Oak Ridge National Laboratory

review

Fall 1981

The COVER: Russ Knapp, leader of ORNL's Nuclear Medicine Technology Group, points out the left ventricle in a human heart model. After a heart attack, damage to this ventricle may be detected by imaging following injection of a radiopharmaceutical such as thallium-201 or radiolabeled fatty acids developed at ORNL. *See article on p. 16.*

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Departments

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Jim McBrayer is no stranger to *Review* readers: In the Fall 1979 issue, he wrote an article with Ronnie Haynes on laws dealing with reclamation of strip mined areas. He has long been interested in the extraction of fossil fuels. He was born in Rowan County, Kentucky, where the oil shales of which he writes are found in abundance. He is shown here in his office in the Environmental Sciences Division, where he is a member of the research staff.

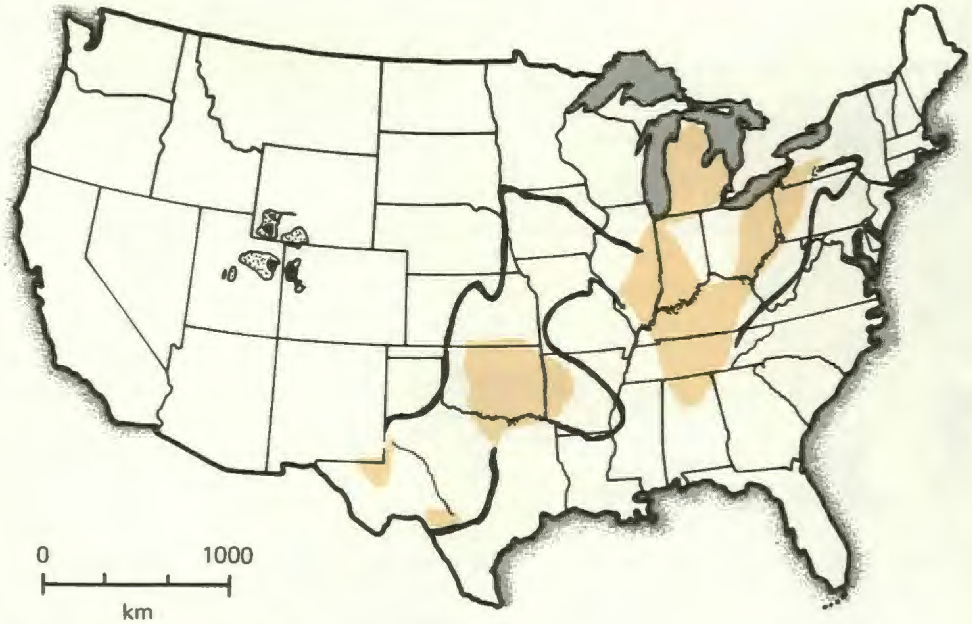
Eastern Shale and the Environment

By JIM McBRAYER

Oil from shale has been an on-again, off-again industry in the United States for the last 125 years. Interest has been generated by the magnitude of the known deposits and by recurring energy shortages. World deposits of oil shale have been estimated at 4×10^{18} kg; more than 8% of these deposits occur in the United States. While mature shale oil industries have developed elsewhere, a U.S. industry has twice been snatched from the brink of commercialization by discoveries of new petroleum fields. Some 50 oil shale plants closed following discovery of oil at Titusville, Pennsylvania, in 1859, and another 200 oil shale companies folded when the east Texas field was discovered in 1930.

Several organic-rich shale deposits occur within the United States, but current interest centers on two—the Green River Formation of the intermontane West and the Devonian deposits of the East. Of the two, the Green River Formation has generated more interest. Located in Colorado, Utah, and Wyoming are some 4.5×10^6 ha of oil shale land with a potential yield of up to 1.3×10^{12} m^3 of oil. (Annual oil consumption in the United States is approximately $9 \times 10^8 m^3$.) By contrast, the eastern shale potential is only 40% as large as the Green River deposits. The Green River shales are also richer, having a Fischer assay (the standard laboratory method for assessing oil yield) averaging nearly 100 mL of shale oil per kilogram of rock, compared with less than 42 mL/kg for the eastern shales.

Several organic-rich shale deposits occur in the U.S.



Nevertheless, interest in developing eastern shales is growing because of the need to exploit all resources to reduce dependence on imported oil and because of constraints expected to limit shale oil production to around 64,000 m^3/day. Primary constraints on rapid development of western oil shales are (1) a scarcity of water in the West for processing shale and for land reclamation and (2) the vulnerability of the sparsely populated West to the boom-town syndrome—the influx of thousands of workers and their families requiring increased services such as water, sewage treatment, roads, schools, homes, police and fire protection, etc. By contrast, water and the required work force are more readily available in the East.

The Devonian Resource

The eastern oil shales are organic-rich marine deposits of Devonian and Mississippian age which lie in a broad band from western New York and Michigan to west Texas. Unlike the western shales, which were formed in a freshwater environment, the eastern shales were formed in a saltwater environment when decaying marine organisms and terrestrial remains settled to the bottom of the Devonian seas, which covered a large portion of the eastern United States about 350 million years ago. These organic sediments were mixed with inorganic sediments that hardened into shale—a fine-grained, thinly layered mixture composed chiefly of clay and quartz.

Under compression, the organic matter was transformed into a coallike organic fraction and kerogen, a heavy hydrocarbon which is intimately mixed with the host rock at ordinary temperatures but breaks down at high temperatures around 500°C (900°F) into shale oil, combustible gases, and a black carbon residue. The conventional method of obtaining shale oil is to heat it in the absence of air (pyrolysis), a method known as retorting. This method, however, transforms only the kerogen fraction into a liquid; for this reason, conventionally retorted eastern shales have lower oil yields than the western shales, which contain primarily kerogen. However, a new hydroretorting technique developed by the Institute of Gas Technology converts the coallike fraction as well as the kerogen in eastern shales into a liquid hydrocarbon, thus substantially increasing the oil yield of Devonian shales.

The eastern shales range in thickness from 3 m in southern Tennessee to more than 425 m in northeastern Pennsylvania, with known oil resources of 64×10^9 m^3. The greatest carbon concentrations occur in Indiana, Kentucky, Ohio, and Tennessee where, coincidentally, deposits are at or near the surface and are of sufficient thickness to be interesting from an economic standpoint.

Private-sector activity has been concentrated in the "knobs" region of Kentucky and its physiographic equivalents across the Ohio River in Indiana and Ohio. The knobs define the outer limits of Kentucky's Blue Grass Basin, and the Ohio and New Albany shales, which are part of the Devonian sequence, outcrop there. Pyramid Minerals and its affiliate, Addington Oil Company, have bought mineral leases on more than 120,000 ha in the area; other industries showing interest in developing eastern shales are Phillips Petroleum Company, Transco Energy Company, Ashland Oil Corporation, and Southern Indiana Shale Oil Company.

Private industry is focusing

In al fresco conference are the members of the research team who have performed the studies at ORNL on the environmental impact of oil shale development. From left, Warren Webb, Jerry Eddlemon, McBrayer, Dick Ketelle, Roz McKeown, and Ginny Tolbert. Not pictured is Doug Waits.

attention on the knobs region because the shales there can be easily removed by surface mining. Surface mining permits recovery approaching 100% of the resource at a cost lower than that of alternative mining methods. Deposits in the knobs region range from 9 to 30 m thick and have mean Fischer assays of 42 mL/kg recoverable by surface mining. By contrast, the shales of the Chattanooga Formation in Tennessee have higher Fischer assay yields (50 mL/kg) but can be mined only by more expensive underground methods. The Antrim Formation in Michigan is thicker (30 to 200 m) and has Fischer assays nearly equivalent to the Kentucky values. The Antrim Formation, however, is overlain by up to 800 m of glacial till and is therefore not accessible by either surface or underground mining. The Dow Chemical Company of Midland, Michigan, has been experimenting with in situ retorting of Antrim shales to produce low-energy gas for use in generating electricity.

Environmental Issues

The environmental impacts of an eastern shale oil industry are generically similar to other extractive or petrochemical industries, except in scale. For example, the energy density of eastern coals may be 18 times that of eastern shales—that is, production of a given amount of energy may require mining 18 times as much shale as coal. Furthermore, one major West Virginia coal (Pocahontas) produces only about 4% ash after burning, whereas a typical eastern shale may yield up to 85% spent shale on retorting, a waste ratio of 20:1 by weight. Thus, a shale industry would produce up to 360 times as much waste as would an energy-equivalent amount of coal.

The size range of a retort that is thought to be most profitable has a production capacity of 6000 to 8000 m^3/day. (A retort is the equipment which separates organic carbon from rock by pyrolysis.) Operating on a Devonian shale having a mean Fischer assay of 42 mL/kg, such a retort would consume up to 190×10^6 kg of ore and produce up to 160×10^6 kg of solid waste for disposal each day. In comparison, the country's largest surface coal mine (AMAX Coal Company's Belle Ayr Mine in Wyoming) produces approximately 40×10^6 kg of coal per day, and the largest underground coal mine (Peabody Coal Company's River King No. 1 in Illinois) produces approximately 4×10^6 kg per day.

Regardless of whether the shale is surface or deep mined, economics most likely will dictate that spent shale be disposed of on the surface. The solid waste disposal problem is exacerbated by the expansion of the shale during processing by 80 to 100% of its original volume. Thus, a shale oil industry will be required to dispose of more volume than it took from the mine. It is interesting to note that an 8000-m^3/day facility could completely fill Watts Bar Lake (1.7×10^9 m^3) with spent shale during a 20-year operational life.

As in the West, potential environmental impacts of the development of eastern oil shales include degradation of water and air quality as well as land disturbance. Because of their marine origin, the eastern shales are pyritic. When the shales are exposed to air by mining, pyrites (iron sulfide) in the shales oxidize, forming sulfuric acid. This is the same mechanism which produces the acid mine drainage associated with some coal mines or the acid overburden potential which complicates some coal

Chattanooga Shale—an Important American Mineral Resource

In the nineteenth century, some early settlers in the region embracing Colorado, Utah, and Wyoming were doubtful at first about the usefulness of shale. These pioneers built shale fireplaces and were dismayed when their stone hearths erupted into flames. However, by the 1850s it became generally known that the "rock that burns" was indeed useful as a source of oil for greasing wagon wheels, lighting lanterns, and other applications. Now that the United States is reluctant to rely so heavily on imported petroleum, the federal government is encouraging renewed development of a shale oil industry in both the West and the East to boost the nation's gasoline and fuel oil supplies.

Eastern oil shales, however, are potentially useful in yet another way. They can be used to produce not only oil (albeit at 40% of the yield rate of western oil shales) but also uranium and critical metals, including those that are largely imported by the United States.

From the 1940s through the 1960s, ORNL developed processes now widely used for commercial recovery of uranium from sandstones and phosphate rock and carried out exploratory development of methods for recovering uranium from leaner resources such as the Chattanooga shales, which cover a wide area extending from lower Kentucky, through Tennessee, and into northern Alabama.

In the late 1940s, before the large deposits of uranium ore were discovered in the West, Keith Brown, Dave Crouse, and Fred Hurst of ORNL's Chemical Technology Division investigated the extraction of uranium from Chattanooga shale. Brown and Al Ryon, also of the Chemical Technology Division, have continued studies of Chattanooga shale and updated the cost estimates of extraction in the 1970s when the nuclear power industry was growing rapidly. In 1978, after the large increase in oil prices, Mountain States Corporation, under contract to the Department of Energy, estimated that oil could be economically produced from Chattanooga shales if the Institute of Gas Technology's Hytort process were used and claimed that uranium could be extracted after oil recovery as easily as from raw shale.

Recently, Mike Silverman of the Engineering Technology Division and members of the Chemical Technology Division confirmed Mountain States' claim and showed that uranium and other useful metals could be leached from Chattanooga shales with sulfuric acid. Currently, the investigation of metal recovery is being continued by Mike Gilliam, Ron Canon, Jack Watson, and Ryon of the Chemical Technology Division, with assistance from Joe Stewart and David Heine of the Analytical Chemistry Division.

A group of ORNL researchers led by Irv Spiewak of the Engineering Technology Division recently conducted an economic assessment of developing Chattanooga shale similar to Mountain States' study. They found a higher return on the investment, mainly because of the doubling of crude petroleum prices in the past three years. The ORNL study also provides guidance on the research needed to establish technically sound processes for economic recovery of oil and metal by-products and for proper disposal of wastes from Chattanooga shale.

ORNL's current effort in testing various processes for recovering useful metals from Chattanooga shales is not without precedent: In the late 1970s, ORNL's Chemical Technology Division investigated methods for efficiently recovering aluminum and other metals from fly ash produced at coal-fired power plants. In fact, it is the capability developed for this work that makes studies on multimetal recovery from shale feasible. As in the case with oil, one

mine reclamations. Additionally, eastern shales contain significant amounts of metals such as nickel, chromium, cobalt, iron, and aluminum, all of which are more soluble in acid environments and are potentially hazardous to fish and other organisms.

Mining shale will have the same potential for erosion and stream sedimentation as other forms of mining, again magnified because of the expected larger mine unit. Waste disposal compounds that potential, however, because the spent shale is finely ground and subject to both wind and water erosion, making it a potential source of both air and water pollution. Stabilization and revegetation studies have not been done, but there is some question as to whether or not the spent shale will prove to be a suitable medium for plant growth. If it is not, an alternative means of stabilization, such as a soil cap, will be necessary.

Socioeconomic impact has been a major issue in the development of the Green River shales. Operation of a 90×10^6 kg/day mine and retort complex requires about 4000 workers, or 75% of the total population of Rio Blanco County, Colorado. By contrast, ten counties in the Kentucky knobs region collectively have nearly the same land area as Rio Blanco County but have a population 160 times as large. Thus, oil shale development in Colorado is viewed as leading to boom-town conditions, whereas incentive for metal recovery from coal wastes and spent oil shales is to reduce the nation's dependence on politically unstable countries for its supply of metals that are vital for industry and defense. The United States is totally dependent on imports for supplies of chromium, cobalt, niobium, and tin; furthermore, it imports large amounts of aluminum, antimony, manganese, nickel, and platinum. These strategic metals are imported from countries in South America, Africa, and eastern Europe.

In 1980 ORNL's Silverman started an investigation into the use of sulfuric acid leach for recovering metals from Chattanooga shale before and after the shale was subjected to oil-producing processes. He found that sulfuric acid leached out critical metals in raw shales and shales that had been subjected to a hydroretorting process developed by the Institute of Gas Technology. IGT's Hytort process, which introduces hydrogen into the retorting process, shows promise in producing higher quantities of oil from low-grade eastern shales. Silverman found that the sulfuric acid leaching method recovered a greater amount of every metal except uranium from hydroretorted shales than was obtained from the raw shales. Recovery of even more of each metal resulted if the hydroretorted shale was roasted (heated in air) before undergoing the leaching process.

Metals leached by Silverman in his studies were aluminum, iron, cobalt, chromium, copper, manganese, molybdenum, nickel, uranium, vanadium, zinc, and several rare earths. The leaching solutions were analyzed for metal content by the inductive coupled plasma technique, which heats constituents in a flame at such a high temperature that each metal emits light of a characteristic wavelength. Based on processing 100,000 tons of shale per day, Silverman estimates that recoverable resources from Chattanooga shale could supply these percentages of U.S. demand: aluminum, 30%; cobalt and uranium, 20%; molybdenum and niobium, 10%; nickel, 3%; iron, 2%; and vanadium, 100%.

Gilliam and his coworkers in the Chemical Technology and Analytical Chemistry divisions are using experience gained from their studies of fly ash processing and earlier studies of uranium recovery from Chattanooga shale to test the technical and economic feasibility of several methods of recovering metals commercially from Chattanooga shales and other eastern shales. They are encouraged by recent studies that indicate that, as with fly ash, the hydrochloric acid system appears to have certain advantages over the sulfuric acid leach method of metal recovery from Chattanooga shale.

Recently, Silverman has been examining a magnetic beneficiation process for concentrating the ferromagnetic and paramagnetic metals (iron, chromium, cobalt, molybdenum, nickel, uranium) while leaving the major portion of the shale behind in the less magnetic material (quartz, calcite, silicates). These early experiments show real promise. Silverman, who initiated the ORNL experimental effort on magnetic beneficiation of coal, thinks that this approach, if successful, could be followed by an alkaline leaching process that would be chemically simpler and more economical for recovering the critical metals than the acid leach processes currently being considered.

Shale may not look like it, but it has the potential of being a national resource. Euripides once wrote, "Leave no stone unturned," suggesting that treasures may be found under certain stones. In the case of shale, treasures may also be found within the stone.—C.K.

such development in Kentucky is widely viewed as an economic boost to a chronically depressed area.

ORNL's Role

ORNL staff members are involved in assessing the environmental impacts of shale development, researching the environmental effects of shale oil production and its residuals, and assisting the Department of Energy in program planning for environmental, health, and safety concerns. A seed-money grant allowed staff of the Environmental Sciences and Energy divisions to carry out an environmental assessment of a possible development of Tennessee's Chattanooga shale. The Chattanooga Formation is unique in that it will require underground mining and surface retorting to produce significant quantities of oil. The thickness and hardness of the Fort Payne Formation, which overlies the Chattanooga Formation, precludes surface mining, and the thinness (about 10 m, including the lower-grade Dowelltown member) and low yields render in situ production impractical.

In addition to the kinds of environmental impacts described earlier, producing oil from the Chattanooga Formation could lead to land subsidence from possible mine roof collapse. Because an oil shale mine would be the world's largest underground mine, impacts from subsidence could be moderately severe. Because the Fort

Oil shale is exposed in Kentucky by hillside road construction, left. On right, author McBrayer examines the oily rock.

Payne Formation contains important aquifers, mining the Chattanooga Formation could have locally severe impacts on groundwater as well.

In a similar activity, Kathy Oakes of the Environmental Sciences Division recently prepared an issue paper on the eastern oil and gas shales for DOE's Environmental Compliance Division under the Assistant Secretary for Environmental Protection, Safety, and Emergency Preparedness. The purpose of the paper was to provide an independent resource for ECD staff as they follow the environmental activities of other DOE units.

Chet Francis of the Environmental Sciences Division has been characterizing leachate from crushed and retorted shales from the eastern United States and is initiating greenhouse studies on the suitability of retorted shale for plant growth. These studies will contribute to a better understanding of potential impacts and will, in turn, influence mining, waste disposal, and land reclamation plans.

Two geochemists in the Environmental Sciences Division, Steve Haase and Steve Stow, are planning a study of the ways in which potentially valuable metals are incorporated into some organic carbon-rich rocks from the eastern United States, including samples of the Chattanooga shale. Such information may prove valuable in assessing the environmental behavior of mined shale upon weathering as well as for developing a technology for metal recovery.

Finally, Carl Gehrs, Chet Francis, and I, also in Environmental Sciences, and Peter Witschi in the Biology Division are part of a team which is preparing background material for DOE's Environmental Research and Development Plan for Eastern Oil Shales. The other members of the team are from Argonne National Laboratory, Brookhaven National Laboratory, Laramie Energy Technology Center, and the Fossil Energy and Energy Research staff at DOE headquarters. As participants in the planning process, we at ORNL are looking forward to continued involvement as an environmental research program is implemented for eastern shales.

Health Effects of Western Oil Shales

ORNL research on shale oil is not limited to eastern shales. Chemists, biologists, and ecologists at ORNL have identified components of some western shale oils that are mutagenic, carcinogenic, or toxic to such organisms as bacteria, mice, and freshwater algae. They also have compared the toxicity of crude and refined shale oils with that of coal liquefaction oils and natural petroleum crudes.

ORNL researchers have received synthetic and natural oil samples for analysis from the Chemical Repository (the Fossil Fuels Research Materials Facility located at ORNL that is sponsored by the Department of Energy and the U.S. Environmental Protection Agency). The ORNL facility also serves the shale oil industry and funding agencies as a clearinghouse for information concerning health and environmental effects of shale oil.

At a June 23–24, 1980, symposium in Gatlinburg, several ORNL researchers reported results of their studies on shale oil. These results have been included in the proceedings of the symposium, a book entitled *Health Effects Investigation of Oil Shale Development*. Two of the book's three editors are Wayne Griest and Mike Guerin of ORNL's Analytical Chemistry Division.

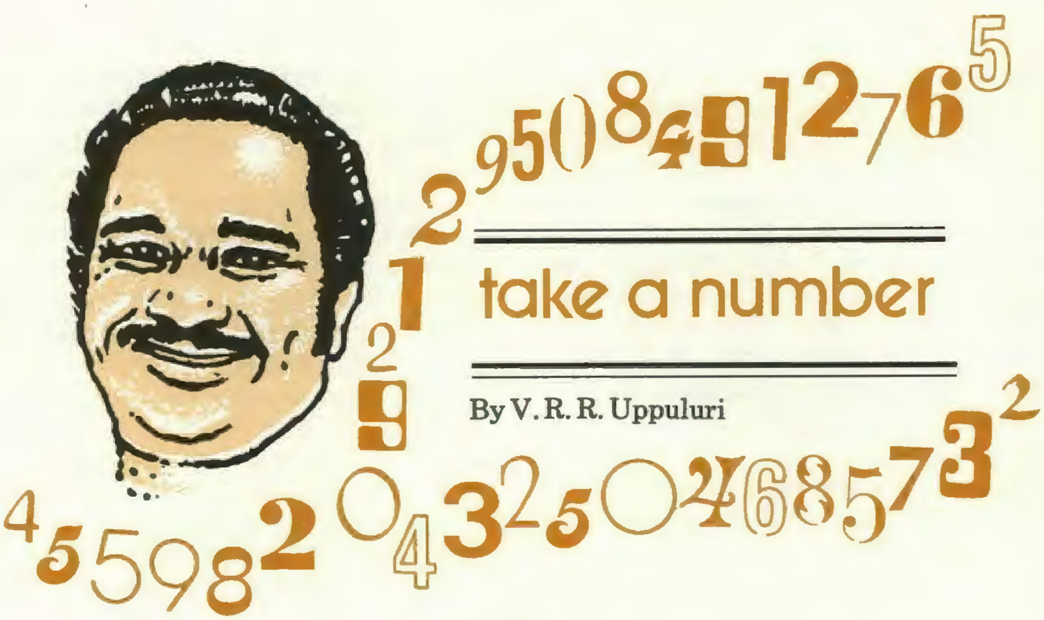
Bruce Clark and C. Ho of the Analytical Chemistry Division have examined several shale oils: (1) an oil from the Paraho Development Corporation in Grand Junction, Colorado; (2) a hydrotreated version of this oil; and (3) jet and diesel fuel derived from the same. They separated the Paraho samples into acid and base fractions and divided the remaining neutral fractions into aliphatic and aromatic classes. Collaborating biologists and ecologists determined that only the crude shale oil produced any significant biological activity. Clark found that petroleum-derived jet and diesel fuels and shale-derived fuels were chemically quite similar.

T. K. Rao and Jim Epler of the Biology Division have conducted short-term microbial tests using bacteria and yeast to determine which oils cause mutations in these microbes. These bioassays, used for rapid identification of mutagenic substances, deserve more extensive testing in animals to determine mutagenicity and possible carcinogenicity in more complex organisms. Rao and Epler found that Paraho/Sohio shale oil is mutagenic in the Ames bacterial test. The mutagenic activity is traceable to the organic matter (specifically, aromatic amines, azaarenes, and other nitrogen-containing polyaromatic hydrocarbons) in the basic and neutral fractions. Their studies showed that hydrotreatment (reducing heteroatom content by heating the oil under hydrogen pressure in the presence of a catalyst) eliminated the mutagenic activity. As with hydrotreated shale oil, no mutagenic activity was shown for shale-derived jet and diesel fuel samples. In ranking natural and synthetic crude oils, Rao and Epler concluded that the coal-derived oils are more mutagenic and natural petroleum crudes are less mutagenic than shale oil.

Mike Holland, L. C. Gipson, M. J. Whitaker, T. J. Stephens, and G. M. Clemmer of the Biology Division and D. A. Wolf of the Computer Sciences Division have been studying the health effects of chronic exposure to Paraho shale oil and its distillates in mice. Skin tumors developed on the backs of mice that received two or three applications a week (for up to 12 months) of crude or hydrotreated Paraho shale oil. Their studies indicated that hydrotreated shale oil was much less potent as a carcinogen than crude shale oil. They also found that distillates are not likely to cause skin tumors in mice but have a greater potential for producing local irritation and systemic toxicity than do the crude materials.

Jeff Giddings of the Environmental Sciences Division has studied the toxicity to freshwater algae of shale oils, coal-derived oils, and natural petroleum. He is interested in the effect of accidental releases of natural and synthetic oils during transportation, storage, and handling on the photosynthesis of algae, the base of most aquatic food webs. Giddings found that the water-soluble fractions of Paraho/Sohio crude shale oil are more toxic to green and blue-green algae than are water-soluble fractions of petroleum products, suggesting that crude shale oil spills might have a more adverse environmental impact than petroleum spills. He also found that water-soluble fractions of some unrefined coal-derived oils are more toxic to algae than the shale oil fractions he tested. Giddings concludes that hydrotreating reduces the toxicity of shale oil to algae by removing nitrogen and oxygen from the most toxic of the oil's known water-soluble compounds—aromatic amines and phenols. These compounds are more soluble in water than their hydrocarbon analogs and therefore are favorably partitioned in water.

ORNL studies have yielded two important preliminary conclusions about western shale oil: (1) in its crude form, it is less toxic than most unrefined coal-derived oils but more toxic than natural petroleum, and (2) partially hydrotreated crude oil and refined products are no more biologically active than their natural petroleum counterparts.—C.K.



take a number

By V. R. R. Uppuluri

Multiplication by 11

Take any natural number, for example, 126, and multiply by 11. We obtain $126 \times 11 = 1386$. If we invert 126 and multiply by 11, we obtain $621 \times 11 = 6831$. Note that 6831 is the inverse of 1386.

Similarly, multiply 1245 by 11 and obtain 13,695 and $5421 \times 11 =$ 59,631. Note again that 5421 is the inverse of 1245 and the products are inverses of each other. How general is this property?

For any natural number in which the sum of any two adjacent digits in the number is less than or equal to 9, the product of the number multiplied by 11 is equal to the inverse of the product of the original number inverted and multiplied by 11.

Note that the product of 128 and 11 (1408) is not the inverse of the product of 821 and 11 (9031) because 128 has adjacent digits 2 and 8, the total of which exceeds 9.

Are we Powerless with Powers?

Take a four-digit number, for example, *abcd.* The problem is to find *a, b, c, d* that satisfy

$$abcd = a^b \times c^d .$$

There seem to be no techniques to solve this problem other than complete enumeration:

$$2592 = 2^5 \times 9^2 .$$

It will be interesting to show that there are no other solutions.

John Googin began work in Oak Ridge for the Manhattan Project in May of 1944 with a B.S. in chemistry and mathematics from Bates College in Lewiston, Maine. Now,with a Ph.D in physical chemistry, awarded by the University of Tennessee, he is a senior staff consultant to the Technical Division of Union Carbide Corporation, Nuclear Division, and his office is located at Y-12. A definite asset to the Nuclear Division technical roster, Googin is an E. O. Lawrence Award recipient (1967), an American Society for Metals Fellow (1974), a Carbide Research Fellow (1976), and a participant in work leading to more than one IR-100 award. Fans of the PBS TV series "Nova" may remember his appearance on "The Plutonium Connection" in 1975. For many years now he has been urging ORNL to become involved in research and development relevant to improved efficiency in personal transportation and was instrumental in gaining the Flywheel Laboratory at Y-12 in support of the work under way at the time at Lawrence Livermore National Laboratory. Since this article was written, LLL has relinquished responsibility for the Flywheel Project, and it is now at ORNL in the Heat Transfer Section of the Engineering Technology Division, under the aegis of DOE's Energy Storage Programs.

Personal Transportation of the Future

One Man's View

By JOHN GOOGIN

The wage earners who live in today's far-flung urban and suburban sprawl are heavily dependent on the personal automobile. This includes even those who are in a carpool and those who have access to the best in modern mass transit. The members of their families who take classes, attend meetings, and go shopping are virtually paralyzed when a car is not at hand. The fact is that we have built our cities and suburbs around the existence of almost instant, anytime, personal transportation, and the removal of that for any reason is going to create a traumatic upheaval among the members of

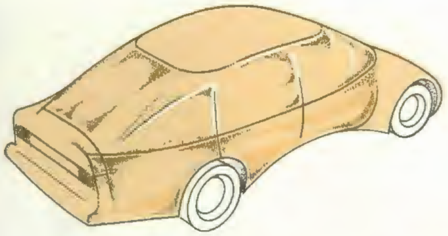
Mechanical energy storage in automobiles can take several forms, the most attractive of which is the flywheel. Until recently, Lawrence Livermore National Laboratory led the field in flywheel research and a laboratory in the Y-12 area in Oak Ridge provided experimental support for LLL's work. Today, however, LLL has relinquished its interest in the technology and ORNL has taken it over. Bob Steele (right), head of the Oak Ridge Flywheel Evaluation Laboratory at Y-12, now under ORNL management, is shown here discussing a materials test with technician B. J. Sutton. The fatigue life of a flywheel is of greatest importance for automotive use. Several new composite materials are being tested at the FEL in the search for the highest energy storage capacity in the lightest medium. The goal is to be able to store between ½ to 1 kWh at 88 Wh/kg. To this end, the wheels are tested on a centrifuge that can take them up to 40,000 rpm. One wheel has achieved 79 Wh/kg; three that have recorded between 65 and 75 Wh/kg are also considered very good (by comparison with the energy level achieved by the state-of-the-art metallic rotor, which is less than 55). Steele is optimistic that the goal will be reached in 1982, well ahead of the projected program goal of 1984.

upper, lower, and middle class American society.

In recognition of this fact, a group in ORNL's Program Planning and Analysis Office invited Gene Goodson, of Purdue University's Automotive Transportation Center, to present a seminar at the Laboratory in November of 1979. The result was the formation of an ad hoc committee, under PP&A's auspices, which looked into areas of research and development to make personal transportation feasible, no matter how much the fuel cost.

The automobile, or something very similar, can be available as personal transportation for the foreseeable future. The fuel will be a liquid, much like diesel fuel. The engine will be of the piston kind, in principle very similar to some of the engines of today. There will be no shortage of materials from which to make this vehicle in quantity, and it will be reasonably safe, comfortable, and affordable.

This may not be the conventional wisdom of the moment, but it is certainly a position that can be defended on technical grounds. These grounds have been derived from the PP&A planning study,



which was designed to help define future opportunities for the Laboratory to make contributions in the field of transportation technology. It was started by Joe Carpenter, at that time in the PP&A Office, and was contributed to by Don Cannon, Joe Cleveland, Allen Croff, Dave Greene, Joe McGrory, Axel Rose, G. Samuels, and Vic Tennery. I then presented it, with biases, to the senior staff. Much of the study's initial position came from the seminar given by Goodson.

The design of the automobile of today is dictated by the market place, and there is no reason to expect a change in dictation. Today's automobiles are much more complex technically than those of the past, but the cost in constant money has not changed drastically. Their complexity can be expected to continue to increase, but the automation of the factories can be expected to keep the number of man-hours required for manufacture at a relatively constant level. The only intractable problem is the exhaustion of the low-cost fuels needed to power the cars. The relatively constant research and development expenditure associated with increasing technical complexity will be used to solve the fuel cost problem and keep the market lively. The capability of computer technology to contribute to the design, manufacturing, and operations of these vehicles has only now begun to be realized and will be central in keeping costs under control and fuel efficiencies up.

How To Do It

The basic principles to be applied for the solution of the fuel problem have been long known, but working out the details is often the most difficult part of the problem. The efficiency of the engines used must be increased. The weight of the vehicles must be reduced to a practical minimum. Air resistance must be lowered, as must all other sources of energy loss. Energy used in acceleration should be recovered in deceleration. Energy used in climbing hills must be recovered in descending them.

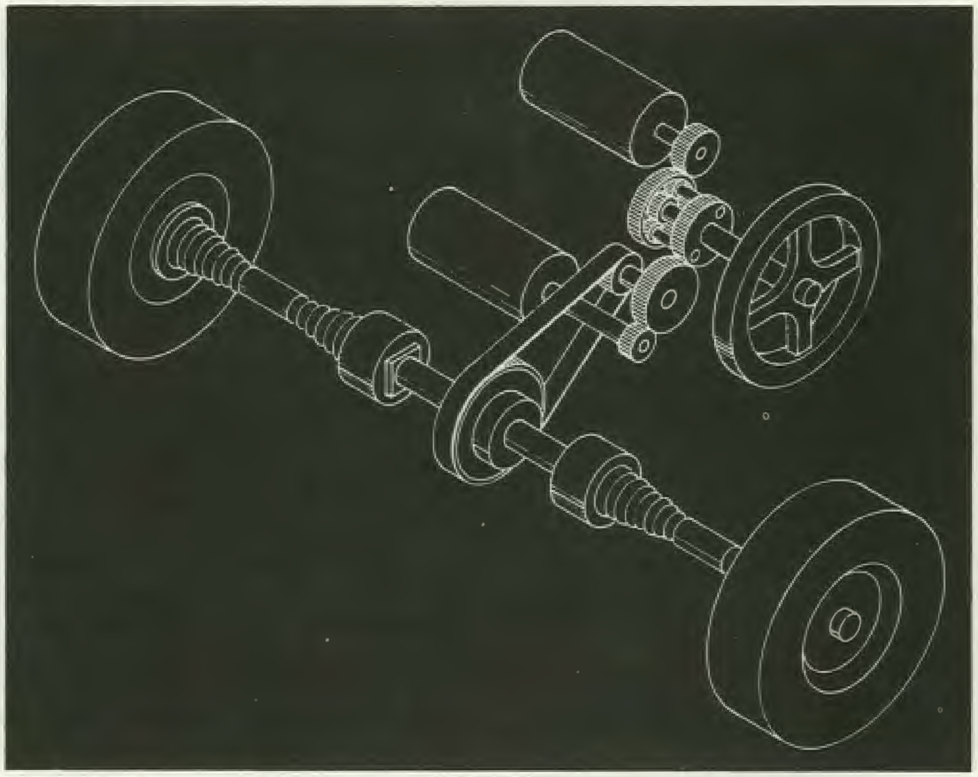
Progress is being made in developing devices for the recovery of energy. A facility has been set up at the Y-12 Plant for testing wheels to be used as components of advanced flywheel systems. The idea is to develop an inexpensive, lightweight wheel that can safely spin at very high speeds. The facility is designed so that the wheels can be safely tested to destruction. It seems certain that wheels can be made that will store more energy per unit of mass than can be foreseen for the best of electric batteries. The indications are, also, that ways for storing energy in and retrieving energy from flywheels can be made less costly and more efficient than those for batteries. These wheels will be made of fibers: S-2 glass, graphite, or strong organic fibers such as Kevlar. Perhaps all three kinds will be used in a single wheel; the differences in fiber properties can be used to optimize a single wheel system.

The means of storing and retrieving energy in a flywheel system can be mechanical or electrical and will be developed as part of the transmission systems of the future. These future propulsion systems will require only a small engine, because the engine will be required to do only the easy jobs of making the vehicle go at a constant speed and keeping the flywheel at the desired speed. All of these functions can be managed by a microcomputer to place great accelerative and decelerative capacities at the driver's disposal for short times, in case he needs to lay down some rubber to pass a truck going up a hill or in case he needs to slow down rapidly without using the brakes and wasting energy. The computerized system will optimize efficiency by providing low-energy-loss transmission operation that can provide any gear ratio required.

Several rivals to the flywheel are under investigation as potential energy management systems for vehicles. Batteries can be used, but much energy is lost from their internal resistance. Compressed air systems lose energy from the heat of compression, which is stored with the compressed gas. All of these systems have the great virtue of partly circumventing the need for fuel-efficient transportation by drastic reduction of vehicle weight. Today's automobile power train designs necessitate lower weight for good fuel economy. Weight reduction, however, limits both the safety of the vehicle and its convenience. Relative freedom from these weight limitations can be achieved by energy storage in an efficient system, which eliminates nearly all of the penalty of weight except for the small added drag from the rolling friction factor.

The Wheels

The drag associated with wheels, tires, and wheel bearings is relatively low, but it is relatively significant in terms of the energy efficient vehicles of the future. There is very little that can be usefully done with the wheel bearings, but tires are a different matter. The tires of the future will become smaller and harder, and wheels may increase in diameter. The elastomers selected as materials for the tires will have low internal friction and generate little heat during operation. Tires will no longer be



Flywheel design for a battery-operated vehicle. If, while coasting downhill, the flywheel (upper right) can be accelerated to 25,000 rpm, energy is generated to recharge the batteries enough to eliminate the severe power drain on the car's battery pack.

largely responsible for a smooth ride; ride characteristics will be improved instead with low unsprung weights, permitting lighter wheels, wheel supports, and drives. Wheel system construction is one of the areas in which the highly weight-efficient materials used in the flywheels will be important. The racing bicycles of today provide a model for the wheel systems of the cars of the future.

With just these features—small, best-of-present-day engines, efficient flywheels for energy storage, and the best possible wheel systems—the otherwise large, traditional American sedan, performing essentially in its current, energy-wasteful mode, can still get 20 or more kilometers to the liter (50 mpg). Because a microcomputer can be programmed to the mission profile of the owner, the brakes need only be used in a true emergency and can therefore last the life of the car.

The Shape

Besides those of the wheels and tires, other drags must be reduced. The American car body of the past was designed much more for eye appeal than for transportation efficiency. Aerodynamics in cars has, until recently, been a matter of guesswork rather than knowledge. Only recently have even the largest of car companies equipped themselves with wind tunnels of a size to test shapes approaching full scale. The cars of our recent past have been only half as good regarding wind resistance as they could have been. Once the car with the small engine, the flywheel, and an efficient wheel system becomes the standard, wind resistance becomes the limiting factor with respect to engine size and fuel economy. When the wind resistance problem is really solved, all cars for a given use will look as much alike as do jet airplanes. They will be rounded in similar ways with flush, curved windows and a minimum of protruding objects such as mirrors and ornaments. As with jet airplanes, of course, they can be painted as desired. Redesigned to the ultimate in these shapes, the car of the good old American size and safety will be getting well over 43 km/L (100 mpg), provided speeds are kept to that reasonable 88 km/hour (55 mph).

But this is not the end of the reduction in air resistance; even when the aerodynamics are good, the cross-sectional area is limiting. Seats that hold three passengers are really not necessary; many car owners have found that the two-abreast seat is just about right. On a car designed for this cozy configuration, much of the frontal area can be reduced, decreasing the air resistance substantially. With that small engine, an efficient flywheel, efficient running gear, that smooth finish and great shape, the future car will step up to the 90-km/L (200-mpg) class. Because length is not as important in creating air drag as is the frontal area, a car having two-abreast seating for six passengers will run almost as efficiently as will the vehicle built for two.

The car I have just described is not yet a reality; the flywheel systems are not ready. The concept, however, has been demonstrated in several ways. Single-passenger test cars have been built with good aerodynamics, minimum frontal area, seating for a nearly supine driver, good running gear, and a very small diesel engine of current design. These cars have gone, at low average speeds like 40 km/hour (25 mph) on smooth, level tracks (thus eliminating the need for a flywheel), as far as 1275 km on a liter of fuel (3000 mpg). This ought to be quite enough to allow most folks to get around in the future without putting much strain on the budget from out-of-sight fuel costs.

Low-Heat-Loss Engines

Heat loss through the cylinder walls, heads, and pistons can be limited by using ceramic materials for parts of these components. The ceramics now available are too imperfect and expensive to be practical for personal automobiles. An ongoing U.S. Army program, however, in which stabilized zirconium oxide components are used, has produced a truck diesel engine that runs without a cooling system—not even the fins of the standard air-cooled engine. This engine puts about 15% more of the fuel energy into the power output shaft than does a conventional engine of the same nominal power, discharging essentially all of the rest into a very hot exhaust.

This very hot exhaust can be very useful. It can be used to operate a second engine to add to the power output. If it is used to operate a Stirling-style engine, about one-third of the heat can be converted to additional power. Because about 60% of the fuel energy of the first engine is discharged into the exhaust, the two engines working together can convert about 60% of the heat of the fuel into useful work, yielding about twice the fuel economy obtained from today's engines. Moreover, enough heat will still be left in the exhaust to heat the car in winter.

Small Motors

These very advanced adiabatic engines of the future may not be much more complex than those of the present. Engine size can be small, because of the capacity for energy storage; about a third of the necessary horsepower can be stored for subsequent use. Therefore, each of the two engines can be a single-cylinder machine. The one into which the fuel is injected may be a two-cycle rather than a four-cycle engine to make it even simpler, smaller, and lighter. The Stirling engine used for the second stage need have only a single cylinder. If the second stage is a more conventional steam machine, it can be expected to be a double-expansion design having two cylinders. The era of the two- and three-cylinder engine is probably coming. Some manufacturers are actively considering two- and three-cylinder configurations for gasoline engines in their very small cars for the near future. The fewer the cylinders, the lower the friction losses, heat losses, and cost.

The advent of super-efficient automobiles will come gradually, as the market place slowly changes. There will be plenty of time for development of the necessary technologies, but it might be a mistake to leave all the effort to the manufacturers, who are motivated largely by short-term needs. The ongoing conversion of the U.S. automobile industry from the standard automobiles of the past to mid-sized vehicles will cost about $80 billion. A second conversion, in the future, to new engines and bodies can be expected to cost about the same amount in constant dollars. A modest investment of a few percent of these figures devoted to advanced, long-range developments could certainly yield sure energy profit next time around. The U.S. Army program previously mentioned spends only a few million a year and bids fair to do rather well. One might, of course, wonder as to the enthusiasm of fuel suppliers and their friends for the early advent of technologies that could rapidly and substantially reduce the need for their product.

Equipped with the engines of the future, that little test car on the smooth, level test track might be expected to get about 2000 km/L (5000 mpg). One could afford to run a car like that on French perfume.

The practical, lightweight, laid-back tandem two-seater with those good flywheel, transmission, microcomputer, running gear, aerodynamic, and engine designs could be expected to be able to go as far as 350 or so kilometers on a liter of fuel (800 mpg) on the interstate at a modest speed. It might be necessary for the highway department to post signs warning of upcoming long hills, so the driver could top off the flywheel before beginning the climb; aside from that, driving should be rather routine. The cost of fuel for this system would be comparable to the cost of oil for today's cars. Of course, the passenger is behind the driver in this tandem two-seater.

For the two-abreast, cozy car for two, four, or six, there will be the inevitable losses because of the poorer aerodynamics. Allowing for passenger comfort, it is not likely that anything better than 170 km/L (400 mpg) can be realized. If this is a $10,000 car and the market will stand paying the equivalent of half the cost of the car for the fuel needed for 160,000 km (100,000 miles), which seems to be the market trend of the moment, diesel fuel at $6.50/L ($25/gal) would not be unreasonable. Such fuel could be profitably manufactured out of almost anything that contains carbon.

Fuel efficiency in the old American six-passenger sedan with lots of comfort, and having the design features described above, would be in the rather modest 65–85-km/L (150–200-mpg) range at modest speed on good highways. Diesel fuel at $2.60/L ($10/gal) should be easily made from coal and easily afforded by those owning this kind of car. It would seem that cars of this kind could be around for hundreds of years.

Flywheel Research

The development that is required

to increase energy efficiency in personal transportation, thereby increasing U.S. fuel independence, needs to be reiterated. To make vehicle weight a secondary rather than a primary variable in the attainment of high fuel efficiency, an energy recovery system is necessary. Such a system recovers the kinetic energy of the vehicle as it stops and makes most of it available for starting again. It recovers the potential energy of the vehicle as it goes down a hill and returns it as the next hill is climbed. It allows optimum operation of the engine system, largely independent of the immediate demands of the vehicle's mode of operation. Several technologies can be used for this. Reversible charging and discharging of batteries with a motor generator system is one, but this system shows little promise of yielding more than 50% recovery. Use of reversible heat engines like the Stirling to heat a thermal storage unit and recover the heat for propulsion is another, but again, half or more of the energy would be lost. In a third possibility, energy might be stored as the mechanical energy of a flywheel, and, if the required transmissions can be developed, 90% of the energy might be recycled. The great potential of the flywheel systems made them one of the centerpieces of the DOE energy conservation program.

readers' comments

Letter to the Take a Number Department

To the "Take a Number" editor:

I was intrigued by the item on dice experiments in your column in the Spring 1981 issue. Your result can be turned into a mathematical magic trick as follows:

The mathemagician (*sic*) asks the subject to throw two dice and, without revealing the result, construct a four-digit number based on the throw and its complement as you described in your column. After dividing the number by 11, the subject is asked to choose any integer from 1 to 9 and add it to the quotient. The mathemagician asks the subject for the result, and then tells him what his original throw was. If the subject's result is N, all the mathemagician has to do is find the integer part of $N-8$ divided by 9.

Of course, this trick can be extended to any number of dice, as you indicated in your column.

Lee Abramson, Acting Chief
Applied Statistics Branch, MPA
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Letters To the Editor

I refer to the letter from me published in the *Review* for Summer 1981, and to the reply by Jim Schreyer. I think you missed my point. I attempted, with little success it seems, to use irony, or light satire, to point out that the expression "glucose sugar" is a pleonasm.

W. M. Woods
114 Tabor Road
Oak Ridge, TN 37830

Reader Woods is exactly right.—Ed.

I enjoyed Alvin Weinberg's review of *Entropy, a New World View*, by Jeremy Rifkin, and I agree, at least in principle, with all Weinberg says. I believe, however, that the review missed the fact that Rifkin isn't really talking about the second law.

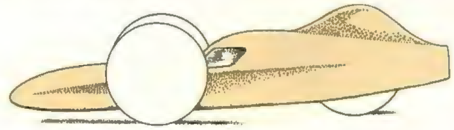
Rifkin's problem begins in 1865, when Rudolph Clausius, the man who gave entropy its name, concluded his paper with the following statement: "The energy of the Universe is constant; the entropy of the Universe moves toward the maximum."

Rifkin, behaving not unlike Pope's poets of little learning, who take only shallow drafts of the Pierian spring, has grabbed the second part of that sentence and run with it.

The Clausius pronouncement was a nice, cosmological, nineteenth-century summary of what he says in the body of his paper. The addition of the mind-catching words "Universe" and "moving toward the

The flywheel can be of great value to an electric car as well as to the internal combustion automobile. It could eliminate the energy losses that occur in battery systems at high charging and discharging rates. Electric cars with flywheels and aluminum air fuel cells might be able to rival the usefulness and versatility of cars with internal combustion engines, an idea for an atomic-powered electric future.

The proposed adiabatic system, in which no heat is lost except to the exhaust, a diesel engine backed up by a high-efficiency second-stage engine like the Stirling to recover the exhaust energy and boost system efficiency to near 60%, is close to the ultimate. No probable way is apparent by which fossil fuel or biomass could be better used to drive vehicles than to make liquids to fuel such a system. The adiabatic first stage can be used with almost any pumpable liquid, thus minimizing the cost of resource conversions. The development of the needed ceramic materials and economical methods for their production would be a more-than-worthy project for a national laboratory such as ORNL.



maximum" distracts the reader from what Clausius really had to say: "Energy is never created or destroyed; entropy is created but never destroyed." Unfortunately, Rifkin has been caught on the catch words, and his book is the result.

The entropy of the world is not increasing inexorably. In fact, at this moment it may be decreasing, if, for example, the side facing the sun is largely covered with clouds while the side away from the sun is largely free of clouds. The largest source of entropy on earth is that generated when sunlight is absorbed at a temperature that is only a fraction of the thermodynamic temperature at which it was emitted from the sun. But that entropy, as well as other entropy generated or released from latent sources and, of course, the primary entropy received from the sun, are all reradiated to space in what, for at least our immediate purposes, is a perfect entropy balance. If we do collect a little more entropy, because, for example, we build up a little more carbon dioxide in the atmosphere, the emitting temperature of the earth simply increases slightly until the balance is established again.

Rifkin's assumption that the world is the same as Clausius' Universe displays a lack of understanding that destroys his whole argument. Rifkin apparently doesn't realize that entropy always tends to flow from any region of higher temperature to a region of lower temperature. In fact, entropy displays all of the qualitative characteristics that we associate with our common-sense understanding of heat. Unfortunately for our understanding of thermodynamics, by the time Clausius discovered the significance of entropy, Joule and Mayer had already assigned the word "heat" in thermodynamics to the energy associated with the transfer of entropy. In any case, the entropy of a system increases only to the point where the temperature of the system is high enough to cause the outflow of entropy to equal the rate at which entropy enters the system, whether from outside or by internal generation.

The kind of disorder that Rifkin is concerned with cannot be compared with the disorder between and within the molecules in Boltzmann's equation. Von Neumann and Shannon, in the case cited by Weinberg, extended the meaning of Clausius' word when they applied it to a disorder characteristic of information. To have entropy in the Clausius sense, a system must also have a temperature and an energy of transfer. Both those entities are missing in Rifkin's analysis.

I am disheartened that such a nonsense book should be so widely accepted. I guess there are more of Pope's poets in the world than I care to be made aware of.

R. N. Lyon
348 East Drive
Oak Ridge, TN 37830

Thanks to radiopharmaceuticals, the human heart can send a message with revealing news about its health or afflicted state. Thallium-201 is now being used in several million patients a year for heart scans. New radiolabeled agents on the horizon promise clearer and safer images of the heart. ORNL plays an important role in the present and future science of heart imaging. It is the only free-world supplier of thallium-203, the stable isotope from which thallium-201 is made. ORNL is on the frontier of nuclear medicine research aimed at developing improved radiolabeled agents for scans of hearts and other vital organs. At right, Kathleen Ambrose communicates with a rat, one of many experimental animals whose hearts are imaged by new radiolabeled agents developed and tested by ORNL's Nuclear Medicine Technology Group.

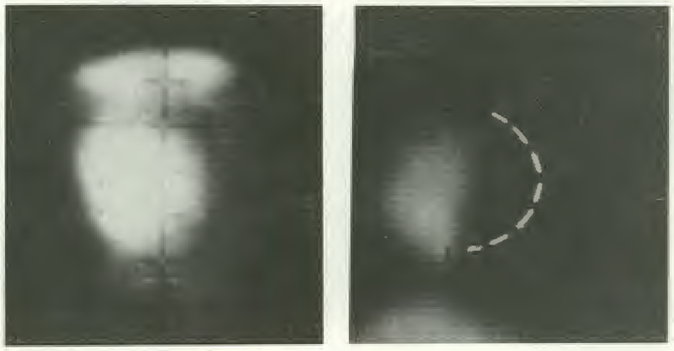
Images of the Heart

ORNL Makes Isotopes for Disease Detection

By CAROLYN KRAUSE

The patient has had a heart attack and seems to be recovering. The physician seeks information on the extent of cardiac damage. Has there been a myocardial infarction—that is, is part of the heart muscle dead? What is the location and amount of tissue affected in the left ventricle, the major muscle that pumps oxygen-rich blood to the rest of the body? Is part of the muscular tissue in a diseased state because it has been deprived of oxygen and nutrients due to clogged arteries and reduced blood flow? To answer these questions, the physician has to choose a method for "taking a picture" of the heart.

The physician could determine the extent of heart attack damage by coronary angiography—a procedure in which a catheter is inserted into an artery for injection of an x-ray-absorbing dye into the coronary arteries. But the doctor opts for a less expensive, safer way



The scan at left of a female rat shows a posterior view of the heart (upper arrow) and liver (lower arrow) after injection of a tellurium-123m labeled fatty acid. At center is an anterior view of an image of a normal rat heart. The image on the right shows an infarcted (tissue-damaged) heart.

to image the heart. The patient's coronary damage is assessed by injecting thallium-201.

Why thallium-201? For a radioisotope to be useful in diagnosing heart disease, it should (1) be nontoxic and selectively taken up by the heart tissue; (2) decay with the emission of gamma photons in an energy range that can be efficiently detected by imaging equipment; and (3) have a physical half-life that is long enough for the diagnostic procedure to be completed without exposing the patient to excessive radiation. In addition, the radioisotope should be administered in an agent that is free of contaminating radioisotopes that would affect image quality or increase radiation burden. Thallium-201 meets these requirements.

Thallium-201 is one of an array of radioisotopes now being used in tests given to one of every four patients hospitalized for medical diagnosis: For heart scans alone, it is used in an estimated four to five million patients a year. In the past five years, it has become one of the preferred methods of assessing heart muscle damage because it is relatively inexpensive, safe, and noninvasive (requiring no exploratory surgery or insertion of tubes).

Oak Ridge National Laboratory has played a key role in meeting the increased demand for thallium-201. The Laboratory's electromagnetic separators have been the sole source of thallium-203 in the free world for many years. Thallium-203, a stable isotope, is shipped to numerous cyclotrons in the United States, Japan, and Europe for transformation to radioactive thallium-201. ORNL researchers have found a way to increase the yield and purity of the enriched thallium-203 product so that a relatively pure and therefore safer radioisotope can be made in large enough quantities to meet the growing demand for it in medical diagnosis.

One reason for the recently reported decline in the heart attack rate, according to many physicians, is that the thallium scan has become widely used as a quick, painless way of indicating the need for therapy to bring heart disease or potential heart problems under control. Thallium scans taken after a heart attack determine whether permanent damage has occurred and how well the patient has recovered. This information guides the physician in selecting a treatment, whether it be a coronary bypass operation or a therapeutic regimen combining exercise with vasodilator drug therapy. If the drugs are used, a subsequent scan might be taken to determine the effectiveness of the drug therapy. Thallium scans are also being used increasingly to help physicians identify potential heart attack victims, who are then counseled about ways to avoid future problems.

A heart scan shows the different levels of radioactivity. After being injected with thallium, the patient lies down under a gamma camera, or body scanner. The gamma rays emitted by thallium-201 in the patient's body excite the electrons of the sodium iodide crystal in the scanner. As the electrons relax, they give up their excess energy in the form of light. Photomultipliers in moving collimators scan the body to determine the spatial distribution of radioactivity by measuring the light emitted by the crystal

(continued on p. 20)

Gene Newman, head of the isotopes section in the Operations Division, holds a vial of the thallium oxide made in the Y-12 calutron. He stands in front of the thallium exhibit in the isotopes display chart in Building 3047.

How the Stable Isotope Program Improved Thallium Production

ORNL's electromagnetic separation facility at the Y-12 Plant is the most versatile isotope production center in the world. More than 250 stable and radioactive isotopes have been produced there for use in a wide variety of research and technical projects. The facility, however, is more than a production facility; research to improve the yield and purity of selected isotopes, particularly those in demand for use in nuclear medicine, is also conducted there.

The production of thallium-203, for example, has been greatly enhanced as a result of research. The impetus for this research in the past decade has been the growing demand for the isotope for heart scans.

The history of thallium production indicates the difficulty of separating thallium-203 from thallium-205 in large quantities and at high purities. Thallium was first produced in the electromagnetic separators two years after the calutrons were diverted from wartime uranium-235 separation to stable isotope production in late 1945. "The purpose of the thallium separations was to use thallium as a substitute element for development of high-throughput uranium separations equipment," says Bill Bell, leader of the Separation R&D Group, which before October 1, 1981, was part of the Isotope Separations Section of ORNL's Chemical Technology Division but now is in the Operations Division.

The quantities of thallium-203 obtained in 1947 ranged from 0.1 to 9 g and the purities ranged from 48 to 86% (86% thallium-203, 14% thallium-205). Subsequent separations were 46 g at 93% purity in 1956, 706 g at 94% in 1965, and 740 g at 92.4% in 1975. The feed material used in the calutrons was thallium as an elemental metal or as a compound with iodine, bromine, fluorine, or nitrogen.

In 1975, Allen Veach of Bell's research group had the idea of trying thallium sulfide as a feed material. It was a bold idea because sulfides of other elements had been tried unsuccessfully in the separators. Working with George Howell, Veach demonstrated that thallium sulfide eliminates two problems encountered by other thallium feed materials. Since 1978 the Calutron Separations Group under Joe Tracy has been producing increasing quantities of thallium-203 at purities of 96 to 97%. In other words, the amount of impurity (thallium-205) has been cut in half (from 8 to 4%) since 1975, a significant achievement.

Why does thallium sulfide work better than the other feed materials? The answer requires a basic understanding of how the calutron works. An invention of E. O. Lawrence of California, the calutron is based on the principle of the mass spectograph but differs in that (1) it uses much larger ion-beam currents and (2) its ion source and receiver pockets are in the magnetic field, not external to it. The main difference between isotopes of the same element is their mass. When a positive ion beam of vaporized thallium is accelerated at high voltages through a magnetic field, the beam splits into beams of thallium-203 and thallium-205 owing to differences in mass. Because thallium-205 has more mass (and a smaller charge-to-mass ratio), its beam is not bent as much in the magnetic field as is that of the lighter isotope. The ion beams have different radii of curvature and enter two different slits in the ion receiver (which may be separated by only 1 or 2 cm). The result is separation of one isotope from another.

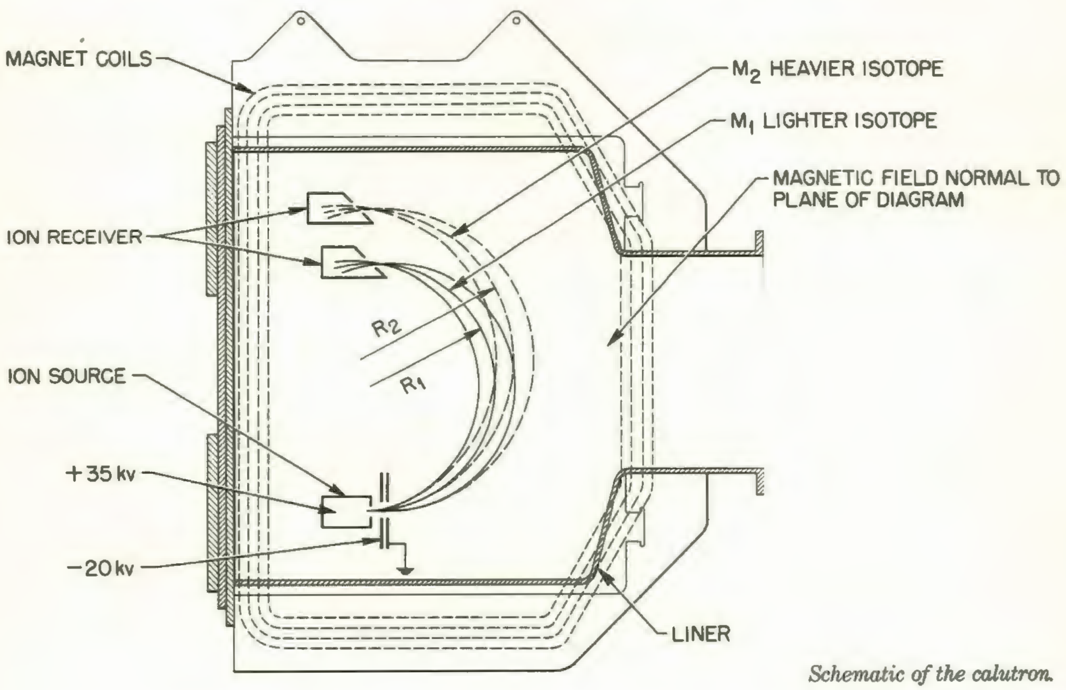
However, separation is not as simple as it sounds. When thallium metal was used as a feed material, it condensed on the electrodes used to accelerate the ion beam and caused severe sparking. This high-voltage discharge between the electrodes altered the position of the ion beam, causing the thallium-205 beam to be swept across the thallium-203 receiver pocket, resulting in contamination and reduced assay purity. Knowing that sulfur has a tendency to quench sparking, Veach thought that thallium sulfide might be a suitable feed material for isotope separation. Indeed, tests showed that sparking was not a serious problem with thallium sulfide because of its higher ionization potential than elemental thallium and because of its lesser tendency to condense on the electrodes.

Another problem with separation is that some of the thallium vapor might not be ionized. This vapor could reach the ion receiver, condense on a pocket, and cause contamination because the vapor contains both isotopes. To avoid this problem, operating pressures must be only high enough to ensure that the maximum amount of vaporized thallium is ionized. Fortunately, thallium sulfide can be pumped more readily by calcium to produce lower pressures than do other thallium feed materials. This is an advantage because the lower the operating pressure, the narrower and more focused are the ion beams. Broad, scattered beams raise the possibility of nonspecific isotope collection (i.e., contamination) in the pockets. Thus, a higher yield and purity of collected material result when pressure is minimized and beam focus is optimized.

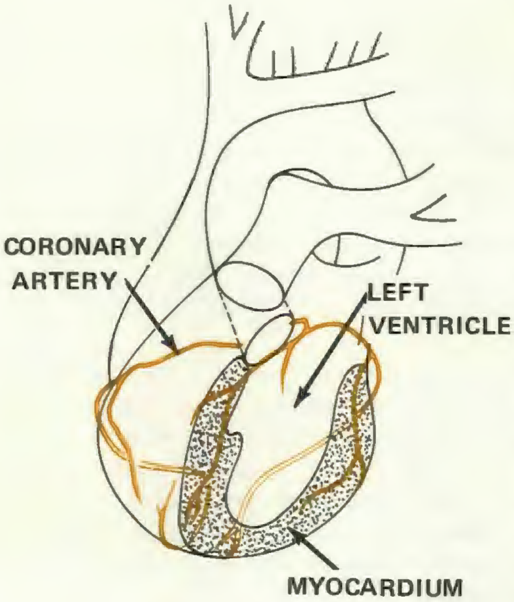
By reducing sparking and operating pressures, thallium sulfide allows an increase in the ion-beam current without sacrificing the purity of the enriched thallium-203 product. As a result, the output of the product has been increased enough per unit operation time to meet the free-world demand for use in the heart scans of up to five million patients a year. This increased production efficiency allows the unit price to be kept down.

"Isotopic assay (purity) is important," says Gene Newman, manager of the Isotope Production, Services, and Sales Section of the Operations Division, "because the less you have of unwanted isotopes in your stable isotope product, the less trace contamination will end up in the final radiopharmaceutical. It is essential to minimize contamination by undesirable radionuclides to keep radiation doses to patients as low as possible."

Thus, research and production units at the ORNL electromagnetic facility have worked hand in hand toward the ultimate goal of helping human hearts.—C.K.



Schematic of the calutron.



This view of the heart shows the major muscle of the heart that pumps oxygen-rich blood to the rest of the body. When blood flow is reduced to the myocardium, depriving it of oxygen and nutrients, the tissue may be irreversibly damaged, resulting in a heart attack.

detectors; the intensity of this light is proportional to the radioactivity emerging from inside the body. This information, which is processed by a computer, appears on a display screen as a scan, or image, of the heart and shows the precise location of diseased or dead tissue.

Thallium-201 is a useful imaging agent for the heart because it is efficiently extracted from the blood by the heart muscle owing to its chemical resemblance to potassium, an element required for heart function. Potassium-43, originally produced at ORNL in 1969, was evaluated as a myocardial imaging agent by 17 medical institutions; their conclusion was that the energies of the radioisotope's gamma photons are too high to be efficiently detected by the instrumentation available in most nuclear medicine clinics. For this reason, thallium-201 rather than potassium-43 has been developed as the agent of choice for diagnosis of heart disease.

Thallium scans indicate if part of the heart muscle is dead—has suffered irreversible damage (infarction)—because that portion will not extract thallium ions and no radioactivity will be present. Thallium scans may also give information concerning blockages of the coronary arteries that supply blood to the heart muscle.

The patient is injected with thallium and a scan is taken at rest and again after exercising on a treadmill or bicycle. At rest, areas of the heart muscle that receive blood from partially occluded arteries will show a decreased uptake of radioactivity. During exercise, these areas will show uptake similar to the normal myocardium. In contrast, dead heart tissue formed as a result of severe myocardial infarction will show decreased uptake both at rest and during exercise. Thus, the differences in distribution at rest and during exercise can be used to differentiate between reversibly and irreversibly damaged heart muscle.

Tellurium and Fatty Acids

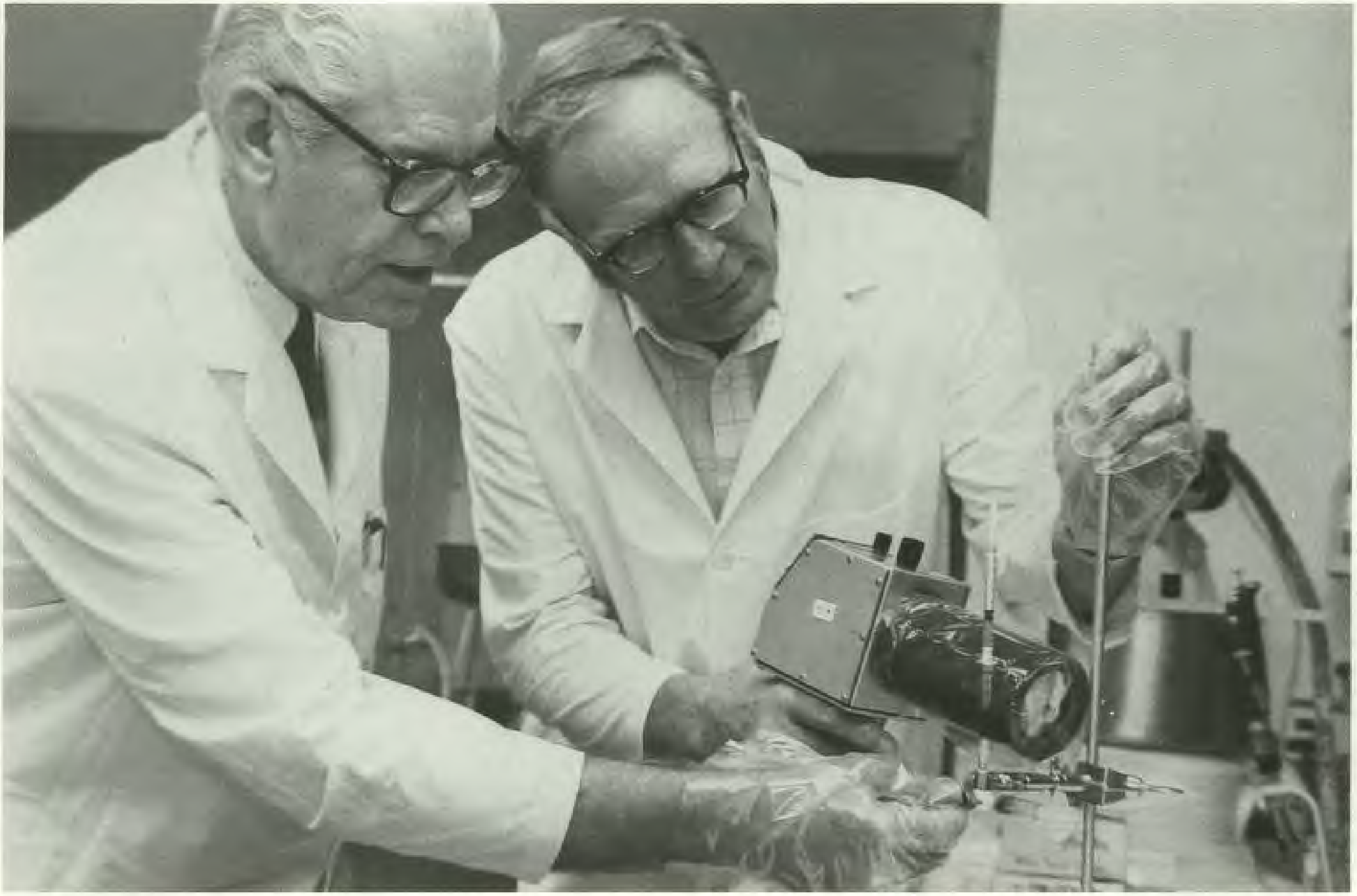
Thallium-201 is a valuable diagnostic tool, but efforts are under way at ORNL and elsewhere to develop radiopharmaceuticals that are less expensive, more efficiently detected by modern scanning devices, safer for patients, able to provide clearer images of the heart, and capable of detecting subtle metabolic changes that precede tissue damage that ensues as blood flow diminishes.

At ORNL the Nuclear Medicine Technology Group in the Health and Safety Research Division has been developing radioactive agents that are potentially superior to thallium in these respects. One particular agent uses radioactive tellurium-123*m*, which is made in ORNL's High Flux Isotope Reactor from the stable isotope tellurium-122 produced in the electromagnetic separators. The other agent now under development uses stable tellurium and radioactive iodine-123, which is produced in a cyclotron from stable tellurium and is currently being used clinically for thyroid scans.

If these agents are found to be clinically useful, they promise to be less expensive than thallium. In addition, radioactive tellurium and iodine produce a higher yield of gamma photons at an energy level that is most efficiently detected by today's advanced electronic scanners. Tellurium-123*m* emits gamma photons within the optimal region for detection with imaging equipment (159 vs 80-90 keV for thallium) but has a long (120-day) half-life. By contrast, iodine-123 emits gamma photons with the same energy but has only an 8-hour half-life. Because a smaller amount of radioisotope has to be injected to get enough gamma photons in the detectable range, the new agents would give a smaller total radiation dose to the patient and thus would be safer. The agents also persist in the heart longer, resulting in a clearer image of the heart. They show promise in evaluating a diseased heart's metabolic capability as well.

The new agents are fatty acids into which either radioactive tellurium-123*m* or stable tellurium (and radioactive iodine-123) has been chemically inserted. The heart is unique in its need for long-chain fatty acids as primary energy sources; this is one way in which it differs from the body's other organs, which extract and oxidize glucose from the blood to get energy. For this reason, ORNL researchers Russ Knapp, Kathleen Ambrose, Tom Butler, Mark Goodman, and Jim Hoeschele chose fatty acids as a natural carrier of radioisotopes into the heart.

Knapp, leader of the Nuclear Medicine Technology Group, ex-



Tom Butler adjusts an experimental generator while Clarence Guyer monitors the radioactive iridium-191m elution with a cutie pie. The generator contains osmium-191, which decays to iridium-191m, an isotope with a five-second half-life that is now being used to identify heart defects in infants in a Boston hospital. Butler and his colleagues are trying to make the generator safer and more efficient. The source of the osmium-191 is ORNL's High Flux Isotope Reactor.

plains why the group initially selected radioactive tellurium for insertion into a long-chain fatty acid. "Tellurium-123*m* is readily available because the stable tellurium-122 isotope is produced in the electromagnetic separators and transmuted to the radioisotope in the HFIR. It emits gamma rays in the limited energy range that is efficiently detected by clinical body scanners, and it is chemically versatile in that it can form covalent bonds within compounds that are naturally concentrated by various tissues. We therefore wished to determine if the presence of tellurium in the fatty acid would inhibit metabolism and be a new means of 'trapping' such compounds in the heart muscle."

Experiments in animals with tellurium-labeled fatty acids demonstrated that this hypothesis appears to work. The ORNL researchers discovered that the presence of tellurium creates a structural perturbation in the fatty acid that causes it to be trapped in the heart. This phenomenon is known as "metabolic trapping" because, after uptake of the fatty acid in the heart, the heart's attempt to metabolize the fatty acid appears to be blocked by the presence of tellurium. Thus, the labeled fatty acid persists in the heart, permitting sufficient time for the radioisotope to provide a clear image of the heart muscle. (By contrast, thallium-201 is redistributed while scans are being taken; the resulting image does not accurately represent the initial distribution but is a composite of the redistribution during imaging.)

Hoping to use this metabolic trapping property of tellurium, Knapp and his associates are now working out the chemistry for inserting stable tellurium into the fatty acid and attaching radioisotope iodine-123. Knapp and a number of other nuclear medicine experts see iodine-123 as the "choice radioisotope of the next decade" because its gamma-ray energies can be efficiently detected and because its 8-hour physical half-life is considered moderate. Iodine-123 is also safer than either radioactive thallium or tellurium because of its higher specific activity (amount of radioactivity per unit weight), which means that less mass has to be injected to get a detectable level of radioactivity. In short, says Knapp, "Using iodine-123 for nuclear scans increases the gap between the dose required for good images and the toxic level. Thus, it is safer for patients." Iodine-123 is produced in accelerators by either proton bombardment of enriched tellurium-124 or by very high energy proton bombardment of natural iodine-127 to form xenon-123, which then decays to iodine-123.

Knapp is hopeful that fatty acids labeled with tellurium or some other isotope can indicate differences in metabolism between normal and diseased heart tissue. Detection of subtle metabolic changes could permit early diagnosis of pathological conditions before they become severe enough to result in tissue deterioration. If physicians had such a technique, they could diagnose potential heart disease and have enough time to start patients on a therapeutic regimen to prevent a heart attack. Says Knapp: "Nuclear medicine is moving in the direction of monitoring metabolism noninvasively. The goal is to follow changes in function as well as in structure of diseased organs."

To better understand how tellurium-labeled fatty acids are taken up by the heart and metabolized, Knapp and his colleagues are investigating fatty acids labeled with tellurium, selenium-75, and sulfur-35. (Selenium-75 is made at the HFIR from selenium-74 enriched in the electromagnetic separators.) Experiments with selenium, which is chemically similar to tellurium, showed that uptake of the selenium agent in the heart is only 50% of that of the tellurium agent. As a result of this finding, Knapp hypothesized that tellurium (unlike the more stable selenium) is oxidized, making the tellurium-labeled fatty acid more specific for heart uptake and more resistant to metabolism.

To test this hypothesis, ORNL researchers will test the effect of chemical oxidation of the selenium within a selenium fatty acid on its uptake by the heart. They will also examine uptake in rat hearts of fatty acids labeled with sulfur-35 (a beta emitter). If modified selenium and/or sulfur fatty acids also show pronounced and prolonged myocardial uptake, the iodine-123-labeled analogs may also be candidates for more extensive evaluation.

Most of Knapp's financial support comes from the Department of Energy, but recently Knapp and his associates received two grants from the National Institutes of Health to evaluate the biological and biochemical properties of long-chain fatty acids and to develop the chemical techniques to make improved fatty acids containing tellurium. Collaborating in this effort are Dr. William H. Strauss, head of the nuclear medicine department at Massachusetts General Hospital, and Dr. George Kabalka of the chemistry department at the University of Tennessee. Questions they will try to answer are these: Why do tellurium-labeled fatty acids show significant uptake in the heart? Are they metabolized and, if so, how? How long are they stored in the heart? Are they excreted? The information obtained from these studies may help researchers design a new and improved diagnostic agent.

Meanwhile, an important step has been taken in making tellurium-labeled fatty acids acceptable for clinical use. Massachusetts General Hospital and Harvard Medical School recently completed chemical toxicity tests on these agents and determined that the acute toxicity, or LD_{50}—the dose at which 50% of the tested animals die—far exceeds the dose expected to be used in patients.

Iridium Generators

Iridium-191*m*, which has only a 5-second half-life, is emerging as an important radioisotope for diagnosing heart ailments in both children and adults. This is possible only because of the existence of today's fast, computerized gamma cameras and because of HFIR's unique ability to make osmium-191, which decays to the radioactive iridium.

The story of how iridium-191*m* is made starts in Oak Ridge. Osmium-190, which is produced in enriched form in ORNL's electromagnetic separators, is prepared for irradiation in HFIR, where its atoms will capture neutrons to become osmium-191. The ORNL reactor is the principal free-world source of large amounts of osmium-191 because of its unique high neutron flux rate (neutrons per square centimeter per second). Osmium-191, chemically converted to potassium osmate, is shipped to Children's Hospital and Massachusetts General Hospital (both in Boston) and Rush-Presbyterian–St. Luke's Medical Center in Chicago, where it is used to generate iridium-191*m*.

An iridium generator has been developed by a group led by Dr. Salvatore Treves at Children's Hospital of Boston and is now being studied in the ORNL Nuclear Medicine Technology Group by Tom Butler to determine ways of making it safer and more efficient. The generator is a 2-in. tube containing an ion exchange resin. Osmium-191, which has a 15.4-day half-life, is placed at the top of the resin, where it decays to iridium-191*m*. Because of differences in chemical properties in the osmium and the iridium, only the iridium at the top will be washed through the resin

with the eluting solution. The iridium solution emerging from the bottom of the tube, which is kept at a patient's bedside, is then injected into the patient's vein. Advanced gamma cameras can take 12 to 15 pictures per second of the radioisotope as it is carried along in the patient's bloodstream. The iridium-191*m* decays to stable, nonradioactive iridium-191.

Several pharmaceutical firms are interested in manufacturing iridium generators because of their relatively long shelf life (over two weeks), low cost (osmium-191 is made in a reactor), and ability to produce a radioisotope with optimal properties—extremely short half-life, extremely low radiation dose to patients, and a high yield of gamma photons at an energy level that is efficiently detected.

The iridium generator now being employed has two chemical problems that limit its usefulness. Butler and his ORNL colleagues are now collaborating with Children's Hospital in Boston to increase the generator's efficiency by overcoming these problems. One problem is that, with repeated use, the osmium-191 parent begins to elute from the generator and contaminate the iridium-191*m*. Injection of osmium-191 is undesirable because it significantly increases the radiation burden to the patient. When this "breakthrough" occurs, the iridium generator is considered no longer useful. Thus, finding a way to prevent breakthrough would extend the lifetime and usefulness of these generators and ensure patient safety.

Jim Hoeschele and John Roberts stand at a hot cell where manipulators are used to process reactor targets. Radioactive osmium, platinum, selenium, tellurium, and other products of neutron irradiation at the High Flux Isotope Reactor are transported in metal carriers to the hot cells in Building 3047 (Radioisotope Development Laboratory). These radioisotopes are used to tag fatty acids, barbiturates, and other agents for organ imaging and other biomedical applications.

Another problem is that the ion exchange system now in use allows recovery of only 10% of the theoretical amount of radioactivity that should be "milked" from the osmium-191. In hopes of improving the elution yield of iridium, Butler and his colleagues are experimenting with other resin materials. The goal is to increase the efficiency of

A Better View of the Brain

In addition to developing radioactive agents to give clearer images of the heart, Russ Knapp and his colleagues are developing and testing agents that concentrate in the brain and indicate the location of a tumor or evidence of a stroke. They have made a series of barbiturate compounds tagged with tellurium-123*m* or selenium-75, both of which are made at the HFIR from stable isotopes enriched in the electromagnetic separators. Preliminary studies in rats show pronounced uptake of these compounds in the brain.

Barbiturates were selected as carriers of the radioisotopes because of their ability to get into the brain by penetrating the blood-brain barrier, which allows only a select group of molecules (oxygen and nutrients, for example) to pass from capillaries into brain cells. The amount of radiolabeled barbiturate in each portion of the brain varies with blood flow. Thus, tagged barbiturate compounds can potentially be used to detect tumors or stroke because of differential blood flow that characterizes these conditions.

To aid its growth, a brain tumor requires more blood than does the rest of the brain. The tumor exhibits a greater uptake of radioactivity because of this and because of a breakdown of the blood-brain barrier. On the other hand, a stroke is characterized by dead tissue and virtually no blood flow. A scan showing little or no uptake of radioactivity in the specific loci of the brain suggests that stroke has occurred and pinpoints the areas of brain damage.

Knapp and his associates are now developing the chemical techniques to insert iodine-123 into barbiturates that contain stable tellurium. This isotope has ideal gamma-ray energies and a short physical half-life, making it safer than radioactive tellurium because it would give patients a much lower radiation dose.

Other radioisotopes produced at Oak Ridge for medical purposes are platinum-195*m* (made in HFIR from platinum-194 produced by the electromagnetic separators), radioactive gold-195 made from stable platinum-195 in the 86-in. cyclotron, and carbon-11, also made in the 86-in. cyclotron. In the Nuclear Medicine Technology Group, Jim Hoeschele and his associates make a compound labeled with platinum-195*m*, which is distributed to investigators interested in studying physiological responses to platinum compounds used for antitumor therapy (platinum is more toxic to tumor cells than to normal cells). Gold-195 is used to label auranofin, a new orally active gold compound that is being evaluated clinically for the treatment of rheumatoid arthritis. Investigators elsewhere work with the radiolabeled compound to study how the compound acts in the body, how widely it is distributed, and how it is metabolized and excreted.

Knapp's group works closely with Dr. Karl Hubner and his associates at Oak Ridge Associated Universities on using carbon-11, a positron emitter with a 20-minute half-life, for patient scans. The ORNL group has helped develop the chemical techniques to insert carbon-11 into amino acids. At ORAU the agents are used for tumor localization, pancreatic imaging, and studies of brain function. The positrons are detected and translated into images by an ECAT (Emission Computerized Axial Tomograph) scanner made locally by EG&G ORTEC.

"Our principal goals," says Knapp, "are to develop new radiopharmaceuticals that might be useful for diagnosing disease and to apply radioisotope technology to understanding biomedical and environmental problems."—C.K.

the iridium generator.

Because iridium-191*m* remains in the blood, has such a short half-life, and is efficiently detected by advanced gamma scanners, it is being used experimentally to detect three types of heart problems.

Neonatal shunt. The Children's Hospital in Boston uses iridium-191*m* for nuclear scans of newborn babies suspected of having a shunt—a common heart abnormality in which blood flows between the right and left atria, chambers normally closed off to each other. Iridium-191*m* is the safest radioisotope available for examining this heart defect in babies because it essentially decays completely in less than 1 minute, exposing patients to a very low total radiation dose. A shunt is diagnosed when the ratio of radioactivity in the baby's lungs to that in the rest of the body deviates from normal.

Abnormal blood ejection. At Massachusetts General, iridium scans are taken on command by a computer which "knows" from electrocardiogram tracings when a patient's heart has filled or emptied. These pictures provide information on ejection fraction (differences in blood volume of the heart chambers after filling and emptying) and on the motion of the chamber walls during contraction. Detection of abnormal ejection fraction values and irregularities in heart motion aid physicians in determining the nature of a patient's heart disease. Massachusetts General found that using iridium-191*m* for ejection fraction studies allows evaluation of ten times as many patients as conventionally used technetium-99*m*, which has a considerably longer physical half-life (6 hours).

Abnormal pacing. The Rush-Presbyterian–St. Luke's Medical Center is investigating the use of iridium scans to pinpoint pacing abnormalities in the hearts of large dogs in which abnormal pacing has been experimentally induced. Results may provide information on a fatal heart ailment called arrhythmia—abnormal contractions produced by a disruption of electrical signals that are intended to synchronize the emptying and filling of the heart's four chambers.

Important ground-breaking research and heart disease detection using iridium-191*m* continues in Boston and Chicago, but the success of these projects hinges on a reactor and a research group in Oak Ridge.

War Against Disease

In another project related to heart disease diagnosis, Knapp is collaborating with Dr. Henry Wagner (the father of nuclear medicine) and Dr. John Waude at Johns Hopkins University and with Dr. Jim Richards at Brookhaven National Laboratory in labeling red blood cells with tin-117*m*, a radioisotope made at HFIR from the stable tin-116 enriched in the electromagnetic separators. Normally, red blood cells are labeled with pertechnetate (technetium-99*m*); this is done by using tin chloride to bind the pertechnetate to the red blood cells. The labeled cells are subsequently injected into the patient (or the pertechnetate and tin chloride are injected separately); a body scanner tracks the cells to measure ejection fraction.

The research Knapp is involved in looks at the possibility of using radioactive tin-117*m* not only to study the fate of tin chloride in the patient's body but also to label red blood cells. The radioisotope has a moderate half-life (two weeks) and yields gamma photons at the 158-keV level, which can be efficiently detected by modern scanners. Preliminary studies indicate that tin-117*m* binds strongly to red blood cells but yields poor images in very low doses owing to its low specific activity.

The electromagnetic separators that produced enriched uranium-235 in 1945 helped bring about the end of World War II. Now, some of these separators are helping to fight another war—the war against disease. Thallium-203, the major product of the calutrons, is being used to make a radioisotope that diagnoses heart disease. (The second highest volume of enriched isotopes is zinc-67, which is transmuted to gallium-67 in the 86-in. cyclotron and sent to clinics for tumor localization scans, thus aiding in the war against cancer.) Other important products of the electromagnetic separators—including tellurium, osmium, and tin—are being used in research at ORNL and elsewhere for improved heart disease diagnosis. These isotopes, however, are made usable through transmutation to radioisotopes in HFIR, using its unique neutron flux rate. ORNL has been producing radioisotopes in its reactors for medical use since 1946, when the Laboratory shipped the nation's first reactor-produced radioisotope (carbon-14) to a cancer clinic. Today, Oak Ridge continues to be on the frontiers of nuclear medicine while contributing to the nation's physical health. ornl

Corrections

On page 10 of the Spring 1981 issue of the *Review*, a photograph was identified incorrectly as being that of Alan Hawthorne. The man pictured is actually Charlie Metcalf, a technician on the DUVAS project. We regret the error.

On page 33, Dave Patek was identified as being in the Reactor Control Group of the Instrumentation and Controls Division. He is a member of I&C's Measurement and Controls Engineering Section.

information meeting highlights

Environmental Sciences, May 11–12, 1981

Lessons of the Hudson River Power Case

For ten years, ORNL scientists served as technical advisors and expert witnesses for three federal agencies involved in a landmark environmental controversy known as the Hudson River Power Case (See ORNL *Review*, Winter 1979). This conflict was finally settled in December 1980. The settlement agreement forbids Consolidated Edison from building a pumped-storage hydroelectric plant on Storm King Mountain but does not require Con Ed and four other New York utilities to build costly cooling towers at three Hudson River power plants to protect fish populations. However, the utilities are required to take less expensive measures to protect the fish, such as (1) installing devices to prevent white perch from being trapped on screens where river water is withdrawn for power-plant cooling and (2) scheduling shutdowns for maintenance during times when young white perch, striped bass, and other fish are most vulnerable to power plants.

As part of the settlement, the electric power companies also agreed to provide a $12 million endowment for the Hudson River Foundation for Science and Environmental Research. Larry Barnthouse of ORNL's Environmental Sciences Division has been named a member of the national panel which will select research projects to be financed by the foundation.

While providing advice and testimony, the Oak Ridge researchers sought to improve their understanding of the impacts on fish of once-through cooling vs cooling towers. Once-through cooling withdraws 20 times as much water as cooling towers and thus threatens to kill larger numbers of fish by trapping them on screens (impingement) or sucking them through screen holes into intake pipes (entrainment). To make quantitative assessments of various impacts such as mortality rates among fish in the vicinity of Hudson River power plants, the ORNL ecologists relied on computer modeling of fish populations. Now that the lengthy case is over, the scientists are evaluating the strengths and weaknesses of population modeling.

"Our years of experience in developing, using, and assessing population models in connection with this controversy," says Barnthouse, "have given us valuable insights about the kinds of models that are useful in contested hearings and about the kinds of questions that scientists can and cannot answer using population models."

One lesson learned, according to

Barnthouse, is that simple models that address short-term impacts are much more useful than complicated models aimed at predicting long-term impacts. No model could answer such questions as this: are the long-term impacts on fish populations of power plant cooling environmentally acceptable? Years of efforts and millions of dollars were spent in unsuccessful attempts to answer this question using sophisticated population models. However, when the right questions were asked, highly simplified models provided useful answers. For example, on the question of vulnerability, it was found by modeling that white perch are much more vulnerable to mortality by impingement than are striped bass. Modeling was also useful for specifying the technological capabilities needed at cooling water intakes to reduce impingement and entrainment and for comparing the relative effectiveness of alternative mitigating strategies. Said Barnthouse: "When the contesting parties turned from confrontation to negotiation, the use of these models for evaluating mitigation alternatives was instrumental in arranging an out-of-court settlement that ended the Hudson River Power Case."

Sulfur Gases and Vegetation

During liquefaction and gasification of coal, several sulfur-containing gases are emitted to the atmosphere. The potential effects of many of these emissions on the growth of agricultural crops and forest trees have not been previously known.

Now, a study done by George Taylor, Sandy McLaughlin, and Dave Shriner of the Environmental Sciences Division has determined the extent of uptake and toxicity to kidney bean plants of five different sulfur gases—sulfur dioxide, hydrogen sulfide, carbonyl sulfide, carbon disulfide, and methyl mercaptan. In the Air Pollution Effects Research Facility, the scientists measured uptake by comparing the pollutant's concentration in air before and after the air is passed through plants in an environmental chamber. They determined toxicity by measuring the net photosynthesis (growth rate) of plants exposed to a range of concentrations of each sulfur gas.

The ORNL ecologists found that, of the five sulfur gases, hydrogen sulfide, sulfur dioxide, and carbonyl sulfide are readily taken up by vegetation, depress photosynthesis, and reduce plant growth. The largest uptake rates occur for pollutants that are highly soluble in water. One surprising result of their study is that hydrogen sulfide is at least as toxic as sulfur dioxide.

Hazard Prediction Methods

The Toxic Substances Control Act requires that chemicals be tested to determine whether they pose a potential hazard to human health and the environment. About two years ago, the Office of Toxic Substances of the Environmental Protection Agency asked ORNL to review and evaluate multispecies laboratory methods and recommend the methods that could best serve as predictive tools in environmental hazard assessment.

Anna Hammons, Glenn Suter, Jeff Giddings, and Larry Barnthouse of the Environmental Sciences Division studied laboratory systems ranging from two interacting species to large, complex microcosms. They held six workshops to solicit opinions on a variety of aquatic and terrestrial tests and made evaluations based on 14 criteria, including cost, sensitivity, reproducibility, realism, and social relevance. Mathematical models were also considered as predictive tools.

They found that few multispecies laboratory systems have been developed specifically for chemical hazard assessment. The tests that they recommended can be made available relatively soon or are potentially useful depending on further research and development. The six recommended aquatic tests available in the near future are algal competition, predation by fish, mixed flask culture (bacteria, zooplankton, algae, protozoa), periphyton communities, sediment cores, and pond microcosms. The three recommended terrestrial tests that could be available soon are soil microbial communities, legume rhizobia, and mycorrhizae/plant symbiosis. Several categories of mathematical models were recommended for further research and development.

Based on ORNL's recommendations, EPA is now funding development of multispecies laboratory tests. ornl

BOOKS

City Behind a Fence *by Charles W. Johnson and Charles O. Jackson. University of Tennessee Press (1981). 272 pp. Cloth, $18.50; paper, $9.50. Reviewed by Waldo Cohn, consultant, Biology Division.*

"Much has been written about the actual production of the atomic bomb, the technical activities at each of the three major development locations, as well as the military use of nuclear energy against Jápan. Virtually no effort has been made, on the other hand, to examine the people and their lives at any of the support communities [Oak Ridge, Hanford, Los Alamos]. It is a curious oversight, if only because successful operation of the communities was so crucial to the successful conclusion of the . . . mission. Yet beyond this matter, these 'secret cities,' each built from the ground up, represent fascinating episodes in American social history. To chronicle the nature of human life in any of them is to report on a distinctly unique setting and chapter in the national past . . . It is hoped that this book provides the needed statement on the Oak Ridge experience . . . ."

So reads the Introduction to *City Behind a Fence*, authored by two professors of history at the University of Tennessee, who have undertaken to remedy the "curious oversight."

Ordinarily, one might expect the examination of a unique social situation to be conducted by sociologists and that social history, like most history, be set down long after the participants have disappeared from the scene. Social history written by participants may make good reading, but may lack objectivity and breadth of coverage. If the writing of a history is postponed too long, the usually drab record may be all the writer has to go on; if done by a nonparticipant, it may lack the flavor of first-hand experience.

The authors of this book appear to have given careful attention to each of these problems. The documents, letters, etc., that make up the written record, many of which have only recently been released from classified status, provided a solid framework of factual information. Scores of participants (i.e., residents from 1943 through 1945) were interviewed. Anecdotal in nature, these interviews enliven what could have become a dull recitation of facts.

But the facts alone are historically heroic enough to create their own interest, and the problem facing the U.S. Army's "Manhattan District" with respect to the town alone was as unique as it was large. How does one create swiftly and in "top secrecy" (President Roosevelt's order) a community of ultimately 75,000 people in a southern submarginal farming area? The assignment, moreover, in a near-desperate war situation, included the mandate to keep reasonably content a civilian population comprising laborers, scientists, craftsmen, engineers, administrators, technicians, storekeepers, teachers, bankers, and other support personnel—as well as their families. Moreover, these people were engaged in a crash program whose purpose was to be known by only a handful. The story of the achievement of this purpose and the surmounting of numerous community and personal hardships is what this book details.

Although the authors have tried to adhere strictly to the development of the community, the close relationship of this development to Project goals called for brief references to the plants and laboratories of the "Clinton Engineer Works." However, the imperative to get the job done (that is, to create a nuclear weapon), makes sense only in the light of the global situation in 1942 to 1943, when the Manhattan District went into action.

In the Johnson and Jackson book, the overriding pressure of the war, which at that time saw the fortunes of the Allies at lowest ebb, is not emphasized nearly enough, when it is mentioned at all. Yet this pressure must be recognized in order to understand the abrupt and seemingly heartless eviction of so many long-time residents of the area that took place in 1942 and 1943 to make way for the town's construction. By the spring of 1942, Japan had conquered most of the South Pacific and southeast Asia, from Thailand up through the Philippines and from the coast of China to Guam and Wake; they had captured Java and leveled the Australian port of Darwin. Japan controlled almost a seventh of the globe. At the same time, German armies, having overrun most of Europe from the Mediterranean to Norway, were approaching Suez and were stationed deep inside Russia. Britain was preparing a last-ditch homeland defense. Washington and London calculated that it would take ten years to reconquer the Pacific, let alone push the Germans back to Germany. Moreover, there was reason to fear that the Germans, having begun work on uranium fission before we had and having captured the heavy-water plant in Norway, might develop a nuclear weapon at any time. Only this background can explain the unseemly haste to evict the few hundred pre-war residents, build the city and plants, and get on with the job. Yet Johnson and Jackson neglect this aspect.

This rude upheaval, which so disrupted lives throughout the local area and which so adversely affected the county governments and their finances, was the start of a long period of bad community relations. The Army needed the goodwill of the people outside the fence, yet the haste of their removal and the demands of secrecy and security had placed the whole project under a cloud of local resentment. When the Army realized this, it sought to act more circumspectly in its dealings with civilians, both inside and outside, and to keep as low a profile as possible. To achieve these objectives, a civilian agency was created to handle the running of the town—from replacing residential light bulbs to bus operations to throwing gravel on roads and streets to operating movie theaters and beer halls. Named the Roane-Anderson Company, it took the brunt of citizen complaints. It was "the best whipping boy the Army ever had" (p. 69).

The book, in concentrating on the problems of masses of people trying to cope, fails to note the attractions that counterbalanced the difficulties, especially among the technical residents. These young scientists and engineers perceived the new technology as providing new worlds to explore and would gladly have put up with even more inconveniences to be able to pursue their adventures into the unknown and untried.

It should be apparent at this point that answers to the question "What was Oak Ridge like in the war period?" will vary widely among those asked. For some, including this reviewer, it was, difficulties and all, the time of their lives. For others, it was a disagreeable experience to be endured and forgotten. For example, the "housing" provided for laborers, and especially for blacks, was scandalously inadequate by any peacetime standard. It is obvious that one cannot take the heterogeneity of individual experiences and come up with a homogeneous "average" experience. The statistics, orders, regulations, etc., so carefully and thoroughly documented by the authors and enlivened by the many photographs are interesting, but hardly exciting. The personal anecdotes, illustrative of individual attitudes, tend to be extrapolated into group attitudes. A single letter to the editor, for example, is taken as the considered opinion of a whole group, or even of a whole community. Indeed, I find the anecdotal evidence of Knoxville-Oak Ridge antagonism in the book at variance with first- and second-hand experiences of the period.

I found other examples of error. The title itself and the picture on the cover of the paperback edition (a troop of girl scouts marching behind a chain-link fence) imply a concentration camp not unlike the one for Japanese-Americans existing at that time in the West. The same photograph appears inside the volume, but without the fence! Clearly, the fence was superimposed on the original photo for dramatic effect.

As one who was there at the time, whose career was made by the work experience, and who looks back on his life during that period with great nostalgia, I found some things in the book in harmony with my recollections; the statistics, the official memoranda, conditions in construction workers' quarters, etc., provided new insights for me. I found the brief, necessary discussions of technical matters to be slightly at variance with fact. While it was certainly true that most workers did not know what they were trying to create, scores of scientists and engineers knew exactly what the goal was, and how their work fitted into the overall plan. They knew from the day they joined "The Project."

Anecdotes and statistics are what social history is made of. Only the first give flavor, but if the quantitation is insufficient, the picture is incomplete. Statistics lack flavor, and as with laws and ordinances, they may have little impact on, or meaning for the individual. In a way, then, the authors undertook a task guaranteed to satisfy nobody. Nevertheless, what they have compiled is a unique survey of a unique social history. It should be read by oldtimers for nostalgia and by those who arrived after 1950 so that they will better understand why Oak Ridge is different. No amount of "normalization" will ever totally remove the vestiges of Oak Ridge's past—why and how the town was built and run.

BOOKS IN PRINT

The following books in print are authored or edited primarily by ORNL staff members:

Earthquake Prediction Response and Options for Public Policy, by Dennis S. Mileti, Janice R. Hutton, and John H. Sorenson, University of Colorado, Colorado Springs (1981).

Water Chlorination: Environmental Impact and Health Effects, vols. 1–3, by R. L. Jolley et al., Ann Arbor Scientific Publishers, Inc., Ann Arbor (1978–1980).

Light Water Reactor Nuclear Fuel Cycle, R. G. Wymer and B. L. Vondra, eds., CRC Press, Boca Raton (1981).

Social Impact Assessment: Experimental Methods and Approaches, by Edward J. Soderstrom, Paeger Publishers, New York (1981).

Mel Feldman has been manager of engineering systems in the Consolidated Fuel Reprocessing Program in the Fuel Recycle Division since 1975, when he returned to the Laboratory after an absence of 19 years. During that time, he never left the nuclear business and has worked in radiation damage studies and in reactor design, managing all aspects of construction and operation, both at Idaho Falls and Argonne National Laboratory. In 1975, he assumed office as president of the American Nuclear Society (see the Spring 1977 issue of the *Review*). In this article, he tells of the methods being devised to perform useful work in such hostile environments as inside a fuel recycle facility.

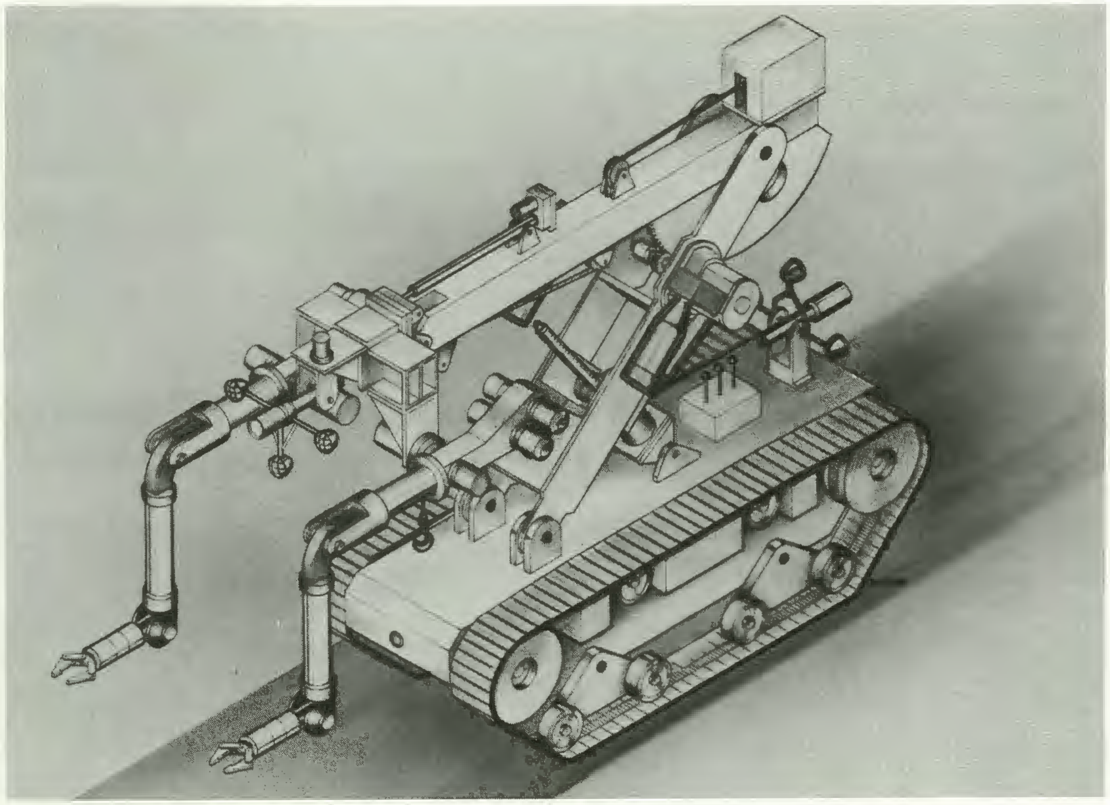
PROJECTED MAN

By MEL FELDMAN

Machines with humanlike attributes are now appearing in numerous areas of our society. Those of us who remember the Buck Rogers' adventures of the 1940s are realizing the transformation of these fantasies to reality in many areas of our lives. The *Star Wars* adventure of the 1970s, while similar in theme, was impressive in its sophisticated use of robots, a technology that may become increasingly prevalent in the 1980s.

Robots are already being used in the automobile industry to weld auto bodies, and in the not so distant future robots may extract metals from the ocean floor and explore planets in our solar system. For the general public, the ultimate goal may be a mechanical domestic of some form in every household, and current technology makes that goal a reasonable reality. In the pursuit of automation in our mechanical and agricultural industries, machines have been developed and refined to perform tasks that previously had been done by people. The transition steps between discrete operations are now also performed by machines, and whether they involve a hay baler or a turret lathe, there is no doubt that production is enhanced whenever work is delegated to machines. Today we are painfully aware of this progress in a field that has become part of our American culture—the production of automobiles: painful because we find ourselves the observers rather than the innovators of progress. The Japanese (and others) have learned how to design machines equipped with artificial (electronic) intelligence that can accomplish a productive work function. The fact that the Japanese have been able to produce what appears to be a better product at a competitive price has caused a degree of national embarrassment. This embarrassment has spawned an awareness of the need for research and development in areas previously unexplored.

Two exciting fields—robotics and teleoperations—are emerging with a common purpose: the projection of human capabilities (hence, "pro-



jected man") into the workplace without the actual presence of the human. Whether the initiative stems from envisioned increases in productivity or leisure time or improved psychological well-being, or if the work environment is actually hostile to man, the solution is similar.

Although the purposes of these two fields converge, they attack the problem from opposite ends of the spectrum of human capabilities. Robotics has been used and is being used to perform those operations that are repetitive and underemploy the average human's capabilities. The excitement in robotics stems from the fact that, although the initial accomplishments in the field are currently confined to the ilk of "pick and place" capabilities, a real potential exists for broadening the scope to include functions that more closely approximate human capabilities.

Robotics

The recent explosion in the capabilities of computer systems has provided the technology with which to begin the expansion of robotic systems. A mechanical and mathematical synthesis of the human sensory receptors—sight, hearing, touch, smell, and taste—is the challenge facing robotic development. The initial application of robotics was automation. Motion was supplied to a work function that involved manipulating objects of fixed dimension in known position. These applications were successful, and the degree of success was directly related to ability to control the fixed dimensions and the known positions. Because the world we live in has an inherent variability both in the dimensions of an object to be moved and in the positions that object will occupy, applications of these man-replacement systems were limited. Examples of this level of robotic application are many and lend themselves to situations of classic humor. The loading devices for putting bottles into shipping cartons comes to mind. As long as the bottle's dimensions, its position, and the position of the carton are precisely known and remain constant, the loader works well. One tipped bottle or one absent carton and the system becomes capable of mayhem rather than useful work.

Man has learned to use sensory information to compensate for this variability; thus, the current and near-term goal in the development of robotic systems is sensory synthesis and the use of artificial intelligence to adjust to variable sensory inputs. Synthesis of one or more of the human senses will be accomplished by mechanics, electronics, and mathematics; the translation of sensory signals into appropriate action is the function of the computer, which serves as system integrator and is analogous to our central nervous system. The larger the library of possible responses to the sensory signals, the greater the latitude and need for control of possible motion responses and, therefore, the greater the variety of use-

A console is being designed that can most effectively place the operator "on the scene" inside such hostile environments as highly radioactive areas. Consultation on this project is multidisciplinary, and includes input from industrial psychologist Margaret Clark, formerly employed at ORNL. Here, Lee Martin, at the controls, discusses the large video projection with John Garin, task leader for remote control engineering on the project.

ful work functions that can be accomplished.

Of the five senses developed in man, those of greatest importance to doing mechanical work are touch and sight; it is in the synthesis of these functions that the current effort is concentrated. For robotics, the developments in touch have been confined to force limitation (part of kinesthetic response). For most work situations, the gripping force can be determined so that work can be accomplished without damage to the item being manipulated. The functions of the muscular system used for balance, force, weight sensing, and obstacle avoidance can be developed to accommodate the work application.

The integration of the robotic equivalent of sight into current systems promises to greatly expand the capabilities of robotics. Current prototypes use a light transmitter and receiver attached to the robot hand. The transmitter—a photoflash tube and a cylindrical lens—is capable of generating a beam of light; the receiver is a multipoint phototransistor (128 × 128 is common).

The initial function of the sight-sensing unit is range finding. For a known position of the hand relative to a described work area (for example, a table top), the reflected beam of light can be used to determine the distance an object is from the hand by simple trigonometry. Because the receiver is a multipoint photosensor, the relative position of the reflecting object in the arc of the beam can be determined. In addition, the beam of light reflects discernible patterns so that rudimentary differentiation of the object's shape can be recorded. The information on distance, position, and shape of the reflecting object is continuously transmitted to a microprocessor from which signals are sent to accomplish specific tasks.

Interest and work in robotics has existed for more than two decades in this country, although a viable product market was lacking. Recently, however, success by the Japanese and other industrial nations in applying these technologies to production has led to a frenzied increase in R&D activity in the United States.

Teleoperations

The other field contributing to the "projected man"—the teleoperator system—originated in the United States in the late 1940s. The need to have work performed in environments hostile to man (e.g., high-radiation areas) led to the development of systems in which an operator could accomplish tasks from behind a protective barrier.

Among the five human senses, sight, touch, and hearing, in that order, are the important senses required to accomplish mechanical work functions efficiently and successfully; in that order, we have attempted to duplicate these senses in teleoperator systems at ORNL.

Early visual systems used mirrors to transmit visual impressions from the workplace to the operator. Image reversal and an unnatural posture for viewing made this form of "seeing" tedious, inefficient, and possibly disorienting. These problems, however, proved academic because, as radiation levels increased, the use of open-topped shielding walls proved to be inadequate. We used a periscope (both over the wall and through the wall), which provided better viewing but suffered the disadvantage of having a fixed optical system both in range of view and range of focus and resolution.

In the early 1950s, a series of developments produced transparent barriers (windows) having densities equal to the opaque barriers or shielding material most commonly in use. Solution-filled windows (zinc bromide is common) with a density equal to concrete and leaded glass with a range of densities approaching that of steel were developed. These windows became the standard for many years. They were subject to radiation damage and to solution and gasket degradation, and they were expensive. Solution-filled windows were intended to provide maximum use of the sophisticated visual capabilities of the human operator, but the field of view was limited by the window configuration; the designer of the contained area (hot cell) had to balance cost (early glass windows cost about $1 per 16 cc and were about 1 m thick) with the limited field of view. Use of transparent barriers also limited the distance of useful vision because the operator could not move closer to the work area. At a distance of 1 m, the closest the operator could get, he could do useful work; at 2.5 m (1.5 m into the cell), his capabilities were reduced; and at 3.5 m, useful work was impossible for most people. In addition, because light transmission was limited to 10 to 20%, the light intensity in the work area had to be increased.

In recent years, the television camera has become the visual transmitter with the greatest potential for "projected man." Mounted on a conveyance mechanism, it is virtually an eye in free space. It can be designed with a variable focus and provisions can be made for both wide-angle and highly magnified, detailed observation. The resolution of detail can be enhanced by increasing the number of available projection lines on the screen.

To further improve visual transmission, any number of electronic options are available; however, most have inherent disadvantages. For one, man has binocular vision and sees the world in three dimensions, whereas the television screen displays only two-dimensional cues. Several studies are being conducted to understand the visual cues that the human operator uses in depth perception and to determine how these cues can be implemented in television viewing. Another disadvantage is that, unless camera position control is coupled to an often cumbersome (human) head control system, operators can become visually disoriented because they have no way of automatically sensing the location of their remote eyes (the cameras). This is in contrast to direct viewing, in which we automatically know where our eyes are directed.

Of course, we can provide the operator with this information by some form of graphic display. However, this makes the sense of orientation a much more conscious process and introduces the potential for error and operator overload. A number of studies into ways of optimizing operator spatial orientation in remote viewing are in progress, particularly for military-related application.

The introduction of force reflection, a component of the human equivalent of touch, into manipulator systems has increased their usefulness by orders of magnitude. In robotic systems, we are developing replacement capabilities; in teleoperator (manipulator) systems, we are attempting to increase use of human capabilities via remote-operation systems.

In studying those biological mechanisms that provide our sense of touch, the two major areas to which we can devote our attention are tactility and kinesthetic force-reflection. Tactility—the perception of touch—consists of that series of subsenses, many of which are located in the fingertips, which triggers initial control of object contact, giving us shear or slip control. Currently, two approaches are taken to synthesizing tactile sensing. The first involves the generation of a proportional signal by the gripping mechanism. For robotics, that signal incorporated in the control system can be used to limit the grip force or control the shear force. For the teleoperator system, the magnitude of grip or shear force can be visually transmitted to the operator. The second approach to tactile sensing, which is perhaps less likely to overload the operator's visual channel capacity and is more natural and more applicable to the teleoperator system, is the generation of an equal force to the operator's fingers. This provides a true sense of touch. Force-reflecting systems for object contact exist, whereas those for shear or slip have only been postulated.

The second and most important biological mechanism controlling sense of touch is kinesthetic force-reflection. Kinesthetic responses are those provided by the muscular system in exerting or resisting force. These forces, integrated through the brain, provide an important sense of contact with our work activities.

The initial work in manipulators made use of those motion-providing mechanisms that were state of the art. The initial choice was the crane, a device with a single force capability—up: a crane cannot push downward or sideways, but it does have travel mobility when mounted on a controllable bridge and trolley. The hook, however, is not a hand, and the single force was neither controllable nor versatile. These limitations led to the development of several intermediate steps: the stiff-armed crane with telescoping tubes, single-direction fingers (power closed, spring return), and the rotating wrist to position the fingers. The design and use of those early power manipulators at ORNL (Tell manipulator, Solid State Division), Argonne, Westinghouse Bettis, Los Alamos, Brookhaven, and General Electric KAPL are well known to most of us old-timers. There were probably others because, in those days, each laboratory was doing its own thing.

From these initial efforts, a commercial power manipulator was developed by General Mills and later by Programmed and Remote Systems Corporation (PaR) and is still standard equipment in our business. It provides a shoulder rotation, an elbow yaw, and a wrist yaw, in addition to the wrist rotation and the finger grip, and was the first manipulator with seven distinct motions. It has lifting capacities of 900 to 1800 kg and, with its seven degrees of freedom, it can be configured to parallel the motions and capabilities of an arm moving in free space. Its major limitation is that the link between the arm and the operator is visual. In actual operation, because it is a machine without a sense of touch, it has only two force capabilities—it can exert either zero or total force. For interfaces between the manipulator and an object, the object (such as a machine) had to be designed to take the total manipulator force.

Contemporary to development of the power manipulator was the master/slave manipulator: a balanced system of parallelogram construction whose mechanical linkages are designed to reflect force in both directions. The bilateral force reflection provides a touch feedback to the operator. These mechanical manipulators are also a standard part of remote operations today. Because they are a mechanical linkage and because they are inserted through the barrier wall, they operate within a fixed working area.

The most sophisticated manipulator of objects is man, mechanically speaking. The more efficiently we can project the capabilities of the human operator into the workplace, the closer we are to accomplishing required work functions within a reasonable time frame.

In 1953, when Roy Goertz at Argonne National Laboratory was developing the master/slave manipulators (four distinct models of a manipulator, each providing a progressively greater latitude of work capability), he began solving the inherent disadvantages of the pure mechanical manipulator. He developed the electric master/slave concept in which mechanical linkages are replaced by synchronously coupled electric drives to effect reciprocal motion at the master and at the slave. Work by Jean Vertut at the Centre d'Etudes Nucleaires in Saclay, France; T. Raimondi in Italy; and Carl Flatau at Brookhaven National Laboratory duplicated this exciting development.

Why was this development so exciting? If the workplace is tailored to manipulator capabilities, the designer can use the available tools of the trade; indeed, we did just that from the 1950s through the early 1970s. Because the electric master/slave had not been developed much beyond the conceptual stage, we designed hot cells that had a 2.5-m depth and work stations in multiples of 2.5-m widths, and we used the windows for viewing and the mechanical master/slave for manipulations. However, not all jobs fit nicely into 2.5- × 2.5-m configurations.

Here at Oak Ridge, we looked at applications of the electric master/slave to fuel reprocessing and fuel fabrication. The canyons for fuel reprocessing at Hanford, Savannah River, West Valley, and Barnwell were built around equipment that did not fit into the rectangular configurations here at ORNL. It became apparent, eventually, that some functions in which the manipulator was needed were complementary. The decontamination and decommissioning of existing radiation facilities, light-water reactor maintenance, breeder reactor maintenance, radioactive waste processing and disposal, and maintenance of fusion devices are all part of nuclear technology, and all possess size and shape characteristics outside our current remote handling limitations. A need clearly existed to provide a means of making manipulation truly remote, that is, away from its operator.

One additional clarification of goals was required before development could proceed. All the necessary work functions could be accomplished in a variety of ways; the factor that determined the method was time. Data were gathered from five independent sources to determine the length of time required to perform a specific set of work functions for several remote systems. Within each study, the work functions were the same, but some differences in work attempted existed between the studies. Only simple work tasks were used, that is, plugging in an electrical connector, fastening a bolt, completing a pipe connection, etc. The first four systems—all consisting of man and the master/slave manipulator—were systems using force reflection (touch). The remaining systems were non-force-reflecting.

It is fairly obvious that as we approach using human capabilities in projected man, we approach maximum work efficiency. The reliability and maintainability of a machine determines its availability to do work; this is true of nuclear reactors as well as automobiles.

During the 1970s, four industrial organizations used the early concepts of Goertz at Argonne to produce sophisticated electric master/slave units. However, these electromechanical units required additional development so that they could perform in a variety of environments.

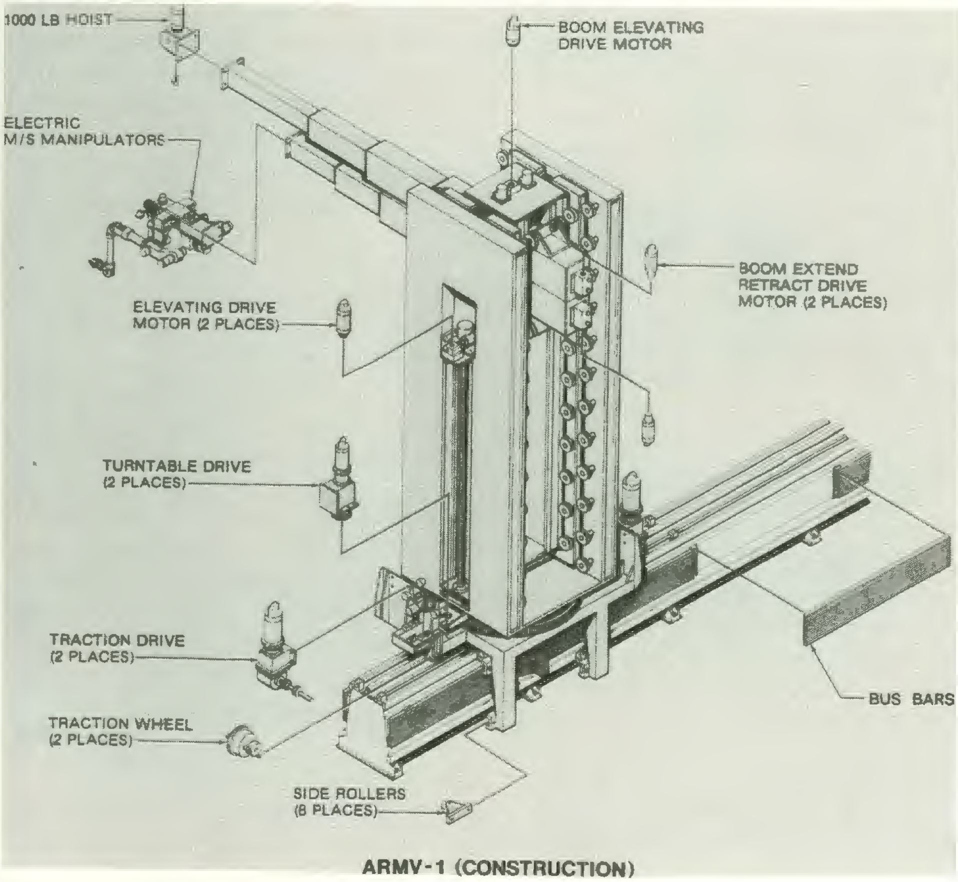
Work at ORNL

At ORNL's Fuel Recycle Division we have recognized the potential value of electronic force-reflecting manipulators and have undertaken a development program to translate that potential into reality. In addition to the manipulator itself, our program has recognized the necessity of development in associated technologies to the eventual availability of a total system.

In its current form, the manipulator is designed to work on a table top. Its elbow is at the level of its shoulder. The most usable configuration for the hands is the anthropomorphic stance, that is, hands and elbow below the shoulder, so we are designing a manipulator in that stance. In addition to those applications in the radioactive environment, it is considered generally advantageous to have the capacity to repair the manipulator remotely. Current manipulator designs are difficult to repair remotely because the tape and cable mechanical linkages are designed for contact maintenance. We are undertaking the replacement of these linkages with gears and torque tubes or with distributed power sources. The goal of this new design is to provide the capacity to replace malfunctioning segments remotely.

Once agreement is reached on the manipulator design, the next major item for consideration is a vehicle for transporting the manipulator and television cameras to the work site, and from one workplace to another. In our applications, the transporter takes the form of an "ARM" (articulated remote maintenance) vehicle or a "rescue" vehicle. Each call for remote work will have a specialized transporter that will adapt the manipulator system to the specific workplace. Situations that require rolling, walking, climbing, and swimming transporters are foreseen. Union Carbide Nuclear Division's robot "Herman I" is a practical example of a transporter.

Transporters of current design are connected to control and power sources by an umbilical cord. The use of manipulators in large reprocessing facilities, for example, in which hundreds of feet will be traveled and multiple units will be used simultaneously, makes the use of



An articulated remote maintenance vehicle (ARMV) is being designed for ultimate testing at the Fuel Reprocessing Program area, near Building 7601.

the umbilical cord impractical.

Because the problems were different, we separated power transmission and signal transmission. Currently, we have investigated battery packs, bus bars, captive cables, and inductive systems for power transmission. We have placed recent emphasis on enclosed bus bars (because of the corrosive atmosphere of a reprocessing plant) and on a hybrid battery system. The hybrid system is applicable to new construction and is designed to supply primary power between work stations; it requires the manipulator to plug in a short umbilical cord at the workplace, thereby converting itself from self-contained power to a hard-wired system. A number of available battery systems have been exposed to radiation fields, and reasonable battery lifetimes, from the standpoint of both radiation stability and recycle stability, are available.

The development of signal transmission has included analysis of inductive systems, radio frequency transmission having repeater stations or special antenna configuration, optical path transmission (both laser and LED), and microwave transmission. All the signal transmission systems rely on multiplex conversions to handle the large number of control signals required by a manipulator and its cameras. The broad band-width required by the cameras and manipulators has limited our selection of signal transmission systems. We are currently concentrating on inductive and radio-frequency systems.

In selecting the proper television camera, light sources, and camera- and light-positioning devices, our program has two criteria: technical selection of devices and operator reaction to these devices. Our work with cameras has led to investigation of standard television cameras (the least expensive to acquire), high-resolution cameras (commercial European systems are higher resolution than the U.S. system, but special high-resolution, domestic systems are available), color cameras, and stereo viewing systems.

After looking into available camera-positioning devices, we decided to develop our own, attempting to synthesize the cues of depth perception on a flat screen to attain the proper angle of viewing. The idea is to provide a sense of presence at the workplace for the operator.

It was during the camera selection process that we saw the need for development in the man/machine interface. The general field concerns itself with efficiently converting the operator's sensory inputs into useful work. A specialized area of the man/machine interface deals with hand/eye coordination. Analysis of the system we are developing reveals a difference in the two major sensory transmissions. The sense of touch is transmitted by the manipulator to the operator in a normal fashion, that is, the operator's muscular systems respond to his receptors and take over the conversion to required action. In the visual system, however, we transmit a signal to the operator via a television screen, and the screen is abnormal vision. We are now studying ways to optimize the visual signals to minimize operator confusion resulting from the television screen representation.

The Fuel Recycle Division has tried to approach this problem as a system study. The generic work undertaken has wide application in the nuclear field and is potentially applicable to even broader areas; indeed, its application runs the gamut from microsurgery to underseas mining.

Human Concerns

No doubt exists that the use of robotic devices can replace many of the repetitive production jobs currently performed by humans. The management advantages are numerous, as the Japanese have proven, but the sociological impacts have evaded discussion. One area of concern has to do with the fact that human workers represent a range of capabilities and limitations. A recognizable segment of the human community has limited production capabilities. The performance of repetitive and generally simple tasks is useful to a production-oriented society. Advanced robotics will take over the more simple production tasks, displacing this segment of the work force; the remaining tasks may be too difficult for these individuals.

A second area of concern is the inherent limitation of the designer. Our machines are designed for human operation and maintenance. We have only one human model from which to work. Is that the most efficient model? If you believe, as some do, that the human form is evolving and is therefore, in its current stage of development, short of the ultimate, we can only hypothesize as to what that ultimate form might be. If the changes are adaptive to fit the earth we inhabit more efficiently, will that adaptive process produce a different model? We have recently worked with design approaches that appear to require a manipulator configuration with an additional joint in the arm. Although the problem we are solving is man-generated, the response is outside the model, and the control sequence is therefore abnormal. The question is: "Is it abnormal or perceptive?" ornl

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awards and appointments

Four ORNL technical achievements won IR-100 awards this year: a vapor monitor developed for protection of synfuel plant personnel, award received by ***Tuan Vo-Dinh***; high-gradient magnetic separation of coal impurities, award received by ***Gene Hise*** and ***Allen Holman***; PERALS, a sensitive spectrometer for identification and analysis of alpha radiation, award received by ***Jack McDowell*** and ***Gerry Case***; and an extreme ultraviolet monochromator, which can detect impurities in plasmas, award received by ***Paul Caldwell*** and ***Ed Arakawa***.

Bob Gray was selected to receive the 1981 Sorby Award from the International Metallographic Society.

Gloria Caton has been elected chairman of the East Tennessee chapter of the American Society for Information Science.

Ken Sommerfeld has been appointed associate director of the Laboratory for Administrative Services, replacing Clyde Hopkins, who has accepted the position of vice-president of the Nuclear Division, with responsibilities for the uranium enrichment program.

Dan Robbins has been asked to cochair the 1982 national midyear meeting of the American Society for Information Science, to be held at the University of Tennessee next spring.

Bill Lyon is the recipient of the *Journal of Radioanalytical Chemistry's* George Hevesy Medal, an international honor that has gone to only four American scientists since its inception in 1968.

Charles Brinkman has been elected a fellow of the American Society of Metals.

Mike Wilkinson has been appointed to the Solid State Sciences Committee of the National Research Council.

Bob Weeks has been appointed a Distinguished Lecturer at Ecole Polytechnic Institut in Lausanne, Switzerland, for six months.

Ronald Ragland has been appointed director of Administrative Services. He will assume these responsibilities in addition to those of the position he has held since 1973, director of the Finance and Materials Division.

Dick Wood has been appointed a National Lecturer for the Institute of Electrical and Electronic Engineers for one year.

Larry Corbin and ***Joe Stewart*** were selected to receive the Harlan J. Anderson Award at last summer's meeting of the Committee on Nuclear Fuel Cycle of the American Society for Testing and Materials.

Jack Cunningham has been named vice-chairman of the Honors and Awards Committee of the American Nuclear Society.

The International Cancer Research Data Bank Program of the National Cancer Institute has awarded its International Cancer Research Technology Transfer Fellowship this year to ***Carol A. Heckman***.

Roger Carlsmith has been appointed director of the newly formed Conservation and Renewable Energy Program.

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