early examples illustrate its research potential. The U.S. Army Corps of Engineers' Waterways Experiment Station has tested the validity of habitat models which describe requirements of different species for food, water, or space. These habitat models, constructed for the field sparrow, pine warbler, eastern meadowlark, hairy woodpecker, indigo bunting, and gray squirrel, are an important baseline for the Corps' impact assessments on major construction projects. Collaborative work with the National Oceanic and Atmospheric Administration's Atmospheric Turbulence and Diffusion Laboratory in Oak Ridge has focused on atmospheric deposition and ecological effects at Walker Branch Watershed and elsewhere in the NERP. The aim is to monitor changing atmospheric conditions and their effect on plant and animal biota.

Nuclear Medicine Cooperation Programs

Users need not always come to us. My final example is the cooperative programs in nuclear medicine with clinics, medical schools, industrial laboratories, and universities. ORNL-developed radiopharmaceuticals are supplied to these institutions for further, extensive preclinical testing and clinical evaluation. The programs effectively bridge the gap between the conception and development of new agents at ORNL and centers having the expertise for their further evaluation. Cooperative arrangements have been an important aspect of the radioisotope research programs for more than 30 years. More recently, these programs have been formalized and expanded to encompass development of new agents for applications in crucial areas of cardiology, cerebral physiology, and oncology. The current subjects include tellurium-labeled fatty acids for evaluation of damage to heart muscle (myocardium), in conjunction with the Massachusetts General Hospital, and diagnosis and evaluation of congenital heart diseases in children using the short-lived iridium-191*m* isotope for detection of abnormal blood flow between the heart chambers, in cooperation with the Children's Hospital in Boston.

Summary

The capabilities I have described are evidence of the trend, not only toward more and larger user-oriented centers at ORNL, but also of the increasing contribution these activities are making, both technically and organizationally. They demonstrate the opportunity and potential for even greater future utilization of one of the most important and distinctive assets of a national laboratory—specialized facilities which are, indeed, a national trust.

The user orientation of many of our programs is quite obviously a two-way street from which both users and we as hosts benefit substantially and which has an overriding benefit to the nation in making more efficient and productive use of always limited resources for scientific and

High on a tower in the Walker Branch Watershed in ORNL's National Environmental Research Park, Steve Lindberg calibrates an air sampler used to collect acidic particles in the atmosphere. The two Petri dishes extending laterally are dry deposition samplers that catch the kind of particles that settle on the forest canopy. This work is being done for the Electric Power Research Institute as well as DOE.

technological research. The user benefits from the opportunity to work at the frontier of his field with state-of-the-art equipment that would be difficult or impossible to duplicate. We as hosts gain the new insights and perspectives that come from working-level interactions with a broader segment of the technical community. Our sponsors benefit from the fuller utilization of the research capabilities in which they have invested and from the assurance that national laboratories have the skills required to build, operate, and manage such facilities in the national interest.

Finally, there is the less tangible but no less important benefit in the improved integration of the overall scientific and technological enterprise in this country. This is a by-product of the creation of centers where the best talents in the academic, industrial, and governmental research communities can meet and work cooperatively to discover, innovate, and solve problems in areas so vital to the nation.

TECHNICAL HIGHLIGHTS

Science and technology at the Laboratory range from the fundamental to the applied. The first highlight is from the applied field.

Krypton-85 and Tritium Light Development

The Operations Division, through its isotopes program, has developed isotopic light sources for use at military airfields as taxiway and runway distance markers. Useful applications of by-product radionuclides are an important part of this program, and now Neil Case offers the use of ^{85}Kr and ^{3}H for reliable low-level lighting. These sources require no external power supply, have half-lives of over ten years, and are reliable under extreme environmental conditions. Light is produced when beta particles from the isotopic sources are absorbed in a phosphor. To obtain a high-beta flux, fission product krypton (which contains about 5% ^{85}Kr) is enriched by thermal diffusion to approximately 40%. The enriched product is then sealed into a quartz tube containing the phosphor. As large supplies of this isotope become available from fuel reprocessing, such taxiway markers could significantly reduce power demand for airport lighting. Tritium-powered lights are being developed as distance markers for military and possibly civilian airfields. Although their intensity is less than the light from ^{85}Kr, good nighttime visibility has been demonstrated for one-meter-high numerals that can be installed quickly, aren't affected by power failures, and are maintenance free.

Initial Results with the Spin Spectrometer

The Spin Spectrometer is sometimes called the "crystal ball" of the Holifield Heavy Ion Research Facility because its fascinating geometry involves a spherical array of 72 sodium iodide crystals used as scintillation detectors. By measuring the energies and directional distribution of all the gamma rays emitted by the excited nuclei as they settle down to ground state, the spin spectrometer provides data

Tom Carlson, standing, and Fred Grimm of The University of Tennessee study output from a laboratory operated by the University of Wisconsin where synchrotron radiation is used for photoelectron spectroscopy studies of gases. This radiation is the light source used to expel electrons from target gases for studies of the forces binding outer electrons in various atoms and molecules.

on the excitation energy and spin of distorted nuclei formed by the fusion of target nuclei with heavy-ion projectiles. From this information the altered structure and shape of these rapidly spinning nuclei can be determined.

In the first measurements with this device, neodymium-146 nuclei were bombarded with a neon-20 beam from ORIC. This is the first experiment in which it has been possible to measure both the energy and spin distributions of the excited nuclei simultaneously. The results obtained thus far confirm the time-honored statistical model of compound nucleus decay with more precision and detail than ever before. They also reveal for the first time the distribution of initial angular momenta leading to fusion. Data on nuclear shapes at high spin are also being extracted from these measurements.

The spectrometer has generated mountains of data in four other experiments, two of them with beams (fluorine-19 and titanium-50) from the new Holifield tandem accelerator. One experiment involved 26 silicon detectors inside the crystal ball to identify charged particles associated with the gamma-ray cascades. The experiment with the titanium beam was a survey in which 50 different materials were bombarded. The purpose of this run was to search for regions of the periodic table where nuclei exhibit unusual behavior.

In the true spirit of a national, sometimes international, user facility, all of these experiments have been collaborations between the Physics Division (principally Mel Halbert, Jim Beene, and Dave Hensley) and scientists from outside ORNL, mainly a group from Washington University in St. Louis led by Demetrios Sarantites. Physicists from Texas A&M University and the Niels Bohr Institute in Denmark have also participated.

Synchrotron Radiation in Electron Spectroscopy

Electron spectroscopies of increasing precision have contributed to our knowledge of why and how molecules are formed electronically. Researchers in the Chemistry Division helped introduce this field to the United States in the 1960s. A key aspect at that time was molecular photoelectron spectroscopy, in which a single line source (He-I radiation) was used to photoeject electrons from molecular orbitals and display them according to binding energies. Thus, one had an experimental way to see, display, and evaluate the electronic structure of molecules and atoms, shell by shell and level by level. But this method, which forms the basis for testing molecular orbital theory, offers more than an energy analysis; it also gives cross sections. From photoelectron energies we learn how tightly electrons are bound in a molecule, but the photoionization cross sections provide information on the nature of molecular wave functions.

Now, synchrotron radiation, having intense beams from the eV to the keV range, has provided an ideal new tool for studying cross sections. Our studies that use a new angle-resolving photoelectron spectrometer are done in the gas phase so that the most basic information can be obtained, but the findings also can be extended to more complex chemical systems and solid-state properties. Along with collaborators at the universities of Wisconsin and Tennessee, Tom Carlson and Manfred Krause have used the Wisconsin synchrotron radiation source to collect data on more than 30 molecules and atoms

Manfred Krause works at the electron spectrometer in Wisconsin with Professor P. R. Woodruff of the University of Aberdeen, Scotland. The instrument, developed and built at ORNL and first used in February 1981, is part of a collaborative program with University of Wisconsin Professor Jim Taylor at the Synchrotron Radiation Center in Stoughton.

from benzene to silver vapor. Discoveries include relativistic and many-body effects in atoms, shape resonance in molecules, and core shell chemical effects. For example, it has been shown for the first time that molecular orbitals that are characterized as lone pairs or localized electrons act like their atomic counterparts. The study of this phenomenon will lead to better characterization of molecular potential, especially in the region of the molecule which is very important to basic study of chemical reactions.

"Sodium Pump" Enzyme System

This highlight comes from the molecular and cellular sciences area in the Biology Division. Sodium pump is the label that biologists give to a ubiquitous enzyme system that keeps the surfaces of cells in good repair and also is the basis for the electrical activity and responsiveness of cells of the nervous system and of muscle, including the heart. Its role is to regulate sodium and potassium, the major mineral ions within cells, which are essential to cell growth, protein synthesis, and regulation of cell volume. The movement of these ions across cell membranes is the basis of the electrical activity and responsiveness of cells that I mentioned. However, because the essential enzyme of the sodium pump operates on the surface of the cell, it is vulnerable to many environmental insults. One of the better known of the specific poisons are drugs of the digitalis family; blockage of the enzyme's activity is the basis of digitalis toxicity associated with overdoses of the drug.

John Cook, using cancer cells as a model system, has shown that these cells maintain their surfaces in good repair by continually turning over and replacing all surface components. Generally, the half-time for this process is 4 days. The sodium pump, however, is given special treatment by the cells and is turned over with a half-time of only five hours. Thus, in these continuously growing cells, if all of the surface sodium pumps are poisoned with tightly binding drugs, the bound drug is taken up into the cells and degraded while new pumps are restored to the surface. The process is rapid enough so that the cells may recover before the normal ion gradients are irreversibly dissipated and the cells die. The essential activity on the cell surface thus appears to be maintained in a state of continuous and specific repair.

Growth of Anaerobic Bacteria

I turn now to an area in microbiology that is of fundamental importance in understanding cell division and repair and which, at the same time, suggests an energy-related application. In this study, Howie Adler has been able to produce partially purified bacterial membranes that remove oxygen rapidly and completely from a variety of aqueous and semisolid environments. The membranes are sterile, nontoxic, and stable. They convert oxygen to water by an enzymatic process. Also, when added to bacteriological media containing irradiated cells mutant at a specific locus involved in cell division, these membranes promote recovery of the cell division process. Adler believes that the activity of the membranes is due, at least in part, to the production of oxygen-

John Cook and Carolyn Shaffer set up an experiment under a hood to examine "sodium pump" enzyme activity on the surfaces of human tumor cells.

free (anaerobic) conditions in the immediate vicinity of radiation-damaged cells. These same membrane preparations provide the researcher with an efficient and convenient way of stimulating the growth of anaerobic bacteria. It is in this capacity that we foresee potential applications to fuel production. Anaerobic bacteria are the source of many hydrogen-producing chemicals and intermediates, such as butanol. This work promises to lead to simpler experiments to study the basic biology of anaerobic bacteria, which could lead to the practical application of such a system as an alternative energy source.

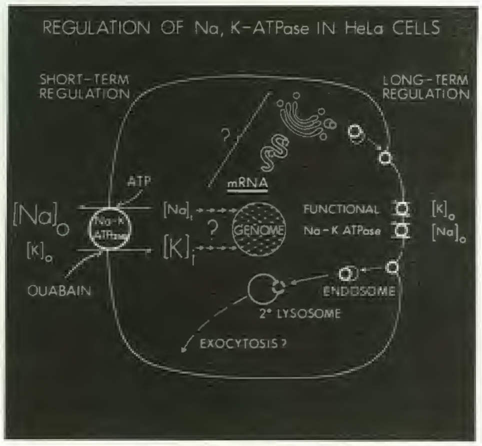
Water and Solid Electrolytes

Studies into basic science in the Chemistry and Solid State divisions are providing insight into ways of extending the operating lives of solid electrolyte batteries. These promise to have a higher power density and lower cost than the conventional lead-acid battery, making them potentially useful to power electric vehicles and for electric utility load leveling. An example is John Bates's sodium-sulfur battery, in which positive ions of sodium move through open channels of a solid electrolyte to react with sulfur at the opposite electrode, freeing the electrons that give the battery its power. A problem has been the declining performance with age due to increasing resistivity in the solid electrolyte—beta-alumina, a layered material composed of sodium, aluminum, and oxygen. The absorption of water into the electrolyte has been identified as the probable cause of the decreased conductivity.

Bates's work has established the mechanisms for reaction of water with these materials, as well as the kinetics and thermodynamics of the various processes. He has shown that electrolytes of the beta-alumina family can absorb significant amounts of water, which causes the increase in resistivity and degradation of other physical properties. The water molecules are sandwiched between the electrolyte's conduction layers, forming hydrogen bonds to neighboring oxygen ions above and below. The strong electrostatic interaction between positive ions of sodium and water and the blocking of conduction paths by water are responsible for the large decrease in conductivity. Bates has shown that the mechanism for diffusion of water involves a series of exchange reactions between water and oxygen ions in the conduction plane, which depend on the temperature, vapor pressure, and alkali-ion composition. Equilibrium concentrations of water to the saturation limits have been determined to be a function of temperature and ambient water vapor pressure such that, given the history of the specimen, water content can be predicted quite accurately. Industrial laboratories have found Bates' results to be valuable in predicting the rate of hydration and the temperature and humidity conditions required to keep the electrolyte dry. This work points toward longer-lived batteries and more attractive vehicle and energy-storage applications.

Ion Implantation of Ceramics

Many of the mechanical properties of structural ceramics, as well as their compatibility, are critically dependent on surface conditions. Teams led by Carl McHargue in the Metals and Ceramics Division and by Bill Appleton in the Solid State Division have explored the use of ion-implantation techniques to modify surface structures and properties of ceramics in beneficial ways. The result is ceramics that show increased hardness, fracture



Schematic of a cancer cell showing the regulation of the movement of sodium and potassium ions across the cell membrane by the "sodium pump" enzyme (Na-K ATPase) on the cell surface. Sodium and potassium are essential to cell growth, electrical activity, and maintenance of cell volume.

toughness, and wear resistance, making them potentially useful for improved cutting tools, valve seats and trim, and other heavy-wear surfaces. In the case of ceramic materials with covalent bonding, the implantation of metal ions produces an entirely different result: an amorphous material, which also may have a useful application where surface finish is a critical feature.

In one material, Al_2O_3, implantation of metal ions such as chromium, zirconium, titanium, nickel, and iron increased the surface hardness by 28 to 45%, and apparent fracture toughness and wear resistance also increased. The structure remains crystalline even at the highest implant damage levels in which large numbers of point defect clusters are found. Annealing treatments have been used to determine the high-temperature stability of the resulting materials and to allow alloy effects to be separated from implantation effects.

An even more dramatic effect on mechanical properties has resulted from implanting nickel ions in TiB_2. Here, hardness was increased by 79% and fracture toughness by 50%. The hardness of these ion-implanted samples was only 10% less than cubic boron nitride, which is second only to diamond in hardness. Ion implantation of two high-temperature structural ceramics having largely covalent bonding, SiC and Si_3N_4, produced an entirely different behavior. Polycrystalline and single-crystal samples became amorphous. The hardness of the amorphous layer was 10 to 20% less than the crystalline material, but fracture toughness was higher by the same amount. The wear test also revealed significantly different deformation characteristics from the crystalline form. One company already has shown interest in the possibility of producing such an amorphous surface layer on SiC high-temperature mechanical seals in which microcracking during closure prevents successful operation.

Gaseous Air Pollutants and Regional Air Quality

Release of pollutant gases from industrial and energy-related facilities has led to air-quality regulations designed to reduce or eliminate adverse health or environmental effects. The level of control required depends, of course, on the toxicity of the pollutant but also may be influenced significantly by characteristics of the region to be protected. Environmental variables such as temperature, humidity, or soil moisture may significantly influence the sensitivity of vegetation to pollutants.

In the Environmental Sciences Division, Sandy McLaughlin, George Taylor, and Ron McConathy are addressing the questions of level and specificity of control for energy-related pollutants across several fronts. Emphasis has been on identifying potential toxicants from synfuels technologies in the early stages of process development so that process controls can be implemented. Their work in the Air Pollution Effects Laboratory on comparative toxicity has shown that relatively few of the probable effluent gases will be toxic at expected release levels. Furthermore, toxicity can be explained to a significant degree by only two variables, molecular size and water solubility. This conclusion provides an important tool for future screening studies.

Results also show the importance of regional differences in relative humidity on uptake of two important pollutants, sulfur dioxide and ozone. Differences between the humid East and the more arid western/southwestern states lead to uptakes of two to three times as much SO_2 and three to four times as much O_3 by vegetation in the more humid environment. Another important predisposing factor influencing plant sensitivity is the presence of other pollutant gases and acid rain, which occur in highest concentrations in the industrialized East. Both laboratory and field studies now are aimed at determining the mechanisms and extent of these multiple pollutant interactions.

Results in characterizing and quantifying the basis for pollutant effects on vegetation have two obvious implications at this point. First, they should be extremely useful in selecting potential sites for facilities that might be the source of gaseous pollutants. Second, they provide a scientific basis for designing air-quality standards tailored to the needs of specific regions of the country.

Environmental Effects of Whole-Tree Harvesting

As a consequence of intensive search for alternative energy sources, the prospect of using woody biomass on a commercial scale has become a viable option.

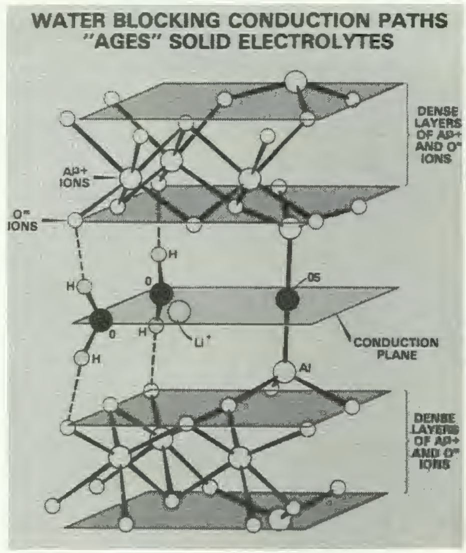
Both on the Oak Ridge Reservation and through the nationwide Short Rotation Woody Crops Program which we manage for DOE, Darrell West and Dale Johnson are seeking a scientific basis for more intensive tree farming, or silviculture. These studies involve two basic methods for increasing forest biomass production. One is to grow genetically superior trees while using intensive management techniques such as irrigation, fertilization, and short-cycle harvesting. The other is to harvest material from the forest which previously has been left on site during saw-log or pulp-wood harvesting. Because conventional harvests remove only about 50% of the plant material in a forest, the residue could be a significant supply of wood for use as a fuel or in chemical production.

What are the potential environmental consequences of such whole-tree harvesting of both natural and planted forest stands? Here, the ORNL experience in analysis of nutrient dynamics in forest systems is making an important contribution. The results of West and Johnson call into question the classical idea that nitrogen would become limiting to forest growth with repeated intensive harvests. Their data indicate that the nitrogen removed by harvesting the aboveground biomass in a 70-year-old forest is replaced in about 45 years through atmospheric input alone.

Previous nutrient cycling data for temperate forests indicated that about 10% of the forest nutrients were aboveground. However, the program's results across the United States now show that nutrient removal through total aboveground harvest may remove significantly more than 10% of some critical elements. On our watersheds, for example, 33% of the total calcium in the surface 45 cm of soil was removed. Because calcium additions from the atmosphere and from mineral weathering could not compensate for this loss, multiple harvests would represent a substantial drain on total calcium reserves in these ecosystems. The ecologists' preliminary conclusion is that whole-tree harvesting could lead to a significant long-term reduction in forest productivity. If their findings hold for other forest types, sustained yields may not be feasible from whole-tree harvesting without substantial fertilizer amendments.

Biomass Digestion

In the Chemical Technology Division, innovative approaches are under way to make the conversion of biomass—not only woody forms but also grasses and animal wastes—into fuels and chemicals a commercially viable process. The most abundant component of biomass, cellulose, is, in fact, a polymer of glucose molecules. Cellulose must be broken down into glucose by microorganisms such as yeast before it can be converted into a fuel (e.g., ethanol). Cellulose can be converted to glucose by enzyme action, duplicating what occurs in nature when fungi, living on cellulosic materials such as trees, produce the enzyme cellulase, which breaks down cellulose into glucose. The problem is that, to carry out the cellulose breakdown, bioconversion processes use large quantities of this enzyme, and it is expensive. Moreover, it is soluble—it can be used only once. Work performed by Jonathan Woodward and colleagues has resulted in new techniques that stabilize and immobilize the enzyme so that it can be used repeatedly at high temperatures. Particularly successful is one method in which cellulase is incorporated onto soluble gel spheres. This material is a derivative of seaweed and is relatively cheap. The enzyme-containing spheres then can be used for biomass digestion, recovered, and reused—a new technique that could well contribute to more economic bioconversion processes.

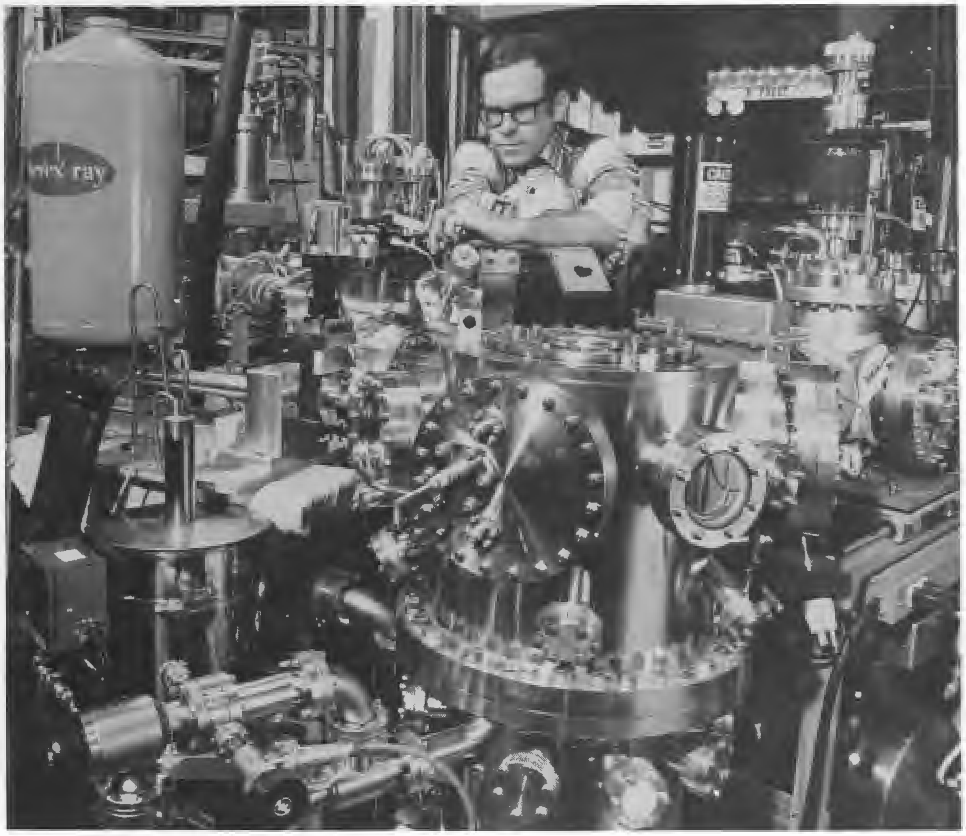


This schematic of the solid electrolyte beta-alumina shows that water blocks conduction paths. ORNL solid-state physicists have identified absorption of water as the likely cause of increased resistivity and declining performance as the electrolyte ages. Beta-alumina is used in the sodium-sulfur battery now being developed as a potential source of power for electric cars.

Wastewater Treatment at H-Coal Pilot Plant

Our biotechnology, as just seen, is a potentially important contributor to the supply side of the energy equation. Even more frequently, however, at ORNL we have come to identify biotechnology with important initiatives in environmental protection and control. In recent years, the ANFLOW process (now being demonstrated successfully on a significant scale at a Knoxville sewage plant) and our work on nitrate removal from industrial wastewaters have been conspicuous examples.

The Chemical Technology Division also has been active in the development of nonbiological wastewater treatment technology for application to the liquid waste



Woody White monitors ion implantation of boron into silicon in an ultrahigh vacuum surface analysis chamber in the Solid State Division accelerator facility.

cleanup from synthetic fuels facilities. One such initiative culminated this year in development of a mobile wastewater treatment system for advanced, onsite R&D at the H-Coal direct liquefaction pilot plant in Catlettsburg, Kentucky. Designed by a group led by Cliff Brown and George Oswald and installed early this year, the unit has a 60 mL/s capacity and consists of modular ozonation, carbon adsorption, and reverse osmosis systems having associated feed storage and surge tanks. Slip streams from various points in the existing full-scale treatment system (which does not include such processes) at the H-Coal site will be used as feed streams to the unit. The major objective is to show that these processes can be developed and used to treat coal-conversion process wastewaters to a degree that would allow the treated waters to be recycled to process areas. Such a development would demonstrate that the zero wastewater discharge options being proposed for many new synfuels plants can actually be achieved. Ashland Oil, as the primary industrial partner in the H-Coal project, has enthusiastically reviewed this development, which also is beginning to receive attention from others interested in the commercialization of synfuels.

Analysis of Chlorine Attack in Direct Liquefaction Processes

H-Coal is one of four coal-liquefaction pilot plants operated in the United States during the past few years to aid in process development as well as evaluation of materials performance. One of the most important resulting lessons about materials behavior is that the relatively high concentration of chlorine in coal (up to 0.3 wt %) introduces corrosion problems not encountered in petroleum refining. At all four pilot plants, very severe corrosion has occurred in fractionation columns used to separate medium-range oil from heavy oil. The problem is worst in the temperature range from 225 to 260°C and is seen to be roughly proportional to the chlorine content of the feed coal. Analytical chemists Juel Emery and Joe Northcutt have shown by neutron activation analysis that chlorine does, in fact, concentrate in the regions of the fractionation columns where corrosion is most severe. Metallurgists Jim Keiser, Rod Judkins, and Vivian Baylor have, in turn, identified the mechanisms by which acidic chlorides, principally HCl, are concentrated in the column. This has led to recommendations for alternative construction materials for future columns. Characterization of the corrosive compounds by the Metals and Ceramics Division, along with the pilot plant observations, have been used by Al Irvine and his colleagues in Chem Tech and by Arnie Olsen's group in M&C to suggest process changes to remove the corrodents and thus alleviate the corrosion problem. This solution is a key step toward improving the reliability of plant performance.

Absorption-Cycle Heat Pump Development

Our heat-pump R&D, under Harry Arnold and Fred Creswick, continues to make a good thing better and to extend the potential range of applications. Development of efficiency improvements in absorption-type heat pump cycles has included gas-fired cycles for residential and commercial applications and an advanced cycle that uses low-temperature waste heat. One example is an ORNL-managed development by Arkla Industries, Inc., of a residential system which employs ammonia and water as the working-fluid pair in an otherwise conventional cycle. That system, now in preproduction tests, is a heating-only unit which is expected to operate with at least 25% greater seasonal efficiency and to yield a 4- vs 7-year payback relative to an advanced gas furnace.

For recovery of low-temperature waste heat, Horacio Perez-Blanco and Gershon Grossman in the Energy Division have achieved analytical and experimental results on advanced absorption cycles for boosting 60°C wastewater to 120°C process steam. The attractiveness of this cycle is that the heat content of the 60°C water is the only energy input, except for minor pumping power. Thus, the capital cost of the heat pump is the only significant expense for upgrading waste heat. In the experimental work, a loop has been constructed in which simultaneous heat- and mass-transfer coefficients for air, water, and lithium chloride can be determined. The objective is to improve desorber performance by using air rather than heat to reconcentrate the refrigerant by driving off water vapor. A prototype unit designed to ORNL specifications is being readied for testing later this year.

EBT-S Results and Implications for EBT-P

The ELMO Bumpy Torus, invented here, is a steady-state plasma-confinement device which uses powerful microwave sources to heat electrons directly. With the evolution of these sources, called gyrotrons, to provide increased frequency and power has come a more broadly based understanding of plasma confinement. Last spring, using 200 kW of applied gyrotron power, electron temperatures of more than 1000 eV (approximately 12 million degrees) were recorded. Most importantly, electron behavior was found to closely follow that predicted by theory.

The magnetic field system in EBT consists of 24 simple magnetic mirrors linked end-to-end to form a torus. With microwave heating, relativistic electron rings form naturally in the midplane of each mirror section. The strong diamagnetic currents associated with each ring depress the local magnetic field to form a configuration that is resistant to magnetohydrodynamic (MHD) instabilities. The higher available microwave power levels have greatly increased the region of stable operation, and the application of higher frequency has led to elevated ring temperatures of 300 to 500 keV.

Ions in EBT-S receive their energy indirectly through coulomb collisions with electrons. At typical EBT-S densities, this collisional coupling is relatively weak and, as a result, ions attain temperatures of only a few tens of electron volts. This year, however, a group led by Wally Baity has begun experiments to heat ions directly with radiofrequency power. Up to 20 kW of steady-state power has been applied at a temperature of 30 MHz to deuterium-ion plasmas, resulting in a tenfold heating of large numbers of ions. In future experiments, they plan to increase the applied power another five times.

These encouraging experimental results, coupled with optimistic theoretical projections, give us confidence in extrapolating EBT-S to the planned larger device called the EBT Proof-of-Principle Project (EBT-P). Permission to proceed with hardware construction was granted last summer and completion is scheduled for mid-1985. The task of this device will be to expand present plasma studies while increasing important plasma parameters to a level that could test whether the bumpy torus concept has the potential to evolve into a viable fusion reactor.

Tokamak Results

The tokamak currently is the leading candidate for development as a fusion reactor. Our own ISX-B device is one of the major U.S. facilities in this program. For the past two years, ISX-B experiments have been directed toward attainment of high values of the plasma "beta," the ratio of plasma kinetic pressure to the pressure of the confining magnetic field. Generally, it is recognized that a beta of 5% or more will be required for a viable fusion reactor, but there are theoretical reasons to believe that the plasma may begin to exhibit instabilities when beta reaches 2 to 3%. The theoretical threshold for the onset of such instabilities can be raised by judicious choice of the plasma cross-sectional shape and profile.

To explore these issues, ISX-B was equipped with ORNL-developed neutral beam systems that delivered 3 MW of auxiliary heating power and the capability to produce a variety of plasma cross-sectional shapes. By injecting increasing amounts of power, the energy content of the plasma has been raised to a beta value corresponding to about 2.5%. This year, Masanori Murakami and his group conducted careful scaling experiments to establish the empirical dependence of observed plasma properties on the major parameters. As an example, the main confining field was varied over the range from 0.75 to 1.4 Tesla, producing a four-fold change in the value of beta. They observed no degradation of the global energy confinement time, even near the maximum beta. While this is encouraging, another phenomenon has given them cause for concern. As the injected beam power was increased, they observed a substantial degradation of energy confinement time (i.e., more auxiliary heating power was required to attain a given value of beta than had been expected). This is not yet understood, hence it is not known whether the effect is relevant under fusion reactor conditions. A possibly related phenomenon is the toroidal rotation of the whole plasma column due to the momentum input from existing neutral beam lines. Measurements indicate that this velocity may be comparable to the ion thermal velocity.

For the near term, ISX-B experiments will focus on trying to understand the reasons behind these experimental observations. Facility upgrades and changes being implemented in support of this program include (1) an increase in the plasma current capability, to take advantage of the observed improvement in confinement as the current is increased; (2) addition of a further neutral beam injection line pointing counter to the existing lines, to explore the effect of halting or reducing plasma rotation; and (3) addition of more powerful diagnostics, particularly to improve the quality and quantity of data on internal electric fields and fluctuations.

Pressurized Thermal-Shock Experiments

Nuclear fission claims our remaining highlights. The first among these concerns the highest priority regulatory issue now being considered by the Nuclear Regulatory Commission—pressurized thermal shock. Pressurized water reactors are susceptible to certain types of hypothetical accidents which, under some circumstances, including operation of the reactor beyond a critical time in its life, could result in failure of the pressure vessel as a result of extensive propagation of crack-like defects in the vessel wall. Accidents of particular concern are those that result in rapid cooling (thermal shock) of the inner surface of the reactor vessel wall, particularly if they also involve substantial primary-system pressure. These are referred to as over-cooling accidents (excessive cooling for a particular pressure) or pressurized thermal shock. Such an event could threaten the integrity of the pressure vessel if a flaw of critical size is present.

An important contribution of the Heavy Section Steel Technology (HSST) program has been Dick Cheverton's development, with Shafik Iskander of Computer Sciences. It is a computer program which performs two-dimensional, linear elastic fracture mechanics analyses for long axial flaws which are subjected to time-dependent thermal and pressure loadings. With this code, drawing on a broad base of experimental data from the HSST program, temperature and stress distributions and stress-intensity factor values can be calculated at the tip of a hypothetical flaw. In this way, crack propagation (and arrest) through the course of an accident can be determined. The supporting experimental data on thermal shock has been obtained by effectively dunking a test cylinder at 100°C into tanks containing liquid nitrogen at −197°C. Cheverton's code is providing an invaluable tool for analyzing over-cooling accidents and determining the sensitivity of the material properties. His work provides an important perspective for the NRC-sponsored materials irradiation programs and for the current evaluation of pressure-vessel integrity. Fourteen to eighteen currently operating reactors have a higher content of copper impurities in pressure-vessel welds and base metal and, therefore, may be more susceptible to radiation-induced embrittlement.

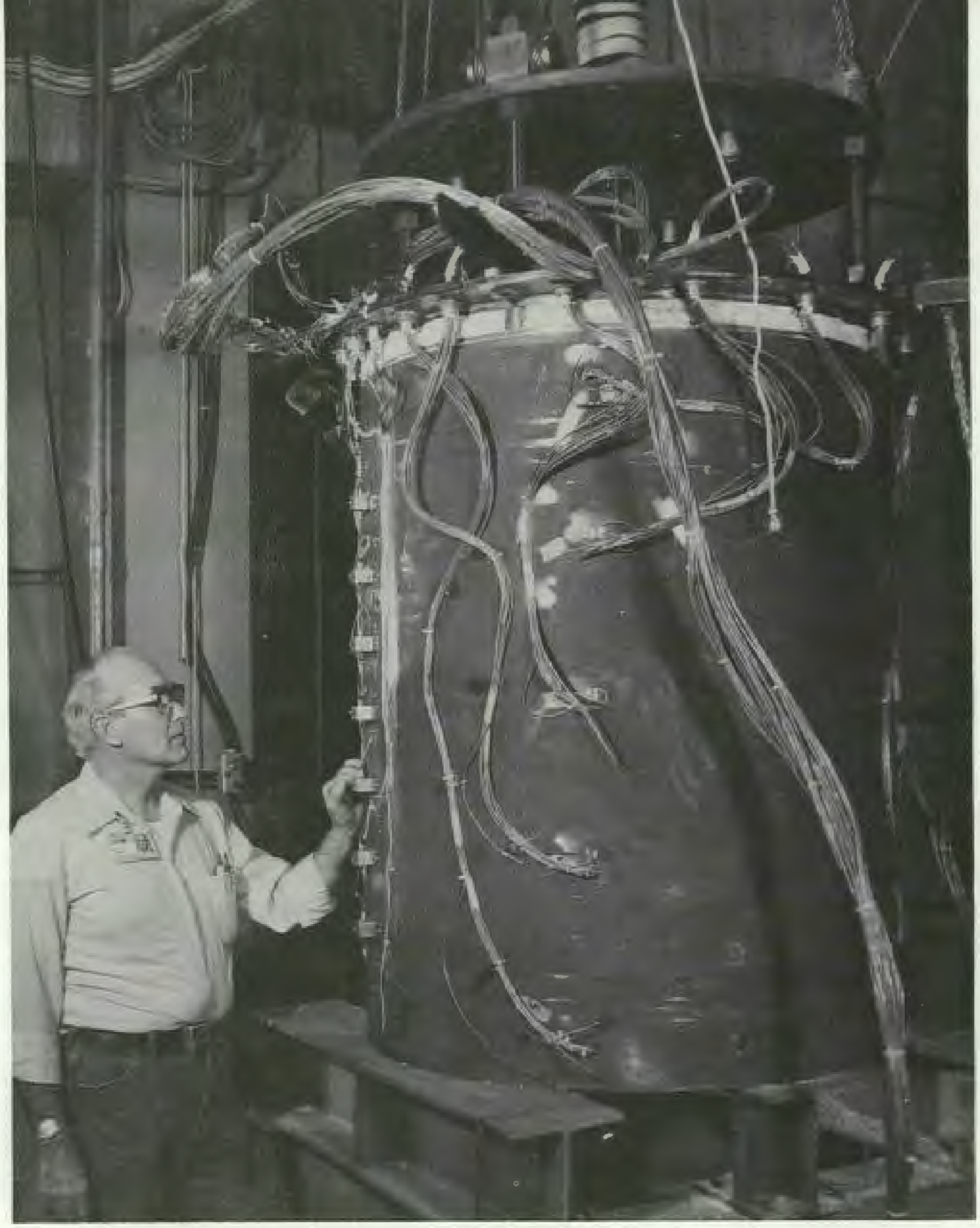
Reactor Vessel Water-Level Measurements

Based on its analysis of events leading up to and contributing to the accident at Three Mile Island, the Nuclear Regulatory Commission has issued requirements for the installation of improved instrumentation for pressurized water reactors. One such requirement is unambiguous indication of inadequate core cooling. The Instrumentation and Controls Division has been assisting NRC with developing the necessary instrumentation to meet this requirement, with impressive results. Dick Anderson and George Miller have developed a measurement system to detect coolant level, coolant density profile, and coolant temperature profile using a single sensor. The sensor itself is a piece of rectangular stainless steel wire which serves as a torsional ultrasonic waveguide and is notched along its length to provide different measurement zones. The velocity of sound is dependent on the density of the fluids surrounding the probe. But the sensor also is sensitive to temperature, so an extensional ultrasonic signal can measure temperatures. The output, which is the temperature and density readings of each zone, permits the coolant level to be calculated in the control microprocessor. This sensor appears to be one of the best long-term solutions for in-vessel measurements because it combines self-calibration, diverse indications of conditions in the vessel, simple installation, good reliability, and resistance to damage. In related tasks, I&C is evaluating short-term coolant-level measurement systems proposed by various reactor vendors and the submitted proposals by utilities that describe their proposed actions to comply with the new NRC requirements.

Mobile Laboratory for In-Service Inspection of Steam Generators

Another instrumentation development, in the Metals and Ceramics Division, improves the capability

Tom King, Jr., checks the wiring of an instrumented vessel used in pressurized thermal shock experiments.



for in-service inspection of steam-generator tubing for both current light-water reactors and future breeder power plants. It involves the use of advanced multifrequency eddy-current techniques and equipment. The computer-based instrumentation provides for enhancement of signals from the conditions being examined (e.g., wall thickness and flaws) and suppression of signals from interfering conditions, such as variation in electrical conductivity and permeability, presence of tube supports, probe motion, etc. Thus, it overcomes the ambiguities and dependence on human interpretation common to present commercial equipment and technology. To demonstrate the new technique, developed by Cas Dodd with L. D. Chitwood, a mobile examination laboratory has been set up for use in field trials on steam generators at two reactors and also for in-service inspection of tubing for the Few-Tube Model being developed by Westinghouse-Tampa Division for DOE. The result is a new tool for obtaining more accurate, quantitative, reproducible data. When the development is completed and transferred to industry, it will be possible to rely more on data from in-service examinations of steam generators.

Solvent Extraction Tests of Coprocessing

The idea of coprocessing was introduced into nuclear fuel reprocessing in response to safeguards considerations. The idea is to keep the plutonium from being separated from the uranium so it cannot be used to fabricate nuclear weapons. This is one in a series of recently developed or improved Purex flowsheet modifications that Les King, John Bigelow, and Emory Collins have been working on in the Chemical Technology Division. Using the Solvent Extraction Test Facility located in a hot cell in the Transuranium Processing Plant, they have studied coprocessing solvent extraction flowsheets for both LWR and LMFBR fuel in mixer-settler contactors, using feed solutions prepared by dissolving kilogram quantities of fully irradiated fuels. Plutonium content has ranged from 0.8 to 23% of the heavy metals. The experiments show that plutonium and uranium in highly irradiated PWR, BWR, and LMFBR fuels can be recovered effectively and decontaminated from fission products by means of coprocessing-type solvent extractions. Further, the conditions necessary for effective use of either hydroxylamine nitrate or nitrous acid for the reductant stripping of plutonium have been established.

Summary and Outlook

The year 1981 was one of several significant program milestones, which should be noted here. We began the year by recognizing, for 1980, one of the best safety performances in the history of ORNL and for the Nuclear Division as a whole.

By December 31, 1981, we had topped that by reaching our 600th day without a lost-time accident—representing a total of just over 14 million manhours. This also marked the first time that ORNL had completed a calendar year without a lost workday case.

This also was a year of numerous special events that keynote progress. In January, the 30-m, small-angle neutron scattering instrument at the High Flux Isotope Reactor was dedicated. In March, the first coupled operation of the Holifield Facility's two accelerators took place. In April, site dedication ceremonies were held for the EBT-P experiment to be built in the Valley Industrial Park. Later in the year, the Fusion Engineering Design Center occupied a new office building on the adjacent site, a structure built by private developers and leased for our use. At the end of May, a dedication was held for the $10-million Component Flow Test Loop in the Engineering Technology Division, a key experimental facility for the HTGR program. By the end of the year, shakedown testing was completed successfully when the three circulators were operated simultaneously through the complete design range of speeds, up to 23,500 rpm. In July, the ANFLOW demonstration plant in Knoxville was dedicated. In November, the new Hydrofracture Facility was dedicated in anticipation of beginning operation early this year.

Finally, it was a year in which the Laboratory won four I•R-100 awards, bringing the ORNL total over a five-year period to 18; for the second year running, won an NSPE award for one of the year's top ten engineering achievements; and, for the first time since the mid-1960s, received two E. O. Lawrence Memorial Awards in a single year—those recently announced for Fred Mynatt and Paul Selby.

What lies ahead? If past is prologue, then we should be amply prepared for one obvious characteristic of 1982—a degree of uncertainty both about budgets and about the future organizational niche for energy research and development and the supporting sciences within the Federal government. For me, this obvious uncertainty is balanced by the knowledge that our capabilities as a Laboratory are strong and proven, that our contributions are widely recognized and appreciated, and that national laboratories in general and ORNL in particular represent vital cornerstones for progress in our society.

Given the role that science and technology must play in our economic recovery, our response to foreign competition, energy, environmental protection, resource utilization and conservation, and in health delivery, it is clear to me that our role is vital and irreplaceable. For that reason, I am confident that national laboratories can only gain, in the long term, from the current reexaminations of their functions and contributions.

More clear to us now than last year at this time is the impact of a new national Administration setting its own agenda and implementing its policies and programs—on energy as well as the full range of domestic and international concerns.

We have an indication now of the translation of new points of view, as outlined in the 1980 campaign, into specific programmatic directions:

- A decreasing Federal role in the support of near-term technologies.
- New support for supply strategies and the nuclear option, less for conservation and renewable energy development.
- A more restricted view of the Federal role in energy demonstrations and greater reliance on private initiatives and the marketplace to bring new technologies to commercial reality.
- Positive support for research and development, particularly basic research in obviously long-term, high-risk (but potentially high payoff) areas where sustained private support is unlikely.

None of these directions is surprising, I think, given the strong commitment to reduce the growth in Federal spending and inflation and the continuing large budget deficits.

On the horizon we see the strong likelihood, once again, that far-reaching reevaluation of the way that energy, as an issue and focus for policy, is organized and structured at the Federal level will occur.

A cabinet-level Department of Energy, if the Administration is successful in persuading the Congress to its point of view, will be a thing of the past. Not likely to be lost in the bureaucratic shuffle, however, is the concept that began with ERDA of an agency charged with carrying out an integrated approach to energy problems, rather than a more limited technology-specific mission, as in the days of the AEC. The proposal, as you know, is for an Energy Research and Technology Agency, ERTA, incorporating most of the R&D elements of ERDA and DOE, which would be located in the Department of Commerce.

Looking more closely at the Laboratory, for the first time since 1974 a change in the slope of our staffing curve is evident—from the modest but steady growth characteristic of the last six or seven post-embargo years to a modest decline as we adjusted to the FY 1982 budget.

On the whole, we believe that past planning choices, program diversification, and administrative flexibility (through such mechanisms as increased subcontracting), have worked to our benefit in adjusting to a time of change. As a result, the impacts we have experienced so far, while unwelcome and frequently painful, have been rather moderate overall and certainly less severe than at many of our sister laboratories.

By all accounts, FY-83 will be an even more severe budgetary test for all parts of the Federal system. In the absence of an obvious, visible supply crisis, we also can expect that energy programs will not occupy a privileged or protected place in budget deliberations. Organizational change or uncertainty, if it becomes a point of contention between the Administration and the Congress, can itself have an important impact through delays in implementing decisions or formulating program plans.

A potentially salutary effect of the Reagan philosophy and budget, especially as it redefines the Federal role in research vis-a-vis development and demonstration activities, may be to restore, to a degree, a more equitable balance at ORNL between the science and technology areas. The much more rapid growth of the technologies in recent years has tended to distort the balance that in the past we have considered desirable.

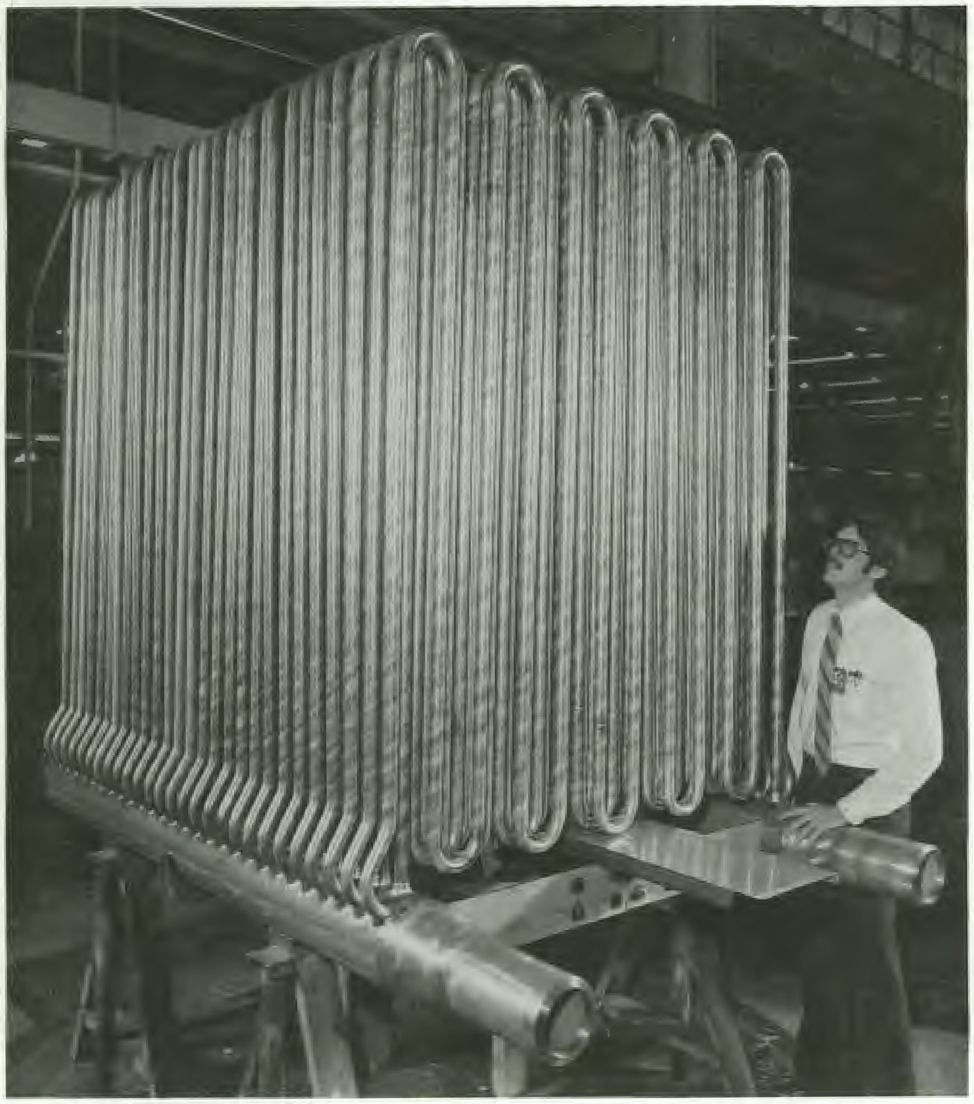
New Initiatives

The process of proposing new intiatives to DOE has allowed the Laboratory to identify and pursue new R&D areas in which we can make significant contributions. As a result, several past initiatives have grown into strong research endeavors; among these are biotechnology, coal chemistry, risk assessment, coal-conversion impacts, high-level waste isolation, high-temperature materials, fission-related instrumentation, nuclear materials, fossil materials, and toxicology. Even in a year of more limited budget horizons, this process serves a useful function, I think, in highlighting productive new directions for our programs which might not otherwise receive attention. The updated institutional plan for FY 1982–1987, *Trends and Balances*, highlights five such desirable new initiatives: an engineering science center, strategic materials for energy, environmental control technology, hazardous waste technology, and global environmental concerns.

The proposed *engineering science center* is designed to advance energy technology development by providing basic engineering information in the areas of transport phenomena and mechanics of solids. The scope of the center would include fluid dynamics, heat transfer, mass transfer, and solid mechanics, with the following objectives: to develop a broader base of fundamental knowledge, to reduce dependence on empiricism, to eliminate overdesign of components, and to provide timely transfer of basic research results to energy technology development. Results will have applications to fossil energy, conservation, nuclear, solar energy, and fusion technologies and to natural resource and environmental assessment. ORNL is perhaps uniquely qualified to organize an engineering science center that would concentrate on research in transport phenomena and solid mechanics because the Laboratory has a long history of technology development which has required engineering science input in these areas (e.g., nuclear fuel-cycle development, thermal-hydraulic reactor-core simulations, and coal-combustion and flue-gas-treatment experiments).

ORNL's mobile laboratory for in-service inspection of steam generators is seen here at the Few Tube Model in Pittsburgh, currently being developed for the breeder reactor program by the Westinghouse-Tampa Division.

Potential shortages of *strategic materials for energy*, especially metals critical to production or conservation, threaten serious problems for both the domestic and world economies. Of particular concern is our increasing dependence on foreign suppliers. However, new domestic supplies of these minerals are potentially available from unconventional sources. We propose that ORNL play a major role in developing and implementing a multidisciplinary research program directed at the identification and solution of long-range resource



Tom Conley inspects the helium-to-air heat exchanger that has since been installed in the Component Flow Test Loop, a key experimental facility for the High Temperature Gas-cooled Reactor Program.

problems. Activities would range from basic geologic characterization of resources to economic analysis, development of processing technology, and substitution analysis. Such a program would focus on efficiently recovering critical fuel materials and metals from sources such as low-grade ores, wastes, or eastern shales. Current efforts, including exploratory assessment of Chattanooga shale as a source of oil, uranium, and strategic metals; recovery of uranium from low-grade ores; and resource recovery from fly ash and coal combustion residues would be unified.

An integrated *environmental control technology* program is necessary to ensure that emerging coal-conversion technologies and potentially important oil-shale technologies are environmentally acceptable and impose no adverse health effects. Data on characteristics of output streams is needed to design efficient control systems and provide for a coordinated, long-term approach to environmental control. As part of an accelerated program, ORNL is proposing new R&D to include basic studies on characterization of effluents from coal-conversion plants and bioassay of their toxicity and mutagenicity, developing and demonstrating advanced control processes, and monitoring and assessing pilot- and full-scale treatment systems. Our past development of biodenitrification processes and advanced municipal and industrial wastewater cleanup systems, such as ANFLOW, are evidence of ORNL's capability to assume a leadership role in ensuring the health and environmental acceptability of coal-conversion technologies, as well as those associated with oil shale and advanced combustion. Such an initiative also would encompass existing and developing environmental control processes for nuclear fission and fusion technologies.

Hazardous materials, as defined and regulated by EPA through the Resource Conservation and Recovery Act, and low-level radioactive waste, as defined and regulated by the NRC, have similar traits for *hazardous waste technology*. Both are political issues with high public awareness and concern. At ORNL, an expanded geoscience research group has contributed to waste management practices by providing (1) predictive capabilities related to the hydrologic circuit, mineral reactions, rock fracture patterns, and trace element transport; (2) information for preventing or minimizing potential adverse effects resulting from man's actions; and (3) methods for mitigating or correcting existing undesirable conditions. Geologic studies include the mineralogy and geochemistry of waste interactions with a variety of elements. One example in the area of fossil-fuel-derived waste is the study of arsenic absorption that is dependent on valence state. Our goal is to build a strong research base to support a unified program in nonnuclear as well as nuclear waste management.

Several emerging *global environmental concerns* are related to energy development and use. The burning of fossil fuels and, perhaps, the cutting of forests without compensatory replanting are causing a steady, measurable buildup of carbon dioxide in the atmosphere which, if sustained, creates the potential for widespread climatic change in the future. Fossil-fuel combustion also may lead to the formation of acids in the atmosphere, which are deposited hundreds of miles from their sources. As with most technology-related pollution problems, an interdisciplinary approach is required to plan and conduct research related to source-term characterization; environmental transport, distribution, and effects; and social and economic consequences. ORNL is investigating the biogeochemical cycles of forest ecosystems so that chemical releases to the environment can be quantitatively related to ecological processes and the effects of these perturbations. We propose to continue a strong and diverse program in experimental research on important biogeochemical cycles (e.g., nitrogen, sulfur, phosphorus, and carbon dioxide) and to expand the work to a global biogeochemistry within a more comprehensive time frame.

Perspective on 1982

Because of all these circumstances, 1982 promises to be most interesting and challenging. Undoubtedly it will be a year of further change. For East Tennesseans, the 1982 World's Fair, with its energy theme, will put a spotlight on the Oak Ridge programs and facilities different from our accustomed international role within the technical community. During the six months of the Fair, we will have the opportunity to interpret Oak Ridge's energy missions and programs to a large nontechnical audience of Fair visitors and domestic and international participants.

The identification of Knoxville and Oak Ridge as an energy center and a center for high-technology development, as symbolized by the Fair, may also be embodied in a more enduring way through Governor Alexander's proposed Tennessee Technology Corridor. This concept would link public- and private-sector interests in high-technology, manpower training, and business development both functionally and geographically, with the Pellissippi Parkway—extended to Maryville—as the focal point. Building on the substantial nucleus of private and governmental efforts already under way, this concept is truly exciting in its implications for the future development of this area. It recognizes the potential for a concentration of science and technology-related activities here comparable to the Route 128 development around Boston and Cambridge, the Research Triangle in North Carolina, or Silicon Valley south of San Francisco. Institutionally, ORNL profits from the further growth of a dynamic technology-oriented community, not to mention new and more accessible outlets for the commercialization of energy-related technologies we develop.

Closing Remarks

Finally, let me express my appreciation to the Laboratory staff as the source of the many outstanding accomplishments and exciting directions which it has been my privilege to cite here. The most important among the many resources and capabilities of a national laboratory is its people—specially trained, dedicated to excellence in their individual specialties, and motivated by the opportunity to help solve problems that are among the most difficult and challenging facing this society and its technical community. ORNL staff members' talents in the creative application of the tools of science and technology enable us to achieve our important institutional purposes and goals. It is they who represent the Laboratory's great strength and vitality, the basis for past successes, and the promise for the future. Those qualities and contributions, to me, reflect the true State of the Laboratory. ornl

take a number

By V. R. R. Uppuluri

DOES "INFORMATION" ALWAYS HELP?

Consider two urns that look identical: one urn contains three $1 bills; the other, two $1 bills and one $100 bill. Contestants randomly select an urn and then randomly draw a bill from the urn, which they keep ("sampling without replacement"). Suppose you are the third contestant to play the game; you are told that the first two contestants have selected the same urn and each has drawn a $1 bill. The urn chosen by the previous contestants is pointed out to you. Now it is your turn to choose one of the urns and pick a bill at random, and you wish to maximize the chance of getting the $100 bill. The question is "Which urn do you select?"

According to Jermore L. Paul (*The American Statistician,* 1981), most people when asked for a quick response say that it seems best to take the urn not previously selected. But as a matter of fact, the probability of obtaining the $100 bill from either urn is 1:4.

A RIGHT TRIANGLE WITH ALL SIDES ODD IS IMPOSSIBLE

A triangle having a 90° angle is a right triangle. The well-known theorem of Pythagoras is that the square of the hypotenuse (z) is equal to the sum of the squares of the remaining sides, denoted by x and y; in other words, $x^2 + y^2 = z^2$. A triplet of integers ($x, y; z$) satisfying this relationship between squares is called a Pythagorean triplet. For example, (3, 4; 5) and (6, 8; 10) are Pythagorean triplets.

It is of interest to note that in a Pythagorean triplet ($x, y; z$) both x and y cannot be odd numbers.

Dave Campbell (right) and Tony Malinauskas discuss the Regovin report of the accident at Three Mile Island nuclear power plant. Studies conducted by Campbell and Malinauskas, in collaboration with Bill Stratton of Los Alamos National Laboratory, provided an explanation for the surprisingly small release of radioactive iodine during the TMI accident. Their findings have had a direct impact on reactor safety research in this country as well as in Canada, Great Britain, the Netherlands, and West Germany.

Iodine and Reactor Accidents

By CAROLYN KRAUSE

The amount of radioactive iodine that escaped into the environment of the Three Mile Island nuclear power plant after the March 28, 1979, reactor accident was far less than expected. That was good news because ^{131}I can be deposited on grass and enter the human food chain through cow's milk; if ingested, it concentrates in the human thyroid gland where it might cause cancer. The amount of ^{131}I measured in the TMI environment was 15 Ci, much less than that detected in the same area after the Chinese bomb test in 1976.

Although the news about ^{131}I emissions was good, it was also puzzling because of a persistent belief that, in a loss-of-coolant accident like that at TMI, a large fraction of ^{131}I (along with the noble gases) would escape into the environment. After all, that's what happened during the Windscale reactor accident in England in 1957.

At TMI, some 8 million Ci of xenon escaped from the plant. At the same time, a large amount of ^{131}I escaped from the reactor fuel and even from the containment building; more than 2 million Ci of ^{131}I ended up in water that flooded the auxiliary building. Why, then, did only about 15 Ci of ^{131}I escape from the plant?

Dave Campbell and Tony Malinauskas of ORNL's Chemical Technology Division and Bill Stratton of Los Alamos National Laboratory have a convincing answer, but so far it has not dispelled the common view held by the nuclear (and even more by the antinuclear) establishment. As a result of studies which were performed for the President's Commission on the Accident at Three Mile Island (the Kemeny Commission), they determined that TMI's ^{131}I emissions were limited by the chemically reducing environment of the water-cooled reactor. Conversely, the greater emissions at Windscale occurred because the reactor was air-cooled and dry, thereby offering a chemically oxidizing environment.

They further pointed out that light-water reactors possess inherent characteristics that limit iodine volatility. The core region contains several tons of zirconium metal, which, at high temperatures, is one of the strongest chemical reductants known. They also contain enough water to fill a fair-sized swimming pool (400 m^3), and under accident conditions, the hot zirconium reacts with water and steam to form hydrogen, also a reducing agent.

The production of elemental ^{131}I is insignificant under these conditions, and, instead, an iodide is formed. It is probably cesium iodide; Cs and ^{131}I both escape from the fuel as the core temperature rises in the 1000–2000°C range.

An aerial view of Three Mile Island and its four cooling towers on the Susquehanna River. Campbell and Malinauskas frequently attend meetings on the island. They serve on Nuclear Regulatory Commission and General Public Utilities advisory committees concerned with removal of the reactor core and cleanup of contaminated water.

Such iodides are much less volatile than elemental ^{131}I and form stable solutions with water.

Campbell, Malinauskas, and Stratton also looked into the reactions of elemental I with water (in the unlikely event that it could be formed during an accident). Elemental ^{131}I is presumed to react rapidly to form equal amounts of iodide (I^-) and a compound called hypoiodous acid, or HOI (an analog of hypochlorite, or ordinary bleach). However, in spite of many attempts, HOI has not yet been proved to exist.

Research is needed to determine whether or not HOI is really significant, and, if it is, how volatile it is and how long it persists. If it does not exist, it is necessary to identify the actual intermediate product. Ultimately, the reaction with water yields iodide (I^-) and iodate (IO_3^-) in a ratio of 5 to 1. Once this occurs, iodine volatility is extremely small, since both species form stable solutions with water.

ORNL's analyses of TMI effluents show that more than 97% of the ^{131}I that escaped the TMI fuel core ended up as dissolved iodide such as cesium iodide and nearly all the rest was iodate. Other measurements show that very little organic iodide was formed, perhaps 0.01% of the total ^{131}I present. Both findings agree with recent analyses of water samples taken from TMI but are contrary to conventional models and regulatory assumptions. For example, the NRC regulatory guides 1.3 and 1.4 state that 91% of the ^{131}I released from the fuel is assumed to be in the form of elemental ^{131}I and that 4% would be organic iodides.

TMI is not the only example that contradicts the common belief concerning the volatility of ^{131}I following a reactor accident. In a large number of experiments and in the few accidents that have occurred, ^{131}I release has always been very small if water was present (in particular, much smaller than the xenon release). In "dry" events, in contrast, ^{131}I and xenon releases have been comparable, and sometimes large.

These conclusions regarding ^{131}I chemistry, presented by Campbell, Malinauskas, and Stratton have sparked a re-examination of ^{131}I behavior in light-water reactors by the NRC (NUREG-0772) and by other countries including Canada, Great Britain, the Netherlands, and West Germany. The problem is not yet settled, however, because the established "mindset" about ^{131}I chemistry is not easily changed. Full resolution of this issue is going to require considerable time and better scientific evidence. ornl

readers' comments

Letter to the Editor

In the Winter 1981 *Review*, the article "CO_2 and Acid Rain" states that rain having a pH between 3.5 and 4.0 is 10–40 times as acidic as normal rain having a pH of 5.6. My calculation yields a range of 40–126 times as acidic for this pH difference. Does the subject pH (for threshold growth responses) encompass the range of 4.0–4.6 rather than the 3.5–4.0 as stated?

Richard A. Strehlow
Chemistry Division

Reader Strehlow's calculations are essentially correct. Unfortunately, the quotation in the Winter 1980 *Review* article, "CO_2 and Acid Rain," combined three points made in the presentation to Assistant Secretary Clusen:

1. Current ambient rainfall over most of the eastern United States has an annual average pH of 4.6 to 4.0 (10 to 40 times as acidic as normal).
2. Thresholds for plant growth responses are in the range of pH 4.0 and 3.5 (40 to 126 times as acidic as "normal").
3. Local (Walker Branch Watershed) annual average pH of rainfall is around 4.1.

Dave Shriner
Environmental Sciences Division

Letter to the Take a Number Editor

In the Fall 1981 *Review*, Dr. V. R. R. Uppuluri posed the interesting question, "Are we powerless with powers?" or more specifically, can it be shown that 2592 is the only four-digit number that satisfies the equation

$$z = abcd = a^b \times c^d \ ? \qquad (1)$$

It turns out that these powers can be overcome by a judicious application of the binominal theorem. The number z can be written as

$$z = 10^3(a) + 10^2(b) + 10(c) + d \ . \qquad (2)$$

Clearly, z/a must be a number between 1000 and 2000. Furthermore, it must be possible to write this number as the product of two factors, in the form

$$z/a = (10 + x)(10 + y)^2 \ . \qquad (3)$$

At least one of the factors in Eq. (3) must be a number between 10 and 20, but it must also be a power of a number less than 10. The only such number is 16. Consequently, either

$$z/a = 16(10 + y)^2 \qquad (4)$$

or

$$z/a = 256(10 + x) \ . \qquad (5)$$

Using the bounds on z/a and the fact that the unknown factors must also be integers and powers of a number less than 10, Eq. (4) gives

$$10 + y = 8 \text{ or } 9 \ , \qquad (6)$$

and Eq. (5) gives

$$10 + x = 4, 5, 6, \text{ or } 7 \ . \qquad (7)$$

In any case, a must be an integer less than 10 and a divisor of one of the factors.

Consequently, the possibilities are

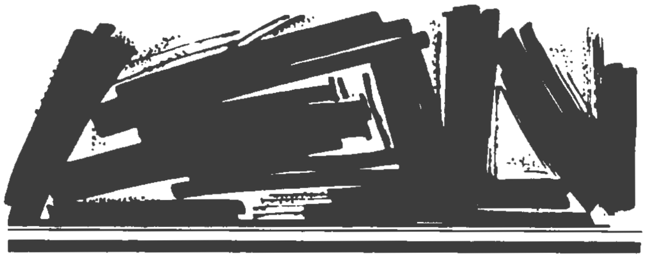
$$z/a = 16(8)^2 \quad a = 2, 4, \text{ or } 8 \ ,$$
$$z/a = 16(9)^2 \quad a = 2, 3, 4, \text{ or } 9 \ ,$$
$$z/a = 256(4) \quad a = 2 \text{ or } 4 \ ,$$
$$z/a = 256(5) \quad a = 2, 4, \text{ or } 5 \ ,$$
$$z/a = 256(6) \quad a = 2, 4, \text{ or } 6 \ ,$$
$$z/a = 256(7) \quad a = 2, 4, \text{ or } 7 \ .$$

At this point, we have to start working like beavers to overcome the powers, which is what Dr. Uppuluri calls "complete enumeration." After trying all thirteen possibilities, two of which are duplicates and two of which are ineligible five-digit numbers, it turns out that only

$$z = (2)(16)(9)^2 = (2)^5(9)^2 = 2592$$

satisfies Eq. (1). Thus, after using the binominal theorem to scout our opponent, and then working like beavers, we have overcome the powers.

John G. Merkle
Solid Mechanics Section
Engineering Technology Division



BOOKS

Sir William Rowan Hamilton *by Thomas L. Hankins, The Johns Hopkins University Press, Baltimore and London (1980), 474 + xxii pp., $32.50. Reviewed by Brian D. Murphy, Computer Sciences.*

Thomas Hankins has given us much more than just a good biography of a leading scientific personality of the 19th century, although that it certainly is. We have here as well a historical account of the times that formed the background for Hamilton's work in mathematics and physics. Thorough in the scientific aspects of his book, the author also deals substantially with the philosophical, religious, and political events that bore so heavily on Hamilton's work and personal life.

William Rowan Hamilton was born in Dublin in 1805 and died in 1865. Since I also grew up in Dublin and was exposed to much lore about him, this book satisfied my desire to put into perspective the bits and pieces of information I had accumulated about Hamilton. Before reading the biography, I was apprehensive that my impression of Hamilton's greatness might be refuted by what I read. If anything, I now think of him as being even greater. He showed intellectual promise at an early age; at ten, he is reported to have had an understanding of ten Eastern languages, in addition to Latin, Greek, and a number of other European languages. At 21, he became Astronomer Royal for Ireland, having won out in a fairly formidable field which included George Biddell Airy, who later became Astronomer Royal at Greenwich. Hamilton continued to achieve fame and was knighted at age 29. As a fitting tribute to a distinguished career, three months before his death, Hamilton was informed that the newly created National Academy of Sciences in the United States had elected him to head its list of foreign associates.

Yet, Hamilton is probably not well known. In Hankins' biography, possible reasons for this lack of notoriety are given. Hamilton is seen to be an idealist interested in a very closely defined and personal concept of science. He was primarily a mathematician—an algebraist, to be more precise. As a physicist, he was unconventional by even 19th century standards. Hamilton and his scientific colleagues would probably describe themselves as natural philosophers. Hamilton was not at ease when dealing with the more mechanistic subjects within the realm of natural philosophy, although some of his discoveries were very relevant to such matters. He was a good verbal communicator but tended to ramble in his papers; he could not resist the temptation to intersperse his mathematical writings with references to metaphysics.

To physicists, Hamilton is probably best known for his formulation of dynamics—Hamiltonian in-quantum mechanics. Also of importance to physical science is his theory of optical systems.

Many mathematicians associate him with quaternions, which Hamilton developed while trying to extend the two-dimensional nature of complex numbers to three-dimensional space. He devoted much effort to developing the idea of quaternions (an 800-page text, 109 papers, and an additional 700 pages of work uncompleted at the time of his death). To some, quaternions are interesting but only deserving of a footnote in the history of mathematics. However, as Hankins points out, they paved the way for the later development of vectors and vector-operator calculus. In fact, quaternions opened up the imaginations of algebraists at the time, which probably led to the development of the algebras of other useful quantities.

Hamilton, however, seems to have failed in his efforts to communicate with the physicists of the day; in fact, he forbade Tait and William Thompson (later Lord Kelvin) to include an appendix on quaternions in a text they were writing. He apparently thought that they couldn't do as well as he could in explaining these principles.

Besides learning about Hamilton, the reader of this book will gain insight into the scientific work of the period. I particularly enjoyed the section on light and optics (Hamilton also predicted conical refraction, which was subsequently verified experimentally). The discussion of the pro and con arguments in the French Academy (and later in the British Association) of both the corpuscular and undulatory theories of light is fascinating.

The book is divided into sections that treat separate aspects of Hamilton's life, including his early social life and marriage. His marriage seems not to have been the happiest—his wife suffered frequent illnesses, and they were separated at times while she was recuperating. Earlier in his life, he had wanted to marry Catherine Disney, but she married a man 15 years Hamilton's senior. This was a disappointment to Hamilton from which he never entirely recovered; throughout much of his adult life, he was unable to put Catherine Disney out of his mind. In the management of his personal affairs (marriage, children, finances), a lack of pragmatism was evident. In fact, Hamilton was in poor financial circumstances at the time of his death.

The section of the book that deals with religion demonstrates Hamilton's sensitive character. A member of the Church of Ireland (Anglican), he was concerned about the religious turmoil of the times, and agonized over religious matters, especially when the Oxford Movement was at its peak. The fact that some of his friends became Roman Catholic at this time caused him much grief. This was also a time of great political and nationalistic turmoil in Ireland, and religious questions were very much a part of all this. The hated tithes that Catholics were required to pay were the target of the Land Movement; mass refusal by Catholics to pay tithes caused great financial difficulties for Hamilton's Uncle James, a clergyman. This was the era following Daniel O'Connell's Catholic Emancipation struggle. It was the time of the Young Ireland Movement, Lady Wilde (Oscar Wilde's mother), and William Smith O'Brien. When O'Brien was convicted of treason, Hamilton interceded in his behalf to have the death sentence commuted.

For me, it was interesting to see 19th century Irish history through the eyes of a member of the Protestant Ascendancy. Though I have difficulty in squaring with Hamilton's views on the Union and the Established Church, he was obviously a genuinely concerned, sensitive, and ethical person.

Hankins' biography is, overall, very well written. Besides its slightly more than 400 pages of text, it includes 50 pages of notes. A quick reading is possible but will not do it justice.

Scientists in Power, *by Spencer R. Weart, Harvard University Press, Cambridge & London (1979). Clothbound, 276 pp. + bibliography, notes, and index, $18.50. Reviewed by Ernest Silver, Engineering Technology Division.*

Spencer Weart is the Director of the Center for the History of Physics, American Institute of Physics, and, as might be expected, he has done his research diligently. To a degree, the story he tells is one already familiar to those of us who have worked in nuclear technology since its early years. The book's subject is basically how the ideas for nuclear chain reactions for both bombs and power reactors developed in the war-threatened and war-torn world of the 1930s and the 1940s.

Weart shows us this history-making development from a unique viewpoint. We tend to think of this primarily as an American story, with input, to be sure, from European refugee scientists such as Teller, Wigner, Fermi, and others but, nevertheless, mainly an American epic. We know, of course, that the American project was undertaken because of a perceived threat that Nazi Germany was developing a nuclear capability (a threat which the late-war and post-war Alsos Mission showed to have been actually less immediate than was thought), but we still think of it as being mainly our story.

According to Weart, however, the saga, in its earliest beginnings, was chiefly a French story and did not even include the major part of the French scientific elite. It was, in fact, the story of a small group, socially and intellectually close-knit, gathered around Frederic Joliot, erstwhile laboratory assistant to Mme. Marie Curie and husband of her daughter and scientific heir, Irène.

The sense of time and place comes through vividly; it is a world of physics so removed from ours today as to be quite fascinating, and it was a *small* world. The physicists knew each other personally; they spent their working lives together in a small district in the Latin Quarter of Paris where most of the prestigious science schools and laboratories of France were concentrated and their summers together in the Breton seaside village of L'Arcouest clustering around Mme. Curie.

The book also describes the struggles of French scientists in the years between the two world wars to obtain sufficient research financing to permit young scientists to earn a living outside of the hidebound university system. In France, that system had been supplemented, since Napoleon's time, by the Ecoles Superieures. Through an old-boy network sanctioned by the government, the Ecole Superieures supplied the leaders in finance, technology, and science. Once stamped a *Normalien* or a *Polytechnicien*, a graduate of these schools (admission to which was by national competitive examination only) was assured a career in the military or the administration. Moreover, such leadership careers were closed to the graduates of even the most prestigious universities outside the Ecole Superieure system.

Another aspect of this story is the tie between politics and science. Many of the leading scientists of the younger post-World War I generation adhered to socialist or communist beliefs, were active in the political left, and looked to the Soviet Union as a model of the proper place of science in society. In particular, Francis Perrin and Paul Langevin, both mentors of the younger Joliot, were politically active leftists and influenced Joliot to move in the same direction.

The book reviews the early history of the solution of the "uranium puzzle," when unexpected half-lives and activities in neutron-irradiated uranium were discovered. Because the phenomenon of fission had not been suspected, increasingly complex and implausible isotope schemes of uranium decay were proposed. People like Meitner, Hahn, and Strassmann in Berlin, as well as an Italian group under Fermi and British workers at the Cavendish Laboratory, all worked on this problem, whose correct solution, namely fission, was at last guessed by Hahn and Meitner in 1939.

The book then follows the efforts of Joliot (who had by then won a Nobel Prize for demonstrating artificial transmutation caused by alpha irradiation of aluminum), with Hans Halban and Lew Kowarski, to verify the fission experiments and to establish the crucial fact that the fission of uranium produced neutrons, making possible a chain reaction.

It is amazing how soon the European scientists, especially Kowarski, came upon the ideas of heterogeneous reactors, reactors as power sources, and indeed, most of the fundamental ideas on which the entire nuclear energy enterprise has been based since then. These ideas, coming as they did when war was breaking out in Europe, were almost immediately embroiled with the war situation.

Leo Szilard, an outsider without money for research or support, had probably the clearest ideas about the war potential of chain reactions. He tried, without much success at first, to induce the scientists of the Allied nations to impose secrecy on their research results. He tried to take out patents on the chain-reaction process as a way of increasing interest in it and exercising some control over its use.

This patent idea was not unique to Szilard, however. Halban, who went to Canada, tried to get patents on fission reactors. He and Kowarski signed agreements with the British, based on those patent applications, that would have made the French full participants in the Anglo-American nuclear effort. However, when Halban reported details of the Allied atomic bomb program to Joliot in Paris in 1944, General Groves and other Americans were furious, believing that Joliot, a known left-wing sympathizer, would turn over to the USSR whatever he learned. The negotiations failed, and France was left out of the early nuclear bomb club to go it alone.

The remainder of the book deals with French efforts to build up nuclear research after the war at the Centre National de Recherche Scientifique, to establish the CEA (the French equivalent of the AEC), and to develop a major nuclear technology center at Saclay.

Although this part of the book makes interesting reading, by the time these efforts were being made the main current of the work had shifted to the United States. The account of the origins of the French posture on nuclear energy and the rapid development of the technology is illuminating. The "Canadiens" (i.e., those French scientists who had gone to Canada during the war, including Kowarski and Goldschmidt) took on the major responsibility in the new CEA. Joliot, although by then a full member of the French Communist Party, retained his leadership of the French nuclear enterprise as high commissioner of the CEA in command of all scientific and technical work.

In his somewhat brief description of the American atomic bomb effort (especially the eventually abandoned heavy-water approach at Argonne, tied closely to the Kowarski-Canadian effort), Weart makes one very thought-provoking point. He recognizes the sense of urgency felt by the American authorities who thought they were in a mortal race with Germany and says, "... a little more money spent at leisure during 1939-1941 on research and development might have saved enormous sums later on, and might even have shortened the war. The value of wide-ranging studies at an early point is worth remembering when new mammoth projects are touted as the solution to this or that national problem."

information meeting highlights

Chemical Technology, Dec. 10–11
Fuel Reprocessing Capsules

Solvent extraction of technetium. In the Purex process, a fuel reprocessing technique developed at ORNL, tributyl phosphate is used as a solvent to extract uranium and plutonium from the spent fuel of nuclear power reactors. A problem with this process is that the fission by-product technetium is dissolved and comes out of solution along with the uranium. When technetium contaminates the extracted uranium, it can cause operational problems in uranium enrichment plants and may even pollute the environment of the plants.

By studying the chemistry of technetium and using rhenium as a model in simulated reprocessing reactions, Dave Pruett and his colleagues in the Chemical Technology Division have derived equations that predict where technetium (in the form of the pertechnetate ion) will end up in a given spent fuel mixture under various process conditions including uranium concentration, acid concentration in the solvent, and temperature. Once they have more information on the effects of other constituents of the reprocessing mixture on the distribution coefficients of uranium and technetium, the researchers hope to refine the equations so that they can suggest ways to alter the Purex process to minimize the technetium contamination of the extracted uranium.

Solvent Extraction Test Facility. A portion of ORNL's Transuranium Processing Plant has been converted to the Solvent Extraction Test Facility. This facility is used to test solvent extraction flow sheets for reprocessing spent reactor fuels. The goal of these experiments is to find the best methods for separating reusable uranium and plutonium from spent fuels. Both irradiated light-water reactor fuel and simulated fast breeder reactor solutions have been used as feed in the SETF.

During partial partitioning experiments, the following methods were tested to control the amount of uranium recovered with the plutonium: addition of an inextractable nitrate salt, selective uranium extraction, and addition of an organic backscrub. During tests to back extract plutonium from the organic solvent, Dennis Benker and other ORNL researchers have found that either nitrous acid (HNO_2) or hydroxylamine nitrate (HAN) may be used as a plutonium reductant if the acidity of the aqueous phase is low and that if HAN is used, the traditional addition of hydrazine may be omitted.

Carbon-14 immobilization. Radioactive ^{14}C, a weak beta emitter, is produced in nuclear reactors by neutron interactions with ^{17}O, ^{14}N, and ^{13}C, which may be present in the fuel, cladding, and coolant. A large portion of the ^{14}C is released to various off-gas streams during the normal operation of nuclear reactors and when the spent fuel is reprocessed. To prevent this radioactive gas from getting into the environment, a process is needed to remove and immobilize ^{14}C, which usually appears in the form of carbon dioxide.

Now, a low-cost process for ^{14}C immobilization has been developed by Gary Haag, J. W. Nehls, and others in the Chemical Technology Division. By experimenting with various CO_2 absorbents, they have found the most effective to be barium hydroxide octahydrate. Their studies indicated fixed-bed reactors that contain barium hydroxide octahydrate flakes have desirable operating characteristics and are capable of high reactant utilization (>99%) and CO_2 removal (i.e., CO_2 concentrations in the effluent are <100 ppb). According to Haag, use of this immobilization process could further reduce the health hazards of the nuclear fuel cycle.

Preventing plutonium polymerization. One of the problems in the separation of plutonium in the Purex process is the formation of Pu polymers, which are the products of the reaction of Pu with water. Plutonium polymers are a problem because the polymer material behaves differently from ionic Pu and does not follow the ionic Pu through the separations procedure. Mac Toth and co-workers in the Chemical Technology Division have found that adding uranyl nitrate to the nitric acid solution inhibits Pu polymerization by hydrolysis. Apparently, the uranyl species occupies sites in the bridge network of the polymer, preventing it from growing or further reacting with more Pu.

Identification of residues in fuel dissolver solutions. The dissolution of spent reactor fuels is slightly less than 100% effective; usually a residue of less than 1% of the fuel weight remains undissolved. Until recently, such residues were uncharacterized and were of primary concern because they could not be properly processed further or left in the wastes without knowledge of their nature and composition. Dave Campbell and coworkers in the Chemical Technology Division, with assistance from Analytical Chemistry Division staff, have recently characterized dissolver residues from dissolution of several spent fuels. Such characterization enables the proper treatment or disposal of the residues.

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awards and appointments

Murray Rosenthal has been elected to the Louisiana State University Engineering Hall of Distinction.

J. M. McBrayer has been notified that his name is listed in the current publication of *Who's Who in Technology Today.*

Clarence F. Barnett and **Jack P. Young** have been elected fellows of the American Association for the Advancement of Science.

Elizabeth Von Halle has been elected to the Governing Council of the Environmental Mutagen Society.

Recently elected fellows to the American Physical Society are **Edward Arakawa, Fred Bertrand, John Hogan, Thomas Noggle, James Rome,** and **John Sheffield.**

Marvin Abraham has been elected a fellow of the American Ceramic Society.

Larry Corbin received an award of appreciation from the Nuclear Fuel Cycle Committee of the American Society for Testing and Materials.

Howard Dickson has received the Elda E. Anderson Award of the Health Physics Society.

The ORNL *Review* was awarded second prize in the 1981-1982 International Technical Publications Competition sponsored by the Society for Technical Communication. Recipients of the award were **Barbara Lyon,** editor, **Carolyn Krause,** staff writer, and **Bill Clark,** art director. Award of Merit (third place) was won by "Uranium Enrichment Annual Report," by **Charles Carmichael,** L. C. Toomer, **Ginger Turpin,** and Oak Ridge Gaseous Diffusion Plant.

At the 1982 publications competition sponsored by the East Tennessee Chapter of the Society for Technical Communication, the following ORNL staff members received awards: **Charles Carmichael** and **Ginger Turpin** (with L. C. Toomer of ORGDP), first prize in annual reports for *Uranium Enrichment 1980 Annual Report;* **Deborah Barnes** and **Alice Richardson,** second prize in annual reports for the ORNL *Institutional Plan—FY 1981-1986;* **Helen Braunstein, Paul Kanciruk, Dick Roop, Frances Sharples, Jesse Tatum, Kathleen Oakes,** and **Myrtleen Sheldon,** third prize in books for *Biomass Energy Systems and the Environment;* **Amy Harkey, J. S. Watson,** and **Brenda Breeden,** third prize in bulletins and brochures for *Conference Materials for the Symposium on Resource Recovery and Environmental Issues of Industrial Solid Wastes;* **C. A. Burtis, Alice Richardson,** and **L. H. Bell,** fourth prize in bulletins and brochures for *Symposium Announcement and Call for Papers: 14th Annual Symposium on Advanced Analytical Concepts for the Clinical Laboratory;* **Carolyn Krause,** third and fourth prizes in feature articles for "Reconstructing Past Climate" and "Of Mice and Mutagens," ORNL *Review;* **Jon Jefferson,** two fourth prizes in feature articles for "Embrittled Reactors: ORNL Studies a Tough Problem" and "It Couldn't Happen at the Laboratory? Don't Kid Yourself" in *Lab News;* **Irene Brogden** and **John Waggoner,** first prize in handbooks and manuals for *ORNL Site Planning, A Master Plan for Site Development;* **Barbara Lyon, Carolyn Krause,** and **Bill Clark,** second prize in house organs for the ORNL *Review;* **William Cottrell, Ann Ragan, Jane Parrott,** and the Nuclear Safety Information Center, second prize in journals for *Nuclear Safety;* **Edward Hagen** and **Ann Ragan,** first prize in journal articles and conference papers for "Common Mode/Common Cause Failure: A Review," *Nuclear Safety;* **Carolyn Krause,** fourth prize in journal articles for "DOE Review Seeks Answers on Carbon Dioxide," *EST News;* **Jon Jefferson** and **Bob Eldridge,** first prize in newsletters for *Lab News;* L. C. Toomer, Jack Kratchman, and **Ginger Turpin,** fourth prize in newsletters for *United States Enrichment News;* **Irene Brogden,** first prize in periodic progress reports for *Metals and Ceramics Division Annual Progress Report for Period Ending June 30, 1981;* **Natalie Milleman,** second prize in periodic progress reports for *Environmental Sciences Division Annual Progress Report for Period Ending Sept. 30, 1980;* **Cindy Robinson, Mike Watkins,** and **Larry Wyrick,** first prize in topical reports for *Toward a More Desirable Energy Future;* **J. W. Roddy,** and **M. G. Stewart,** second prize in topical reports for *A Survey: Utilization of Zeolites for the Removal of Radioactivity from Liquid Waste Streams;* **R. L. Graves, C. D. West, E. C. Fox,** and **Cynthia Chance,** fourth prize in topical reports for *The Electric Car—Is It Still the Vehicle of the Future?.*

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Dan Richter inserts a lysimeter plate to collect soil water for analysis. ORNL ecologists are studying the effects of whole-tree harvesting on forest productivity.