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review

Recovering Silver From Photo Wastes

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THE COVER: Electrochemists Franz Posey (front) and Al Palko have developed highly efficient methods of recovering silver from ORNL's photographic and photocopier waste liquids. See the article on page two.

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EDITORIAL

A Valedictory

This issue of the *Review* is the last one that will have my name on the masthead. By the end of September this year, I will have shifted gears, so to speak, and be launching into a new life-style. To have been associated with both this magazine and the Laboratory which it celebrates for 15 years has been a singular treat. The *Review* has come into a number of blessings in that time, a few of which are significant enough to mention here. Not the smallest of these blessings was the magazine's inception at the hands of Dave Sundberg. Dave, who had earlier designed and started *The Atom* at Los Alamos, was brought here from the editorship of *Nuclear News* in 1966 by Alvin Weinberg. Dave's assignment was to design an ORNL journal along the lines of the *CERN Courier*, published by the Conseil Européenne pour la Recherche Nucléaire in Geneva. The extent to which the *ORNL Review* never entirely measured up to those standards rests squarely on my shoulders, because Dave almost immediately moved on to directorship of the Office of Public Information and I then inherited the *ORNL Review*, which I have not relinquished till now.

In 1973, when the Laboratory underwent the gravest reversals in its history, Acting Director Floyd Culler personally saved the *Review* from falling as did many of the larger, crumbling programs. In 1975, shortly after taking office, the new director, Herman Postma, instructed the *Review* to supplant the Laboratory's annual report, an honor which we have since tried to live up to by offering in any four-issue series a broad cross section of Laboratory programs and research for the year covered. In that same year, Director Postma also gave his imprimatur to the acquisition for the *Review* staff of the leading science journalist in the area—Carolyn Krause. Carolyn, who, with Jon Jefferson, will take over the magazine from me, can claim principal responsibility for the international prizes that the magazine has since received.

Not the least of the blessings was the assigning, back in 1967, of artist Bill Clark to sole responsibility for the design of the publication. I am lucky to have had a chance to work with someone of his talents and discerning eye, and, with every issue, I have learned from him. He, too, has garnered many prizes for the *Review*.

Because no Laboratory director can afford the time to monitor the contents of the magazine's every issue, a mentor was assigned from the beginning to represent Laboratory management. First to critique and support the selection of manuscripts was Art Snell, who since has retired but who is, happily, in occasional residence. He guided with a light hand and infrequent mild demurral—an early supervision for which I will always be grateful. At his departure, we were again fortunate in the assignment as his replacement of Alex Zucker, a man of equally high scientific and literary standards. He has served as the magazine's severest critic and staunchest protector and will continue to ensure its high quality, as will the others remaining on the staff.

So, this slight alteration in the masthead marks no great change. The magazine will prevail. The loss is only mine.—B. L.

J. R. Jones inspects a Hazardous Waste sticker on one of the 176 210-L (55-gal) drums in which photocopier waste liquids containing silver are stored. It is hoped that up to 23,000 L (6000 gal) of this effluent will be run through the pilot plant to recover its silver.

Tom Oakes shows a silver ingot recently made of recovered silver from photocopier waste.

Silver Recovery from ORNL Wastes

By CAROLYN KRAUSE

There is a silver lining to the cloudy liquid wastes generated by ORNL's photographic and photocopying equipment. Nearly 107,000 L (30,000 gal) of waste liquids produced each year at ORNL contain silver, which had a market value of $10 per troy ounce in 1981 and as high as $40 in 1979. The precious metal has been recovered electrolytically from ORNL waste liquids since 1968, but interest in recovering a higher percentage of the silver content has been kindled recently because of new environmental regulations forbidding discharges of high concentrations of toxic metals.

ORNL chemists have now developed two processes for highly efficient recovery of silver from Laboratory wastes. Unlike hundreds of other researchers who have developed silver-recovery processes, their primary motivation was to remove a potential environmental hazard; to recover wealth from waste was secondary.

The wastes generated by ORNL's Photography and Reproduction departments contain silver ions in concentrations ranging from about 0.5 to 20,000 mg/L. These wastes must be treated before they can be legally discharged to the environment or to secondary sewage-

Gary Westmoreland inspects the silver ingot made by melting down silver extracted from ORNL wastes. On the left is a jar of cloudy photocopier solution that awaits treatment in the pilot plant behind him. At right is a jar of treated waste clean enough to meet legal limits for discharge into the environment.

treatment facilities. Tennessee law specifies that the acceptable discharge level to the environment for silver ions is 0.05 mg/L.

The state law is so stiff that electrolytic silver-recovery processes developed by private industry (including Eastman Kodak Company in Rochester, New York) cannot meet Tennessee's environmental standards for photographic effluents, even though the best electrolytic processes can recover 98% of the silver. ORNL's new processes, however, which are 99.99% efficient, can yield liquid wastes clean enough to dump down the drain.

There is a good reason for Tennessee's stringent law: besides being a precious metal, silver is toxic. Silver ions can destroy the bacteria used at secondary sewage-treatment plants to treat liquid wastes.

Because ORNL's photocopier, or photoreproduction, wastes contain high concentrations of silver, they have been stored in 208-L (55-gal), plastic-lined metal drums and plastic carboys. Now, however, these wastes are being treated in a pilot plant in ORNL's Chemistry Division. The pilot plant promises to save money in the long run because (1) the cost of chemicals used may be less than the current market value of the silver recovered and (2) ORNL will no longer have to spend an estimated $40,000 per year for disposal expenses, plus container costs and shipment fees.

Sharon Robinson checks the temperature of the 110-L (30-gal) reaction vessel used for testing the hypochlorite-hydrazine process of recovering silver.

The pilot plant uses sodium dithionite in a new silver-recovery process developed by Franz Posey and Al Palko of the Chemistry Division. (Palko is now retired.) Both men are electrochemists who developed various electrolytic methods for removing toxic metals from waste streams in the 1970s for the National Science Foundation's Environmental Program at ORNL. Ironically, they found they had to abandon the electrolytic approach and turn to traditional chemistry to find a practical, cost-effective, and highly efficient process for silver recovery.

Trial and Error

The story of how ORNL researchers became involved in extracting silver from wastes began in 1979 when ORNL's environmental coordinator, Tom Oakes, became concerned that the Laboratory's effluents were violating Tennessee and the Environmental Protection Agency's limits for silver. Oakes asked Joe Stewart and Marion Ferguson of the Analytical Chemistry Division to analyze photoreproduction wastes for silver. When they found that the content of the effluent sample exceeded the maximum level permitted by the EPA, Oakes banned the release of photoreproduction wastes to streams and ordered that these wastes be held in drums and carboys for subsequent shipment to a landfill or other approved disposal site.

Gary Westmoreland prepares to install a filter in the cross-flow filtration system used to filter out silver in hard-to-treat wastes from the storage area near Building 7000. Looking on is Mike Eisenhower.

Franz Posey adjusts the vent tube at the top of the 760-L (200-gal) stainless steel vessel which is part of the silver recovery pilot plant in Josh Johnson's laboratory in the Chemistry Division.

Photographic wastes are less of a problem. Since 1978 the Photography Department has recovered silver electrolytically from fixing solutions used to develop black and white photographs, papers, and films, including x-ray films. The department employs a metallic replacement method to recover silver from bleach-fix solutions used in developing color photographs.

Meanwhile, Oakes and Stewart discussed the need for ORNL to develop an efficient treatment process for silver-bearing photoreproduction wastes to meet environmental constraints and save ORNL the cost of disposing of a huge volume of liquid wastes, which contain colloidal silver from developer rinses and high concentrations of dissolved silver in fixer solutions.

In early 1980, Brian Kelly from Oakes' group was discussing the photographic waste problem with electrochemist Al Palko, an amateur photographer who develops film in his darkroom at home. During the conversation, Palko pointed out that he and Posey had tried electrolytic methods of cleansing waste streams of silver, mercury, lead, and other toxic metals as part of the Environmental Program. Kelly encouraged Palko and Posey to try developing a highly efficient electrolytic separation scheme for silver-bearing wastes.

Abandoning their corrosion studies temporarily, Posey and Palko set out to test a silver separation scheme that they thought would work well. Using porous graphite electrodes, they ran a process that recovered most of the silver but

was impractical because it re-released the silver ions within a short time.

More Silver Through Chemistry

Searching the literature, Posey and Stewart discovered approximately 10,000 papers, articles, and patent disclosures that relate to silver-recovery procedures. Those which appeared to be efficient enough to meet today's environmental limits for wastewater discharges presented other problems, such as formation of colloidal precipitates or sludges that are difficult to filter and may pose an additional disposal problem.

In their reading, they found that many silver-recovery processes use electrolysis, which normally removes 80 to 90% of the silver, not enough to meet EPA standards. Posey and Palko had tried electrolysis only to find that the process had two limitations. First, the silver thiosulfate complex at the electrode surface reacted with adsorbed hydrogen (an intermediate in a side reaction) to form silver sulfide, which plugged the pores of the graphite electrodes; because the electrodes became plugged quickly, they were no longer useful for removing silver from effluents. Second, the silver sulfide sludge was itself a disposal problem. Of course, silver could be recovered from this sludge, but only by using an expensive process.

The source of the silver sulfide problem is the thiosulfate fixer—usually sodium thiosulfate or ammonium thiosulfate—used to make a photographic image permanent. Although a developer is used to convert to silver metal the tiny amount of the film's silver halide that has been activated by light, a fixer is used to remove the large amount of unreacted silver halide so that it will not react further with light. Typically, more than two-thirds of the silver in the emulsion comes out in the effluent, which contains 5 to 6.5 g/L of silver.

Posey and Palko decided to experiment with the electrolytic solution to search for chemical reactions that prevent the formation of silver sulfide. They investigated methods of decomplexing the silver or converting the thiosulfate to another chemical form. They used electrochemical techniques to follow reactions in the photographic solutions involving oxidation (removing electrons) and reduction (donating electrons).

At one point, Posey suggested that they use sodium hypochlorite to get rid of the thiosulfate. He had read that hypochlorite had been

used in other silver-recovery processes for removing the thiosulfate. His idea, however, was to oxidize the thiosulfate by drawing the photographic solution into a reservoir of hypochlorite rather than by the commonly used reverse method of adding the hypochlorite to the silver effluent. By adding the fixer to the hypochlorite, he was able to maintain oxidizing conditions; this ensured that the silver liberated by oxidation of the thiosulfate reacted with chloride (reduction product of hypochlorite) to precipitate silver chloride, rather than the silver sulfide that precipitates under reducing conditions. The reaction was followed by monitoring the oxidation-reduction potential of an inert electrode in solution.

"In most processes," says Stewart, "the silver-bearing material is treated with hypochlorite, which turns the material into a black colloidal precipitate of silver sulfide, which is very difficult to filter. What Posey did was to reverse the process and run the fixer solution into the hypochlorite and add a few drops of a 'magic ingredient' to get the silver out in the form of a greyish spongy mass of agglomerated silver particles that can be filtered easily."

"Constructive Bumbling"

The magic ingredient was hydrazine, a powerful reducing compound of hydrogen and nitrogen used, in the anhydrous state, as a fuel in the United States space shuttle. Posey came upon hydrazine while experimenting with a number of reducing agents, doing what he calls "slopjar chemistry." When he tried diluted hydrazine on a fixer solution that had been treated with hypochlorite, it worked beautifully. Says Posey: "We found that only a few drops of hydrazine were sufficient to form a silver colloid in solution, which then coagulated into an easily filterable precipitate of pure silver metal. The principle of constructive bumbling works. Sometimes it's better to be lucky than smart."

Posey and Palko tried the new process on spent fixer from ORNL's Photography Department. They ran the fixer into a reservoir of hypochlorite and allowed the silver chloride precipitate to remain in the pot for a day "to let Doctor Time work on it," as Posey puts it. Then they added hydrazine and watched as the strong reducing agent converted the silver chloride to pure silver. Analysis by Stewart showed that hypochlorite-hydrazine treatment of the effluent significantly reduced its silver content, biological oxygen demand, and chemical oxygen demand. Once the silver was filtered out, the remaining solution was clean enough to pour down the drain. The recovered silver, according to Stewart's x-ray fluorescence analysis, was 99.9% pure, with just a trace of iron, magnesium, and bromine.

Palko then attacked the problem of recovering silver from the developer and developer rinse used in the Reproduction Department. Silver in photoreproduction developer eludes recovery because it is predominantly in the form of a colloid—a suspension of finely divided particles that tend not to settle out of solution and resist being filtered. Palko found he could precipitate the silver in filterable form by using hydrazine. Hydrazine apparently causes the silver ions to come out of solution and serve as nuclei for the agglomeration of the colloidal silver, which resembles black cottage cheese.

"The successful development of these silver-recovery processes," says Posey, "would have been difficult without the coordination of analytical services and continuing encouragement provided by Joe Stewart and his colleagues."

A Better Technique

In late 1981, when environmental managers at ORNL became concerned about the possibility of Laboratory pilot-plant operators being exposed to the toxic chemical hydrazine, Posey decided to try another chemical mentioned in the literature which has the advantages of being safer than hydrazine and cheaper than hypochlorite. The chemical, a powerful reducing agent used by the textile industry, is sodium dithionite; it had been tried by others before in silver-recovery processes but always produced what Posey did not want—silver sulfide.

Posey thought that, if the chemical were used under the right conditions, it might recover nearly all of the silver without making silver sulfide. Sure enough, he found that his goal could be achieved by properly controlling pH, adding reagents slowly, and using an argon or nitrogen blanket to prevent the sodium dithionite from reacting with oxygen from the atmosphere.

Subsequently, Posey and Palko showed that sodium dithionite can also act in the same manner as hydrazine for precipitation of silver from developer and developer rinse. This new process allows very efficient recovery of silver without the toxicity hazard associated with the use of hydrazine. Earlier this year they developed a thionite process for silver recovery from spent x-ray fixer. This modified process overcame the problem of the high alum content of x-ray fixer; alum interferes with the process used for silver recovery from photographic fixer. Finally, they developed a process for treatment of a mixed photoreproduction effluent containing the developer, developer rinse, activator, and activator rinse.

Recovery of Precious Metals

Recovery of precious metals such as silver, gold, platinum, and iridium has been performed at ORNL for 15 years. By recovering these metals from wastes and either selling or recycling them for further use, ORNL saved $1,804,409 in 1981 alone, according to Bill Graves, head of the Materials Department in the Finance and Materials Division. Most of the savings (slightly more than $1 million) resulted from recovery of iridium.

As for silver, ORNL saved $16,635 in 1981 by selling scrap x-ray film, silver-bearing scrap, and discarded hypo solution used in processing x-ray, black-and-white, and color film. Silver was recovered from solution by electrolytic, metallic displacement equipment located in ORNL's Photography Department. Discarded hypo solutions are collected from 13 locations in the Laboratory and delivered to the processing system. Arrangements for the transfer are made by Bill Longaker, field engineer in ORNL's Plant and Equipment Division.

Other film wastes are collected in silver-recovery cartridges, which are delivered to the Materials Department for sale on a bid contract arranged by the Purchasing Division.

Now that ORNL has a new silver-recovery process that is being tested in a pilot plant, there is hope that even more silver can be recovered for sale, not only from photographic film wastes, but also from 23,000 L (6000 gal) of photocopier wastes currently being stored in drums.

Posey and Palko's new silver-recovery "recipe" for mixed photoreproduction effluent addresses the problem of the effluent's acidity. "Sodium dithionite will not work properly in neutral or acidic solutions," Posey says, "so we had to raise the pH and make the solution basic." This was accomplished by adding water and ammonium hydroxide (ammonia) to the effluent to attain the proper dilution and pH. Ammonia also helps achieve agglomeration of the silver. After bubbling argon through the solution to protect sodium dithionite from exposure to atmospheric oxygen, Posey added the sodium dithionite and heated and stirred the mixture. All the silver was removed in pure form.

Pilot Plant

Enthusiastic about the processes developed by Posey and Palko, Stewart and Oakes asked the Chemical Technology Division to test these processes for ORNL effluents on an engineering scale and to evaluate the economics of treating ORNL waste, both the backlog and that currently generated. A small plant for treating 95-L (25-gal) batches, using the hypochlorite-hydrazine and sodium dithionite processes, was assembled in January. The plant, operated by Sharon Robinson, demonstrates the feasibility of scaling up the process. A subsequent engineering study determined that it would not be economically feasible to process batches on a small scale and that existing equipment could be used for process scaleup.

A decision was made to assemble a full-scale pilot plant using existing equipment in one of the laboratories of Josh Johnson in the Chemistry Division. The pilot plant, operated by technician Gary Westmoreland, is now being used exclusively to test sodium dithionite processes. Consisting of a 760-L (200-gal) vat and cross-flow filtration equipment to filter out silver from the liquid wastes, the pilot plant is conveniently located in Building 4500S, where photoreproduction wastes are generated, thus saving labor and money in getting the wastes to the silver-recovery plant.

Preliminary results indicate that all but 0.2 to 0.5 mg/L (0.5 ppm) of silver can be recovered from photoreproduction wastes in the new pilot plant. Discharge into the sanitary sewer system dilutes the remaining silver concentration well below EPA and Tennessee limits. "This meets EPA and Tennessee's limits for allowable silver in discharges of wastewater," says Mike Eisenhower of Oakes' environmental management group. Eisenhower has the responsibility of seeing that ORNL's treated discharges of silver-bearing wastes do not exceed environmental limits.

For each 570-L (150-gal) batch of photoreproduction waste run through the pilot plant, about 400 g of silver is recovered. Silver was worth only about $7 per troy ounce this past summer, but this value constantly changes and is likely to rise in the near future. Use of the new silver recovery process will save ORNL approximately $80,000 in disposal and shipping costs. At current values, recovered silver could be worth up to $25,000 annually.

ORNL has been concerned with the value of silver since the late 1960s when the precious metal recovery program began and when the last 67 of 14,700 tons of silver once used in the electromagnetic isotope separators was returned to the U.S. Treasury Department. Now, however, the value of silver is of interest because it not only saves ORNL money but also may permit ORNL to solve an environmental and legal problem in a cost-effective way. ornl

take a number

By V. R. R. Uppuluri

Fair Games with Dice

When a standard cubic die is rolled once, either one, two, three, four, five, or six dots appear on the top face. When the die is not loaded, each of these six events occurs with probability 1/6.

One can make a fair game between two players A and B, where, in a single roll, player A wins if the number of dots appearing on the top face of the die is either 1, 2, or 3 and player B wins if 4, 5, or 6 dots appear. Thus, with one die and one roll one can have a fair game in which the chance of either player winning is 50:50.

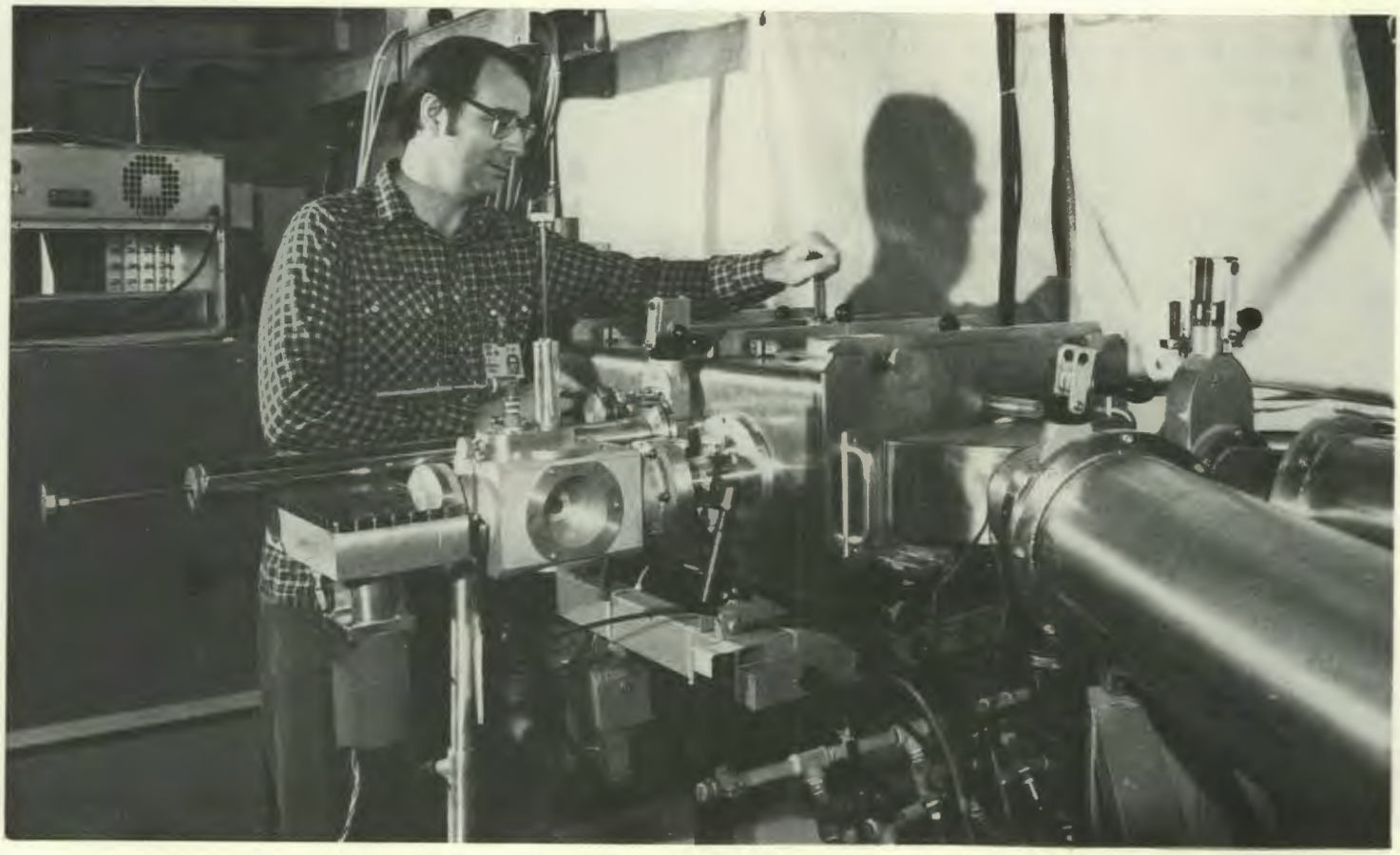
Let us generalize the conditions used for a single die into rules for a simple game with any number of dice: None of the totals that may appear on the top faces in a single roll can be neglected, and the two players have an equal number of choices. It is interesting to note that, under these rules, no such fair game between players A and B is possible when two dice are rolled once and the total number of dots on the top faces determines the winner.

Once again, when three dice are rolled once and the total number of dots on the top faces determines the winner, a fair game (50:50 odds) between players A and B is possible. More specifically, player A can opt to win if the total number of dots on the three faces is less than or equal to 10. The probability of this event is 1/2.

In general (unless we add complexity to the rules), when we roll an even number of dice once, no fair game with even chances between two players is possible; whereas when we roll an odd number of dice once, such a game is possible.

A Property of Triangles

In a plane, let A, B, and C denote the three vertices of a triangle and let *a* denote side BC, *b* denote side CA, and *c* denote side AB. If angle B is twice angle A, then $b^2 = a^2 + ac$. The converse of this statement is also true: if $b^2 = a^2 + ac$, then $B = 2A$.



Ron Mlekodaj of the UNISOR staff lowers the focal plane, which has slits for selecting mass-separated beams for study.

UNISOR: *The First Decade*

By RUSS MANNING

Most of what physicists know about the structure and behavior of the atomic nucleus has come from experimental work with stable or nearly stable nuclei. These stable nuclei exhibit characteristic neutron-proton configurations, or ratios, which make them stable, placing them in what is called the "valley of stability."

Russ Manning is a former ORNL employee who left the Chemical Technology Division in 1976 to pursue a writing career. Since then his articles on science, travel, and the outdoors have appeared in numerous periodicals across the country. His writing has won awards from the East Tennessee Chapter of the Society for Technical Communication and the Tennessee Outdoor Writers Association. He is currently a science writer and editor for ORAU. Photographs for this article were taken by ORAU photographer John M. Richards, Jr.

Several rather successful nuclear structure models, such as the shell model and the collective model, were partially based on this strong correlation between proton and neutron numbers of the stable nuclei. To further test the validity of these models, many physicists believed it necessary to study nuclei with proton and neutron numbers different from the stable and near-stable nuclei (i.e., unstable, or short-lived, nuclei).

That was the purpose of establishing the University Isotope Separator at Oak Ridge in 1971, an isotope separator on-line to the Oak Ridge Isochronous Cyclotron at ORNL. The higher energies and heavy-ion beams available at ORIC made it possible to produce nuclear reactions yielding isotopes far from stability, those with half-lives of less than 100 seconds.

An isotope separator was needed, explains Gene Spejewski, director of UNISOR, "because all the processes we know about for making unstable isotopes pro-

duce not just the specific nuclide for study, but a whole family of nuclides. To do any kind of reasonable experiment, we had to make a separation of some kind."

UNISOR was formed as a user group to involve researchers from various institutions. Several universities joined the project, and the State of Tennessee provided funds for the separator. Oak Ridge Associated Universities agreed to act as the fiscal agent, and so UNISOR became a division of ORAU. Over the years, DOE has supplied most of the funds for operating expenses.

Ten universities renewed their UNISOR participation in 1981. Investigators from these and other research institutions are supported by the UNISOR staff, which is responsible for development and maintenance. Ron Mlekodaj and Ken Carter have worked with Spejewski since the early years; Georg Leander recently joined the staff as a theoretician.

An executive committee made up of one representative from each member institution oversees UNISOR. The committee currently is headed by Lee Reidinger, acting chairman of the Physics Department of The University of Tennessee, Knoxville. Once a research proposal is accepted by the program advisory committee of the ORNL Holifield Heavy Ion Research Facility, all UNISOR member institutions are invited to participate in the approved experiment.

Facility Development

A formidable task during the first ten years of UNISOR has been the development of the facility, connecting all the major components—the accelerator, the isotope separator, the collection and measurement devices—and developing the capability to produce and study nuclei that appear interesting.

"Physicists have known for a long time how to make unstable nuclei," says Spejewski, "and we've known how to make mass separations. But with most such projects, the problems are in the interfaces, in connecting the pieces together."

To produce nuclei far from stability, a target material is bombarded by a heavy-ion beam which travels down an evacuated tube from the isochronous cyclotron at energies of 50 to 200 MeV. The heavy ions available from ORIC include those of carbon, nitrogen, oxygen, and neon. With the recent addition of the 25-MV tandem accelerator at HHIRF, beams of higher energy and higher mass are now possible.

The product nuclei that result from the collision of the heavy ions with the target are highly excited and spew out neutrons to make unstable neutron-deficient nuclei. An initial interface problem was how to get these product nuclei from the target to the isotope separator before decay is complete. (The nuclei eventually undergo

beta decay to more stable configurations of protons and neutrons, which places them back in the valley of stability.) It was first necessary to get the product nuclei into an ion source.

Because of the large linear momentum of the heavy ions, the product nuclei recoil out of the target and are trapped in a catcher, usually graphite felt mounted in the wall of an ion source. To get the product nuclei to diffuse out of the graphite and into the source, the UNISOR staff designed the ion sources to reach high temperatures of 1000–1800°C. Current development of sophisticated ion sources that can attain higher temperatures of 2500–3000°C makes it possible to study more isotopes, especially the difficult lead, bismuth, and gold isotopes and the rare earths.

Once the product nuclei have vaporized into the ion source, they are ionized (usually by an electrical discharge), extracted by means of an electric field, and accelerated down a second beam tube to the isotope separator.

An alternative method is a recently developed helium-gas jet system in which the product nuclei are stopped in the helium and pumped into an ion source, eliminating the need for a catcher. This new project is coordinated by Dennis Moltz of the ORNL Physics Division, with pieces of the system constructed by several member universities. Although not as efficient as the standard technique, it eliminates the time necessary for vaporization, an important factor when studying isotopes that are very unstable and thus very short-lived.

Once in the isotope separator, the product nuclei are electromagnetically separated according to mass. Defin-

Dennis Moltz adjusts the new helium-gas jet system, which when coupled to an ion source, will eliminate the need for a graphite catcher and, thus, the time necessary for vaporization. Moltz completed post-doctoral work at ORNL and recently became a research associate with the University of South Carolina, assigned to the ORNL Physics Division.

ing slits then select mass-separated beams of individual isotopes for study.

Another interface problem was the collection of the mass-separated nuclei and delivery to the measuring devices which monitor the decay process to determine, for example, isotope decay rates and energy losses via emissions. At first, aluminum-coated mylar tape transport systems powered by three motors were used. More recently, the UNISOR staff developed a simplified system using a continuous loop of common 8-track recording tape mounted on a single reel and driven by a single motor.

Two of the mass-separated beams travel down beam tubes and are focused onto these transport tapes. A third beam is collected at the separator. The tapes carry the deposited nuclei to detectors.

Because the UNISOR facility is designed mainly for decay-spectroscopy measurements, various detectors are used (germanium, silicon, sodium iodide, and plastic) for energy spectra and timing measurements of gamma rays, x rays, conversion electrons, and alpha and beta particles. Computer-based systems are used for data acquisition, analysis, and control of the experiments.

To aid in the analysis, a nuclear orientation facility has been proposed which will use a magnetic field and an extremely cold temperature (15 mK) to align the intrinsic angular momentum of the nuclei. Emitted gamma rays will form a pattern as a function of angle around the aligned direction of nuclear spin, which will allow the researchers to deduce the spins and parities of nuclei.

A fourth mass-separated beam line is directed to a newly installed laser optical spectroscopy system which can be used to precisely determine the hyperfine structure of atomic levels that result from the interaction of the nucleus with the atomic electrons. These measurements enable the researchers to independently measure certain ground-state properties, in particular the ground-state spins of odd-mass nuclei.

The new laser system contains a dye laser in which the molecules of an organic dye absorb the light of an argon pump laser and become excited. In making the transition down to the ground state, the molecules emit light in a continuum. The dye laser can then be tuned to pick out a particular frequency, which is used to excite the hyperfine structure in the atoms or ions.

Ken Carter of the UNISOR staff and Carrol Bingham of UT have done much of the work with the laser system. "While the fundamental principles of hyperfine structure and isotopic shifts have been known for more than 40 years," says Carter, "the use of dye lasers has made it possible for researchers to apply these principles to nuclei with very short half-lives and of very small quantities."

Nuclear Physics

Of the approximately 5000 isotopes thought possible, UNISOR during its first decade has characterized over 50 new ones, establishing half-lives, energies and intensities of gamma rays, and alpha decay energies, and determining masses using positron-endpoint energies.

During this work one of the important contributions of UNISOR has been the study of nuclear shape. "Nuclear physicists like to study various aspects of nuclei," says Reidinger of UT, "but a recurring theme is shape. Once that's understood we can then go on and understand the finer details of nuclear structure."

UNISOR made its reputation studying the mercury-thallium region. "Many new things turned up there that we had never seen before," says UNISOR's Mlekodaj. One of these was shape coexistence in even-mass mercury isotopes. In the early 1970s, measurements of the root-mean-square radius of mercury isotopes at the European Organization for Nuclear Research in Geneva indicated a sudden change in shape between the heavier and lighter isotopes, from mercury-187 to -185. The researchers at UNISOR began looking at many different states of isotopes in this region, first in mercury-188, and then by 1976 with Joe

Hamilton and the Vanderbilt University group, they had moved out to mercury-186 and -184.

From these studies, UNISOR accumulated evidence for the coexistence of a nearly spherical shape and a prolate, or football, shape at slightly different energies in each of several mercury isotopes. They had observed crossing spectral bands built on different nuclear shapes. "We were able to see the band members (nuclear energy states) belonging to a given shape both above and below the crossing point in both bands," explains Spejewski. "This was the first clear demonstration that there really was that kind of structure—two states with rotational bands built on them, with different kinds of deformations for the states."

All of this was quite unexpected at the time because mercury is close to lead, which has a closed nuclear proton shell. It was thought that there could not be deformed shapes near closed shells, so finding deformed shapes this close to lead's "magic" proton number was surprising.

In their work with odd-mass, neutron-deficient gold, mercury, and thallium isotopes, the UNISOR group with the help of Ed Zganzar of Louisiana State University found, in addition to the near-spherical and prolate shapes, a nonaxially symmetric (triaxial) deformed shape—something like a flattened football. Finding it in all three of these elements demonstrated that triaxiality is a general feature of nuclei in this region.

The researchers also found that they could successfully apply a simple model that described an odd-mass nucleus as a single nucleon coupled to a core of tightly bound pairs of neutrons and of protons. The single particle in a sense acts as a probe of the structure of the rest of the nucleus and in particular can tell something about the shape. The model fit the UNISOR data so well that it was used to describe the shape of nuclei and to predict the different kinds of deformations and couplings in the gold-thallium region.

Studies with the odd-mass thallium isotopes also demonstrated that problems existed in the classical shell model description of nuclei. The researchers observed energy states, which should have been up in the next-higher shell in the shell model, moving down and intruding into the next-lower major energy shell. If a simplified view of the classic shell model were correct, these states could not have existed at such a low energy. This was an experimental demonstration that the shell model and magic numbers depend on the position of the valley of stability. If the region of stability had happened to extend through a different group of nuclei, it might not have been so easy to recognize a pattern of magic numbers to formulate a nuclear shell model. In fact, the magic numbers are not magic far from stability.

Barry Ritchie (left), a 1979 Ph.D. student with the University of South Carolina, and Jerry Cole set up a coincidence system which takes measurements with pairs of detectors.

Recently, work with old UNISOR data on the structure of odd-mass gold isotopes has supported the idea of supersymmetry in nature, which is incorporated into one of the more recent nuclear models, the Interacting Boson-Fermion Approximation. In this model, paired nucleons, bosons, interact with an odd fermion, a single nucleon. Supersymmetry is the case when these particles, having quite different properties, behave similarly. John Wood of the Georgia Institute of Technology has demonstrated that the supersymmetric scheme of the IBFA explains much of the systematics of gold-193.

In addition, Ken Toth of the ORNL Physics Division has been making a systematic investigation of alpha-particle decay in neutron-deficient isotopes between tin and lead. In contrast to the mass region above lead, alpha decay in this region is rarely observed; although most nuclei between tin and lead are alpha-particle unstable, their decay energies are small enough to make their alpha decays difficult to observe. As these nuclei become more neutron-deficient, however, their decay energies increase and alpha decay begins to be observable. "Measuring an alpha-particle energy gives us a handle on the mass of the nucleus we're looking at," says Toth, "which is something that gamma-ray studies don't normally provide. Alpha-decay energies therefore give us an excellent way to test predictions of mass in nuclei far from stability. I should also add that alpha decay is an extremely convenient way to identify new

Gene Spejewski, director of UNISOR, and Ken Carter of the UNISOR staff discuss an experimental run at the isotope separator control console.

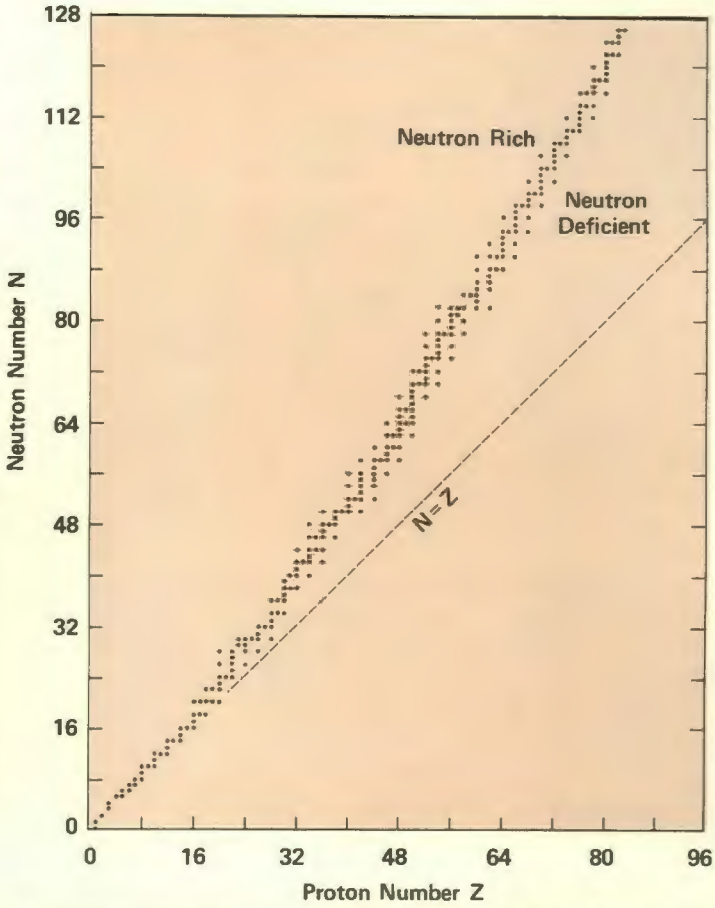
isotopes whose properties can then be examined in more detail by using other techniques."

Moltz of ORNL has been involved in positron end point energy studies, which determine mass differences following positron decay. A positron spectrometer for these studies was recently developed by Frank Avignone at the University of South Carolina with help from Bernard Kern of the University of Kentucky and physicists at ORNL. Experiments have been run with rubidium and krypton isotopes. "If the mass of the decay daughter is known," says Moltz, "then the mass differences can be used to extrapolate back to the mass of the nucleus farther from stability. What we end up doing is, in a predictive sense, checking mass formulas, at least parts, since none work consistently well in all areas."

"That is one of the most important comparisons we can make," says Spejewski, "because, in a sense, everything we know about nuclear physics is embodied in these mass formulas. If we can predict the masses of nuclei, we are closer to understanding nuclear structure."

The Future

The researchers at UNISOR will continue to study the gold-mercury-thallium-lead region, which has proven to be so rich in information. "We want to extend farther from stability," says Spejewski. "Our history has



The proton and neutron numbers of the stable nuclei define the valley of stability. To one side of this stability line, unstable nuclei are neutron rich; to the other side, neutron deficient. Exotic nuclei to either side decay by beta emission, each, in effect, becoming a different chemical element, until they reach a proton-neutron configuration which places them back in the valley of stability. Physicists would like to establish decay schemes starting far to one side of stability, passing through stability, and extending far to the other side. By characterizing the different isotopes in the decay schemes, the physicists test the predictions of nuclear structure models.

UNISOR Consortium

University of Alabama at Birmingham
Furman University
Georgia Institute of Technology
University of Kentucky
Louisiana State University
University of South Carolina
Tennessee Technological University
The University of Tennessee
Vanderbilt University
Virginia Polytechnic Institute and State University
U.S. Department of Energy
Oak Ridge National Laboratory
Oak Ridge Associated Universities
State of Tennessee

shown that every time we're able to expand the region so that we can make more experimental measurements, we find something different and interesting."

The higher-energy beams from the tandem accelerator will make it possible to extend the mercury studies to the lighter 182 and 180 isotopes. And the heavier calcium beams can be used to produce the 184 and 186 isotopes of lead.

In addition to the Z = 82 region of lead, the Z = 50 region of tin should also be rich in nuclear structure information. Theoretical calculations show that another interesting area contains the neutron-deficient cerium nuclei. Positron end point energy measurements, alpha-decay measurements, and laser hyperfine structure measurements will continue. The helium-gas jet system will be used to try to discover new nuclei farther from stability.

The UNISOR group would also like to produce nuclei with a neutron excess—all they have studied thus far have been neutron-deficient nuclei. Although neutron-excess nuclei are usually produced using neutron beams from reactors, some nuclear reactions with heavy ions produce nuclei that are neutron rich. So far, however, UNISOR researchers have been unsuccessful in producing any. With the heavier ion beams from the tandem accelerator, they will try again.

"We'll continue to increase the capabilities of the facility," says Spejewski, "so that we will be able to look in any new directions that appear important in the light of new ideas or experimental results. By developing the technology, we hope to be able to take advantage of the possibilities of finding new and interesting physics."

"A major accomplishment of UNISOR in its first decade," says Paul Stelson, director of the ORNL Physics Division, "has been to bring together nuclear physicists from the ten or so universities which were somewhat isolated and lacked the facilities to do interesting experiments. By coming together, they were able to build up a set of equipment and techniques that is competitive on a worldwide basis. UNISOR transformed the way nuclear physics is done in this part of the country. I see a bright future." ornl

GLOSSARY

BETA DECAY—An unstable nucleus decays by undergoing spontaneous transmutation involving transformation of a nucleon and beta emission; depending on whether the nuclide is neutron rich or neutron deficient, either (1) a neutron within the nucleus decays to a proton by emitting an electron and an antineutrino or (2) a proton within the nucleus decays to a neutron by emitting a positron and a neutrino.

CLOSED SHELL—In the nuclear shell model, a shell is filled, or closed, for nuclei near stability when the number of neutrons or protons equals a magic number (see MAGIC NUMBERS).

GROUND STATE—Atoms or nuclei in excited states tend to return to the ground state, the lowest possible energy state of the system.

HYPERFINE STRUCTURE—The interaction of the atomic nucleus with the atomic electrons causes a shifting, or splitting, of the atomic energy levels and is seen under high resolution as a hyperfine structure of the atomic energy spectrum.

MAGIC NUMBERS—The binding energies of a nucleus are unusually large if the number of neutrons, protons, or both is one of the magic numbers 2, 4, 8, 20, 50, 82, or 126.

NUCLEAR SPIN—Because neutrons and protons behave as though they are spinning, nuclear spin is the result of the spins of the neutrons and protons of which the nucleus is composed and is represented by either an integral or a half-integral number. The spinning nucleus possesses an angular momentum.

NUCLEONS—The constituents of the nucleus, the protons and the neutrons, are referred to by the general term, nucleon.

PARITY—Only in wave mechanics can a system of particles possess parity, which describes how the mirror image of a system behaves; parity is positive if the mirror image is the same; negative if it is different.

POSITRON END POINT ENERGY—Because the total energy released in beta decay is shared by the two emitted particles, the energies of the positrons are not distinct but form a continous spectrum. The maximum is the end-point energy and represents the total energy released in decay.

ROTATIONAL BAND—A deformed, or nonspherical, nucleus can rotate about its nonsymmetrical axes, causing a flopping motion; the allowed energy states of such rotations cause a distinct pattern, a rotational pattern, in the energy spectrum of the nucleus.

Z—The symbol Z is used to denote atomic number, that is, the number of protons in the nucleus.

BOOKS

Polywater, *by Felix Franks, MIT Press (1981). 208 pp., $15.00. Reviewed by Ellison Taylor, consultant to the Chemistry Division.*

About ten years ago, the short, silly life of polywater came to an end, not with a single clean shot, but with the steady accumulation of evidence that everybody's samples of supposed polywater were simply samples of water contaminated with salt, silica, sweat, or what have you.

In case you've forgotten, "polywater" was one name given to a supposed new form of liquid water thought to be discovered in Russia in the early 1960s. N. N. Fedyakin started it with a paper, "Changes in Structure of Water Condensed in Capillaries." He and his research moved almost at once from Kostroma to the Moscow Laboratory of B. V. Deryagin, a surface chemist of wide fame who became the chief protagonist of what they called "modified water."

In June 1969 a group led by Ellis R. Lippincott of the University of Maryland published infrared and Raman spectra of a similar material and proposed both a polymeric structure and the name "polywater." For a few months, polywater attracted the attention of such publications as the *New York Times* and the *Wall Street Journal*, but within about a year, it was shown to be ordinary water having dissolved impurities—just a brief aberration of science, quickly discovered by the usual process of repetition.

The author of *Polywater* is Felix Franks, well known to chemists and others as the editor of a multivolume treatise on water. The dust jacket notes that he is known in the trade as "Water Franks," and in the text he admits to having acquired the label of water expert.

As far as I can tell, Franks has the history straight. Further, he provides information not easily available otherwise on unpublished activity by the British in the field. However, be careful what you believe. Many of his explanations for the nonscientist and other items of information are completely wrong.

After a prologue, Franks begins with an introduction to the properties of ordinary water, one of them being the specific heat. Here he propounds a rule: ". . . and yet another rule states that the specific heat of a solid is higher than that of the same substance in the liquid state." None of my chemist friends has ever heard of this rule, and a casual search turned up 17 inorganic compounds that follow the "rule" and 54 that do the reverse. With organic compounds, the score was 0 for and 5 against. Some rule! It is true that water shows a wider difference than most substances, but it is merely an extreme example of the usual behavior, not an exception to any rule.

Franks gets into even worse trouble when he tries to explain the high specific heat of water. He points out correctly that the specific heat of ice is about half that of liquid water, and then says, ". . . when energy is supplied to liquid water, only half of it is used to raise the temperature; the remainder is stored away in the bulk of the liquid." He seems to believe that there are certain degrees of freedom in water ("the bulk of the liquid") which can somehow absorb heat but do not participate in exhibiting the temperature of the liquid, that is, which would not return heat to a thermometer (or a finger) at a slightly lower temperature when immersed in the liquid.

An apparent bit of irony trips up the author at another point. In discussing Ellis Lippincott, the spectroscopist whose paper brought polywater fever to the United States, he lists Lippincott's credentials, including the fact that he had been awarded the "Hildebrand" medal. "This turned out to be particularly ironic because Joel Hildebrand, one of America's premier chemists, was to take a quite uncompromising stand against all his fellow scientists who had been naive enough to take Deryagin seriously." The real irony is that Lippincott's medal was the "Hillebrand" medal, named for William Francis Hillebrand, the famous analytical chemist at the National Bureau of Standards a generation ago. Given by the Washington, D.C., Section of the American Chemical Society, it is a natural for a prominent chemist at the University of Maryland.

Franks ridicules the American press for playing up American vs Russian contributions, but he chooses an unfortunate example. He says, "The more subtle way of searching for a non-Russian originator of polywater is exemplified by an in-depth account of polywater in the *Saturday Review* of September 6, 1969. Here we are told about an American chemist, Walter Patrick. . . . One of Patrick's students, a Russian immigrant named J. L. Shereshefsky. . . found that water in capillaries had an even lower vapor pressure than that predicted from its curvature by the Kelvin equation. . . . This manner of tracing developments back to their true origin is fairly pointless. . . . Quite apart from this, Fedyakin, working on his own in faraway Kostroma, must have been

completely unaware of the existence, let alone the work, of one Walter Patrick." The fact is that the first reference in Fedyakins's first paper is to Shereshefsky. So much for the presumed ignorance prevailing in faraway Kostroma.

I have not discussed the more general aspects of the book. Perhaps I should have ignored the mistakes, but nothing is more fun for the self-righteous than uncovering error. And, on the subject of polywater, self-righteous is what I am, according to Franks, in my article "The Great Polywater Doodle," ORNL *Review*, Winter 1971.

Resources and Development, *Peter Dorner and Mahmoud El-Shafie, eds., The University of Wisconsin Press (1980), 506 pp, $25.00. Reviewed by A. D. Kelmers, Chemical Technology Division.*

"Among the features often observed in areas of shrinking resource production are persistent unemployment, uneven economic response (even to sharply increasing prices), frequent year-to-year instability in production, and technological stagnation." When I opened this book on the New Book Shelf in ORNL's Central Research Library, this quote caught my eye. Nothing could better characterize the domestic minerals and metals industry. *Resources and Development* is a compilation of contributions to a seminar on Natural Resource Policies held at the University of Wisconsin in 1977–1978. The presentation is unusually lucid, and the book contains a new and perceptive view of long-range aspects of resource availability.

The seminar took a new approach to problems of resource development, and the chapters contain many new and exciting ideas—some of which may be relevant to ORNL's Strategic Materials/Resource Recovery activities. The "Club of Rome" impending-crisis approach to future resource and demand limits, which was in vogue in the early 1970s, is refuted. Based on the existing information on known reserves (for minerals, fuels, or foods) and an exponential increase in consumption, this approach showed that, for most resources, a supply-availability crisis which would limit future growth would develop in only one or two decades. The authors compare the experience of the past decade with the predictions of such models. Experience showed something quite different: Exploration for minerals and even for oil has outraced consumption. Not only has consumption not increased exponentially, the rate of increase for most resources has actually decreased. For many minerals and metals, the long-term trend is toward decreased per capita consumption in the United States. Thus, no limiting resource crises exist.

The authors accept that all nonrenewable resources are finite. However, they point out that attempts over the past 30 years to predict when limits might occur have been so poor (nearly all predictions have been wrong, some dramatically so) that the best that can be said at this time is that we do not know how to make such predictions. For example, over the last decade not only has the amount of copper in proven reserves increased, but even the grade of copper ore has improved. Also, despite a doubling of crude oil consumption each decade, proven reserves have continued to expand more rapidly than consumption. In the uranium industry, consumption in the 1980s and 1990s will be much lower than predicted, making proven reserves of uranium ores now appear adequate to last until well into the next century.

Chapter 2, "Availability of Mineral Resources," is especially pertinent and may be particularly useful to staff members having interests in the strategic materials/resource recovery areas. Two aspects of the minerals and metals industry mentioned are particularly relevant. Although no resource limits exist, there is a maldistribution on the earth's surface. For example, the world chromium supply is concentrated in South Africa, cobalt in Zaire, platinum in the Soviet Union, and coal in the United States. Maintaining easy world access to the resources is a political problem and is not amenable to a technological fix. Also, the authors state, there are ". . . two main categories of technological change of interest in mineral production: (1) industry-specific advances that increase resource availability or lower costs or both [and] (2) application to mineral production of general technological advances. . . . Only the first kind of technological change might be stimulated by increased market prices for mineral raw materials. Unless (or until) raw materials and energy constitute a much larger fraction of the total cost of final products, it is wishful thinking to suppose that increased difficulties in mineral production will by themselves bring about broad-front technological change of the second type."

Subsequent chapters discuss market structure, economic and social development, food and population, international order and law, and socioeconomic-resource modeling studies. The final chapter addresses the question of "Resource and Developmental Policies." The authors recognize that rapid popu-

lation growth and the desire of new nations for more rapid economic growth and development have brought a fundamental change in resource use and availability. They suggest that novel policies will be required to deal with resource issues and that free trade can no longer be expected to do an acceptable job (i.e., price cannot be the only agent for determining resource use and consumption). They suggest joint action and international cooperation—some sort of "global compact" to administer power and eliminate resource-development abuse. Research on policy questions is vital to a determination of developmental strategies and policies in the public interest.

To some extent these conclusions may be seen as self-serving. The seminar was cosponsored by the Organization of Arab Petroleum Exporting Countries, the Arab Fund for Economic and Social Development, and the Kuwait Fund for Arab Economic Development. Nonetheless, developing nations are in a position to make their voices heard in the future on resource policy, and it would be to our advantage to be aware of their views.

Books in Print

The following books now in print have been written or edited primarily by ORNL staff members:

Laser and Electron-Beam Interactions with Solids, B. R. Appleton and G. K. Cellar, eds. North-Holland, New York (1982).

Histological Atlas of the Laboratory Mouse, William D. Gude, Gerald E. Cosgrove, and Gerald P. Hirsch. Plenum Press, New York (1982).

Light Water Reactor Nuclear Fuel Cycle, Raymond G. Wymer and Benedict L. Vondra, eds. CRC Press, Boca Raton, La. (1982).

Scientific Basis for Nuclear Waste Management, Vol. 3, John G. Moore, ed. Plenum Press, New York (1982).

Introduction to Nuclear Reactions, G. R. Satchler. John Wiley & Sons, New York (1982).

Advances in Molten Salt Chemistry, Vol. 4, Gleb Mamantov and J. Braunstein, eds. Plenum Press, New York (1982).

Water Chlorination: Environmental Impact and Health Effects, Vol. 3, Robert Jolley, William A. Brungs, and Robert B. Cumming, eds. Ann Arbor Science Publishers, Inc., Ann Arbor, Mich. (1982).

Defects in Semiconductors, J. Narayan and T. Y. Tan, eds. North-Holland, New York (1982).

Analytical Chemistry in Nuclear Technology, W. S. Lyon, ed. Ann Arbor Science Publishers, Inc., Ann Arbor, Mich. (1982).

Proceedings of the Second International Symposium on Molten Salts, Jerry Braunstein and J. Robert Selman, eds. The Electrochemical Society, Inc., Pennington, N.J. (1981).

Mechanisms in Respiratory Toxicology, Vol. II, Hanspeter Witschi and Paul Nettesheim. CRC Press, Boca Raton, La. (1981).

readers' comments

To the editor:

John Googin's article on the flywheeled automobiles and the high mileages obtainable (Fall 1981) was dynamic and good reading. However, one question arose in my mind: does such a car have a cigarette lighter? The human element enters; the mileage achievable might depend upon whether or not the driver is a smoker.

A. H. Snell, consultant
Physics Division

Author Googin replies:

Art Snell's comment on the implications of the low energy requirements of the possible future car is most stimulating.

On the matter of the cigarette lighter, there is no problem with a flywheel-containing system. Just as one can have high acceleration rates, one can have any size lighter one wishes up to a multihorsepower plasma torch, as long as there is a healthy time interval between smokes. The problem comes from such persistent energy-consuming devices as headlights and high-powered speakers for the radios and tape players. These could considerably reduce the mileage and the cruising speed.

The car of the future should have a minimum of efficient lights and a maximum of reflectors. It should have individual headsets for the music system and no regular speakers.

With good insulation and double windows there should be no problem with heating, but there is a cooling problem. Perhaps the comfort problem in hot weather will be solved by using the small amount of waste heat from the power plant to supply dry air to allow full use of the occupants' personal cooling systems.

An oil company's drilling rig, rising against a backdrop of Wyoming mountains, embodies the tension between resource development and wilderness preservation. This rig is next to a proposed wilderness tract; the U.S. Forest Service recommends allowing exploratory drilling within the tract itself. (Photograph by Chip Rawlins.)

Minerals in the Wilderness:

how important are they?

by JON JEFFERSON

Picture yourself overseeing millions of hectares of federal land in the western United States. It's your job to plan the uses for the land in a district larger than several of the smaller eastern states combined.

The land currently provides grazing range for cattle and sheep. It yields timber. It offers camping, hunting, and other recreational opportunities. It harbors deposits of oil and gas, uranium, and coal. And some of the land embodies the qualities Congress had in mind when, in

Ed Oakes, center, and Al Voelker, far right, discuss preliminary resource evaluations with Bureau of Land Management staff in Moab, Utah. BLM staff, from left, are geologist Jim Piani, land manager Pete Christensen, and wilderness coordinator Diana Webb.

1964, it created the National Wilderness Preservation System.

The Wilderness System now includes about 30 million ha (80 million acres) of protected land. During the next decade, up to another 10 million ha (24 million acres) may be added. The possible additions include nearly a thousand Wilderness Study Areas, which range in size from a few hundred to a few hundred thousand hectares.

In reviewing the thirty WSAs in your district, you must consider the potential uses of each one and determine whether the area is most suitable for wilderness or for other, less restricted uses.

The task is somewhat akin to walking a barbed-wire fence. On the one hand, you must consider the importance of the wilderness attributes of the tract: its scenery, wildlife, and opportunities for solitude or primitive recreation. On the other, you must weigh the value of keeping the land available for grazing or lumbering, recreational vehicles, or—often most controversial in the mineral-rich West—mining and drilling.

Scrutinizing your decisions and recommendations about the WSAs are enthusiastic—sometimes rabid—people from both sides of the fence: preservationists and prospectors, wilderness groups and oil companies. If they disagree with your recommendations, they will certainly take you to task—maybe to court.

Such is life in the western district offices of the Bureau of Land Management, the Department of the Interior's steward of more than 160 million ha (400 million acres) of government-owned land in the western states and Alaska.

ORNL/SAI Method Evaluation

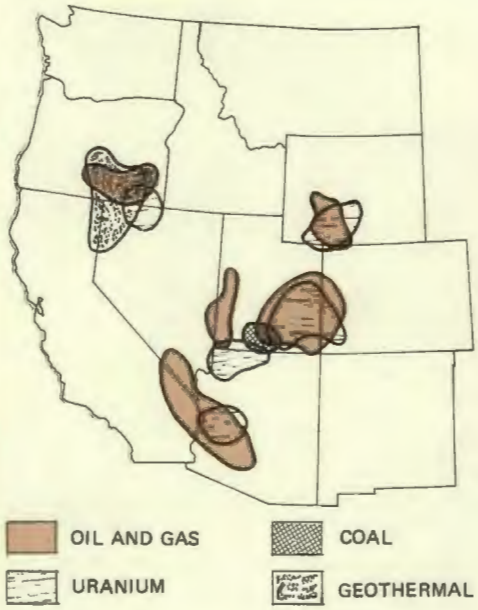
To assist in the large, complex, and sometimes controversial job of deciding which WSAs should be preserved, a technique developed by ORNL and Science Applications, Inc., is being used. The technique, a way of evaluating an area's energy-resource potential, was developed mainly by Al Voelker of ORNL's Energy Division and Ed Oakes of SAI.

The ORNL/SAI Resource Evaluation Method has already been applied to more than 3 million ha (7 million acres): Bureau of Land Management tracts, U.S. Forest Service lands, and areas along rivers being considered for the National Wild and Scenic Rivers Preservation System. BLM has recently adopted the method in a proposed assessment guidebook for its geologists. Voelker and Oakes have described the method to a National Academy of Sciences committee on resource assessment and have testified on some of their findings to a congressional subcommittee investigating the desirability of opening wilderness to mineral development—a move proposed by Interior Secretary James Watt but later dropped.

Although, as consultants, Voelker and Oakes are not directly responsible for land-use decisions, they have experienced firsthand some of the tensions involved. They told the Capitol Hill subcommittee, for example, that there is little reason to open existing wilderness areas to development, since these areas contain only an estimated 3% of the nation's undiscovered oil and gas resources. That testimony, which countered the figures quoted by would-be energy developers, made the head of a national mining-industry group "so mad at us he won't even return a call," says Voelker.

The ORNL/SAI project dates back to 1978, when the U.S. Forest Service was surveying large roadless areas of its lands for possible inclusion in the Wilderness System. The Forest Service, like BLM, must consider energy and mineral resources in its land-use decisions. The Department of Energy became involved because one of DOE's main functions is to encourage the orderly development of U.S. energy resources; DOE is mandated to comment on all federal programs and actions that may reduce the availability of publicly owned energy resources. DOE's Office of Resource Applications asked ORNL to develop a method for evaluating the energy resources of these potential wilderness areas. In 1979, when the Forest Service completed all its wilderness reviews, BLM

The energy-rich regions shaded on this map include many Wilderness Study Areas. An ORNL/SAI study recommends accelerated studies of these WSAs.



became the main user and a co-sponsor of the project.

A Realistic Alternative

The most important feature of the ORNL/SAI Resource Evaluation Method, say Voelker and Oakes, is that it's geared directly to the needs of the typical land manager, who often has to make fast decisions about the fate of large tracts of land.

Ideally, land-use decisions that affect mineral resources should be based on detailed field explorations. In wilderness planning, however, reality is most often a pressing schedule and a tight budget. For example, the Department of the Interior legally has until 1991 to complete its wilderness reviews, but Secretary James Watt wants the reviews finished within two years, even though no extra money is available to speed up the schedule. What's more, thorough exploration requires the drilling of numerous test holes, which can compromise the very qualities valued most in wilderness.

By contrast, the ORNL/SAI method is fast, inexpensive, and nondestructive. The method relies on existing geologic data instead of field exploration. "We wanted to find a way of doing credible work within the budget and time constraints that land managers operate under," says Oakes. "Field assessments take two to three years per district and cost about $12 an acre; our method takes about six months and costs about twenty cents an acre." Although the evaluation results are not as definitive as field exploration, the method is a realistic alternative when time and money are short. It's also a good way of identifying areas where more detailed studies would be worthwhile.

Resource Ratings

The heart of an ORNL/SAI evaluation is a set of simple numerical ratings that indicate at a glance the importance of an area's resources, separately and as a whole. The ratings allow immediate comparison of the resource value of different areas, even if the kinds of resources are not the same. Besides the ratings, the evaluation provides several levels of referenced technical data—a "pyramid of information" whose top is clear and useful to a nontechnical manager and whose base is credible to a professional geologist. Lynn Jackson, the staff geologist for BLM's Moab District (in southeastern Utah), calls the rating system "a straightforward way of relaying information to a nontechnical person, one that's helped our management quite a bit. Having tried to write some of these resource assessments earlier myself, I was quite impressed with their method. I wish I'd had something like it to guide me."

The method uses a highly systematic approach to gathering, interpreting, and summarizing the geologic data. A core team of two or three resource geologists is organized at the start of each evaluation, with additional consultants or part-time staff added whenever needed. ORNL and SAI have provided the core team in all resource assessments so far. "We're not particularly interested in doing one after another," says Oakes, "but it gives us a foundation for improv-

Time and weather have uncovered uranium-bearing ore (dark bands) in this formation within a proposed wilderness area in Capitol Reef National Park, Utah. The road is excluded from the proposed wilderness area.

ing the method. That's the way we test our design and our understanding. We're brought back to reality by it sometimes."

Besides Voelker and Oakes, the core team includes Helmuth Wedow, a Knoxville geologist on subcontract to the project; others helping with the evaluations are Robert Poling, an SAI geologist, and Paul Intemann, a geologist in ORNL's Energy Division.

Starting with broad, regional-scale references such as U.S. Geological Survey maps and reports, the team gradually narrows its focus to data about the individual WSAs. This approach ensures a broad perspective. "The BLM people are busy policing the district," says Oakes. "They deal with individual companies, individual drill holes, and individual permits, so it's sometimes hard for them to step back and see things in a regional or national context. Besides, it's easy to get carried away by the euphoria of a discovery or by the weight of someone's opinion unless you have some way of checking yourself."

Once familiar with the geology of the region, the core team characterizes the district itself in terms of its past and present production and, by looking at analogous areas elsewhere in the world, its potential for the future. The team plots resource occurrences on overlay maps, outlining favorable geology to show areas of promise within the district. Then it locates and studies the available information about the characteristics of each WSA, such as size, location, water resources, accessibility, and terrain.

The team works together closely, so that its members will share a common understanding of the area's geology. Consensus is one of the method's cornerstones: "The test of our work is whether we've presented an understanding of an area, one that most geologists familiar with the area would agree with," says Voelker. The team then discusses its preliminary conclusions with the BLM district staff members. The final evaluation may be adjusted to reflect their judgments, because they will have to defend any recommendations that are challenged.

After the team has gathered and interpreted the data (sometimes from as many as a hundred sources for a single WSA), it develops the numerical ratings.

Measures of Importance

The method provides dual ratings for individual resources: oil and

County officials in Moab, Utah, had this bulldozer cut a swath into a proposed Wilderness Study Area, hoping to force its removal from the BLM study. (Photograph courtesy of Moab Times-Independent.)

A Bulldozer for Emphasis: *"The stakes are really high"*

One of the current proving grounds for the ORNL/SAI Resource Evaluation Method is Utah, which is divided into five Bureau of Land Management districts. Utah's exceptional scenic beauty and large undisturbed areas make it one of BLM's high-priority areas for wilderness review. The study of the Utah Wilderness Study Areas is to be completed next spring.

The Moab District (named for the small, eastern Utah town where it's headquartered) contains 2.5 million ha (6.5 million acres) of BLM lands—an area nearly one-fourth the size of Tennessee. The district's thirty one WSAs contain about twice the land in the Great Smoky Mountains National Park.

One of the proposed Moab WSAs, Negro Bill Canyon, has become a local *cause celebre* in the conflict between preservationists and would-be developers. In 1979, when BLM was deciding what areas were suitable as WSAs, local officials had part of the Negro Bill Canyon area bulldozed, hoping to render it ineligible for consideration. The tactic didn't work, but BLM later decided that state-owned land in the canyon would make it unsuitable as federal wilderness; however, a Sierra Club suit to the Department of the Interior's Board of Land Appeals won the restoration of most of the area to the wilderness study this spring.

The local county commission, unhappy with the restoration, charges that BLM is refusing to acknowledge the existence of a road in the area. According to the Moab *Times-Independent*, the commission has threatened to grade the road "to emphasize its existence."

According to the ORNL/SAI evaluation, some of the Moab WSAs—including Negro Bill Canyon—have fairly high potential for oil and gas; some may contain large uranium deposits and a good bit of potash. The coordinator of the Moab District's wilderness reviews, Diana Webb, explains how such resource potential complicates BLM's job:

"We have a very polarized public out here. Half the people are wildly in favor of designating as much wilderness as possible; the other half are wildly in favor of designating *no* wilderness, and of removing national parks as well.

"A lot of people here make their living looking for minerals. If they can't go in and stake claims, they see a potential loss of income. On the other hand, if uranium is found on their claim, they can make a million dollars overnight. The stakes are really high; that's why people feel so strongly."

The ORNL/SAI Resource Evaluation Method may help ease some of the tensions, according to Webb. "We have a difference between the *perceived* mineral values and the *actual* mineral values. We hear a lot of 'Everybody knows that area is full of uranium (oil, gas).' Having an outside study gives us a way to counter those perceptions."

Why an outside study? "Out here, people on both sides distrust BLM. So having an outside agency come in lends some credibility to our recommendations. It also gives us a fresh perspective."

There is yet another reason why good resource evaluations are important to Webb and her colleagues: when BLM's evaluations of mineral resources and other factors indicate that an area is suitable as wilderness, the U.S. Geological Survey and the Bureau of Mines must then make a detailed mineral assessment of the area. As Webb notes, "Obviously we don't want to be in the position of having said 'This area doesn't contain any important resources' and then have USGS or BM say 'Yes it does.'"

gas, coal, uranium, geothermal energy, and hydropower, plus any other minerals thought to be important in the area.

The first part of each rating indicates the area's favorability for the resource: high, moderate, low, or none (f4, f3, f2, or f1, respectively). The second part indicates the degree of certainty that the resource actually exists (or not) in or near the tract: from highly certain (c4) to uncertain (c1). The best resource rating for a WSA is therefore f4/c4, a rating that indicates a high geologic favorability and high certainty. The worst is f1/c4, a very unfavorable rating about which there is little doubt. (An f4/c1 rating, high favorability but very low certainty, suggests that a more detailed study might be worthwhile.)

The criteria for favorability and certainty ratings are defined as objectively as possible for each resource. An f4 rating for oil and gas, for example, requires geologic evidence that suggests the area contains more than 8 million m^3 (50 million bbl) of oil or more than 8.5 billion m^3 (300 billion ft^3) of gas. A c4 certainty rating for oil and gas is used only when there is abundant direct evidence of occurrence (e.g., productive wells, oil seeps, and tar sands) or nonoccurrence (e.g., dry test holes). Similar objective criteria guide the ratings for the other resources. Because these criteria are central to the success of the method, most of the development time in the project has been devoted to perfecting them.

After reaching a consensus on the individual resource ratings, the core team rates the overall importance of the area, also on a high-to-low scale of 4 to 1. The overall-importance rating (OIR) synthesizes the individual favorability and certainty ratings, as might be expected, but also reflects other factors not previously considered, such as accessibility, economics, environmental constraints, and national needs and priorities.

To understand the need for the OIR, consider the task facing the land manager who must evaluate the resources of thirty WSAs. If each of those areas has dual ratings for five resources, the manager must in effect assimilate and balance 300 ratings before having a good understanding of the region's relative resource potential. The OIR simplifies the task considerably.

Because it reflects many factors, some of which defy numerical weighting, the OIR is necessarily more subjective than the individual ratings. Deriving the OIR mathematically was a tempting alternative but, say Voelker and Oakes, the available data are too limited and often too unreliable to justify such a rigid approach. The method is meant not as a cookbook, but as an aid to judgment. Like the favorability and certainty ratings, the OIR is derived with the aid of carefully defined rating criteria.

Theoretically, the OIR could be affected by biases and misperceptions. In practice, though, the method's systematic criteria, its emphasis on consensus, and its provisions for external review serve as safeguards against bias.

An Example

Consider the evaluation report for one Wilderness Study Area: Negro Bill Canyon, in Utah's Moab District. The report first identifies the tract and gives its location and size. Then it describes the geologic features of the tract and the surrounding area. Next come the resource ratings.

Negro Bill Canyon has an overall-importance rating of 3 minus: fairly high, but less so than other 3-rated areas because of its limited size and accessibility. Contributing to the fairly high OIR are the ratings for oil and gas (f3/c2), uranium (f3/c2), and potash (f3/c3). Less important are copper and manganese (each f2/c1). Coal and geothermal are each rated f1/c4.

Narrative sections justifying each rating in detail follow. The report concludes with a listing of the most useful references on the area's resources—for Negro Bill Canyon, the report lists 46—and maps showing the favorable zones for each resource and the location of mines, oil and gas wells, and other resource-related features.

Besides Negro Bill Canyon, there are thirty other WSAs in the Moab District. Each WSA is the subject of a similarly structured report. Some of the reports, especially those on neighboring WSAs, may contain much the same information, but each report is written so that it can stand alone; that feature makes it easier to focus discussion on WSAs of particular uncertainty, controversy, or interest—like Negro Bill Canyon (see box).

"You never know everything"

The reports on Negro Bill Canyon and the other Wilderness Study Areas are not, Voelker and Oakes stress, definitive evaluations. Rather, they are attempts to synthesize and present, as clearly as possible, the available data. "We've never said that ten years from now, what we've said will still be right," says Oakes. "But you get the best information you can right up to the decision point, then you make the decision and stand by it. Later, if your information or needs change, you can reevaluate these decisions.

"Most other resource-assessment methods are very data oriented. They say, 'Don't make a decision unless you know everything.' Of course, you never know everything. Our method is different in its sensitivity to the needs of the land manager, who has to make—and defend—decisions on the basis of the available information." ornl

information meeting highlights

Engineering Technology, March 25–26

Flywheel Evaluation

In the age of declining oil supplies, the search is on for innovative ways to make automobiles fuel efficient. One of the approaches supported by the Department of Energy has been the development of lightweight flywheels. These devices store energy during periods of excess supply by increasing the kinetic energy of a spinning wheel. If effective transmission systems are developed, flywheels should be able to store energy when the car is slowed or stopped and return as much as 90% of that energy when that vehicle is subsequently accelerated.

Flywheel systems using metallic rotors have been built, but tests show that they generally are unsafe, too heavy, and not particularly economical. Several industries are now developing lightweight flywheels made of fibers held together with epoxy. It is believed that some of these composite flywheels have the potential to be safe, to store sufficient energy without an overriding weight penalty, and to be cost effective over the lifetime of the automobile.

To find out which flywheel designs are likely to meet these criteria, Union Carbide–Nuclear Division engineers led by Robert S. Steele have tested a variety of composite wheels in the Oak Ridge Flywheel Evaluation Laboratory, which was developed by DOE's mechanical energy storage program for this specific task. The flywheels are tested to failure, to determine their maximum speed or the maximum number of cycles attainable between two speeds. Changes in flywheel dimensions, shape, structure, stability, and temperature are recorded for detailed analysis following the destructive testing. Recording devices include x-y plotters, tape recorders, high-resolution television cameras, and computerized data-acquisition equipment.

ORFEL tests showed that the flywheels designed by Garrett AiResearch Corporation and General Electric Company have the potential of meeting the desired criteria; thus these are being studied during this fiscal year. Other flywheel designs were rejected because of flaws such as unwanted vibrations, lack of balance, material failure, and premature cracking.

In some cases, ORFEL results have guided flywheel developers in redesigning flywheels whose flaws showed up only after high-level testing in that facility. For example, Steele was able to detect relative motion between the disk and hub of the GE flywheel. The elastomeric joint between these parts has now been redesigned using the data and suggestions offered by his test engineers. Concludes Steele: "Flywheel development has been speeded by ORFEL's commitment to the performance of comprehensive tests that produce high-quality, quantitative results."

Which Is Cheaper: Coal or Nuclear?

If you were an executive of an American electric utility company and had been asked to decide whether to order a nuclear-, coal-, oil-, or gas-fired power plant next year for startup in 1995, which choice would you consider to be the most economic?

If you consulted Jerry Delene, an ORNL engineering economist, he would tell you this: Avoid oil- and gas-fired plants because future supplies are precarious and prices will continue to rise. Go with nuclear power if your utility is in the eastern United States. If you are located in the Rocky Mountains states, choose coal. Delene, however, would emphasize that social, political, and financial factors may change the decision.

In an ongoing study, Delene and his colleagues have kept an eye on the ever-changing picture of capital investment costs, operation and maintenance costs, coal prices, and nuclear fuel costs in two areas—Boston and Denver. Their data indicate that coal prices vary widely from region to region and even within a given geographic region. High-sulfur eastern coal is currently more expensive in the East than low-sulfur western coal is in the West. Coal-fired systems in both regions require installation of costly flue-gas desulfurization equipment to keep pollutant emissions within legal bounds.

The capital cost of nuclear power plants was found to exceed that of coal plants, as well as other types of plants, principally because of indirect costs and interest rates. However, Delene and his associates found that this cost difference is offset in the East by the fact that nuclear fuel is more economical than coal, natural gas, or oil.

Says Delene: "Nuclear fuel is the economic choice over coal for baseload electric power generation at the eastern location, and coal is the economic choice at the western location. At both locations, baseload power generation by either natural gas or oil is more expensive than either nuclear- or coal-fired generation."

Fusion Energy Division, April 5–6

Tokamaks: Results and Plans

If doughnut-shaped fusion reactors using magnetic confinement are to be cost effective as a source of electricity, they must be able to attain high beta. Beta is the ratio of the reacting plasma pressure to the magnetic pressure. Recent results from ORNL's Fusion Energy Division are encouraging the belief that betas at a reactor-relevant level may be achieved soon in the tokamak program.

For the past two years, a substantial theoretical and experimental effort on the Impurity Studies Experiment (ISX-B) has been directed toward explaining an apparent saturation in beta. Previously, it was thought that beta would rise linearly with increased neutral-beam power used for heating the plasma (a superhot gas composed of hydrogen nuclei and electrons). ISX-B data in 1981, however, indicated that beta trails off instead of rising proportionately with beam power.

Among the possible causes of the degradation of plasma confinement are resistive instabilities of the plasma-magnetic field system, which can increase heat conduction to the wall. A theoretical study, involving personnel from the Computer Sciences Division and collaboration with the University of Texas, has led to the development of a formula for an enhanced thermal diffusion rate which results from instability-generated fluctuating magnetic fields. Experimentally, similar fluctuations are seen and the measured diffusion coefficients agree well with theoretical predictions. The encouraging feature of this result is that the problem should be alleviated in more powerful tokamaks which use stronger magnetic fields and higher temperatures. Both the magnetic system and the heating system in ISX-B are being increased

Murray Rosenthal, ORNL Associate Director for Advanced Energy Systems, explains a model of the Large Coil Test Facility to (from left) Sen. Howard Baker, Tennessee Governor Lamar Alexander, and Robert J. Hart, manager of Oak Ridge Operations. Roger Hibbs, President of Union Carbide Corporation's Nuclear Division, stands behind Sen. Baker. The Large Coil Test Facility, under contruction at ORNL, will test superconducting magnets to be used on future fusion energy research devices.

The $36-million Large Coil Test Facility, which is designed to test superconducting magnetic coils similar to those needed to confine plasmas economically in large tokamaks, is 60% completed. Construction will be completed next year, and tests of all six coils—from U.S. industry and Japan, Switzerland, and the European Community—will begin in 1984.

EBT: An Update

The Elmo Bumpy Torus Proof-of-Principle facility (EBT-P) is being designed and will be built by McDonnell Douglas Astronautics Company for ORNL in the Oak Ridge Valley Industrial Park. Principal subcontractors include General Dynamics Corporation and Gilbert Associates, Inc. The device is estimated to cost $86 million and is slated to go into operation as early as May 1985, but current budget projections leave these cost and schedule estimates open to question.

EBT-P is a toroidal device having 36 modules, each with a superconducting magnetic coil made of niobium-titanium. The magnets are designed to confine a steady-state hydrogen plasma within a stainless steel toroidal vessel. Two developmental magnetic coils for the EBT-P have already been fabricated and successfully tested at ORNL.

ORNL research in support of EBT-P includes development of gyrotrons in cooperation with industry and development of components for distributing microwave power from the gyrotrons to heat the EBT plasmas.

The objectives of EBT-P will be to demonstrate that EBT plasmas of intermediate values of beta can be stably confined and that a power-producing EBT is a viable concept.

On the experimental side of the EBT program, a core electron temperature of 1 keV (as measured by soft x-ray emission) was attained by microwave heating in EBT-S, ORNL's experimental device. Electron temperatures appear to rise proportionately with an increase in microwave power. Radio-frequency power similar to that employed in

to permit the achievement of a better operating region.

In the U.S. toroidal confinement program, which includes tokamaks and stellarators, a part of the effort is devoted to advancing the toroidal concept. A stellarator differs from a tokamak in that it uses an external coil system to produce a helical magnetic field to contain the plasma. Because a transformer-driven plasma current is not needed, a stellarator may operate at steady state. Among the many types of stellarators, the torsatron has continuous helical coils carrying current in the same direction. ORNL theorists, experimentalists, and engineers are now studying various kinds of stellarator configurations to find those which, theoretically, have good confinement and beta capabilities and are also attractive from an engineering standpoint. This work was undertaken here because of ORNL's recognized expertise in this area; recent encouraging results from Japan and West Germany have also stimulated interest in stellarators.

The results of the ORNL studies should lead to the construction of the Advanced Toroidal Facility (ATF-1), which will replace ISX-B in the mid-1980s. An ATF configuration has been developed which has not only the desirable characteristics of the torsatron-type device but also modular coils. It is called the Symmotron (symmetric modular torsatron).

In other developments in ORNL's tokamak program, the pellet fueling project demonstrated that a prototypical centrifugal injector can produce 150 pellets per second and significantly increase the density of the ISX-B plasma.

Studies of the effects of injecting two neutral beams of hydrogen atoms in the same direction relative to the plasma current (co-injection) or in the opposite direction (counter-injection) in ISX-B indicate that co-injection has the advantage of inhibiting accumulation of impurities in the plasma interior, whereas counter-injection tends to enhance impurity buildup.

Because the wall of a tokamak reactor will be constantly bombarded by high-energy neutrons from the plasma, studies are under way to determine the relative resistance of materials to neutron radiation damage, including swelling and changes in mechanical properties. ORNL's Metals and Ceramics Division is conducting tests on austenitic stainless steel and ferritic steels, which are candidates for the Fusion Engineering Device. Long-ranged-ordered alloys developed at ORNL and vanadium alloys will also be investigated, and studies of the relationships between the microstructure and properties of materials will be continued to identify ways of tailoring alloys to minimize radiation-induced swelling in fusion reactors.

short-wave radio broadcasting is being used in ion cyclotron heating experiments to heat the ions of the EBT-S plasma. Results indicate that ion heating is obtained at high harmonics of the ion cyclotron frequency. Doubling of beta of the electron rings (which help stabilize EBT plasmas) was also seen at the highest levels of ion cyclotron heating. Neither observation is understood, but theorists are currently trying to interpret these effects.

Using laser-induced resonance fluorescence spectroscopy, ORNL's Solid State Division in collaboration with KFA Jülich in West Germany measured the density and distribution function of aluminum impurities in EBT-S plasmas. In this technique, concentrated light of the proper frequency is beamed from a pulsed dye laser into the plasma; aluminum in the hydrogen plasma is excited by the laser light and then decays by emitting photons. By measuring the intensity of this fluorescence, the density of aluminum was determined for distances of between 5 and 14 cm from the vessel wall. The technique will be applied in ISX-B and EBT-S to detect and measure neutral hydrogen and other wall-generated impurities that tend to cause energy losses in the plasma.

Solid State Division, April 21–22

Mechanisms of Metal Fracture

The tragic DC-10 crash at Chicago's O'Hare International Airport in May 1979 was caused by the failure of a pylon which connects an engine to the airplane's wing. Metal fatigue in bolts was believed to be partly responsible for the collapse of the walkway at the Hyatt Regency Hotel in Kansas City, Missouri, during a July 1981 tea dance. In each accident, more than 100 people were killed.

As these incidents show, the failure of metal parts under prolonged stress can have devastating effects. They suggest the need to be able to predict how long various materials can hold up under stress and to understand why some metals crack under a given stress while others do not.

ORNL's basic studies of the mechanisms of metal fracture using a high-resolution electron microscope have offered the first direct experimental confirmation of the theory of fracture proposed by British scientists B. A. Bilby, A. H. Cottrell, and K. H. Swinden. One dramatic result of these studies is a video recording that captures the movement of dislocations near cracks in metals under stress. Dislocations are slippages of rows of atoms several atomic spaces relative to other planes of atoms.

One of the objectives of these studies by Mike Ohr, Joe Horton, and S. Chang of the Solid State Division is to understand why structural materials, which are normally tough, fracture in a brittle manner in harsh environments at relatively low stresses. In the cases of high-temperature energy systems such as breeder reactors or coal liquefaction facilities, structural materials must endure radiation or corrosive environments in addition to applied stresses.

Structural materials such as stainless steels are normally tough because, if any tiny cracks exist in the steel, the crack-tip area is deformed plastically by emitting dislocations and moving them through the material. That is, when the material is under stress, the crack tends not to grow because the energy is dissipated through the movement of dislocations from the crack tip. As the dislocations move to accommodate the prolonged or repeated stress, the material undergoes a permanent change in shape, or plastic deformation.

Mike Ohr and his colleagues got an inside look at the atomic behavior of metals when they captured on videotape the movements of dislocations in a notched piece of metal that was stretched in an electron microscope in a tensile specimen holder designed by Horton. Transmission electron microscopy at a magnification of 300,000X shows the actual movement of dislocations from the crack tip through the material.

Observations in the electron microscope show that, for each metal studied, a limited number of dislocations are generated at the crack tip in response to an externally applied stress. The number of dislocations is an indication of the fracture toughness, or resistance to cracking, of the material.

For example, copper was found to have 100 times as many dislocations generated as tungsten, indicating 100 times the fracture toughness of tungsten—that is, it can be bent or stretched much longer before breaking. Ohr explains that dislocations relax the stress on a material and prevent or slow the growth of small cracks.

What determines the extent of plastic deformation at the crack tip? Says Ohr: "Careful examinations of the crack-tip deformation of various metals and alloys under stress in an electron microscope have shown that there is a zone near the crack tip which is devoid of dislocations. We call this area the dislocation-free zone. Dislocations generated at the crack tip tend to move through the dislocation-free zone and join other dislocations in the plastic zone, with the maximum density of dislocations being near the crack tip in what we call an inverse pileup. Fracture occurs by propagation of the crack into the dislocation-free zone, which moves just ahead of the growing crack."

Ohr and his colleagues also made the interesting discovery that the dislocations move away from the crack tip as the specimen is stressed and return to the crack tip and disappear as the stress is reduced under cyclic loading conditions.

Ohr, Horton, and Chang have studied several different metals, including aluminum, molybdenum, copper, and tungsten. By counting the number of dislocations in front of a crack in each material under stress, they have determined the degree of difficulty in generating dislocations at the crack tip. This critical stress intensity factor for dislocation generation determines how long the metal can resist cracking or breaking under prolonged or repeated stress. Such information may prove useful to designers of energy systems, airplanes, and building structures.

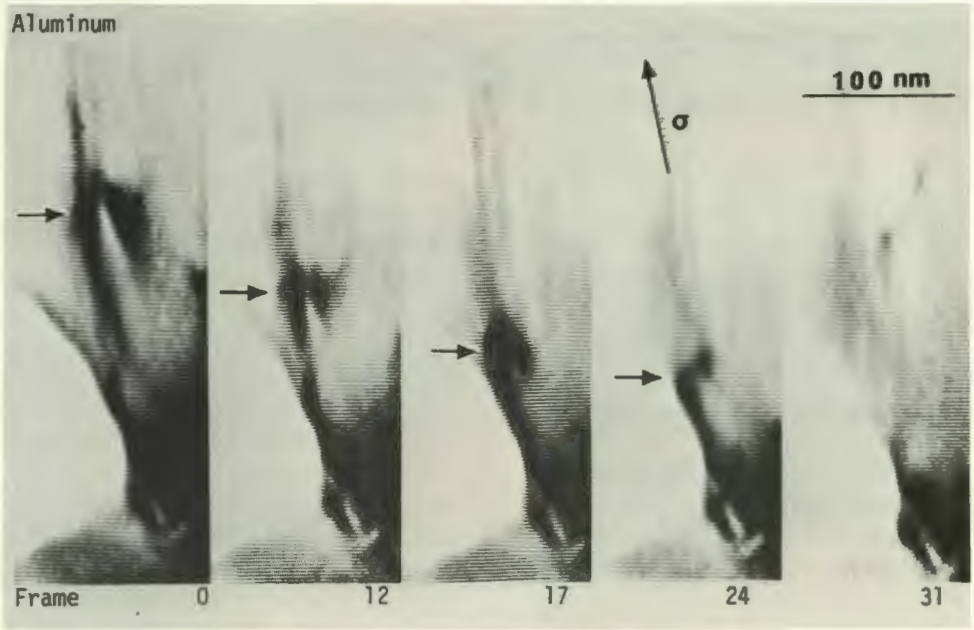
Melting Observed in Laser-Annealed Silicon

In the late 1970s ORNL solid-state physicists developed the technique of laser annealing for removing damage in silicon caused by ion implantation of dopants. They used the laser-annealed, ion-implanted silicon for making experimental solar-electric cells of potentially high efficiency.

Since then, solid-state scientists have been speculating about what structural and phase changes may be occurring in the semiconductor material during the annealing process. Two theoretical models have been proposed. One theory is that the pulses of laser light cause the crystalline surface of the silicon to convert momentarily to a "cool plasma-fluid" no warmer than 400°C. The other theory holds that the silicon surface melts, losing its crystalline structure temporarily as its temperature reaches the melting point of 1410°C.

During 1981 ORNL solid-state physicists using synchrotron x rays have shown that laser annealing causes significant heating of pure silicon and induces melting in boron-implanted silicon. Their findings were reported in the February 1, 1982, issue of *Physical Review Letters*.

Ben Larson, Woody White, and Tom Noggle of the Solid State Division and Dennis



When applied stresses are removed from a metal that is starting to crack, dislocations (area resembling a black crook) can return to the crack tip.

Mills of Cornell University carried out time-resolved studies of silicon samples at the Cornell High Energy Synchrotron Source during annealing by a pulsed laser (shipped by truck from ORNL to Cornell). Produced by a single "bunch" of electrons as they whirl around a circular racetrack every 2.5 microseconds, synchrotron x-ray beams are 100,000 times as intense as the radiation emitted from the largest x-ray tube. Because the annealing of silicon occurs in 100 to 200 nanoseconds following the firing of the laser pulse, synchrotron radiation pulses are the only source of x rays intense enough over a very short time (0.1 nanosecond) to follow laser-induced structural and phase changes.

In these experiments, silicon is a self-thermometer; that is, its lattice expands as it becomes hotter, just as mercury expands and rises up a tube in a room thermometer. To determine the extent to which silicon heats up during laser annealing, the ORNL physicists measured the amount of silicon lattice expansion by x-ray diffraction. Their first experiments with pure silicon showed that, during laser annealing, it had expanded 0.75%, which indicates that it was heated to 1150°C before cooling. This finding casts doubt on the validity of the cool-plasma theory, but it did not fully substantiate the melting theory.

When the physicists looked at laser annealed, boron-implanted silicon, they found that the silicon lattice expanded by an amount consistent with the melting point temperature of 1410°C. At one point, no scattering of x rays was observed from the boron-implanted region; this indicated that the surface of the silicon had attained a non-crystalline molten state. As the silicon cooled after a laser pulse, the melted layer recrystallized rapidly.

"Our synchrotron radiation studies," says Larson, "show that the melting model correctly explains the effect of laser annealing on silicon. In addition, synchrotron x rays have provided the first real-time structural information on crystal growth at high (meters per second) solidification rates. And they have given us a sensitive probe of thermal expansion of the lattice as a function of depth—below the crystal surface—during the annealing process.

"These studies have provided fundamental information on the laser annealing process," Larson said. "What may even be more important is that this work has demonstrated that diffraction measurements can be made in billionths of a second, thus facilitating the study of fast-transient phenomena in solids."

Superconductivity and Magnetism in Cold Matter

In a number of materials chilled to a few degrees above absolute zero, one may find one of two properties: (1) ferromagnetism, in which the electron spins are simultaneously aligned in parallel, or (2) superconductivity, in which electrons flow freely through a material without resistance because the electrons form pairs in which the spins are in antiparallel alignment. Because electron spins are in opposing directions, these two competing forms of long-range order tend to annihilate each other. Therefore, one would not expect to find superconductivity and ferromagnetism in the same material.

Nevertheless, research at ORNL's High Flux Isotope Reactor and elsewhere has turned up evidence for the coexistence of superconductivity and ferromagnetism in two materials containing rare earths. Using neutron diffraction and bulk resistivity measurements, Herbert Mook of ORNL's Solid State Division in collaboration with David Hinks, Sunil K. Sinha, and George W. Crabtree of Argonne National Laboratory found that a single crystal of erbium rhodium boride can accommodate both superconducting and ferromagnetic regions when cooled to a temperature between 0.7 and 1 K. A modulated magnetic moment component is also found in this temperature range. Below 0.71 K the modulated magnetic moment disappears suddenly, with loss of superconductivity and a transition to a normal ferromagnetic state.

Previous studies on powders of erbium rhodium boride at Brookhaven National Laboratory suggested that there might be a coexistence state, but the ORNL study on a crystal pinned down the coexistence state to a narrow temperature range and determined the properties of the modulated component of the moment. Mook attributed the success of the ORNL study partly to the fact that Hinks was able to grow, for the first time, a crystal of erbium rhodium boride at Argonne. It is the only such crystal in existence.

Another material in which ferromagnetism and superconductivity may coexist is holmium molybdenum sulfide. This discovery was made at the University of Geneva in Switzerland in the early 1970s. Holmium molybdenum sulfide and erbium rhodium boride are similar in that they each contain a rare earth, which forms an ordered lattice of magnetic ions within the crystal, and a transition metal, which acts as a superconductor at low temperature.

Mook and his associates are continuing their experiments to test their hypothesis that coexistence of the superconducting and ferromagnetic phases over a finite temperature range suggests the existence of "a remarkable new pseudophase, namely a mosaic of microscopic superconducting and ferromagnetic regions with a characteristic length of 2000 Å."

awards and appointments

No less than six IR-100 awards were the ORNL harvest in this year's competition. The winners were: The in-core temperature, density, and level measurement system, developed by **G. N. Miller, R. L. Anderson,** and **S. C. Rogers;** the inductively coupled plasma spectrometer, developed by **J. H. Stewart Jr.;** dispersed-metal-toughened ceramics, developed by **Chester Morgan** and **Arthur Moorhead,** shared with ORNL-Ceramics containing metallic precipitates, developed by **J. Narayan** and **Y. Chen;** GraphNOL, developed by **Walt Eatherly** and **Ray Kennedy;** ORNL-Super 9 Cr–1 Mo alloy, developed by **V. K. Sikka, R. E. McDonald, J. F. King,** and **Pete Patriarca;** and the monazite process for stabilization of high-level radioactive waste, developed by **Lynn Boatner** and **Marvin Abraham.**

Walt Eatherly has been elected chairman of Committee C-5 on Manufactured Carbon and Graphite Products of the American Society for Testing and Materials.

John Ridley, Jim Kolb, and **Mike Karnitz** were recipients of a Certificate for Creative Excellence from the U.S. Industrial Film Festival for their work on the film "An Energy Opportunity" on the subject of district heating.

Bob Jolley has been elected chairman of the Division of Environmental Chemistry of the American Chemical Society for a two-year term.

Elizabeth Johnson, Betty Maskewitz, and **Enzo Ricci** have been named fellows of the American Nuclear Society.

Stan David has been honored with the American Welding Society's James F. Lincoln Gold Medal Award, presented annually for a single-author paper published in the society's publication, *Welding Journal.* He also served as General Chairman of the 1982 International Conference on Welding Technology, sponsored by the American Welding Society, Northeast Tennessee Section, and the American Society for Metals, Joining Division.

M. B. Herskovitz has been named a fellow in the Instrument Society of America.

Among the officers elected to the Central Region Chapter of the Institute of Nuclear Materials Management are **H. C. Austin,** chairman, and **John Wachter,** treasurer.

Susan Whatley has been nominated to the Executive Committee of the Society of Women Engineers for the 1982–1983 term. In this capacity she will be responsible for all committees involved with the student sections of SWE and will be the Executive Committee Director for Student Affairs.

James Barker has returned to ORNL to assume the responsibilities of director of the Employee Relations Division, replacing Joe Vogt.

Michael Kania was selected to receive the Borchers Medal from the Rhine-Westphalia Technical University of Aachen, Federal Republic of Germany.

Jack Lackey has been named secretary of the Nuclear Division of the American Ceramic Society for 1982–1983. He was also appointed contributing editor to *Communications,* a publication of the American Ceramic Society, for a two-year period.

ORNL's outstanding safety record of 15 months without a lost-time accident has earned it a succession of awards. Union Carbide Corporation has selected the Laboratory for its Outstanding Safety Performance Gold Award, the first individual UCC-operated facility to be so honored. The National Safety Council has given its Award of Honor to the Laboratory for the seventh consecutive year. In addition, the NSC cited ORNL for Best Record for Research and Development Laboratories in 1981 and awarded it first place in the Chemical Section Safety Contest, Division 1, Group 1, in a field of 40 major chemical research and production facilities.

R. E. Barker has been named chairman-elect of the local chapter of the American Institute of Chemical Engineers. He has also been appointed to the Physical Properties Committee of the ASPEN Users Group.

J. R. Hightower was named Engineer of the Year by the Knoxville–Oak Ridge Section of AIChE for 1982.

W. W. Pitt has been selected to serve on the ASTM-D34 Committee on Waste Disposal and the Research and Program Committees for the Water Pollution Control Federation.

Ray Wymer has accepted a second three-year appointment on the Subcommittee on Nuclear and Radiochemistry of the Commission on Physical Sciences, Mathematics, and Resources of the National Research Council in the National Academy of Sciences.

Lorraine Abbott was named Outstanding Member of the Year by the Oak Ridge/Knoxville Section of

the American Nuclear Society (1981–1982).

David Bartine was awarded the Certificate of Governance by the Board of Directors of the American Nuclear Society.

R. B. Perez, Gerard de Saussure, and **J. Barhen,** with J. Munoz-Cobos and R. Q. Wright, won the Best Paper Award at the 1981 Winter Meeting of the American Nuclear Society, Reactor Physics Division.

C. V. Dodd served on the Organizing Committee for the Fifth International Conference on Quantitative Nondestructive Evaluation in the Nuclear Industry, 1982, sponsored by the American Society for Metals in cooperation with the American Nuclear Society, the American Society for Nondestructive Testing, and the French Society for Nondestructive Testing.

Gerald Slaughter was elected chairman of the American Society for Testing and Materials–American Society of Mechanical Engineers–Metal Properties Council (ASTM-ASME-MPC) Joint Committee on the Effect of Temperature on the Properties of Metals.

James Weir, Jr., received a Certificate of Appreciation from the Oak Ridge Chapter of the American Society for Metals.

Everett Bloom, H. H. Haselton, J. T. Hogan, Jim Lyon, Y-K. M. Peng, John Sheffield, and **T. E. Shannon** received DOE Certificates of Appreciation for their contributions to the Fusion Engineering Device.

Charles Yust was elected vice-chairman of the Nuclear Division of the American Ceramic Society for 1982–1983.

Chain T. Liu received the Platinum Membership (honorary life membership) to the International Precious Metals Institute, its highest personal award.

Jack Cunningham was appointed chairman of the Advisory Technical Awareness Council of the American Society for Metals for one year.

J. H. Smith was elected a director-at-large of the American Society for Nondestructive Testing.

David Braski placed third in Category A (electron or ion beam techniques) in the 1981 METASERV International Metallography Competition sponsored by The Institution of Metallurgists for his TEM investigation of helium implanted in an Fe/Cr/Ni alloy.

Joseph Carpenter received a DOE Letter of Commendation for his "outstanding performance" in directing the Materials Project component of the Energy Conversion and Utilization Technologies Program.

David P. Edmonds was appointed a member of the Subgroup on Strength in the Ferrous Alloys of the Boiler and Pressure Vessel Committee of the American Society of Mechanical Engineers for a five-year term.

Barbara Walton was selected by the Environmental Sciences Division for its second Annual Scientific Achievement Award. In addition, she was chosen to be a Diplomate of the American Board of Toxicology.

R. E. Dial was re-elected National Secretary of the American Society of Certified Engineering Technicians.

J. A. Carter has been appointed to a three-year term on the editorial board of *Analytical Chemistry.*

W. D. Shults has been elected program chairman and president-elect of the local chapter of Sigma Xi.

W. S. Lyon has been appointed editor of *Analytical Chemistry in Nuclear Technology,* the proceedings of the Twenty-Fifth Conference on Analytical Chemistry in Energy Technology, Gatlinburg, October 6–8.

Tom Row has been elected first vice-chairman and chairman-elect of the Power Division of the American Nuclear Society.

Carl Burtis has been elected to two international panels in clinical chemistry. He is a new member of the Commission of Automation and Clinical Chemical Technology of the International Union of Pure and Applied Chemistry and also of the Expert Panel on Instrumentation of the International Federation of Clinical Chemistry.D

First place in the Industrial Category and the Seal of Approval from the Professional Photographers of America went to **David Fahey** for his photograph entitled "Laser Inspection of Fusion Mirrors" at the Southeastern Professional Photographers' Association Exhibition of 1982. The photograph also was accepted for inclusion in the General Exhibit of PPA's 91st International Exposition of Professional Photography this year in Las Vegas.

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A butte typical of the wilderness areas in Utah under controversy between the developers and the preservationists. *See article on page 18.*