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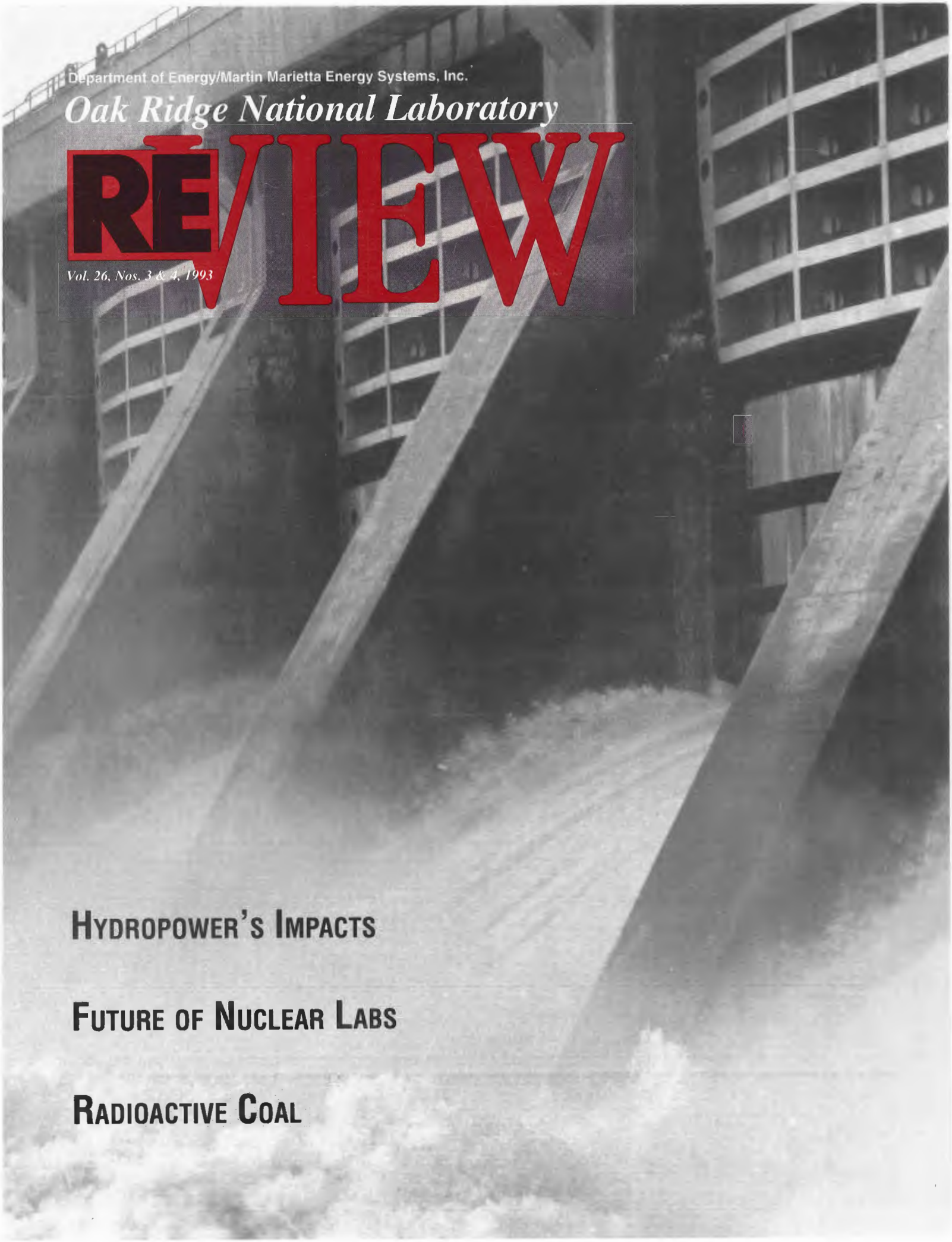

HYDROPOWER'S IMPACTS

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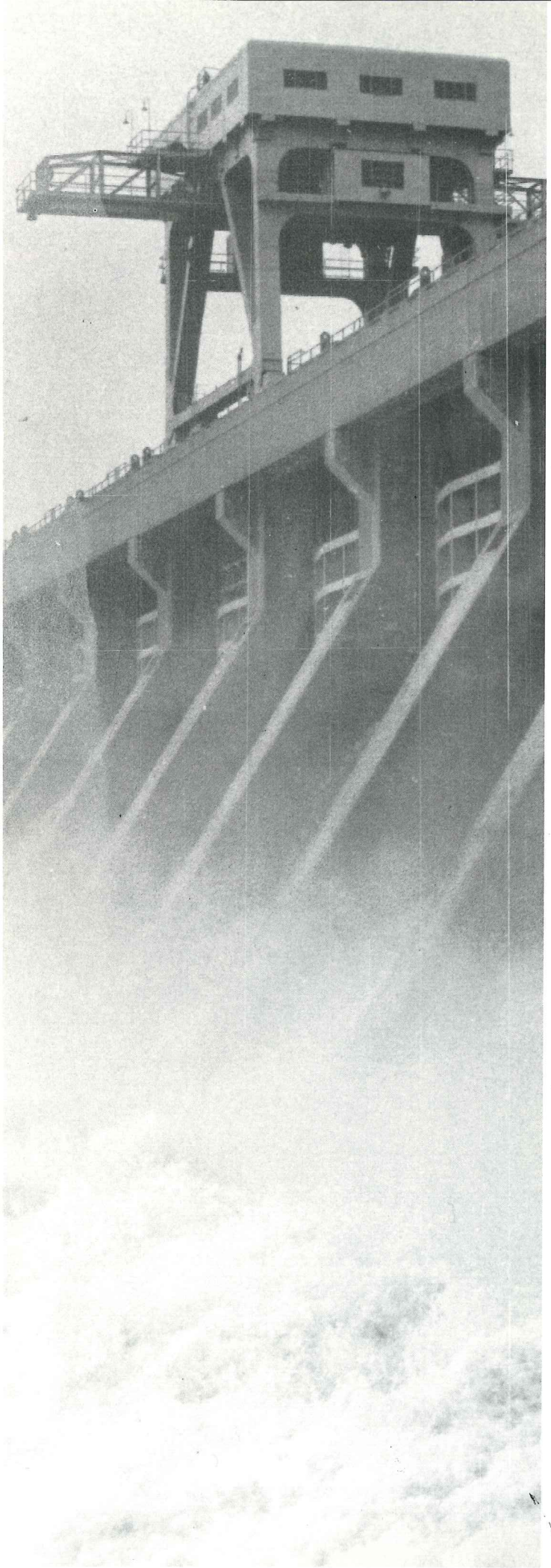

ON THE COVER

View of the John Day Dam in Washington, one of many hydroelectric projects on the Columbia River in the Pacific Northwest. This federal dam is operated by the U.S. Army Corps of Engineers; its hydropower is distributed by the Bonneville Power Administration. ORNL researchers have been evaluating the effects of dams on fish populations in the Columbia River. They have also been evaluating the environmental and socioeconomic impacts of smaller nonfederal dams in the Pacific Northwest for the Federal Energy Regulatory Commission. This work is discussed in the article on p. 2.

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REVIEW

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FEATURES

DEPARTMENTS

Hydropower: Licensed To Protect the Environment

Editor's note: The following edited interview with Mike Sale and Chuck Coutant, both of ORNL's Environmental Sciences Division, explores the issues involved in developing hydropower resources in the United States. ORNL conducts assessments and other studies associated with licensing hydropower projects for the Federal Energy Regulatory Commission . It also performs research for the Department of Energy and others on methods to avoid or minimize the environmental impacts of hydropower projects and provides advice to other state and federal agencies and private industry. Sale is leader of the Hydrosystems Group in the division's Ecosystems Studies Section and program manager for FERC projects for the Energy Division. Coutant is a senior ecologist in the Environmental Sciences Division.

Why is hydropower important to the United States?

Mike Sale: The energy of flowing water is the most readily available, renewable, and clean domestic source of electricity that we have right now. It is available in most parts of the country that have high rainfall and mountainous areas. In terms of total production, hydropower is America's leading renewable energy resource; it is more reliable and efficient and less expensive than geothermal, biomass, wind, and solar energy. Perhaps most important, it is a clean source of power—it produces no carbon dioxide, sulfur dioxide, nitrous oxides, or any other air emissions. In addition, it produces no solid or liquid wastes.

Hydropower is also one of the least expensive sources of electricity in the United States. For every kilowatt-hour (kWh) of electricity produced by a hydropower plant, only 0.6 cents is needed to finance its operation and maintenance. By comparison, these costs at nuclear and coal plants are 2.2 cents/kWh and 2.1 cents/kWh, respectively. Our own region, the Tennessee Valley, has the benefit of low electrical rates primarily because a high percentage of its electricity comes from hydropower.

Currently, hydropower is a critical component of many electrical systems. Throughout the world it provides one-fifth of the electricity used, and it is second to fossil energy as a source of power. In the United States, it provides 10% of the electricity used, down from 14% 20 years ago, but more than petroleum and far more than the other renewable energy technologies combined. U.S. hydropower plants produce the energy equivalent of 500 million barrels of oil per year. On a regional basis, hydropower is a source of 14% of the electricity used in the Rocky Mountain states and 63% of that used along the Pacific coast. The Pacific Northwest is the region of the country that relies most heavily on hydropower; two-thirds of its electricity comes from its 58 hydroelectric dams.

I don't mean to imply that hydropower is problem-free, but these facts illustrate the importance of hydropower.

What is the status of the nation's hydropower resources?

Sale: About half of this country's hydropower projects are federal and half are nonfederal. Nonfederal hydropower projects receive 50-year licenses from the Federal Energy Regulatory Commission (FERC) and must be periodically relicensed. For example, some 156 hydropower projects built in 1943 will have to meet new requirements this year before their licenses are renewed. Further modifications may be required to protect environmental values, such as the declining salmon population in the Pacific Northwest.

In some cases, instead of renewing a license, FERC may decide the best solution is to remove the dam and restore free flow to aid salmon migration. These decisions could result in a reduction in hydropower production and an increase of as much as 8% in electricity rates for consumers in the Pacific Northwest.

Through our contracts with FERC and DOE, ORNL is involved in making recommendations on the requirements that should be incorporated into the operating licenses of hydroelectric power plants. The Laboratory supports development of hydropower that is compatible with the environment.

Hydropower is one of the least expensive sources of electricity in the United States.

The Grand Coulee Dam in Washington was one of the first large federal hydroelectric projects in the United States. Both federal and nonfederal dams in the Pacific Northwest have had an adverse impact on salmon populations. ORNL has evaluated the environmental and socioeconomic impacts of nonfederal dams throughout the United States for FERC.

The Laboratory supports development of hydropower that is compatible with the environment.

View of Fond du Lac Dam and Hydroelectric Project on St. Louis River in Minnesota. The dam, which is owned and operated by the Minnesota Power Company, is facing relicensing by the Federal Energy Regulatory Commission. *Photograph by Mike Sale*

How will hydropower be replaced if it is lost?

Sale: The impacts of lost power production during relicensing will probably be greatest in the areas of the country that rely on hydroelectric dams for peaking power—electricity needed during times of high demand. These dams store large amounts of water and then release it quickly to match peak demands. Associated water-level fluctuations in rivers can have undesirable environmental and social effects. Given today's sensitivity to environmental values, such projects may not be allowed to continue this type of operation. Hydropower peaking may have to be replaced by gas turbines or coal-fired plants or conservation programs to encourage less use of energy.

Coutant: If part of the hydroelectric capacity is lost, the power can be supplied by other parts of the power grid. For example, the Canadians are anxious to sell hydropower to the United States. Our country's biggest foreign source of power is Quebec Hydro, which sells a tremendous amount of electricity to New England and New York City. The Pacific Northwest could import more power. Of course, doing so would aggravate our balance-of-payments problem. It should also be pointed out that the large Canadian hydropower projects have serious environmental impacts.

In addition to producing clean power, what are some other environmental benefits of hydroelectric dams?

Sale: Reservoirs at hydropower projects have a large recreational value; they are extensively used for fishing, boating, water skiing, and swimming. They offer expanded habitats for fish, ducks, geese, pelicans, eagles, and ospreys. They also provide storage for water supplies and help control floods, minimizing soil erosion. Recreational opportunities almost always increase where hydropower is developed.

What are the adverse environmental impacts of hydropower projects?

Coutant: Because most hydroelectric projects have dams, a river habitat is often replaced by a lake habitat. Thus, habitats for wildlife on land and for organisms in the water are destroyed or altered by impoundments of rivers. Examples in Tennessee are the Little Tennessee River and Tellico Lake.

The biggest issue in the Northwest has been blocking upstream and downstream movement of fish. Salmon must be able to migrate upstream from the ocean to reproduce in fresh water. Even

with the use of fish ladders to help salmon go up over dams and enter upstream spawning areas, the presence of hydroelectric dams essentially has changed the migration pattern of fish. The coho, chinook, and sockeye salmon populations of the Northwest, which once were abundant, are either on or will soon be on the endangered species list. They are headed for extinction, in part, because of hydropower. However, federal dams, not nonfederal dams, are primarily responsible for the reduction of the Pacific Northwest salmon population from about 16 million to 300,000 wild fish each year. The bottom line is that hydropower production is decreasing as new environmental protection is enforced.

Another view of the Fond du Lac Dam, one of several nonfederal projects being studied by ORNL. *Photograph by Mike Sale*

Recreational opportunities almost always increase where hydropower is developed.

Another big problem now is getting the young fish back downstream and into the ocean. On the way they can be killed as they pass through the turbines.

Development of hydroelectric dams can have adverse effects on water quality in several different ways. Tree clearing can result in soil erosion and landslides, causing a buildup of sediments that can clog up streams. Spilling of water over spillways can result in supersaturation of the water with gases from the air. The gas bubbles, which are absorbed into fish tissue, may cause damage and ultimately kill the fish. Supersaturation was a big problem in the Columbia River. Then it was determined that the high pressure from high water plunging down over the spillway into the basin below forced atmospheric gases into solution, making the basin water supersaturated.

Poor water quality for aquatic life can be a problem in the Tennessee Valley because our reservoirs have limited natural flow in summer. Thus, water becomes stratified, with warmer water collecting at the surface and cooler water lying at the bottom. Because the bottom water is isolated from aeration, it loses its oxygen. Because this water is very cold and low in dissolved oxygen, striped bass and other fish cannot live in it.

When this deep water is passed through hydropower turbines, it is still low in dissolved oxygen and it can make the river downstream of the dam uninhabitable, as well. Lack of oxygen in deep reservoir water can cause certain metals to dissolve more readily from surrounding rocks, and these metals are released to the downstream river where they can cause problems.

Sale: Another problem with dams is that, even if the water quality is not degraded, major habitat changes can occur if the natural hydrology of the river is changed. This issue is normally lumped under the term "instream flow" problems. If the

Another big problem now is getting the young fish back downstream and into the ocean.

Reregulation weir constructed by the Tennessee Valley Authority below the South Holston Dam. The structure both aerates water discharged from the dam and dampens flow fluctuations resulting from intermittent releases. *Photograph by Glenn Cada*

amount of water released downstream changes, either on a seasonal basis or, in the short term—say, on an hourly basis—that can have adverse effects on fish and other organisms.

Coutant: An important advantage of hydroelectric dams for power production is that generation patterns can be easily controlled and the release pattern can be made to fit the changing levels of demand for electricity. In a typical daily generating cycle in the summer, the highest demand comes at midday and afternoon because of the need for lots of air conditioning. Like a yo-yo, the river level goes down and up as water is dumped fast in a high electricity demand period and held back during low demand periods. For a shallow river, these fluctuations are like the tide coming in and out. Flow fluctuations can strand fish in shallow water and dry out the habitat. Thus, the change-of-flow rate must be regulated to protect the environment.

Sale: The need for minimum flow to protect aquatic habitat is the most common problem that must be addressed in licensing and relicensing hydroelectric dams. If the flow is too low, fish or other organisms may suffer. Minimum flows are established to protect a wide range of natural resources, such as fish, water snakes, and, in unusual cases, even resources like the fossilized tracks of dinosaurs. Depending on the location of a project, dam releases must be satisfactory for kayakers and white-water rafters or for Native American tribes to carry out their traditional religious practices. Instream flow must be regulated to protect all these interests.

Dams: Multiple Uses and Types

Of the 80,000 dams in the United States, only about 2400, or 3%, are used for hydropower. The others are used in the following ways: recreation, 35%; stock and farm ponds, 18%; flood control, 15%; public water supply, 12%; irrigation, 11%; and other uses such as trade navigation, 6%. Dams that are not used to produce electricity can have as many environmental impacts as the hydroelectric dams. Existing dams also have significant undeveloped hydropower potential.

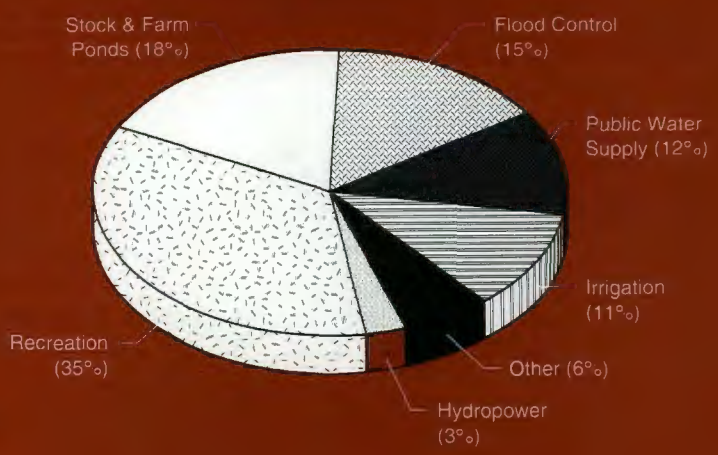
A good example of a dam with more than one use is the Grand Coulee Dam in Washington. It not only generates power but also pumps water up from Lake Roosevelt to supply the state's irrigation system.

There are three types of hydropower projects: impoundment dams, diversion hydropower, and pumped storage. Impoundment dams store water, which may be released at a later time to meet rising demands for electricity.

Diversion hydropower facilities rely on part of a river being channeled through a canal or pipe for carrying water to a downstream powerhouse. They may or may not require a dam. The original hydropower facilities at Niagara Falls were of this type.

Pumped storage requires an upper reservoir and a lower one. High-volume peaking power is generated when water flows through a turbine from the upper to the lower reservoir. The turbine is reversed to pump water back to the upper reservoir during the off-hours using cheaper electricity from another power station, for example, from a baseload nuclear plant. This seemingly inefficient approach to power generation is practical because many nuclear plants are more efficient if they run constantly to meet a certain level of power demand. Because considerably less power is normally needed at night, the nuclear plant's electricity can be used then to pump water from the lower reservoir to the upper one for later use in helping to meet unusually high, and often costly, electrical demand.

Of the 80,000 dams in the United States, only 3% are used for producing electricity.



Can these environmental problems be solved?

The need for minimum flow to protect aquatic habitat is the most common problem addressed in licensing hydroelectric dams.

Sale: In most situations, the answer is a strong *yes*. Many environmental problems of hydropower are fixable, and ORNL is making important contributions in this area. Proper siting, design, and operation can solve most of the problems. We have already mentioned the use of fish ladders, aeration, and flow control on large dams. These are examples of environmental mitigation, actions by which impacts are avoided, minimized, offset, or somehow compensated for. At hydroelectric projects, a number of actions can be taken to avoid or minimize an impact before it occurs. ORNL staff have been actively involved in evaluating these problems and designing solutions for more than a decade. Right now, we are helping DOE start up a new technology development program with industry cost-sharing to make hydropower more environmentally friendly.

Mike Sale

Coutant: At large dams in the Pacific Northwest, fish ladders have been around for years to get adult salmon from the ocean past the dam into the river above so they can hatch their young in fresh water. The fish ladder is a classic example of mitigation. Now it is being realized that even resident fish move around a lot seasonally in fresh water for spawning and migration. Thus, they need some kind of passage. In Oregon, resident trout, which migrate for dozens of miles in the fresh water of the Klamath River, benefit from fish passages. Using fish ladders, they go from the main river environment, which essentially has no spawning habitat, into a few selected tributaries, where their spawning occurs. Their young spread out through the river and then, as adults, swim past the dams to return to the spawning area and start a new generation.

In many cases, if turbines are designed right, developers can avoid the problem in which fish are drawn into the turbine blades and killed. Intake screens can be designed to prevent fish from being drawn into the turbine. Certain turbine designs having blades that are properly spaced and turned at the right revolution are not a threat to fish. What is needed is a good standard design for turbines that is proven to protect fish and that will be considered for use by all developers of hydropower.

It is also known that turbines can be operated to minimize their harmful effect on fish. Traditionally, hydropower operators tilt the blades of a turbine rather than stopping it when they want to change the horsepower applied to the generator. Such operation causes considerable turbulence, killing most of the fish passing through. However, research has shown that running a turbine as close to maximum efficiency as possible not only generates power efficiently but also allows more of the fish to pass through unharmed. Today, on a big hydropower dam such as on the Columbia River, which has a dozen or more turbines and generators in a line, the most effective operating

scheme is to keep some turbines fully on and others off to match the power demand.

What are some other examples of mitigation?

Coutant: There are many examples where actions are taken to fit the particular circumstances. For example, if a developer is going to destroy a wetland habitat by flooding the land to make a reservoir, the developer can compensate by setting up a wildlife refuge nearby. In this way, loss of habitat in one area is compensated for by creation of habitat in another.

In another example, developers of a hydropower project may acknowledge that their operation may kill a certain number of fish per day in the turbines. So, to make up for this loss, they agree to build a fish hatchery capable of producing an equivalent or greater number of fish.

Chuck Coutant

What other conflicts and issues arise in hydroelectric development?

Sale: In gathering information on the impacts of relicensing hydroelectric dams, we have found that these dams' multiple uses are both their biggest strength and their biggest weakness. It is a weakness because of the conflicts among many different vested interests on how to use a reservoir system. For example, the white-water rafters disagree with the reservoir bass fishermen on the amount of flow needed. Developers of residential areas along the shorelines of existing lakes are in opposition to the people who want to preserve the forest to protect its endangered species. A classic conflict over water use is the one between those who want to use the water in the dam strictly for hydropower generation and those who want to divert some of it to supply industrial and agricultural needs. Ironically, hydropower being a nonconsumptive water use is more compatible with environmental instream values than consumptive, out-of-bank uses, such as water supply.

Turbines can be operated to minimize their harmful effect on fish.

Coutant: Interestingly, authorized uses of a hydroelectric project can have conflicts, and there can be conflicts between authorized uses and other demands. For example, authorized uses of the TVA dams are power generation, flood control, and recreation such as fishing, swimming, boating, and water skiing. Here's the problem. To achieve flood control, it is desirable to lower the dam level by releasing more water over the spillway, making space for the extra water that a flood would bring. However, dock owners who use the lake for recreation do not want the reservoir dropped 30 feet in the summer because then they could not use their docks. So TVA has developed standard rules on raising and lowering the lake level to try to accommodate both the recreation interests and the need for flood control.

ORNL's Role in Hydropower Development

ORNL has three major roles in hydropower development. One role is support to the Federal Energy Regulatory Commission in preparing environmental impact statements and conducting environmental assessments on hydropower projects. These documents help determine the requirements included in the operating license for a particular project. This regulatory compliance role is carried out by staff from the Energy and Environmental Sciences divisions.

Another role is to conduct applied research and development for the U.S. Department of Energy. "Since 1978 the Laboratory has been the lead environmental research facility for DOE's hydropower program," ORNL researcher Mike Sale notes. "We have been conducting studies to help promote environmentally sound hydropower development, providing guidance to regulators, resource managers, and developers on solving environmental problems. Support to DOE also includes regulatory analysis.

"We completed a study for the DOE Policy and Planning Office in which we recommended administrative and regulatory options that could streamline the current licensing process. The results of this study were provided to Vice President Gore, who headed a 'reinventing government' team that recommended ways to make the federal government more efficient. There is a lot of room for improvement in hydropower because it is one of the most overregulated energy industries."

ORNL's third role is to perform basic research for DOE and organizations such as the Electric Power Research Institute. "For example," Sale says, "we are trying to better understand the basic mechanisms by which fish populations respond to the problems that dams cause, such as poorer water quality, low instream flow, and mortality during fish passage upstream and downstream of dams. We are studying mitigation measures for these problems to determine if they are cost effective."

"Since 1978 the Laboratory has been the lead environmental research facility for DOE's hydropower program."

ORNL staff also play a strong technical advisory role. "We provide advice to a number of different organizations," Sale explains. "Our group members are involved across the country in reviewing documents, directing research by others, and working on various technical committees for industry and other federal agencies."

For example, ORNL's Chuck Coutant, who was recently elected second vice president of the American Fisheries Society, currently serves on the Scientific Review Board of the Bonneville Power Administration's Columbia Basin Fish and Wildlife Program, a $100-million-a-year program supported by rate payers in the Northwest to rehabilitate the salmon population. "A board of about a dozen people assesses the quality of the technical work and its direction to make sure it is state-of-the-art science." Coutant says. "In this way we become a sort of national catalyst to help make sure environmental fixes that work are being considered throughout the country."

Sale: Another issue is that, in the Northwest and elsewhere, the rights of Native Americans must be protected, even if it conflicts with what the rest of society wants. Since the 1800s the tribes have had a treaty with the U.S. government that recognizes them as a separate nation. They can set their own rules for fishing and environmental use. They have a right to have enough salmon at the spot where they usually fish, to have enough water in the river for their traditional religious bathing practices, and to ensure that no water touches any manmade structure that has religious significance.

In the Skagit and Nooksack river basins in Washington, we have been interviewing tribal members to determine the problems they have with present and planned hydro facilities and to explore solutions. We ask general questions about the possible impacts and the types of mitigation or compensation they would consider acceptable.

Coutant: In looking at the socioeconomic aspects of a hydroelectric dam, we have to consider its relative value as an environmental resource versus its value as a source of power. It used to be accepted that the value of hydropower was so great that only major environmental damages would offset it. Some people are questioning that assumption now. More and more, people are insisting that hydropower pay its way so that the result is no net loss for fish and wildlife. Because hydropower is extracting an economic benefit, it has been argued that it should give something back to protect and develop other affected resources. And that can be done. But one of the major socioeconomic conflicts right now is how best to balance the values of environmental resources and hydropower.

The Wadhams hydroelectric project in northeastern New York began operation in 1904. Refurbishment in 1983 included installation of an experimental fish screen to prevent turbine-passage losses of juvenile Atlantic salmon. *Photograph by Jim Francfort, Idaho National Engineering Laboratory*

These dams' multiple uses are both their biggest strength and their biggest weakness.

How do you put a value on environmental resources?

Coutant: It may seem easy to put a dollar value on a commercially used fish like salmon, but there are complications. We know how much it will sell for in the marketplace. But what is the value of salmon if the fish are not directly consumed? What is the value to somebody who likes to drive up in the mountains and see a free-flowing river and pristine mountains with trout and salmon swimming and spawning instead of a bunch of hydroelectric dams and power lines? That is hard to measure or estimate.

People are willing to pay extra on their electric bills just to know that there is a fish population out there, even though they may never even go fishing or eat these fish. That is a nonuse value, one that should be included to get a representative set of dollar values for costs and benefits. Quite a bit of research still needs to be done to arrive at an acceptable set of procedures for placing resource values on the environmental resources at hydroprojects. For example, the values for each salmon in the Pacific Northwest may range from

Fish ladder at the Lower Monumental Dam on the Snake River in Washington. This is one of two ladders that allow upstream passage of adult salmon and steelhead above the 100-foot-tall dam. *Photograph by Jim Francfort, Idaho National Engineering Laboratory*

What is the value of seeing a free-flowing river or pristine mountain stream?

$10 to $500 to $900 per fish, depending on how you derive the value. There is a lot of controversy in that area because, if the value is low, installing a fish ladder may not be justifiable; if it's high, then a ladder can be justified.

Are there special hydropower issues in other parts of the country?

Coutant: Water allocation in the Central Valley of California is probably the world's stickiest natural resource issue, and hydropower cannot be separated from it.

Sale: One example is an environmental impact statement we have just completed for FERC on a multipurpose hydropower project on the Mokelumne River. The project's primary purpose has been municipal water supply, but because it also produces hydroelectricity, it is licensed by FERC. The project's operators are obligated to protect the fishery resources downstream and to release water to downstream water users—farmers who need irrigation for their food crops. Recently, a higher value has been placed on the protection of the fishery resources than when the project was first developed. So we are doing a reallocation study to determine if more water can be provided to the fish without adversely affecting the other water users in the river basin. That is tough because there is only so much water to go around. The difficulty comes in quantifying the value of water to the different users, including the value of water to the fish.

Coutant: The traditional water allocation system in western states was first come, first served. Anybody who was first to lay a claim to a certain amount of water could pump it out to irrigate crops or meet some other need. Over time, as more and more people laid claims, more water was allocated. Today the new users, like those who want water for East Bay in the San Francisco area, must guarantee that water will be available to those with "prior rights"—the so-called prior or senior users. So more dams have been built to meet these growing needs. Unfortunately, the original allocation didn't include fish uses at all. It is only recently that instream flows have been established to protect fish species that are nearing extinction.

How many projects are you concerned with in the Pacific Northwest and in California?

Sale: In the Pacific Northwest, we are working on 17 FERC licensing projects. We have nine small diversion projects in the Skagit River Basin and seven in the Nooksack River Basin plus the relicensing of a large project on the Skagit River. These small projects in Washington will each produce about 5 megawatts of electricity. In California, we have an assessment for a license renewal on a large project on the Mokelumne River and a similar project on the Tuolumne River. We're also involved with some projects in the upper Mokelumne River Basin. One is a reservoir and the other deals with the proposed renewal of a hydropower license for the operation of nine small dams by the Pacific Gas and Electric Company.

In California, we are also evaluating changes in the operation of one large dam—the New Don Pedro Project on the Tuolumne River. This project supplies drinking water to the city of San Francisco and the two largest irrigation districts in the country, the Modesto and Turlock irrigation districts.

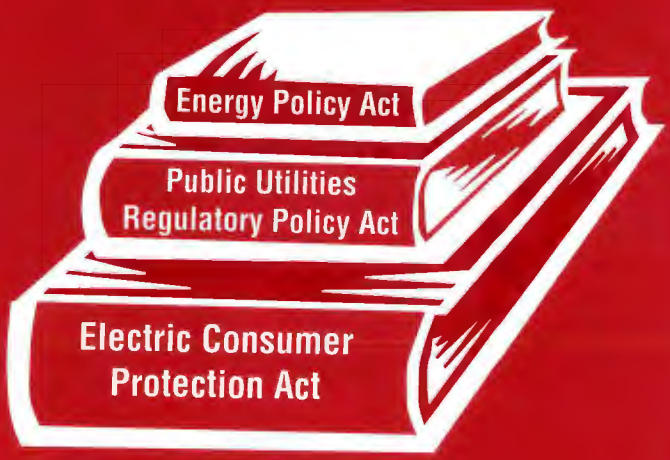
Diminishing Federal Authority for Hydropower

Three major laws affecting hydropower development have been passed in the past 15 years. These laws are the Public Utilities Regulatory Policy Act of 1978, or PURPA; the Electric Consumer Protection Act of 1986 (ECPA); and the Energy Policy Act of 1992 (EPACT). All three laws change the rules by which hydropower projects are developed, specifically nonfederal hydropower projects. The laws that have been passed more recently have addressed the benefits of environmental resources, states' rights, and the roles of regulatory agencies other than the Federal Energy Regulatory Commission. Another important law is the Northwest Power Act of 1980, which mandates protection of salmon in the Columbia River Basin and ensures an economical source of electrical energy.

More recently, because of ECPA and EPACT, federal authority over hydroelectric projects has been diminished. Federal agencies such as the Fish and Wildlife Service and the National Marine Fisheries Service, as well as state agencies that must issue water quality certificates, now have the authority to influence the decisions of the Federal Energy Regulatory Commission. Hence, a number of agencies have acquired much stronger roles in deciding the types of mitigation needed for hydropower development.

"These changes are still being sorted out in the courts and probably will be for quite some time," Sale says. "This regulatory uncertainty makes it very difficult for hydropower developers to be able to anticipate project development needs and costs. The rules keep changing during the 6 to 10 years it takes to build a hydropower plant. That is a major problem for the hydropower industry right now—learning how to cope with changing environmental values and regulations intended to protect those values."

A number of agencies have acquired much stronger roles in deciding the types of mitigation needed for hydropower development.



"In some cases, activists are seeking to actually remove dams."

Tailwater of Comanche Dam on the Lower Mokelumne River in California. This existing project is being reevaluated by the Federal Energy Regulatory Commission to determine if new mitigation measures are needed to protect the anadromous salmon there. *Photograph by Chuck Coutant*

Tailwater of Dashields Lock and Dam on the Ohio River, the site of a proposed hydropower licensing study by ORNL for the Federal Energy Regulatory Commission. *Photograph by Chuck Coutant*

What kind of research is the Laboratory doing in support of environmental mitigation for hydropower projects?

Sale: Our most important current project is the Environmental Mitigation Study for DOE. We have conducted a survey around the country to see what mitigation schemes have been used and to determine which ones work well and which ones don't. We have published a report on our findings.

We have asked for DOE support in developing standardized designs for fish baskets and intake fish screens to help fish move safely upstream and downstream. In the 1970s, Steve Hildebrand established DOE's Hydropower Environmental Program. In the early 1980s, we conducted field research on fish-habitat relations and managed subcontracts with the U.S. Fish and Wildlife Service on fish mortality in turbines. Jim Loar and Glenn Cada were major contributors to this research.

We would like to do more of the laboratory and field work. Now we're doing a fair amount of computer modeling work, a type of paper study. We're modeling the life cycle of the Chinook salmon using available data. For example, we're determining the effects of various conditions on fish migration, spawning, and egg development. Then by plugging in data on conditions in the Mokelumne River before and after hydropower development, we can predict the effects of the new dams on the fish population.

Unfortunately, sometimes unresolvable problems arise because of the multiple uses of a hydroelectric dam. It may be that, even with environmental mitigation, the harmful impacts to

a recreational fishery in a reservoir cannot be eliminated. So then you have to enter a process of trying to strike a balance by determining the best combination of multiple uses in the river. And that is another area where I think we've got some unique expertise here at the Laboratory in dealing quantitatively with multiple objective problems.

Do you have a good example of a case where this balancing was done successfully?

Sale: Yes, in our work in the Ohio River Basin. We dealt with license applications for 26 hydroprojects planned for 500 miles of river. The potential cumulative impacts of these projects included a serious decrease in the river's water quality—specifically, its dissolved oxygen content—and we had to figure out the best combination of the proposed projects that would satisfy the needs for hydropower and protect the environment. So we put together a combination of models in which we simulated the interactions between the dams at different levels of development and then we optimized that development to maximize hydropower production and protect the dissolved oxygen resources of the river. Our conclusions in the environmental impact statement, which were challenged by fish and wildlife resource agencies, were completely upheld in the U.S. appellate court. This was a very important precedent for FERC licensing.

Why did the fish and wildlife agencies challenge you?

Sale: It was basically a policy conflict. Fish and wildlife resource agencies often choose to fight their battles by taking policy positions without providing any technical basis for those positions. In this case, they wanted 100% protection of the water quality and fish resources, even though it would have been impossible to develop any hydropower at that level. Our trade-off analysis using computer modeling demonstrated that it is possible to have both protection of the environment to generally accepted standards and a significant amount of hydropower production at the same time. At first, developers thought we were hard on them, but then they realized that the resource agencies were even tougher and that our recommendations had a sound technical basis and were feasible.

A sad end to this story is that very few of the 16 projects that were licensed will be constructed now because of economic, not environmental, reasons. The developers of these projects cannot get power sales contracts in the region.

What specific studies are being done on environmental mitigation for hydropower?

Sale: The work we're currently doing for the DOE hydropower program is a series of case studies of the environmental benefits and costs of state-of-the-art fish passage facilities. We can go as far as possible to quantify fisheries benefits versus the dollar cost of implementing these protection measures. Unfortunately, even when we pick the best cases in which we're least data-limited, we still are not able to get all the way to any kind of a dollar-dollar trade-off analysis. However, the case studies that we completed in September 1992 show a large range of situations, some of which have very high benefit-cost ratios and some of which have extremely low or zero benefits but very high costs. The case studies demonstrate that we can do a better job of identifying designs that work for specific sites.

What we're trying to do with our case studies is to describe a range of different situations, show the success stories and the failures, and explain why certain measures failed and what might have worked better in most cases. We hope that our report will keep people from reinventing the wheel or making the same mistakes again in the future. We've also identified expensive procedures that should not be implemented until more research and field verification are done.

ORNL researchers' conclusions were upheld in the U.S. appellate court.

From Hydropower to Water Resources Research?

Since 1978 ORNL researchers have been studying the environmental impacts of hydropower development for DOE. Since 1983 they have been preparing environmental impact statements for hydroelectric dams for the Federal Energy Regulatory Commission. This work has been a logical evolution from the Laboratory's involvement in the early 1970s in preparing environmental impact statements for nuclear power plants and other energy-producing facilities and its research in aquatic ecology.

Today many staff members of the Laboratory's Environmental Sciences and Energy divisions have expertise in preparing environmental impact statements and assessments. ORNL has one of the few groups that has more than 20 years of experience in using state-of-the-art techniques to do environmental assessments.

"I think our real strength is in quantitative analysis of biological effects and linking those effects to developmental objectives," Mike Sale says. "We have maintained our niche because of our unique capabilities in evaluating the environmental and socioeconomic effects of hydropower and other sources of energy."

As an expert on the reactions of fish to the effects of energy production, Chuck Coutant has turned his attention from nuclear energy to hydropower. "I came to the Laboratory in 1970 to study the effects on fish of hot-water discharges into streams from the once-through cooling systems of nuclear power plants," he says. "From my studies of the impacts of power-station cooling reservoirs on fish, I naturally progressed to evaluations of the effects on fish of hydropower development and other water uses."

Another evolution may be ahead—from hydropower studies to broader research on water resources. "Water resources must be better managed because the demand on water is increasing in so many places," Sale says. "Water resources can become even more scarce as a result of climate change, population growth, and increases in discharges of contaminants. To increase water resources, we may have to use high-tech water treatment to purify tainted water and desalination to turn salty ocean water into fresh water for drinking and irrigation. We will also have to learn to use the water we have more efficiently."

The Laboratory has had a lot of experience in developing water-treatment techniques and desalination using nuclear energy. In addition, Sale argues, ORNL's experience in dealing with conflicting uses for hydroelectric dams "may allow us a foothold in solving the problems of multiple resource management on large river basins—problems that have traditionally been the concern of agencies like the Corps of Engineers and the Bureau of Reclamation."

"Today many staff members of the Laboratory's Environmental Sciences and Energy divisions have expertise in preparing environmental impact statements and assessments."

Who is working with you on quantifying the costs of environmental mitigation?

Sale: The work that we're doing for DOE is a joint effort between ORNL and Idaho National Engineering Laboratory. The engineers at INEL are handling the cost side of the study, and we're working more on the benefit side. Don Jones in the Energy Division is also contributing to the fish passage report that we're working on right now. He is reviewing the procedures for trying to put a resource value on fish populations, as well as a dollar value. That turns out to be a rather controversial problem because a number of different types of values are associated with maintaining a fish population. It is not just the direct use; there are a lot of nonuse values as well.

Slope instability and winter storms have washed out a road near the site of a proposed small-scale hydroelectric plant in the Mount Baker–Snoqualmie National Forest in Washington. *Photograph by Glenn Cada*

How are environmental impact statements prepared for hydropower projects?

Sale: Usually we do a statement for each individual project, but FERC has moved toward doing basinwide impact assessments. Because many hydroprojects on river basins are fairly small, FERC tends to lump them together and do one big impact statement on basinwide projects instead of on individual projects. In the late 1980s we did one for the Ohio River basin, and more recently, we prepared impact statements for the Skagit basin and the Nooksack basin, both of which are in the state of Washington. Lumping projects together not only is more efficient but also it forces the government to evaluate the cumulative impacts on a river basin of a number of proposed hydroprojects. We need to look at interactions between projects that might result, say, in water quality deterioration or the blockage of salmon migration.

What are the worst problems faced by developers and operators of hydropower facilities?

Sale: Regulatory uncertainty is a big one. The laws have changed so much in the past few years. Developers who want to try new designs for hydroelectric dams must go through multiple reviews by federal and state agencies to get approval. Hydropower developers have a tough time because they must face a nightmare of federal and state regulations.

Regulatory burdens cause another problem: The mounting cost of the time-consuming process from planning to development to operation. The cost is uncertain because the process takes 6 to 10 years and the rules can change half a dozen times in that period. Also, the developer won't learn all the mitigation requirements that must be met until late in the process. It makes it difficult for a developer to figure the amount of money that must be borrowed and the return on the investment.

A third problem is that the environmental community is hot on the trail of the hydropower

The salmon populations are crashing on both the east and west coasts, and everybody is very concerned about it.

Site of a proposed small-scale hydroelectric plant on a high-elevation trout stream in the eastern Sierra Nevada mountains in California. *Photograph by Glenn Cada*

Pipeline that carries water diverted from the Owens River in eastern California to Los Angeles. Because water diversions constructed since the turn of the century have dried up the Owens River, hydropower plants were recently proposed for many of its tributary streams in the Sierra Nevada Mountains.

developers right now. This is a particularly bad time for the developers, and in many cases, for good reason. The salmon populations are crashing on both the east and west coasts, and everybody is very concerned about it. So there is a lot of pressure on hydropower developers from people who see the dams as villains. Some environmental groups are now trying to put certain rivers under federal protection to stop further hydropower development.

Coutant: In some cases, activists are seeking to actually remove dams that either block fish migrations or slow water flow so much that young salmon migrating downstream can't make it. These efforts have so far led to firm plans for removal of one small dam on the Olympic Peninsula and completion of one test draining of a major federal dam on the Snake River in 1992, with another major test draining planned for 1994. The Snake River dam would not be removed, but the water returned would move like a flowing river during the time the young salmon migrate to the sea. The costs of both removal and drainage are very high. The prospect of more actions like these has the hydropower business very edgy.

Does ORNL ever recommend against a proposed hydroelectric dam?

Sale: Absolutely. Some proposed hydropower projects just should not be built because of their location. Some would have unresolvable problems; for example, they would interfere with fish runs or the cultural practices of Native American tribes. In those cases we recommend to FERC that these projects not be developed.

Coutant: What's ironic is that what seems to be a perfect site may turn out not to be right after all.

One example in the Northwest is a site that has no resident fish because it is blocked by a waterfall. In terms of fish, it's perfect for a hydropower project. Unfortunately for the developer, the site is a traditional religious area for a Native American tribe. The tribe will not give up its heritage, so the developer will probably have to abandon the project.

What's the bottom line?

Coutant: In many cases, a small investment up front in research will solve many of these problems and save considerable money in the long run. Economists are needed to study some of these questions. Good research conducted hand-in-hand with hydropower developers and equipment suppliers can lead to standardized power plant designs to protect the environment and streamlined licensing actions to encourage the most appropriate hydropower development. Government investment in this type of research at ORNL and elsewhere would be small compared to the payoff. This argument would be especially true if the research and development projects were truly joint ventures among government laboratories, the hydropower industry, and the regulatory agencies.

Sale: I would say three things are needed to keep hydropower among our country's valued energy sources: research and development, education, and streamlined regulation. Progress in all three areas is not occurring as quickly as we would like, but we are moving in the right direction.

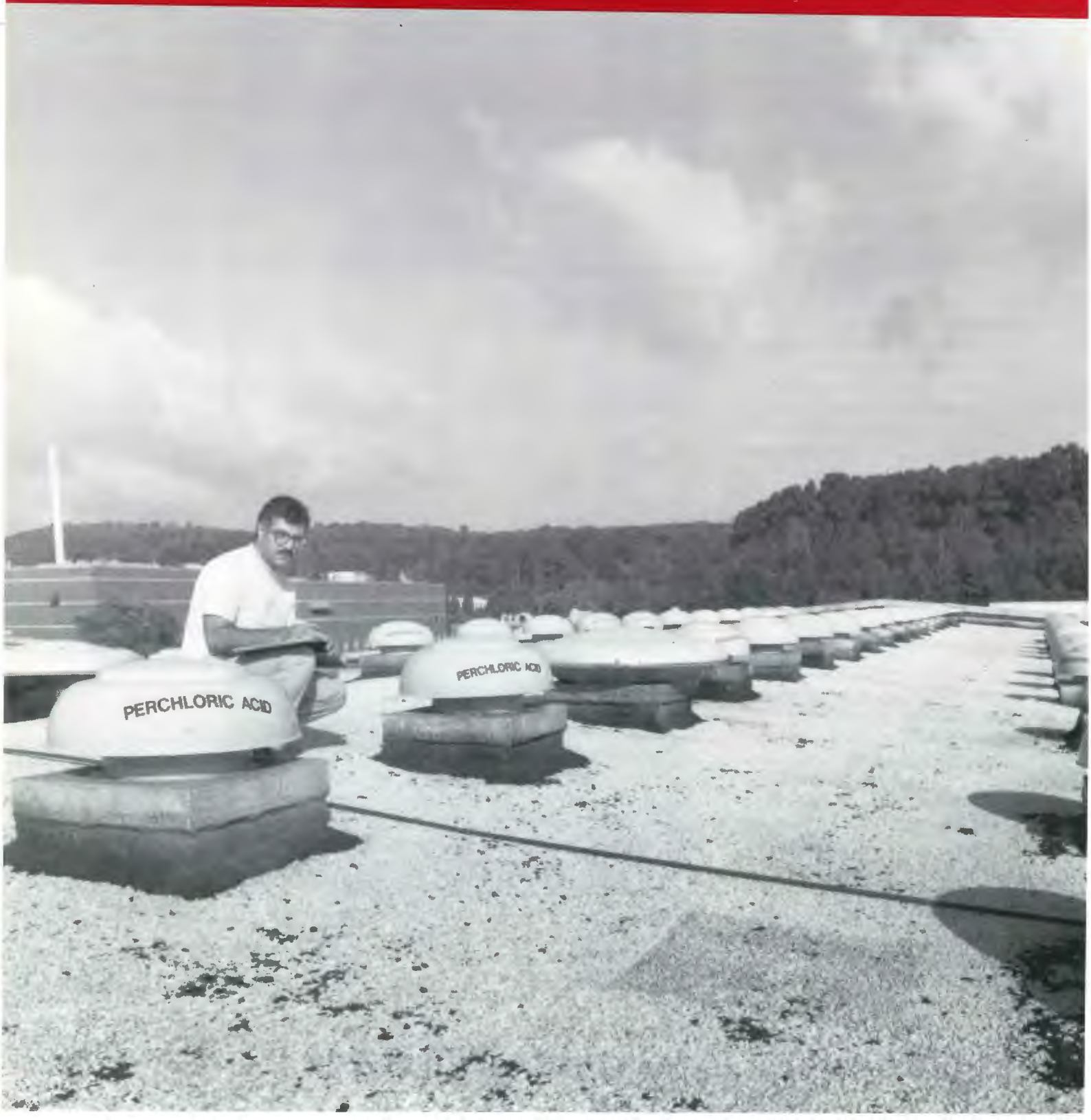
Glenn Cada and Jim Loar, both of ORNL's Environmental Sciences Division, measure the discharge of Bradley Creek in North Carolina as part of a study of trout-habitat and stream-flow relationships in 1983 for the DOE hydropower program. *Photograph by Mike Sale*

Richard B. McLean (right) and Michael J. Sale are the past and present managers, respectively, of ORNL's hydropower-related support to the Federal Energy Regulatory Commission. *Photograph by Bill Norris*

A small investment up front in research will solve many of these problems and save considerable money in the long run.

Discovery for Safety: Getting Acid Off Hoods

By Wayne Scarbrough



In September 1990, industrial hygienists making a routine surveillance of individual laboratories at ORNL discovered a possibly explosive situation that had been building since the earliest days of the Laboratory's existence.

During the walk-through, Ann Shirley first observed the use of perchloric acid hotter than 100°C in a laboratory hood, a protective enclosure that provides ventilation of noxious fumes, dusts, and gases to enable the safe handling of chemical, biological or radioactive materials. The problem was that the hood was not approved for perchloric acid. Shirley had become aware of such a potential problem after discussions with Mark Haskew and other ORNL industrial hygienists. Her quick check confirmed that the acid, in fact, had been used more than once in the hood, which had a ventilation system that was unable to handle the chemical properly.

Shirley reported the problem to Charlie Phillips, an ORNL industrial hygiene group leader. He observed the same problem in a hood that was to be taken out of operation for another reason. He reported the episode to a committee that regarded it as a safety-and-health red flag for all of ORNL. For Phillips and the committee, it raised the question of how many other hoods not rated for perchloric acid had been used for such work at the Laboratory in the past five decades.

Perchloric acid is popular in chemical processing because it offers all the desirable properties of mineral acids without introducing ions such as chloride, nitrate, and sulfate, which often interfere with other chemical reactions. But perchloric acid has a dangerous downside: When it dries, it leaves behind a perchlorate salt that can be flammable and highly explosive when subjected to heat or impact or reaction with other specific chemicals. If hot perchloric acid is used in a vent system that does not have internal wash-down capabilities, the salts will show up over time in the hood, baffles, filters, fans, ducts, and exhaust stacks.

When additional research by ORNL industrial hygiene personnel indicated that, indeed, hot perchloric acid had been used in other unapproved fume hoods during ORNL's 50-year history, Laboratory management acted swiftly. Murray Rosenthal, then ORNL deputy director, placed an immediate moratorium on the use of hot perchloric acid, halted all maintenance on laboratory hoods, and convened a special committee to launch a survey of ORNL's 700-plus fume-hood systems.

The findings? Forty fume-hood vent systems were contaminated with the salts at levels deemed dangerous by the National Fire Protection Association (NFPA). "It doesn't take much of this stuff to be dangerous," says Phillips, who manages ORNL's perchloric acid project. "A single gram of perchlorate salt has been linked to disastrous explosions in vent systems."

No Accidents at ORNL

Although no such accidents have occurred at ORNL, the industrial hygienists were aware that in 1962 a maintenance worker on an Atomic Energy Commission–related project was killed and two others were seriously injured in an explosion touched off by routine use of a small ball peen hammer and 6-inch chisel. The workers were dismantling a perchloric acid fume vent system when the explosion—violent enough to be heard 4 miles away—occurred.

Several other accidents involving perchloric acid are documented in the literature, and rumors circulate about explosions and fires during numerous informal salvage operations around the country, Phillips said.

"With this in mind, we knew we had to act right away to ensure the safety and health of ORNL personnel," said Marwan Bader, an ORNL industrial hygienist and perchloric acid project site manager. The state Environmental Protection Agency, recognizing that quick action

When additional research indicated that hot perchloric acid had been used in other unapproved fume hoods, Laboratory management acted swiftly.

Marwan Bader, an industrial hygienist at ORNL, logs information on ORNL's perchloric acid decontamination project, of which he serves as site manager.

The committee generated a plan to decontaminate the hoods and return them to use.

Perchlorate salt deposits are visible on the inner walls of this duct elbow of a laboratory hood.

was needed, agreed to allow removal of the perchlorates as an emergency response action under the Resource Conservation and Recovery Act (RCRA).

"It was decided that a committee must be put in place quickly to oversee handling of the project and that this committee should represent all aspects of the work at ORNL, including industrial hygienists, chemists, industrial safety experts, health physicists, engineers, fire safety engineers, maintenance personnel, and environmental compliance advisors," Bader explained.

Action Plan

In addition to identifying hoods in which perchloric acid had been used over the years, the committee directed development of sampling and analysis protocols and techniques to analyze the amount of perchlorates present, set a threshold designating serious contamination, and generated a plan to decontaminate the hoods and return them to use.

The threshold for contamination was set conservatively, Bader said, with respect to national standards. "The NFPA code pertaining to perchlorate contamination says that, if a methylene blue test turns to violet, that's positive for the presence of perchlorates," he explained.

"We found that this color change occurs at a level of about 750 parts per million (ppm). We went a step further and set our own standard at 500 parts per million," he said. A methylene blue test is similar in principle to a litmus test. A few drops of the test solution in a small quantity of water washed from the area to be tested will produce a violet precipitate if perchlorates are present.

The committee picked 3 of the 40 contaminated hoods for a pilot decontamination study, and a temporary enclosure was built in which the hood baffles, fans, ducts and other parts were to be cleaned. The main superstructures of hoods were cleaned in place in the laboratory. The enclosure included four 96-cubic-foot tanks and facilities for decontaminating parts on which any radiological material was found.

Before any testing or hood dismantling began, health physics surveys and industrial hygiene evaluations were performed, workers were trained in all areas necessary, including RCRA, and any protective clothing or gear was issued. Maintenance workers who actually took apart the vent systems donned ballistic gear similar to that used by police bomb squads.

Keep Them Wet

The key to dismantling the hood systems, Phillips says, is to keep everything wet. "Perchlorates aren't a problem as long as they are kept wet," he said. "It's the anhydrous form that poses a potential for instantaneous fire or explosion." Team members wet the hoods and

other vent system components simply by spraying them with water, then peered through fiber-optic scopes into confined areas, such as behind hood baffles, to ensure that even the hard-to-reach spots were wetted down.

Once dismantled and while still thoroughly wetted, the hood baffles, fans, exhaust stacks, and sections of duct were wrapped in plastic and carefully transported to the temporary enclosure for thorough decontamination.

The highest concentration of perchlorates found ranged from 140,000 ppm at an elbow in a duct to 800,000 ppm on the inlet side of a filter housing. "Those are very high concentrations," Bader said, "considering the small amount of perchlorates necessary to trigger a powerful explosion under the right circumstances."

But that's not the number of greatest concern that came out of the pilot project: Workers removed nearly three *pounds* of perchlorate salts from a *single* hood vent system. The perchlorate buildup gave inner walls of the duct the soft, chilly appearance of a freezer in need of defrosting.

"It's likely that many other federal labs, university labs and industrial facilities throughout the country have these same legacy buildups of perchlorate contamination in their systems and just aren't aware of it," Phillips said, "or aren't fully aware of the potential safety and health risks involved."

In fact, since the presentation of the ORNL problem and solution at April 1992 meeting of the American Chemical Society, the details of the copyrighted procedures for the ORNL-developed decontamination methods have been in great demand by universities and industry. ORNL presentations at the American Glove Box Society conference in Seattle in August have further piqued the interest of those who suspect they may have similar problems. An ORNL talk given at the October DOE Safety Conference in Chicago generated still more interest.

"The pilot study was fantastic, very well accomplished," Bader said. "The techniques developed for the three test hood systems proved completely effective." Furthermore, the ORNL methods cost one-fifth the amount of outside contract estimates to decontaminate and dismantle a typical hood.

A welcome surprise, Phillips said, was that the procedure deregulated low-level radioactive contamination in several of the treated vent systems. "This alone will save approximately $12,000 per hood each year because those hoods no longer require 'contamination area' posting and the related expenses," he said.

Not only were the protocols effective, efficient, and practical, they were convincing. So much so that the NFPA modified their testing methods for perchlorate salts based on an ORNL proposal to the organization.

A full-blown effort is now under way at ORNL to remedy the remaining 37 contaminated hood vent systems. One cleanup operation is up and going, and funding proposals are out for more startups.

Phillips is pleased. "We had to abate a possibly substantial fire and safety hazard, and we did it well. We did it within environmental safety, Occupational Safety and Health Administration, and radiological controls," he said. "Most importantly, the safety and health of ORNL workers is being significantly protected."

Wayne Scarbrough is a member of the Martin Marietta Energy Systems Public Affairs staff based at ORNL. A version of this article was published in the Winter 1994 issue of Safety Connection.

"It's likely that many other facilities throughout the country have these same legacy buildups of perchlorate contamination in their systems and just aren't aware of it."

Coal Combustion: Nuclear Resource or Danger?

By Alex Gabbard

Over the past few decades, the American public has become increasingly wary of nuclear power because of concern about radiation releases from normal plant operations, plant accidents, and nuclear waste. Except for Chernobyl and other nuclear accidents, releases have been found to be almost undetectable in comparison with natural background radiation. Another concern has been the cost of producing electricity at nuclear plants. It has increased largely for two reasons: compliance with stringent government regulations that restrict releases of radioactive substances from nuclear facilities into the environment and construction delays as a result of public opposition.

Partly because of these concerns about radioactivity and the cost of containing it, the American public and electric utilities have preferred coal combustion as a power source. Today 52% of the capacity for generating electricity in the United States is fueled by coal, compared with 14.8% for nuclear energy. Although there are economic justifications for this preference, it is surprising for two reasons. First, coal combustion produces carbon dioxide and other greenhouse-gases that are suspected to cause climatic warming, and it is a source of sulfur oxides and nitrogen oxides, which are harmful to human health and may be largely responsible for acid rain. Second, although not as well known, releases from coal combustion contain naturally occurring radioactive materials—mainly, uranium and thorium.

Former ORNL researchers J. P. McBride, R. E. Moore, J. P. Witherspoon, and R. E. Blanco made this point in their article "Radiological Impact of Airborne Effluents of Coal and Nuclear Plants" in the December 8, 1978, issue of *Science* magazine. They concluded that Americans living near coal-fired power plants are exposed to higher radiation doses than those living near nuclear power plants that meet government regulations. This ironic situation remains true today and is addressed in this article.

The fact that coal-fired power plants throughout the world are the major sources of radioactive materials released to the environment has several implications. It suggests that coal combustion is more hazardous to health than nuclear power and that it adds to the background radiation burden even more than does nuclear power. It also suggests that if radiation emissions from coal plants were regulated, their capital and operating costs would increase, making coal-fired power less economically competitive.

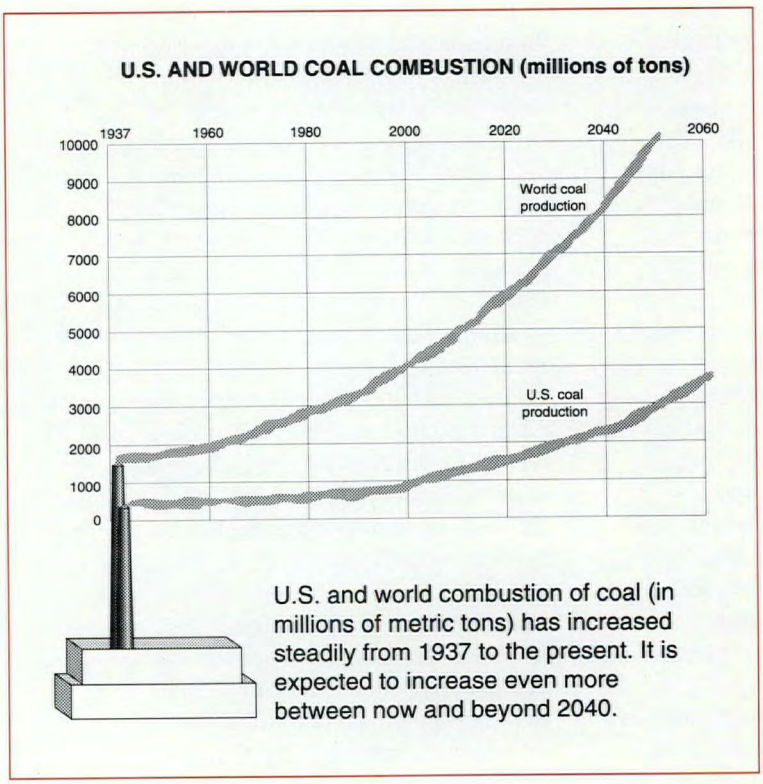
Finally, radioactive elements released in coal ash and exhaust produced by coal combustion contain fissionable fuels and much larger quantities of fertile materials that can be bred into fuels by absorption of neutrons, including those generated in the air by bombardment of oxygen, nitrogen, and other nuclei with cosmic rays; such fissionable and fertile materials can be recovered from coal ash using known technologies. These nuclear materials have growing value to private concerns and governments that may want to market them for fueling nuclear power plants. However, they are also available to those interested in accumulating material for nuclear weapons. A solution to this potential problem may be to encourage electric utilities to process coal ash and use new trapping technologies on coal combustion exhaust to isolate and collect valuable metals, such as iron and aluminum, and available nuclear fuels.

Americans living near coal-fired power plants are exposed to higher radiation doses than those living near nuclear power plants that meet government regulations.

Makeup of Coal and Ash

Coal is one of the most impure of fuels. Its impurities range from trace quantities of many metals, including uranium and thorium, to much larger quantities of aluminum and iron to still larger quantities of impurities such as sulfur. Products of coal combustion include the oxides of carbon, nitrogen, and sulfur; carcinogenic and

Alex Gabbard at the coal pile for ORNL's steam plant.



U.S. and world combustion of coal (in millions of metric tons) has increased steadily from 1937 to the present. It is expected to increase even more between now and beyond 2040.

The amount of thorium contained in coal is about 2.5 times greater than the amount of uranium.

mutagenic substances; and recoverable minerals of commercial value, including nuclear fuels naturally occurring in coal.

Coal ash is composed primarily of oxides of silicon, aluminum, iron, calcium, magnesium, titanium, sodium, potassium, arsenic, mercury, and sulfur plus small quantities of uranium and thorium. Fly ash is primarily composed of non-combustible silicon compounds (glass) melted during combustion. Tiny glass spheres form the bulk of the fly ash.

Since the 1960s particulate precipitators have been used by U.S. coal-fired power plants to retain significant amounts of fly ash rather than letting it escape to the atmosphere. When functioning properly, these precipitators are approximately 99.5% efficient. Utilities also collect furnace ash, cinders, and slag, which are kept in cinder piles or deposited in ash ponds on coal-plant sites along with the captured fly ash.

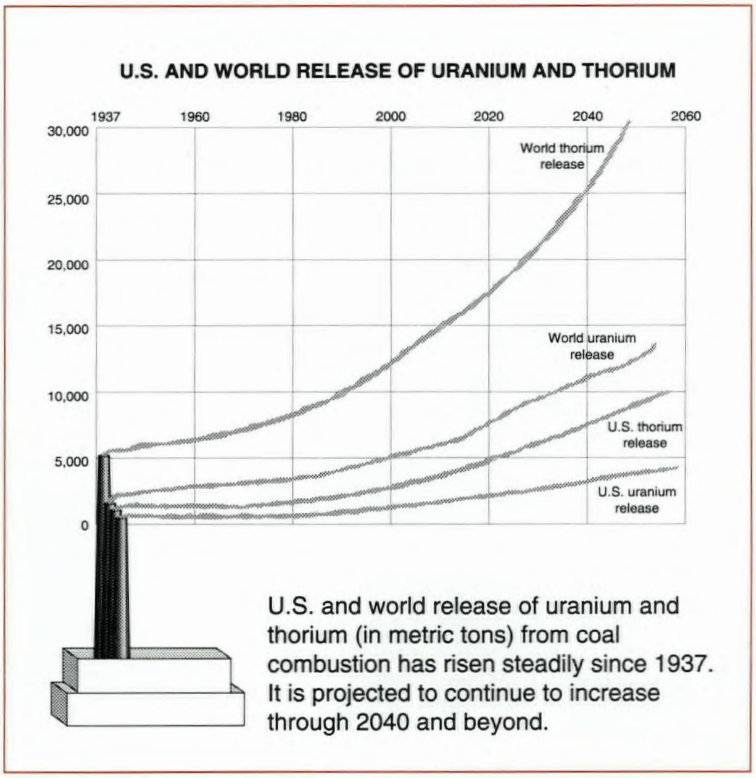
Trace quantities of uranium in coal range from less than 1 part per million (ppm) in some samples to around 10 ppm in others. Generally, the amount of thorium contained in coal is about 2.5 times greater than the amount of uranium. For a large number of coal samples, according to Environmental Protection Agency figures released in 1984, average values of uranium and thorium content have been determined to be 1.3 ppm and 3.2 ppm, respectively. Using these values along with reported consumption and projected consumption of coal by utilities provides a means of calculating the amounts of potentially recoverable breedable and fissionable elements (see sidebar). The concentration of fissionable uranium-235 (the current fuel for nuclear power plants) has been established to be 0.71% of uranium content.

Uranium and Thorium in Coal and Coal Ash

As population increases worldwide, coal combustion continues to be the dominant fuel source for electricity. Fossil fuels' share has decreased from 76.5% in 1970 to 66.3% in 1990, while nuclear energy's share in the worldwide electricity pie has climbed from 1.6% in 1970 to 17.4% in 1990. Although U.S. population growth is slower than worldwide growth, per capita consumption of energy in this country is among the world's highest. To meet the growing demand for electricity, the U.S. utility industry has continually expanded generating capacity. Thirty years ago, nuclear power appeared to be a viable replacement for fossil power, but today it represents less than 15% of U.S. generating capacity. However, as a result of low public support during recent decades and a reduction in the rate of expected power demand, no increase in

nuclear power generation is expected in the foreseeable future. As current nuclear power plants age, many plants may be retired during the first quarter of the 21st century, although some may have their operation extended through license renewal. As a result, many nuclear plants are likely to be replaced with coal-fired plants unless it is considered feasible to replace them with fuel sources such as natural gas and solar energy.

As the world's population increases, the demands for all resources, particularly fuel for electricity, is expected to increase. To meet the demand for electric power, the world population is expected to rely increasingly on combustion of fossil fuels, primarily coal. The world has about 1500 years of known coal resources at the current use rate. The graph on p. 26 shows the growth in U.S. and world coal combustion for the 50 years preceding 1988, along with projections beyond the year 2040. Using the concentration of uranium and thorium indicated on p. 26, the graph on this page illustrates the historical release quantities of these elements and the releases that can be expected during the first half of the next century, given the predicted growth trends. Using these data, both U.S. and worldwide fissionable uranium-235 and fertile nuclear material releases from coal combustion can be calculated.



U.S. and world release of uranium and thorium (in metric tons) from coal combustion has risen steadily since 1937. It is projected to continue to increase through 2040 and beyond.

Because existing coal-fired power plants vary in size and electrical output, to calculate the annual coal consumption of these facilities, assume that the typical plant has an electrical output of 1000 megawatts. Existing coal-fired plants of this capacity annually burn about 4 million tons of coal each year. Further, considering that in 1982 about 616 million short tons (2000 pounds per ton) of coal was burned in the United States (from 833 million short tons mined, or 74%), the number of typical coal-fired plants necessary to consume this quantity of coal is 154.

Using these data, the releases of radioactive materials per typical plant can be calculated for any year. For the year 1982, assuming coal contains uranium and thorium concentrations of 1.3 ppm and 3.2 ppm, respectively, each typical plant released 5.2 tons of uranium (containing 74 pounds of uranium-235) and 12.8 tons of thorium that year. Total U.S. releases in 1982 (from 154 typical plants) amounted to 801 tons of uranium (containing 11,371 pounds of uranium-235) and 1971 tons of thorium. These figures account for only 74% of releases from combustion of coal from all sources. Releases in 1982 from worldwide combustion of 2800 million tons of coal totaled 3640 tons of uranium (containing 51,700 pounds of uranium-235) and 8960 tons of thorium.

Based on the predicted combustion of 2516 million tons of coal in the United States and

12,580 million tons worldwide during the year 2040, cumulative releases for the 100 years of coal combustion following 1937 are predicted to be:

U.S. release (from combustion of 111,716 million tons):

Uranium: 145,230 tons (containing 1031 tons of uranium-235)

Thorium: 357,491 tons

Worldwide release (from combustion of 637,409 million tons):

Uranium: 828,632 tons (containing 5883 tons of uranium-235)

Thorium: 2,039,709 tons

The population effective dose equivalent from coal plants is 100 times that from nuclear plants.

Radioactivity from Coal Combustion

The main sources of radiation released from coal combustion include not only uranium and thorium but also daughter products produced by the decay of these isotopes, such as radium, radon, polonium, bismuth, and lead. Although not a decay product, naturally occurring radioactive potassium-40 is also a significant contributor.

According to the National Council on Radiation Protection and Measurements (NCRP), the average radioactivity per short ton of coal is 17,100 millicuries/4,000,000 tons, or 0.00427 millicuries/ton. This figure can be used to calculate the average expected radioactivity release from coal combustion. For 1982 the total release of radioactivity from 154 typical coal plants in the United States was, therefore, 2,630,230 millicuries.

Thus, by combining U.S. coal combustion from 1937 (440 million tons) through 1987 (661 million tons) with an estimated total in the year 2040 (2516 million tons), the total expected U.S. radioactivity release to the environment by 2040 can be determined. That total comes from the expected combustion of 111,716 million tons of coal with the release of 477,027,320 millicuries in the United States. Global releases of radioactivity from the predicted combustion of 637,409 million tons of coal would be 2,721,736,430 millicuries.

For comparison, according to NCRP Reports No. 92 and No. 95, population exposure from operation of 1000-MWe nuclear and coal-fired power plants amounts to 490 person-rem/year for coal plants and 4.8 person-rem/year for nuclear plants. Thus, the population effective dose equivalent from coal plants is 100 times that from nuclear plants. For the complete nuclear fuel cycle, from mining to reactor operation to waste disposal, the radiation dose is cited as 136 person-rem/year; the equivalent dose for coal use, from mining to power plant operation to waste disposal, is not listed in this report and is probably unknown.

During combustion, the volume of coal is reduced by over 85%, which increases the concentration of the metals originally in the coal. Although significant quantities of ash are retained by precipitators, heavy metals such as uranium tend to concentrate on the tiny glass spheres that make up the bulk of fly ash. This uranium is released to the atmosphere with the escaping fly ash, at about 1.0% of the original amount, according to NCRP data. The retained ash is enriched in uranium several times over the original uranium concentration in the coal because the uranium, and thorium, content is not decreased as the volume of coal is reduced.

All studies of potential health hazards associated with the release of radioactive elements from coal combustion conclude that the perturbation of natural background dose levels is almost negligible. However, because the half-lives of radioactive potassium-40, uranium, and thorium are practically infinite in terms of human lifetimes, the accumulation of these species in the biosphere is directly proportional to the length of time that a quantity of coal is burned.

Although trace quantities of radioactive heavy metals are not nearly as likely to produce adverse health effects as the vast array of chemical by-products from coal combustion, the accumulated quantities of these isotopes over 150 or 250 years could pose a significant future ecological burden

and potentially produce adverse health effects, especially if they are locally accumulated. Because coal is predicted to be the primary energy source for electric power production in the foreseeable future, the potential impact of long-term accumulation of by-products in the biosphere should be considered.

Energy Content: Coal vs Nuclear

An average value for the thermal energy of coal is approximately 6150 kilowatt-hours(kWh)/ton. Thus, the expected cumulative thermal energy release from U.S. coal combustion over this period totals about 6.87×10^{14} kilowatt-hours. The thermal energy released in nuclear fission produces about 2×10^{9} kWh/ton. Consequently, the thermal energy from fission of uranium-235 released in coal combustion amounts to 2.1×10^{12} kWh. If uranium-238 is bred to plutonium-239, using these data, the thermal energy from fission of this isotope alone constitutes about 2.9×10^{14}

Views of the Tennessee Valley Authority's Bull Run and Kingston steam plants. These facilities burn coal to produce steam for generating electricity for Oak Ridge and the surrounding area. *Photographs by Alex Gabbard*

Ash pond at Bull Run Steam Plant. Ash produced by coal combustion contains radioactive elements, including fissionable fuels such as uranium and plutonium.

kWh, or about half the anticipated energy of all the utility coal burned in this country through the year 2040. If the thorium-232 is bred to uranium-233 and fissioned, the thermal energy capacity of this isotope is approximately 7.2×10^{14} kWh, or 105% of the thermal energy released from U.S. coal combustion for a century. The total of the thermal energy capacities from each of these three fissionable isotopes is about 10.1×10^{14} kWh, 1.5 times more than the total from coal. World combustion of coal has the same ratio, similarly indicating that coal combustion wastes more energy than it produces.

The energy content of nuclear fuel released in coal combustion is greater than that of the coal consumed.

Consequently, the energy content of nuclear fuel released in coal combustion is more than that of the coal consumed! Clearly, coal-fired power plants are not only generating electricity but are also releasing nuclear fuels whose commercial value for electricity production by nuclear power plants is over $7 trillion, more than the U.S. national debt. This figure is based on current nuclear utility fuel costs of 7 mils per kWh, which is about half the cost for coal. Consequently, significant quantities of nuclear materials are being treated as coal waste, which might become the cleanup nightmare of the future, and their value is hardly recognized at all.

How does the amount of nuclear material released by coal combustion compare to the amount consumed as fuel by the U.S. nuclear power industry? According to 1982 figures, 111 American nuclear plants consumed about 540 tons of nuclear fuel, generating almost 1.1×10^{12} kWh of electricity. During the same year, about 801 tons of uranium alone were released from American coal-fired plants. Add 1971 tons of thorium, and the release of nuclear components from coal combustion far exceeds the entire U.S. consumption of nuclear fuels. The same conclusion applies for worldwide nuclear fuel and coal combustion.

Another unrecognized problem is the gradual production of plutonium-239 through the exposure of uranium-238 in coal waste to neutrons from the air. These neutrons are produced primarily by bombardment of oxygen and nitrogen nuclei in the atmosphere by cosmic rays and from spontaneous fission of natural isotopes in soil. Because plutonium-239 is reportedly toxic in minute quantities, this process, however slow, is potentially worrisome.

The radiotoxicity of plutonium-239 is 3.4×10^{11} times that of uranium-238. Consequently, for 801 tons of uranium released in 1982, only 2.2 milligrams of plutonium-239 bred by natural processes, if those processes exist, is necessary to double the radiotoxicity estimated to be released into the biosphere that year. Only 0.075 times that amount in plutonium-240 doubles the radiotoxicity. Natural processes to produce both plutonium-239 and plutonium-240 appear to exist.

Conclusions

For the 100 years following 1937, U.S. and world use of coal as a heat source for electric power generation will result in the distribution of a variety of radioactive elements into the environment. This prospect raises several questions about the risks and benefits of coal combustion, the leading source of electricity production.

First, the potential health effects of released naturally occurring radioactive elements are a long-term issue that has not been fully addressed. Even with improved efficiency in retaining stack emissions, the removal of coal from its shielding overburden in the earth and subsequent combustion releases large quantities of radioactive materials to the surface of the earth. The emissions by coal-fired power plants of greenhouse gases, a vast array of chemical by-products, and naturally occurring radioactive elements make coal much less desirable as an energy source than is generally accepted.

Second, coal ash is rich in minerals, including large quantities of aluminum and iron. These and other products of commercial value have not been exploited.

Third, large quantities of uranium and thorium and other radioactive species in coal ash are not being treated as radioactive waste. These products emit low-level radiation, but because of regulatory differences, coal-fired power plants are allowed to release quantities of radioactive material that would provoke enormous public outcry if such amounts were released from nuclear facilities. Nuclear waste products from coal combustion are allowed to be

dispersed throughout the biosphere in an unregulated manner. Collected nuclear wastes that accumulate on electric utility sites are not protected from weathering, thus exposing people to increasing quantities of radioactive isotopes through air and water movement and the food chain.

Fourth, by collecting the uranium residue from coal combustion, significant quantities of fissionable material can be accumulated.

In a few year's time, the recovery of the uranium-235 released by coal combustion from a typical utility anywhere in the world could provide the equivalent of several World War II–type uranium-fueled weapons. Consequently, fissionable nuclear fuel is available to any country that either buys coal from outside sources or has its own reserves. The material is potentially employable as weapon fuel by any organization so inclined. Although technically complex, purification and enrichment technologies can provide high-purity, weapons-grade uranium-235. Fortunately, even though the technology is well known, the enrichment of uranium is an expensive and time-consuming process.

Because electric utilities are not high-profile facilities, collection and processing of coal ash for recovery of minerals, including uranium for weapons or reactor fuel, can proceed without attracting outside attention, concern, or intervention. Any country with coal-fired plants could collect combustion by-products and amass sufficient nuclear weapons material to build up a very powerful arsenal, if it has or develops the technology to do so.

Of far greater potential are the much larger quantities of thorium-232 and uranium-238 from coal combustion that can be used to breed fissionable isotopes. Chemical separation and purification of uranium-233 from thorium and plutonium-239 from uranium require far less effort than enrichment of isotopes. Only small fractions of these fertile elements in coal combustion residue are needed for clandestine breeding of fissionable fuels and weapons material by those nations that have nuclear reactor technology and the inclination to carry out this difficult task.

Fifth, the fact that large quantities of uranium and thorium are released from coal-fired plants without restriction raises a paradoxical question. Considering that the U.S. nuclear power industry has been required to invest in expensive measures to greatly reduce releases of radioactivity from nuclear fuel and fission products to the environment, should coal-fired power plants be allowed to do so without constraints?

This question has significant economic repercussions. Today nuclear power plants are not as economical to construct as coal-fired plants, largely because of the high cost of complying with regulations to restrict emissions of radioactivity. If coal-fired power plants were regulated in a similar manner, the added cost of handling nuclear waste from coal combustion would be significant and would, perhaps, make it difficult for coal-burning plants to compete economically with nuclear power.

Because of increasing public concern about nuclear power and radioactivity in the environment, reduction of releases of nuclear materials from all sources has become a national priority known as "as low as reasonably achievable" (ALARA). If increased regulation of nuclear power plants is demanded, can we expect a significant redirection of national policy so that radioactive emissions from coal combustion are also regulated?

If increased regulation of nuclear power plants is demanded, then we can expect a significant redirection of national policy in regulation of radioactive emissions from coal combustion.

Although adverse health effects from increased natural background radioactivity may seem unlikely for the near term, long-term accumulation of radioactive materials from continued worldwide combustion of coal could pose serious health hazards. Because coal combustion is projected to increase throughout the world during the next century, the increasing accumulation of coal combustion by-products, including radioactive components, should be discussed in the formulation of energy policy and plans for future energy use.

One potential solution is improved technology for trapping the exhaust (gaseous emissions up the stack) from coal combustion. If and when such technology is developed, electric utilities may then be able both to recover useful elements, such as nuclear fuels, iron, and aluminum, and to trap

greenhouse gas emissions. Encouraging utilities to enter mineral markets that have been previously unavailable may or may not be desirable, but doing so appears to have the potential of expanding their economic base, thus offsetting some portion of their operating costs, which ultimately could reduce consumer costs for electricity.

Both the benefits and hazards of coal combustion are more far-reaching than are generally recognized. Technologies exist to remove, store, and generate energy from the radioactive isotopes released to the environment by coal combustion. When considering the nuclear consequences of coal combustion, policymakers should look at the data and recognize that the amount of uranium-235 alone dispersed by coal combustion is the equivalent of dozens of nuclear reactor fuel loadings. They should also recognize that the nuclear fuel potential of the fertile isotopes of thorium-232 and uranium-238, which can be converted in reactors to fissionable elements by breeding, yields a virtually unlimited source of nuclear energy that is frequently overlooked as a natural resource.

In short, naturally occurring radioactive species released by coal combustion are accumulating in the environment along with minerals such as mercury, arsenic, silicon, calcium, chlorine, and lead, sodium, as well as metals such as aluminum, iron, lead, magnesium, titanium, boron, chromium, and others that are continually dispersed in millions of tons of coal combustion by-products. The potential benefits and threats of these released materials will someday be of such significance that they should not now be ignored.

The amount of uranium-235 alone dispersed by coal combustion is the equivalent of dozens of nuclear reactor fuel loadings.

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Nuclear Materials for Fuels

As coal is burned, thorium-232 (^{232}Th) and uranium-238 (^{238}U) are released as exhaust products in coal ash. What could be done with these isotopes if they were recovered? At least one scenario is readily apparent.

Because atoms of ^{232}Th and ^{238}U do not split, or "fission," when bombarded with slow (thermal) neutrons, they are referred to as "fertile," rather than fissionable, materials—materials that can be used to "breed" nuclear fuel by the addition of a neutron to each atomic nucleus. For example, when the nucleus of a thorium atom absorbs a neutron, it becomes ^{233}Th, which decays in relatively short order to ^{233}U, a nuclear fission fuel. Similarly, plutonium-239 (^{239}Pu), an efficient fuel for both reactors and nuclear weapons, can be bred by the capture of neutrons from fissioning Uranium-235 (^{235}U) in a blanket of ^{238}U.

A potential source of the neutrons required to breed nuclear fuels from these isotopes is the fission of ^{235}U—the reaction that powers nuclear power plants. The fission of each ^{235}U nucleus releases 2 or 3 neutrons that either produce more fissions, breed new fuel through capture in fertile materials, or decay into a proton, an electron, and an anti-neutrino. In a "breeder" reactor environment ^{238}U or ^{232}Th can capture enough of these neutrons to breed more fissionable material than is consumed during fission of the original ^{235}U fuel in the reactor.

Typical nuclear power plants rely on the heat produced from the splitting of ^{235}U and heat from its "daughters," radioactive elements formed in the process. This heat converts the water circulating through the reactor to steam, which drives turbines for generating electricity. The same process could be fueled by the fission of ^{233}U or ^{239}Pu, isotopes that could be bred from the discarded leftovers of coal combustion.

Biographical Sketch

W. Alex Gabbard is leader of the High Temperature Fuel Behavior Group in the Nuclear Fuel Materials Section of ORNL's Metals and Ceramics Division. He is a principal investigator for the Laboratory's Nuclear Energy Program. He served in the U.S. Navy during the war in Vietnam and earned an M.S. degree in physics from North Carolina State University. He came to ORNL in 1980 to work in the Fusion Energy Division, where he held leadership positions in support of two experimental fusion devices, the Impurity Study Experiment and the Advanced Toroidal Facility. When he transferred to the Metals and Ceramics Division in 1990, Gabbard became a group leader in charge of design and development of the Core Conduction Cooldown Test Facility for testing ceramic-coated nuclear fuel under simulated accident conditions. In addition to his technical publications, Gabbard has published seven books and a number of magazine articles. He has written both fiction and nonfiction, covering subjects ranging from Southern humor to world-class automobiles.

At least 73 elements found in coal-fired plant emissions are distributed in millions of pounds of stack emissions each year. They include:

Aluminum	Chromium	Molybdenum
Antimony	Cobalt	Nickel
Arsenic	Copper	Selenium
Barium	Fluorine	Silver
Beryllium	Iron	Sulfur
Boron	Lead	Titanium
Cadmium	Magnesium	Uranium
Calcium	Manganese	Vanadium
Chlorine	Mercury	Zinc

The Future of Nuclear Research Centers

By Alvin W. Trivelpiece

Editor's Note—The following is an edited version of the speech delivered in Russia by ORNL Director Alvin W. Trivelpiece during the celebration of the 50th anniversary of the Kurchatov Institute, a nuclear research laboratory in Moscow.

It's a great pleasure to be back in Russia and a great privilege to join in the observation of the 50th anniversary of the Kurchatov Institute with so many distinguished colleagues from around the world. Certainly, the world was a very different place 50 years ago—perhaps no place more so than Russia. Our predecessors in the mid-1940s could scarcely have imagined the events that would precipitate today's gathering of Russians and Germans, Americans and Japanese, Hungarians and Indians, British and Polish, French and Chinese. Even five years ago this agenda in this forum might well have seemed another half-century out of reach.

Anniversaries offer convenient vantage points for reflecting on the past and taking measure of the future, regardless of whether their timing is particularly significant. But it so happens that this anniversary, which many of us in this room share, really does represent a watershed—a time of transition from one great era to another.

The Kurchatov Institute, the Oak Ridge National Laboratory, and so many sister enterprises sprang from one single objective: creation of an atomic bomb. And the success of this endeavor changed forever the way science is conducted. No longer would the great majority of scientists be working in semi-isolation in this university laboratory or that industrial setting.The urgent and complex demands of the atomic weapons race required a new model, a new approach to science. In the United States and Europe, the solution was large government research centers where scientists, engineers, mathematicians, and others could collaborate on their nations' highest defense priority. And in a phenomenon somewhat like assembling enough uranium to reach a "critical mass," the synergy of these people working toward a single goal produced results faster and better than could have been possible under the old system.

Over the past five decades, these research centers have expanded on their success by going beyond their original mandates to address the great scientific challenges of our times. Virtually all of the diverse, peacetime activity in laboratories such as this one and ORNL can be traced to that original, wartime mission.

Technologies Born of War

I thought at this turning point it might be instructive to take a look at those fields of science and technology that have blossomed out of our World War II–era research. I've selected seven examples. Although they reflect the ORNL experience, they are, to a remarkable degree, universal.

The first, and most obvious, example is nuclear power—one of the first postwar applications of the Manhattan Project in the United States. It is a little-known fact, but the world's first electricity from nuclear fission was produced at ORNL. The first *officially* recorded generation of nuclear power took place in 1951 at a large government reactor in Arco, Idaho. But three years earlier, in 1948, engineers and operators in Oak Ridge had hitched ORNL's Graphite Reactor to a toy steam generator and lit a flashlight bulb with 1/3 watt of electricity. For the two decades following the war, there was tremendous activity and excitement in the field of nuclear power as many different reactor designs were developed and piloted at ORNL and other laboratories.

The result is that 23% of the world's electricity needs today are met with nuclear power. In the United States, nuclear power is in a holding pattern, pending solutions to technical challenges and economic and social impediments. But other nations continue to build nuclear plants, and at some point it is likely that a new generation of nuclear plants will emerge in the United States as well. To prepare for that likelihood, the U.S. nuclear industry is developing new standard plant designs—designs that emphasize modularity and

The challenge for nuclear power is to develop solutions to the twin problems of accident potential and waste disposal.

ORNL Director Alvin Trivelpiece addresses an audience at the Kurchatov Institute in Moscow, Russia, during a celebration of its 50th anniversary. Looking on is Boris Saltykor, minister of science and technology at the Kurchatov Institute.

In the field of biology, our wartime work led to standards for radiation exposure that are still observed worldwide.

passive safety. The first of these designs should be available for commercial order by the mid-1990s.

A number of energy analysts have tried to project a fuel mix that will serve the world's needs in the middle of the next century, given the prospect of population growth and global warming. Our own analysts at ORNL conclude that reducing carbon dioxide emissions over the next 30 to 50 years can be accomplished only if three conditions are met: higher energy efficiency, a substantial growth in the use of renewable energy, and an expanded role for nuclear power.

The challenge for nuclear power is to develop solutions to the twin problems of accident potential and waste disposal—solutions that are both technologically *and* socially acceptable.

Another obvious outgrowth of the Manhattan Project was the production of radioisotopes, which quickly became big business for the United States and is now even bigger business for Russia. The world's first grams of plutonium-239 were produced in ORNL's Graphite Reactor in 1943. Three years later, we made our first shipment of radioisotopes for private use: a sample of carbon-14, which went to a cancer hospital. For two decades, ORNL's Graphite Reactor was the western world's foremost supplier of isotopes, which have been used for medicine, industry, agriculture, and research. In the United States radioisotopes are used in 36,000 medical procedures conducted each day and 50,000 treatment programs and almost 100 million laboratory tests conducted each year. These figures underscore the truth in an often-repeated quote from Alvin Weinberg, former ORNL director: "If at some time a heavenly angel should ask what the laboratory in the hills of East Tennessee did to enlarge man's life and make it better, I daresay the production of radioisotopes for scientific research and medical treatment will surely rate as a candidate for the very first place."

A third example, and a particularly strong one for ORNL, is materials science. Even in the 1940s, we were exploring the causes and effects of radiation damage in reactor materials—and designing higher-performance alloys that could withstand neutron bombardment and resist embrittlement. Work on various reactor designs over the years also led to heat-resistant ceramic fuels. These, in turn, have now led to toughened structural ceramics for such things as advanced diesel engines and gas turbines. Advanced materials designed at ORNL have been selected for use in jet engines and in turbocharger rotors for truck diesels that are built to go 1 million miles. Nuclear science–based research also spawned such revolutionary materials developments as ion-beam processing for complex semiconductors and ion implantation for hard, corrosion-resistant surfaces. And close on the horizon are a vast array of new products and processes made possible through advanced materials, among them new semiconductor technologies, optical ceramics for communication networks and optical computers, fusion materials, and polymers with tremendous surface hardness and new electromagnetic properties.

In the field of biology, our wartime work focused on the effects of radiation on people and animals. This work led to standards for radiation exposure that are still observed worldwide. From these beginnings evolved a biology program that has produced diverse and far-reaching results: discovery of the role of the Y chromosome in determining gender in mammals, discovery of the function of messenger RNA, the first successful bone marrow transplant, and development of techniques for freezing animal and human embryos for later implantation.

Today, our biology research has two strong focuses: First, understanding the mechanisms of genetic damage, using research tools such as transgenic mice to induce changes that can help us pinpoint key developmental genes in humans. Second, exploring and reengineering the fundamental workings of the cellular proteins that regulate the intricate biochemistry of life.

Promising applications for the future include biotechnology for energy production and waste treatment, protein engineering for boosting crop yields, development of monoclonal antibodies for cancer treatment, and the mapping of human

genes so we can understand—and begin to cure—genetic diseases and disorders.

One inescapable result of our wartime work is, frankly, an environmental mess of our own making, at our own facilities. But even as contaminated wastes were first being produced, our predecessors began working on technologies to monitor and store them. Over the years we've developed a number of innovative ways of addressing these problems. These include radwaste isolation techniques, waste-shipment standards, and the use of genetically engineered organisms that consume waste or emit light to show researchers when, where, and at what rate waste is being consumed.

Over the past 50 years, we've expanded our focus to include broader environmental issues, such as nutrient cycling through various ecosystems, the acid-rain cycle, and the effects of different types of power plants. In the future, we expect to focus on two major challenges: improving ways to dispose of nuclear and hazardous wastes and increasing our understanding of such complex environmental phenomena as ozone depletion and global climate change.

High-performance computing is another clear case of a technology that grew out of weapons research. It was developed and employed specifically for modeling bombs. Since then, it has been applied to a wide range of mathematically complex challenges, including designing aerodynamic spacecraft, modeling the microstructure of superconductors, and—apparently hardest of all, judging by current practice—forecasting the weather . . . *accurately*. In the United States, the science community has identified several specific "Grand Challenges" for itself, all of which require tremendous computing power. Among these high-priority areas of research are mapping the human genome, modeling global climate change, and engineering advanced materials.

And finally, my last example—and one I am closely associated with—is high-energy physics. Although accelerators don't trace their origins to World War II, the state of the art was advanced considerably by scientists working to separate uranium-235 for use in atomic weapons. Specifically, they improved methods of building electronic and detection equipment and of fabricating accelerator components. After the war, these new techniques were put to work building larger and more reliable accelerators for both nuclear and high-energy physics. At ORNL, two major contributions were made to this field: First, we built the world's first heavy-ion cyclotron; and second, we advanced the technology for sector-focusing cyclotrons. Both of these were important milestones in the quest for machines of increasing energies for particle physics.

Today, many of us are pinning our hopes for the next great leap in high-energy physics on the Superconducting Super Collider (SSC). Many of us expect the SSC to have a profound effect on the fundamental understanding of matter, which, in turn, should spur new insights in many other fields of science. Many scientists also think the construction and operation of the SSC will push the state of the art in such technological fields as computing, intelligent information processing, robotics, fast electronics, magnets, and materials.

Changes for the Future

In a nutshell, that's where we've come from, where we are now, and a hint at where we're going. Our missions have evolved remarkably over the past 50 years, and they will evolve remarkably over the next 50. In one respect in particular, I expect to see considerable change: Our research institutions were created to meet state-defined defense needs. And although our scope later broadened to address a host of other challenges, our laboratory research continues to be directed by the government. In the years ahead, I think we'll see far more collaboration across public and private lines to meet the needs of our citizens.

This is already beginning to happen in the United States, where the character of government research labs has changed dramatically. As recently as the late 1970s, for example, we hosted only a few hundred visiting researchers a year in Oak Ridge. Last year, by contrast, we hosted 4300 guest researchers (one-third of whom were from

I think we'll see far more collaboration across public and private lines to meet the needs of our citizens.

industry) and 24,000 precollege students at ORNL. Throughout the U.S. national-lab complex, similar changes are happening.

This change is embodied in the concept of "technology transfer," which has become a top priority of the U.S. government as it tries to restore America's competitive edge in an increasingly competitive world economy. The importance of technology transfer is reflected by the steady stream of legislation passed since 1980 to facilitate sharing of government equipment and expertise with private industry.

We must proceed much farther and much faster in collaborations on nuclear safety, environmental protection, and other urgent challenges.

Through this legislation, we now have mechanisms that enable national labs to enter into cooperative research and development agreements with industry that promote licensing of government-developed technologies and that reward scientists if an invention is commercialized successfully.

The U.S. Congress will be considering two bills that promote greater public/private collaboration. The House of Representatives' version goes so far as to require that 10 to 20% of the budgets of federal laboratories be devoted to collaborative activities with private industry and state or local governments. It is unclear at the moment whether ORNL and its sister labs will be required to meet such specific spending targets. But clearly, the federal government expects us to play an increasingly active role in revitalizing the U.S. economy.

Of course, technology transfer is a two-way street, requiring both government push and market pull. The private sector understands this, so it has conducted studies of its own on how to facilitate the process.

One primary recommendation to come out of the private sector is that industry leaders be allowed to participate in setting the broad research agenda at government labs. On its face, this may seem threatening to government researchers. But there is plenty of evidence to suggest that there is already considerable overlap between industry's needs and the laboratories' capabilities. For example, when the Council on Competitiveness, a consortium of business leaders, surveyed industry to determine its most critical needs, the top four categories turned out to be areas of strength at the national laboratories: advanced materials and processing, advanced computing, environmental technologies, and manufacturing technologies.

Advice for Russia

Although Russia does not yet have such separate and distinct public and private sectors, there is much to be gained here by improving methods of moving research results and technology developments from the laboratory into the marketplace. As reforms continue, it could show great foresight to think about forging these kinds of technology transfer links with emerging industry. By starting now to emphasize such transfer of technology, the Russian scientific community can avoid the delays and barriers that kept the U.S. laboratories isolated from the needs of industry for years. Instead, you can lay the foundations for exciting growth and partnership as private industry here begins to take hold.

Over the past several years, we've seen astonishing demonstrations, especially here and in Germany, of how dramatically political boundaries and barriers can blur and sometimes vanish. So, too, can scientific ones. In fact, as it becomes increasingly clear that we are all part of one world, scientific boundaries and barriers must start to be erased. We already have a head start in that direction, for even during the Cold War, U.S. and Russian scientists collaborated on challenges of mutual interest, most notably fusion. But now we must proceed much farther and much faster in collaborations on nuclear safety, environmental protection, and other urgent challenges.

The trend in science is to use bigger and bigger instruments to study smaller and smaller things. But "big science" is too expensive for each laboratory, or even each country, to pursue individually. The Superconducting Super Collider, for example, carried a price tag as high as $11 billion. And ORNL's Advanced Neutron Source, which will be the world's finest research reactor when it is completed early in the next century, will cost about $2 billion. Even "small-science" tools such as electron microscopes and mass spectrometers cost $1 to 2 million apiece.

International Collaboration

Now more than ever, the challenges of humankind require interlaboratory, international collaboration: new energy sources for the future; an understanding of genetic diseases and disorders; better ways of handling the toxic, hazardous, and radioactive downside of our progress. These are challenges of humanity, not of nation states. And our laboratories must be the centers of intellect to solve these problems.

What's required of us to do this? Two things: to connect research with human needs and to collaborate across traditional divides. We know how, *technically*, to solve many of the problems facing the world today. But bringing the right solution to bear on the right problem often proves elusive. To be truly successful in our missions, we must work more effectively not just with each other—and not just with industry—but also with our own government officials and with leaders and organizations throughout the world.

The stakes are very high—perhaps far higher than they were 50 years ago. The world's population is likely to double by the middle of the next century. We must find ways to help developing nations improve their lot while preserving the natural environment. Otherwise, we'll all pay a high price: widespread deforestation, rising levels of greenhouse gases, irreversible climate change, worsening famines, and growing world tensions between the haves and the have-nots.

Three and a half centuries ago, the English poet John Donne wrote words that seem fitting as we look back 50 years and as we look ahead: "No man is an island, entire of itself; every man is a piece of the continent, a part of the main; if a clod [of earth] be washed away by the sea, Europe is the less, as well as if a promontory were, as well as if a manor of thy friends or of thine own were; any man's death diminishes me, because I am involved in Mankind."

All of us here today are likewise "involved in mankind." All of us share in the opportunities and responsibilities facing us. During the past half-century, we accomplished much. During the next, there is much, much more for us to do.

Our laboratories must connect research with human needs.

RE: Awards and Appointments

Bill Manly

Bob Van Hook

Marv Poutsma

William D. Manly, a former ORNL researcher and now a technology transfer consultant to Martin Marietta Energy Systems, Inc., received the National Medal of Technology, the highest technology award presented in the United States, in ceremonies held at the White House on September 30, 1993. He was honored for his work in Oak Ridge in advising technology policymakers and promoting industrial uses of materials technology developed at federal research laboratories. During his career at ORNL and several private firms, he led the development of materials with such familiar trademark names as Hastelloy, Stellite, and Haynes. Manly, who came to ORNL as a metallurgist in 1949, was once director of ORNL's gas-cooled reactor project and associate director of what is now the Metals and Ceramics Division.

Peter Cummings has been named a University of Tennessee-ORNL Distinguished Scientist.

Robert I. Van Hook, Jr., has been appointed deputy director of ORNL, replacing **Murray Rosenthal,** who has retired.

Jerry Swanks has been appointed ORNL associate director for Operations and Environment, Safety, and Health, succeeding **Bill Morgan,** who has retired.

M. L. (Marv) Poutsma has been named director of the new Chemical and Analytical Sciences Division, which combines part of the old Analytical Chemistry Division with the Chemistry Division.

G. D. Robbins has been named manager of the new Analytical Services Organization of Energy Systems, which consolidates the analytical services from ORNL's old Analytical Chemistry Division and other Energy Systems plants in Oak Ridge.

Calvin E. Pepper has been elected chairman of the American Welding Society's Qualification and Certification Committee.

Lynn A. Kszos has been appointed to the Ecology Committee of the Water Environment Federation.

John McCarthy received the 1992 Editors' Citation for excellence in refereeing technical papers for *Water Resources Research,* an international journal of the American Geophysical Union.

Tommy Wright has been selected a 1993–94 Research Fellow by the American Statistical Association, the National Science Foundation, and the U.S. Bureau of the Census.

Larry S. Hawk has been named an Honorable Mention winner in the 1993 Rolex Watch U.S.A. Award for Enterprise program for his efforts to help blind people communicate with a Braille writing device.

Thomas H. Row received a 1993 leadership award from the American Nuclear Society.

Paul S. Rohwer has been appointed associate director of the Health Sciences Research Division.

Nic Korte of ORNL's Grand Junction office has accepted an appointment to serve on two committees within the Arizona-Nevada Academy of Science, the High School Grant-in-Aid Committee, and the Outstanding Science Teacher Award Committee.

Jacqueline M. Grebmeier has been appointed to the National Research Council's Committee on the Bering Sea Ecosystem and the National Science Foundation's Arctic System Sciences Ocean-Atmosphere-Ice Interactions Science Steering Committee.

Numerous ORNL employees were honored for their outstanding accomplishments in research management and operational support activities at the annual Martin Marietta Energy Systems Awards Night, held June 18, 1993. **Robert J. Lauf** was named Inventor of the Year, **Eal H. Lee,** Scientist of the Year, and **Donald DeAngelis,** Author of the Year.

Administrative and Office Support Awards for providing exceptional support to the missions and programs of ORNL by office, clerical, or administrative support staff went to **Jamie K. Bain,** for

outstanding support and service to the Metals and Ceramics Division in the area of environmental compliance; **Marvel D. Burtis,** for outstanding performance in helping the Carbon Dioxide Information Analysis Center provide distinguished information products; **Ruth Hengstler,** for her sustained and outstanding contribution to the efficient and cost-effective operation of the Metals and Ceramics Division Procurement Office; **Debbie Moore,** in recognition of her extraordinary, sustained service and assumption of a high level of responsibility in handling the daily personnel issues in the Biology Division; **Linda K. Plemons,** in honor of exemplary administrative support to the Analytical Chemistry Division, the Laboratory, and Energy Systems; and **Toni K. Sawyer,** for unselfish acceptance of a two-month assignment as section secretary and preparation of a DOE Office of Technology Development document that received commendation from DOE Headquarters.

A Community Service Award was presented to **Larry S. Hawk** in recognition of outstanding and noteworthy contributions to voluntary activities that provide significant benefit to the community, including his outstanding service to Volunteers for Medical Engineering, the Direct Manual Braille Slate Fund, and church and community activities.

Employees who received Invention Awards in recognition of their contributions to ORNL through technical innovation are **Mike Harris,** who was principal inventor of the "electric dispersion reactor," a new concept in controlling and facilitating emulsion-phase reactions; and **R. J. (Bob) Lauf,** in recognition of sustained contributions in devising innovative solutions to a wide variety of technologically important problems and transferring the inventions to industry.

The following ORNL managers received Management Achievement Awards for exemplary management contributions in areas of functional management, project management, or technical/scientific management: **John E. Jones, Jr.,** in recognition of his leading the Engineering Technology Division to excellence in research and development and environmental, safety, and health compliance through teamwork and the application of Energy Systems values; and **L. E. (Gene) McNeese,** for his leadership resulting in outstanding performance of ORNL's Waste Management and Remedial Action Division.

Operations Support Awards honoring exceptional support activities in areas such as plant and equipment support, waste management, vehicle fleet operation and maintenance, and health and safety were presented to **David H. Cook, R. Dowe Dabbs, Steven E. Fisher, George F. Flanagan, James Freels, Uri Gat, Sherrell Greene, Richard E. Hale, Michael Jenkins, Sr., B. Lamar Lepard, David G. Morris, Robert H. Morris, Joan T. Muecke, Janet E. Norris, Larry D. Proctor, Richard B. Rothrock, John Sanders, Rusi P. Taleyarkhan, Charles F. Weber, Mary L. Wells,** and **Mark W. Wendel** for their outstanding accomplishment in completing the Safety Analysis Report for the High Flux Isotope Reactor; **Carl A. Burtis,** for meritorious service in support of the Energy Systems Drug Testing Program and the quality assurance activities of the ORNL Health Division; **Mark Kohring, Paul Burn, George Flanagan, Milt G. Kreger, Alan M. Krichinsky, Robert (Rob) McKeehan, Allen J. Millet,** and **David Renfro,** in recognition of their exceptional leadership and contributions to the ORNL Safety Analysis Report Update Program and to Hot Cell Streaming Assessment activities; **W. R. Rich,** for using innovative management and personal initiative to vastly improve the safeguards and security posture of ORNL; **C. R. Sherlin,** in

Tom Row

Paul Rohwer

Bob Lauf


Eal Lee


Don DeAngelis


John E. Jones

recognition of his sustained exceptional performance in many operations and support activities within the Plant and Equipment Division as well as ORNL; **Doug Turner, David F. Hall, Brad McClelland, Brad D. Patton, W. R. Rich, Fred J. Schultz,** and **Martin W. Tull,** for team excellence in preparing for receipt of off-site waste; **Kim S. Gaddis,** for exceptional operations services in support of upgrading procedures in the Enriched Uranium Organization; **Judy H. Campbell, Michael R. Aaron, Janice M. Asher, Lydia S. Corrill, Deborah Counce, Leigh Ann Daniel, Larry Davis, Cathy Dulling, Robert A. Eldridge, Ronald Harnett, Charlene M. Horak, Wanda G. Jackson, Walter S. Koncinski, Jr., Cathy Lamb, Gloria Llanos, Patricia Lund, Sandi Lyttle, Jacqueline T. Miller, Vicky Rolfe, Judy Scalf, Lisa K. Sellers, Nancy Smith, Kathy Swain, Judy Thirloway, Tina M. Thomas, David R. Watson, Rebecca A. Wilker, Anne R. Wilson,** and **Pam Wood,** for outstanding publication support for the Advanced Neutron Source Conceptual Design Report; **Donna S. Griffith,** for outstanding contributions to the corporate and central services organizations through the Columbus Initiatives.

Employees who received Publication Awards in recognition of superior performance in the authorship of a paper, technical article, book chapter, or book that represents a significant advance in the author's professional field are **Donald DeAngelis,** in recognition and honor of his development and analysis of powerful models leading to integration of classical concepts and development of new directions for understanding ecological systems; **Cyrus Baktash, Jerry D. Garrett, Andrew Smith,** and **Dave F. Winchell,** in recognition of their important discovery of identical bands in neighboring nuclei and the implication of this discovery to long-held theories of nuclear structure; **Eli Greenbaum,** in honor of his measurement of a new and important physical parameter in biomolecular electronics; **Mark R. Harpel** and **Fred C. Hartman,** in recognition of their modification of one of the basic enzymes of photosynthesis so as to increase its useful product relative to other diversionary pathways; **George Wignall, Kristoffer Almdal, Frank Bates, Mark Gehlsen, Lotte Hansen,** and **Jeffrey H. Rosedale,** in recognition of their determination of the molecular-weight scaling in critical polymer mixtures by small-angle neutron scattering; **Karren L. More, David A. Koester,** and **Robert F. Davis,** for their significant contribution to the understanding of mechanisms of performance of silicon nitride structural ceramics; **KerChung Shaing, Richard Hazeltine,** and **Heiji Sanuki,** in honor of their development of a theory for strong shocks in tokamak plasmas.

Research and Development Accomplishment Awards for contributions of a technical nature to the activities of the Laboratory in the areas of research, development, or engineering went to **T. M. (Ted) Besmann, Millicent Clark, Kevin M. Cooley, Richard A. (Rick) Lowden, Jerry C. McLaughlin,** and **David P. (Dave) Stinton,** for their superb development of chemical vapor deposition technology that accelerates ceramic composite fabrication time from weeks to hours and tailors special ceramic coating properties; **John B. Bates, Nancy J. Dudney, Greg R. Gruzalski, Chris F. Luck,** and **Ray A. Zuhr,** in honor of their important discovery of a new amorphous lithium electrolyte for microbatteries; **Eal H. Lee, Monty B. Lewis,** and **Lou K. Mansur,** in recognition of their significant development of hard-surfaced polymers, a new class of materials having hardness and wear resistance greater than that of metals, by ion beaming processing; **Alfred J. (Al) Mattus,** for his critical development of a novel liquid radioactive waste treatment process that destroys nitrate, reduces final waste disposal storage volume, and produces a stable ceramic-based wasteform; **Ray A.**

Popp, in honor of his important development of a model animal system for the investigation of sickle-cell disease; **Mark Robinson,** in recognition of his pioneering the theory and computer simulation of atomic collision processes in solids; **M. (Peggy) Terzaghi-Howe** and **John R. Ford,** to honor their achievement of isolating pulmonary cells at risk from alpha radiation and demonstrating that the direct effect of alpha particles is not carcinogenic; **Marc B. Wise, Michelle V. Buchanan, Mike Guerin, Greg B. Burst,** and **Cyril V. Thompson,** in recognition of their development of direct-sampling ion-trap mass spectrometry for environmental analyses.

In technical support, awards were given for noteworthy and excellent contributions to technical advancements to **Norman D. Farrow,** to honor his highly innovative and cost-effective field support related to environmental monitoring and restoration; **Georgia M. Guinn,** in recognition of her integral role in the measurement and characterization of genetic damage caused by radiations and chemicals; **Kaye F. Russell,** in recognition of her outstanding and sustained contributions to development of the ORNL Atom Probe Facility and the use of this facility in materials research; **Charlene A. Woodward,** for her outstanding assembly, execution, sample analysis, and improvement of technical experiments in biological processing research; **Rick W. Jones, W. D. (Bill) McBrayer, Larry D. Phillips, Dale A. Treece,** and **Ken S. Weaver,** for their outstanding performance in the fabrication and assembly of the Future Command and Control Vehicle.

Man H. Yoo has received a Humboldt Research Award for Senior Scientists from Germany's Alexander von Humboldt Foundation.

Stan David has received the Charles H. Jennings Award and the Comfort A. Adams Lecture Award from the American Welding Society.

Linda L. Horton has been named a trustee of the American Society of Metallurgy International.

Camden R. Hubbard has been awarded first prize in the poster category by the American Ceramic Society.

Patsy T. Thornton has been named to the Pi Lambda Theta International Honor and Professional Association in Education.

Thomas B. Powell has been named a Certified Quality Engineer by the American Society for Quality Control.

Dave Bartine has been appointed associate director of the Engineering Technology Division.

Donald L. DeAngelis has been appointed to the Evaluation Committee for Research in Aquatic Ecology for the Swedish National Research Council.

Chester Richmond has been elected to lifetime honorary membership in the National Council on Radiation Protection and Measurement (NCRP). He also was appointed to the Regional Board of Directors for the Eisenhower Mathematics/Science Consortium of the Appalachian Educational Laboratory. In addition, he has been named to the Mathematical Sciences Education Board of the National Research Council and has received the Award for Volunteer Effort from the Delta Sigma Theta Sorority–Oak Ridge Alumnae Chapter.

James R. Thompson has been elected a fellow of the American Physical Society.

The name of the **Health and Safety Research Division** has been changed to **Health Sciences Research Division.**

Craig Little has been named head of the Environmental Technology Section of the Health Sciences Research Division at ORNL's Grand Junction Office.

Peter Mazur has received the 1993 Distinguished Service Award from the American Association of Tissue Banks.

Marvin S. McCarty has been elected president of the East Tennessee Chapter of the American Society of Safety Engineers.

Chet Richmond

Craig Little

Randy Nanstad

Gerry Bunick

Liane Russell

Linda Horton

Carolyn Hunsaker

Randy Nanstad has been named a fellow of ASM International, formerly known as the American Society for Metals.

Gerry J. Bunick has been elected president of the American Crystallographic Association's Small Angle Scattering Group. **Stephen J. Henderson** will serve as president-elect.

Liane B. Russell has received the Marjory Stoneman Douglas Award from the National Parks and Conservation Association and the Woman of Impact Award from the American Association of University Women's Oak Ridge Branch.

Fred C. Hartman has been appointed to the U.S. Department of Agriculture's National Research Initiative Review Panel.

John M. Simonson has received the 1993 Sunner Award at the 48th Calorimetry Conference.

Margaret B. Emmett and **Robert M. Westfall** have received Outstanding Service Awards from the Oak Ridge/Knoxville Section of the American Nuclear Society.

Alvin W. Trivelpiece has been named to the Oversight Committee of the Tennessee Systemic Initiative for Mathematics and Science.

Emily D. Copenhaver has been named 1993 Woman of the Year by the American Business Women's Association's Double "L" Chapter.

Amy K. Wolfe has been named a fellow of the American Anthropological Association.

Tommy Wright has been appointed to the Steering Committee of the Tennessee Systemic Initiative for Mathematics and Science.

Thomas S. Kress has been named to the Advisory Committee on Reactor Safeguards of the Nuclear Regulatory Commission.

Vance K. Wilkinson has been named a fellow of the Institute of Industrial Engineers.

Bob E. Booker has been named to the Knox County Regional Solid Waste Planning Board of Knox County, Tennessee.

Marcy L. Espegren has been named to the 1993 "Expanding Your Horizons" Conference Committee at Mesa State College in Grand Junction, Colorado.

Linda L. Horton and **Philip S. Sklad** have been named directors for Physical Sciences of the Microscopy Society of America.

Chain T. Liu has received the 1994 Fellow Award from the Minerals, Metals, and Materials Society. He is one of only 100 fellows of the society in the United States.

Glenn R. Young has been named a fellow of the American Physical Society.

Leo B. Holland has received the 1993 Meritorious Performance in Reactor Operations Award from the American Nuclear Society, Reactor Operations Division.

I. Lauren Larsen has received the Environmental Sciences Division's Distinguished Achievement Award for Operational Support.

John F. McCarthy has been appointed to DOE's Waste Isolation Pilot Project Scientific Review Panel.

Robert L. Siegrist has been appointed to the Groundwater Committee of the Water Environment Federation.

Carolyn T. Hunsaker has been appointed director-at-large of the Water Environment Federation's Board of Control. She has also been elected chair of the Applied Ecology Section of the Ecological Society of America.

Ralph Moon has been appointed associate director of the Solid State Division.

Steven G. Hildebrand has been appointed director of the Environmental Sciences Division.

Dorothy Skinner received the Award for Research Excellence from the Crustacean Society at its 1993 annual meeting.

John F. McCarthy has been appointed to a scientific review panel to evaluate DOE's long-term plans for

storing low-level radioactive materials.

The **Carbon Dioxide Information Analysis Center** has received an exceptional Public Service Award from DOE Secretary Hazel O'Leary.

Peter J. Blau has been elected a fellow of ASM International.

Lynn Boatner, Stan David, Roxanne Steele, and **John Vitek** won the Second Place Award in the American Association for Crystal Growth's Crystal Photograph Competition.

Martin Marietta Energy Systems has received an Award of Excellence in Technology Transfer from the Technology Utilization Foundation, *NASA Tech Briefs,* and the Federal Laboratory Consortium.

William E. Doll has been selected to chair the Hazardous Waste Committee of the Near Surface Geophysics Section of the Society of Exploration Geophysicists.

Jonathan E. Nyquist has been appointed to chair the Groundwater Geophysics Committee of the Near Surface Geophysics Section of the Society of Exploration Geophysicists.

Carl Edward Oliver has been appointed associate director of ORNL's newest directorate, Computing, Networking, Informatics, and Education (CNIE). CNIE encompasses the Engineering Physics and Mathematics Division, the Computing Applications Division, the Center for Computational Sciences, the Office of Laboratory Computing, and the Office of Science Education Programs and External Relations.

Robert C. Ward has been named deputy associate director of CNIE.

S. Marshall Adams served as scientific book editor for the Ecological Society of America on a book entitled, *Biodiversity of the Southeastern United States: Aquatic Communities.*

R. H. Gardner has been named as a charter member of the Electric Power Research Institute's Scientific Advisory Committee for the Environmental Risk Advisory Program.

R. D. Hatcher has been appointed to the National Academy of Science's Commission on Geosciences, Environment, and Resources to serve on the Board of Radioactive Waste Management's New York State Review Committee.

Ellen D. Smith has been elected chairperson of the City of Oak Ridge's Environmental Quality Advisory Board.

Thomas J. Wilbanks has earned the 1993 Distinguished Geography Educator Award from the National Geographic Society.

Daniel W. McDonald has been appointed director of the Instrumentation and Controls Division. He succeeds **Bill Eads,** who is on assignment to the Office of Science and Technology of the Tennessee Department of Economic and Community Development.

Stephen G. Hildebrand has been appointed director of the Environmental Sciences Division.

C.T. Liu has been named a fellow by the Minerals, Metals and Materials Society.

Glenn W. Suter has been named to the editorial board of the new journal *Human and Ecological Risk Assessment.*

Charles D. Scott has been selected as the 1994 recipient of the David Perlman Lecturer Award by the Biochemical Technology Division of the American Chemical Society.

Charles E. Mulkey has been elected a fellow of the American Society of Engineers.

Terry Lashley has been elected to the Tennessee Science Teachers Association's executive board.

Donald R. Miller has been elected national director of the National Management Association (NMA) and has been named to the organization's national board of directors. He has also been designated a certified manager by the Institute of Certified Professional Managers. At the local level, **Richard K. Genung** has been named president of the NMA's Energy Systems chapter; **Alston E. Hodge** has been named the organization's Program Committee chairman; and **John E. Jones** and **Raymond W. Tucker** have been named members of the chapter's board of directors

Robert H. Gardner has been appointed chairman of the scientific review committee for the Environmental Sciences Division's Sustainable Biosphere Initiative. He also has been named a charter member of the Electric Power Research Institute's scientific advisory committee for the Environmental Risk Analysis Program.

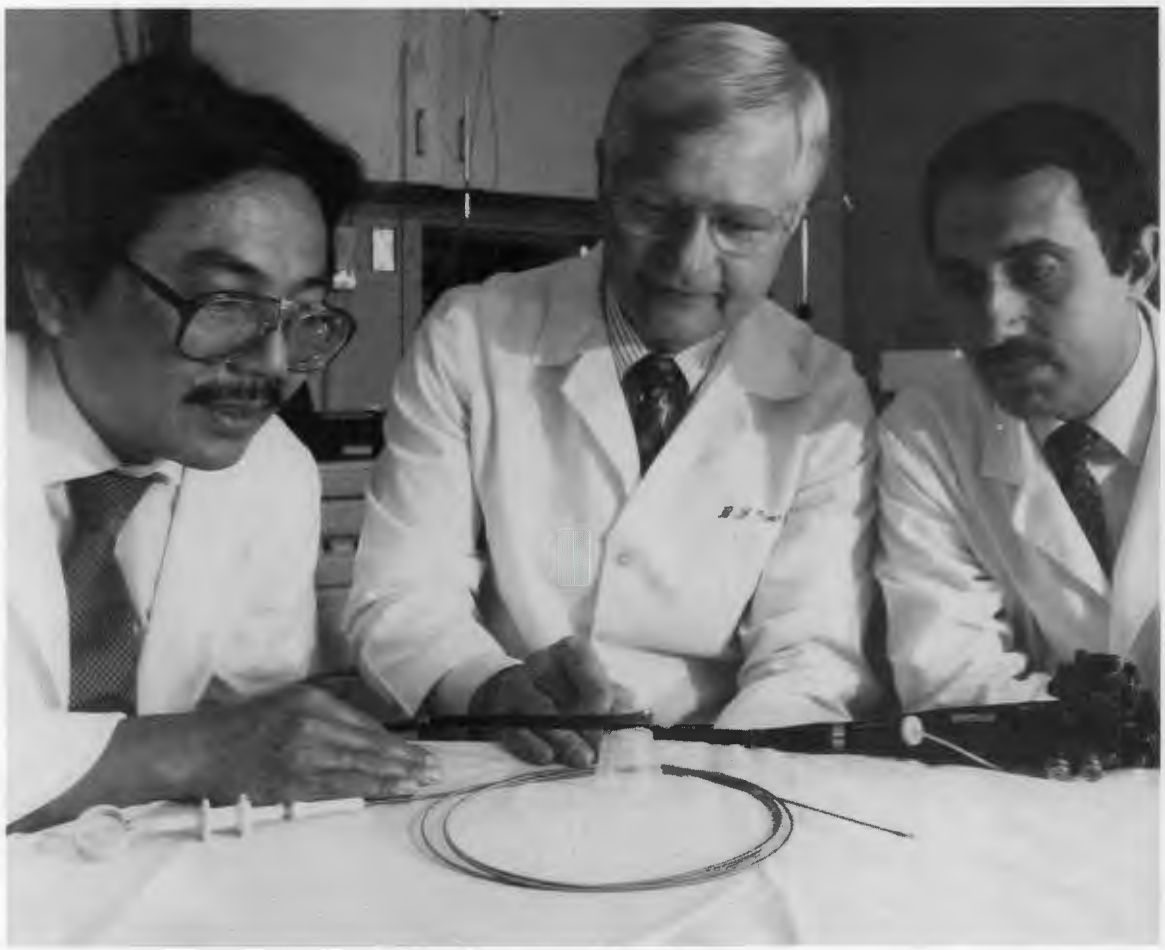
Robert D. Hatcher, Jr., has been appointed to the Nuclear Regulatory Commission's Nuclear Research Review Committee, the National Academy of Sciences Commission on Geosciences' National Committee on Geology.

Robert W. Roussin has been elected a fellow of the American Nuclear Society.

Robert T. Santoro has been assigned to the Joint Central Team for the multinational effort to design the International Thermonuclear Experimental Reactor (ITER).

Carl C. Trettin has received an award of appreciation from the Southern Appalachian Man and the Biosphere Program for his role as chairman of the organization's 1993 Wetland Conference.

Nonsurgical Laser Technique Detects Cancerous Tumors



Tuan Vo-Dinh of ORNL (left) and Bergein Overholt and Masoud Panjehpour, both of Thompson Cancer Survival Center of Knoxville, have developed a new laser technique for nonsurgically diagnosing cancerous tumors in the esophagus.

A new laser technique for nonsurgically diagnosing certain cancers has been developed by scientists from ORNL and the Thompson Cancer Survival Center in Knoxville, Tennessee. The research team, led by Tuan Vo-Dinh of ORNL's Health Sciences Research Division, and Bergein Overholt and Masoud Panjehpour, both of the cancer center, has informally dubbed the technique an "optical biopsy" because laser light is used to determine whether a tumor is malignant or noncancerous.

The researchers say the new method could change the course of medicine in diagnosing certain tumors because no tissue must be removed and the diagnosis is made almost immediately. In more than 200 tests of over 50 patients at the Thompson Cancer Survival Center, the method has accurately diagnosed almost all tumors of the esophagus.

Conventional biopsy of such tumors requires the use of a pincer-tipped cable to physically remove tissue for analysis. Such a surgical procedure entails recovery time for patients and an expensive, time-consuming laboratory analysis to determine malignancy.

In the new method, instead of the biopsy "pincer" cable, a fiber-optic cable is inserted in the biopsy channel of an endoscope, an instrument for

visualizing the interior of a hollow organ. Laser light is directed through the cable's optical fibers onto the tissue. The tissue absorbs the laser light and, depending on the light's wavelength, reemits it as a fluorescent "glow," which is spectrally analyzed. Using a special data analysis method, the researchers discovered that the spectral "fingerprint" of a malignant tumor can be distinguished from that of a noncancerous tumor This method can be used to diagnose some cancers rapidly without surgery, thus improving the effectiveness and decreasing the cost of cancer diagnosis and therapy.—*Wayne Scarbrough*

Energy Savings for Low-Income Households

In Wisconsin, an elderly woman watches workers blow high-density cellulose insulation into the wall cavities of her home and install a high-efficiency gas furnace. In Ohio, a widowed mother of four young children observes a series of "blower-door tests" that tells the weatherization crew when to stop sealing cracks and crevices in her leaky house. In Georgia, a disabled veteran looks forward to seeing his front yard through new storm windows and wonders how much lower his fuel bills will be.

All live in low-income households. Most importantly, they are participants in the Department of Energy's Weatherization Assistance Program, the nation's largest energy conservation program and one of its oldest. ORNL has played an important role in evaluating this program.

The Weatherization Assistance Program has been operated by DOE since 1976 to increase the energy efficiency of dwellings occupied by low-income households. Its goals are to reduce their energy consumption, lower their fuel bills, increase the comfort of their homes, and safeguard their health. It targets vulnerable groups, including the elderly, people with disabilities, and families with children.

According to the U.S. Department of Health and Human Services (HHS), the average low-income family spends 12% of its income on residential energy, compared with 3% for the average U.S. family. The program helps pay for the conservation measures that low-income families need but cannot afford. It also provides an infrastructure of rules and guidelines and a network of more than 1100 agencies located across the nation that can deliver weatherization services with funding from a variety of sources in addition to DOE. This "leveraging" is an important strength of the program.

Between 1978 and 1989, DOE provided 45% of the $4.4 billion used to weatherize the homes of low-income households in the United States. Other sources of federal funding for weatherization are the Low-Income Home Energy Assistance Program administered by HHS and Petroleum Violation Escrow, or "oil overcharge," monies. Utilities also fund low-income household weatherization.

The new method could change the course of medicine in diagnosing certain tumors.

In 1990 DOE initiated a nationwide evaluation of its Weatherization Assistance Program, with assistance from ORNL. One finding is that more homes were weatherized, more money was spent, and more energy was saved in the North than in the South, in part because DOE allocates its weatherization funds more to areas that have greater heating than cooling needs. Overall, preliminary results indicate that the program saves energy, improves homes, and provides jobs.

Marilyn Brown and Linda Berry, both of ORNL's Energy Division, led a team that collected and analyzed data from agencies, utilities, households, and the National Oceanic and Atmospheric Administration to determine the costs of conservation measures, the amount of energy saved, other benefits of the program, and the cost effectiveness of the program in three regions of the United States—cold climate, moderate climate, and hot climate. They examined almost 15,000 single-family and small multifamily dwellings weatherized under DOE guidelines during 1989 and compared them with more than 3600 control homes.

The ORNL researchers found that the measures installed and procedures used in 1989 varied widely among local agencies administering the DOE program and that the differences across climate regions were quite

ORNL has played an important role in evaluating DOE's Weatherization Assistance Program.

Photographs of a single-family dwelling before and after its energy efficiency was improved by DOE's Weatherization Assistance Program.

pronounced. "In cold climates," Brown says, "we noted high installation rates for ceiling, wall, and floor insulation and space- or water-heating tuneups, repairs, or replacements, but we observed low installation rates for storm and replacement windows and new doors. Also, integrated energy audits, blower-door testing to assist air sealing, and space-heating diagnostics were used more often in the cold climate region than the other regions."

In the moderate-climate region, the researchers found higher installation rates for storm windows, space-heating measures, and air-leakage control measures such as weatherstripping and caulking. In the hot-climate region, installation rates were lower for wall insulation and space and water heating but higher for replacement windows and doors. Unlike the cold-climate region, integrated energy audits, blower-door testing, and space-heating diagnostics were rarely used in the hot-climate region.

Studies suggest that integrated audits, insulation, and space-heating retrofits and replacements result in the greatest energy savings, and these are the measures emphasized by the local weatherization agencies in the cold climate. "In contrast," Brown says, "housing rehabilitation measures that cannot be expected to significantly lower energy usage are emphasized more by agencies in the hot region, reflecting the more dilapidated state of low-income housing in the South."

The program clearly saves energy, the ORNL researchers found. Weatherized gas-heated homes used 13% less electricity overall and 18% less gas for space heating than they consumed before weatherization. Weatherized electrically heated homes used 12% less electricity overall and 36% less electricity for space heating. They calculated that weatherization in 1989 of 198,000 single-family and multifamily homes by the program's 1100 local agencies saved the equivalent of 600,000 barrels of oil during 1990–91, or a projected 12 million barrels of oil over the 20-year lifetime of these conservation measures.

In 1989 the average direct cost per dwelling of weatherization was $1050, but 8% of the homes had installation costs under $300 and 9% had expenditures of more than $1800. An additional $500 on overhead and program administration is spent, on average, per weatherized home.

The ORNL researchers were surprised to find no discernible energy-savings benefit from use of

the blower-door test to determine if a home is properly sealed to minimize heat losses. This finding is attributed to the fact that blower doors were just being introduced into local agency procedures in 1989 (see photograph at right).

"Today blower doors are used more extensively, and most state agencies offer training in their use," Brown says. "In fact, low-income weatherization agencies have been leaders in the use of blower doors nationwide. Although blower doors may have been ineffectively used in 1989, such problems are undoubtedly less characteristic of the program today."

Brown and Berry also estimated the value of the program's nonenergy benefits. They include environmental benefits from reduced use of fuel, employment of workers who weatherize dwellings, federal taxes generated from employment, avoided costs of unemployment benefits, enhanced property values for homes, extended dwelling lifetimes, and a decrease in home fires caused by faulty heating equipment.

The researchers found that the Weatherization Assistance Program is a cost-effective government investment; its benefits exceed its costs based on each of the three perspectives employed (installation, program, and societal) in which various benefits and costs are weighed. The program is also cost effective for two types of dwellings from all three perspectives.

A field contractor tests the air leakage rate in a house for DOE's Weatherization Assistance Program. He is using a blower door, a variable-speed fan specially equipped to fit inside a door frame. Its pressure gauges and other instruments enable the operator to measure the air flow through the fan as well as the fan-induced pressure on the dwelling. Because leakier houses require higher fan speeds to induce a certain pressure difference, a blower door can measure the relative leakiness of a house. When used as a diagnostic instrument, it can also reveal the location of many leaks, making it possible to seal the house to minimize heat losses.

ORNL researchers found the program clearly saves energy.

"Weatherization of detached single-family and small multifamily dwellings was cost effective from all three perspectives," Berry says, "but weatherization of mobile homes was not cost effective when the definition of benefits is limited to energy savings—the program perspective.

"Perhaps the most striking result of our evaluation," Berry adds, "is the tremendous diversity among local weatherization agencies. Some weatherize 15 homes in a year, whereas others weatherize thousands. Some agencies achieve savings of 30 to 40% of preweatherization energy consumption, others

The Weatherization Assistance Program is a cost-effective government investment.

produce no measurable savings. Some employ state-of-the-art procedures, leverage a wide variety of financial and technical resources, and perform sophisticated self-evaluations designed to constantly improve their performance. Others follow the same procedures year after year, do not evaluate their impacts, and rely only on DOE funding."

The United States still has 24 million households that are eligible for participation in DOE's Weatherization Assistance Program. Brown says that, to meet these needs, she would like to see more partnerships and a pooling of resources among utilities, DOE's Office of Energy Efficiency and Renewable Energy (which funded the ORNL study), energy service companies, and community action agencies that have experience in providing weatherization services.—*Carolyn Krause*

ORNL Plays Large Role in ITER Fusion Project

ORNL is playing a major role in development of the International Thermonuclear Experimental Reactor (ITER), which is the largest international scientific project ever attempted. The goal of the multibillion-dollar project is to demonstrate the scientific and technological feasibility of fusion energy.

Participants include the European Community (Euratom), Japan, the Russian Federation, and the United States. The project is being conducted under the auspices of the International Atomic Energy Agency.

Charles C. Baker, a staff member of ORNL's Fusion Energy Division and an editor of the *Fusion Engineering and Design* journal, is manager of the U.S. ITER Home Team. It is one of four teams working on the engineering design of the ITER with the Joint Central Team. The central team is based in San Diego, California; Garching, Germany; and Naka, Japan.

The ITER will be a tokamak, a doughnut-shaped device in which the hot fusion plasma—a mixture of ions and electrons—will be confined by superconducting magnets. No electricity will be produced at the ITER.

The conceptual design of the ITER was completed in 1990. Engineering design work, under way since 1992, is expected to be complete in 1998. Construction is planned for 1998–2005, and operation should begin in 2005.

Baker says the ITER project will help the United States meet its fusion goals. "It will advance fusion science and technology, increase industrial involvement in fusion technology, take advantage of international collaboration to spread out costs, bring the world's best minds in fusion together, and establish a model for other megascience projects."

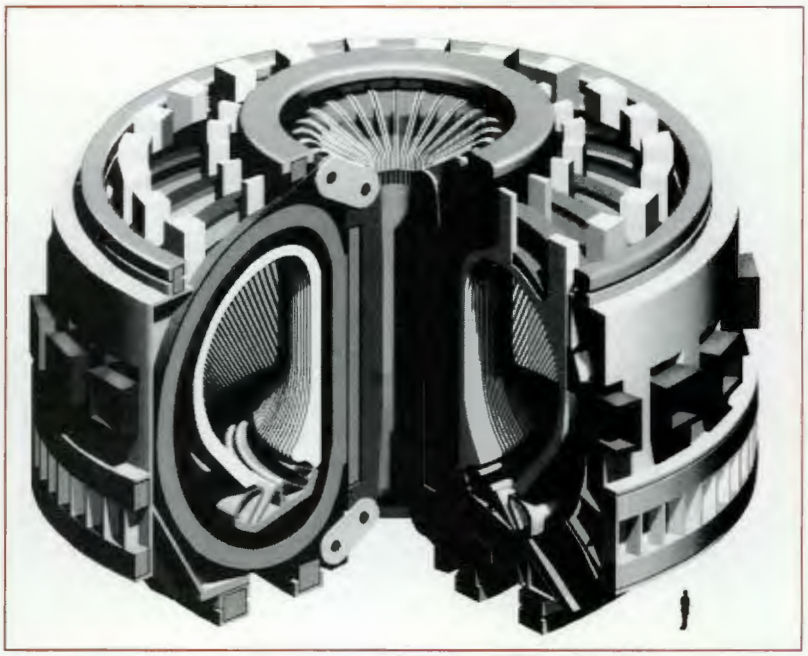
ORNL materials researchers under Arthur Rowcliffe and Everett Bloom, both of the Metals and Ceramics Division, are working on developing advanced high-performance materials for fusion reactors. They include austenitic and ferritic stainless steels, carbon-fiber composites, and vanadium alloys.

ITER officials are debating whether to include advanced materials in the tokamak design. Baker says the ITER design will probably emphasize use of the lower-performance materials such as austenitic stainless steels because their properties are well known.

ORNL work for the U.S. Home Team, including the materials development, is managed by plasma physicist Nermin Uckan of the Fusion Energy Division. She is also in charge of ITER-related design studies on plasma performance for the U.S. Home Team. David Lousteau of Energy Systems' Engineering Division is deputy manager. Other ORNL work for the ITER includes remote handling, plasma technology development, and reactor engineering design.

"There is little doubt that we can create plasmas to meet requirements for heat and power production," Baker says. "The key to fusion success—and our greatest challenge—is to integrate engineering components and technologies. The dilemma for fusion researchers is that, unlike for fission, test reactors must be built as large as the future commercial ones to demonstrate that practical fusion energy is possible. However, a potential advantage for fusion power plants will be their environmental and safety features."—*Carolyn Krause*

Largest Reactor Vendors in Europe and Japan



Schematic of the proposed International Thermonuclear Experimental Reactor. ORNL is playing a major role in its development. ORNL's Charles Baker is manager of the U.S. ITER Home Team.

The ITER project will help the United States meet its fusion goals.

Until 1980 most nuclear power plants operating throughout the world were "made in the U.S.A." Four vendors—Westinghouse Electric, General Electric, Babcock & Wilcox, and Combustion Engineering—had supplied 80% of the world's commercial reactors in the 1960s and 1970s.

Since 1980, more than 70% of the western world's commercial reactors have been provided by vendors in Europe and Japan. They are Framatome of France; Siemens of Germany; Asea Brown Boveri of Sweden and Switzerland; and Mitsubishi, Hitachi, and Toshiba, all of Japan.

What is the future of the nuclear industry? Who will be the chief vendors? What will be their future reactor products? Who will be their customers? These questions have been explored in a study conducted by two ORNL researchers—Charles W. Forsberg of the Chemical Technology Division and Larry Hill of the Energy Division, together with William J. Reich of the Chemical Technology Division and William J. Rowan, a consultant.

According to the report, nuclear power suppliers are no longer organized along single-company, national lines. "Since 1980, vendors are using three organizational structures to increase sales and reduce risk.

"First, international corporations such as Asea Brown Boveri—the largest industrial equipment manufacturer in the world—own multiple reactor vendors in multiple countries.

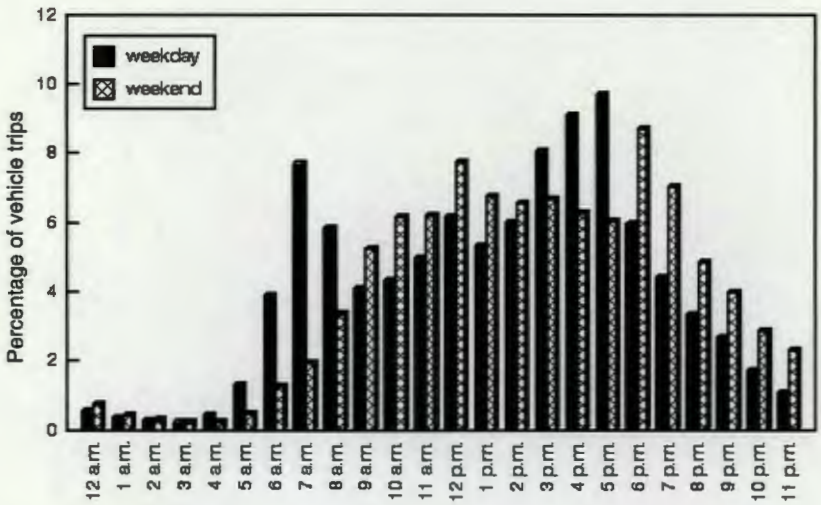
"Second, international joint ventures between multiple reactor vendors have been created to sell, design, and build nuclear power plants. The largest such joint venture and the dominant European group is Nuclear Power Incorporated (NPI), which is controlled by Siemens and Framatome.

Third, international consortia for joint sales and product development have been created. An example is the Hitachi–General Electric–Toshiba group.

What changes can be anticipated in the nuclear industry in the 1990s? Because of historical business relationships, the report's authors expect that NPI partners Siemens and Framatome will be major suppliers in Eastern Europe and the former Soviet Union. They also believe that the biggest future impact on the international market will be the Japanese vendors.

"Japan has the largest domestic nuclear power construction program in the 1990s," Forsberg observes, "and it is now beginning to export nuclear power equipment."

Since 1980, more than 70% of the western world's commercial reactors have been provided by vendors in Europe and Japan.



ORNL researchers are finding that rush hour is becoming nearly an all-day affair, as shown in the graph above.

According to the report, a vendor capability is being developed in the People's Republic of China.

Although many types of reactors have been developed, the report states that the market will continue to be dominated by three reactor types—pressurized-water, boiling-water, and Canadian heavy-water reactors.

Besides the utilities in 28 countries that now operate or are building nuclear power plants, future customers may include 25 countries with economies large enough to support such facilities. Most future reactor sales are expected in countries along the Pacific Rim, such as Japan, China, Taiwan, South Korea, and Indonesia.

"These countries," Forsberg says, "have a larger demand for nuclear power plants than other nations because of a combination of factors. They have limited indigenous energy resources, rapid growth in electricity demand, and better acceptance of nuclear power."—*Carolyn Krause*

Researchers Track Traffic Trends

A new report produced by ORNL researchers Patricia Hu and Jennifer Young for the U.S. Department of Transportation paints an increasingly crowded picture of life on America's highways. In fact, their work shows rush hour has become nearly an all-day affair, stretching from dawn until dusk, with only a brief midmorning lull.

The report, *Nationwide Personal Transportation Survey,* highlights a number of reasons for this increased traffic. More drivers are driving more cars more often than ever before. Society itself is also changing.

More women are working outside the home, and more women are getting drivers' licenses. They still don't drive as much as men, but they're closing the gap. Teenagers are driving more too—nearly twice as much as they did in the 1960s. Retirement-age folks are also driving 40% more miles per capita than in 1969.

"You can't really compare driving habits people had 30 years ago with the way we drive today," says Hu. "Thirty years ago, people could walk to the store, to school, even to work. We can't do that anymore."

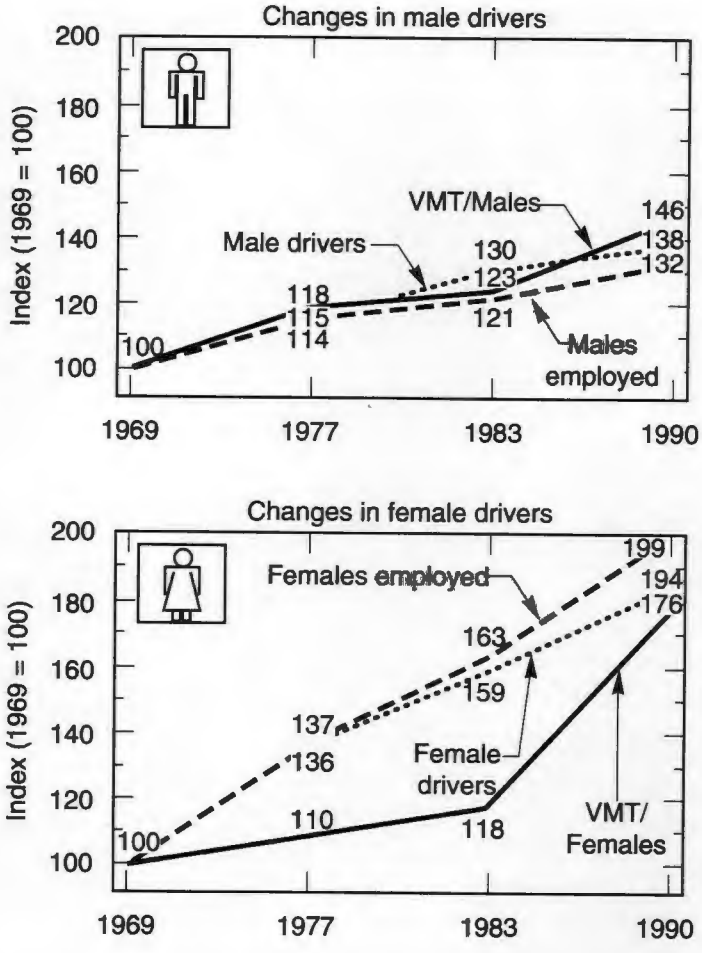
Hu and Young analyzed travel data gathered through a random telephone survey of over 22,000 U.S. households. The report also tracks information on vehicle ownership, household travel patterns, and other travel-related information for 12 months before the survey. The nationwide travel survey is conducted by the U.S. Department of Transportation every 5 years.

The next survey will be conducted in 1995, and, despite the comprehensive nature of this survey, Hu would like to do a few things differently the next time. "We would like to study the movement of people," she says, "to determine where they are going and why. I also think the issue of telecommuting—working at home and communicating with the office by computer—should be addressed."

Fuel consumption is another area Hu would like to see studied in the 1995 survey. Current figures are based on the year, make, and model of cars reported in the survey, along with Environmental Protection Agency mileage estimates. "But that doesn't tell the whole story," says Hu. "To associate travel habits with fuel economy, we need to get fuel economy figures for individual cars."

You'd think that a never-ending rush hour, rising gasoline taxes, and a growing hole in the planet's ozone layer would have the public clamoring for greater access to transportation alternatives, such as buses and trains.

"We asked people about that," says Hu. "They say it's more convenient to use their cars."



Increases in the number of women in the workforce and women with drivers' licenses correspond with a sharp increase in the vehicle miles traveled (VMT) by women, as shown above. Increases in driving by men have been less dramatic.

More women are working outside the home, and more women are getting drivers' licenses.

Plasma-Spray Diamond Coating: Hard Act to Follow

Using plasma spray deposition, researchers can deposit versatile diamond coatings on large, complex-shaped components.

Eugene Price of ORNL helped develop a diamond-coating process that converts glassy carbon to diamond. Using a technique known as plasma spray deposition, he and his Y-12 Plant colleagues can deposit thick pure diamond or diamond-boron carbide composite coatings on large, complex-shaped components.

Diamonds—not the kind that are a girl's best friend, but their industrial-grade cousins—are the materials of choice for durable coatings on the wear surfaces of both high-tech equipment, such as chemical reactors, and more conventional tools, like drills, grinding wheels, and saws. Besides being the hardest known coating material, diamond can also be used to produce semiconductors that are thousands of times more efficient than the standard silicon variety, resulting in electronic components that are faster, more powerful, and more rugged. Diamond is also the most transparent substance in the far infrared end of the spectrum and can be used to coat optical devices, such as windows and lens components on spacecraft, to protect them from abrasive dust and other particles.

The popularity of diamond coatings for a variety of applications has put a premium on finding faster, more efficient diamond-coating processes. One of the most promising developments in this area has

been the discovery by Roland Seals and Cressie Holcombe, both of the Oak Ridge Y-12 Plant, and ORNL's
R. Eugene Price of a diamond-coating process that converts glassy carbon to diamond. Using a technique known as plasma spray deposition (PSD), these researchers can deposit thick pure diamond or diamond-boron carbide composite coatings on large, complex-shaped components.

For years, efforts to expand the applications of diamond coatings have been frustrated by the limitations of traditional chemical vapor deposition (CVD) processing, which requires very precise, ultraclean conditions and can be used only to treat relatively small surfaces. On the other hand, PSD coatings are easily applied to almost any surface using a much simpler and more economical process that produces coatings 50 times quicker and 50 times thicker than those produced using CVD. These thicker coatings are much more durable and guard against small pinhole defects that lead to complete coating failures in wear and high-abrasion applications. The simpler PSD process can also be adapted for use in the field, allowing use of diamond coatings in new areas, such as protecting drill bits for oil exploration and extending the lives of cutting blades used in industrial and farm settings.

In applications where a combination of PSD and CVD coatings would be advantageous, a thin CVD coating can be applied over a layer of plasma-spray-deposited diamond, resulting in a thick diamond coating with outer layers identical to those now provided by CVD. For example, CVD coatings are sometimes more transparent than those resulting from PSD and should yield overall better performance in certain uses, such as protective overcoats for optical mirrors.
—Jim Pearce

Geomagnetic Device Probes Impacts of Solar Storms

Electric power systems in the Northeast and other U. S. areas are vulnerable to solar geomagnetic storms. ORNL researchers want to find better ways to reliably warn the nation of a solar storm so that electric utilities can protect their systems from sudden power losses and equipment damage.

A team led by Randy Barnes and Eddy Tapp, both of ORNL's Energy Division, has constructed and begun operating a geomagnetic field monitor. Scientists are using data from the ORNL monitor, along with information from the U.S. Geological Survey and Electric Power Research Institute (EPRI), to better understand the effects of solar storms on Earth's magnetic and electric fields.

Scientists are using the ORNL monitor to understand the effects of solar storms on Earth's magnetic and electric fields.

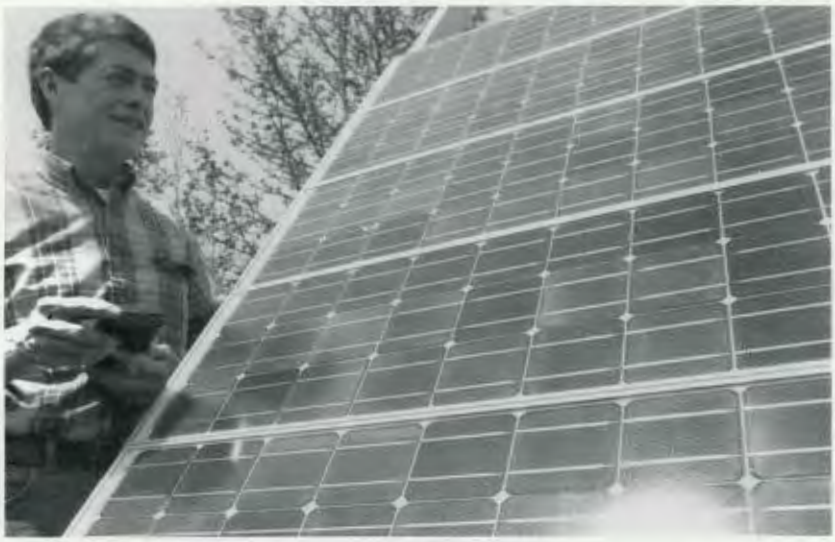
Solar storms can trigger power blackouts and cause equipment damage, trips of equipment and power lines, and disturbances such as humming transformers. The Northeast and other U.S. and Canadian areas sitting on igneous rock and using long, heavily loaded transmission lines to import power are particularly vulnerable to solar storms. The reason is that the ground's high resistance causes large geomagnetically induced currents to flow in high-voltage transmission lines.

On March 13, 1989, as a result of a solar storm, a major blackout occurred in the Canadian province of Quebec. "A similar storm," Barnes says, "could cause major blackouts in the Northeast, costing between $3 billion and $6 billion in lost output."

During solar storms, Earth's magnetic field moves back and forth like a wave. These fluctuations cause small variations in the magnetic field at ground level, providing important information on solar geomagnetic storms.

"Our monitor will gather comprehensive data on the changes in the magnetic fields over time, thus filling gaps in our fundamental understanding of solar storms," Barnes said. "By comparing our data with information from other sites, we can determine how much fields vary from place to place. This knowledge can be used for developing a reliable method for warning electric utilities that a solar storm is imminent and that they should take precautions."

What precautions? According to "A Weather Eye on the Sun," in the December 8, 1990, issue



Randy Barnes checks out the operation of a geomagnetic field monitor built at ORNL to better understand the effects of solar storms on Earth's magnetic and electric fields.

"If a power company got warning that a geomagnetic storm was about to hit, it might choose to rely on expensive local power."

of *The Economist*, "The American system relies more on long-distance transmission now than it ever has before—to a large extent because growth in demand for electricity in the Northeast has been met by importing electricity from elsewhere in the country. These long links are the most vulnerable to magnetic effects.

"If a power company got warning that a geomagnetic storm was about to hit, it might choose to rely on expensive local power rather than cheap but much-traveled power for the duration. That would reduce the risk of a gridwide failure."

Located in a field near the Laboratory, ORNL's geomagnetic monitor consists of a partially buried three-axis magnetometer, which indicates the direction and magnitude of Earth's magnetic field, and two 100-meter (328-foot) electric field sensors that measure large fluctuations in electric fields caused by ground currents. A small computer powered by a 1.2-by-3-meter (4-by-10-foot) panel of solar cells logs and temporarily stores six channels of data at the rate of one sample per second on each channel around the clock.

Researchers plan to use the system almost exclusively to monitor future solar storm activity. As the severity of geomagnetic storms peaks about every 11 years, ORNL researchers expect that the United States and Canada will face particularly serious vulnerability problems during the next solar cycle early in the 21st century.

Electric utilities, power equipment manufacturers, EPRI, and the Tennessee Valley Authority also are conducting research on developing measures for protecting systems against the effects of solar geomagnetic storms. Solar storm impacts on electric power systems were first observed in the United States in 1940.

The laboratory's geomagnetic field monitor program is funded by DOE's Office of Energy Management.—*Brian Daly and Carolyn Krause*

Removing Cesium-137 from Contaminated Soil

Brian Spalding and Gary Jacobs had a problem. They were working on trapping cesium-137 and other radioactive wastes in the soil using a process called in situ vitrification (ISV). This waste treatment regimen basically cooks the contaminated area—soil, contaminants, and all—into a big, glassy lump, trapping the contaminants inside. As the soil is heated, steam and other escaping gases are trapped, analyzed, and treated to remove any potential source of airborne contamination.

That's where the problem cropped up. Spalding and Jacobs, researchers in ORNL's Environmental Sciences Division, found that cooking the soil caused more cesium-137 to be released and trapped in off-gas filters than they expected. This

was a bit of a surprise, considering that the near impossibility of getting cesium-137 out of soil was one of the reasons ISV was developed in the first place.

A common by-product of nuclear fission research, cesium-137 can be found in the soil and in stream, lake, and river sediments around several DOE facilities, waste disposal sites, and nuclear power plants. When it is released into the environment, cesium-137 latches onto particles of clay, eventually forming an almost permanent bond.

"A lot of people have developed techniques to take radionuclides out of the soil," says Spalding. "But cesium-137 is probably the toughest to get out of just about any soil. It has always been thought to be nearly impossible. Powerful acids had to be used to destroy half the soil to get the cesium out—that's just not practical for decontaminating large volumes of soil—the volume of contaminated waste produced was greater than the original amount."

While investigating the source of the extra cesium, Spalding and Jacobs began to suspect that as the soil was heated, polyvinylchloride (PVC) piping used to slide radioactive sludge into the ISV test trenches melted, allowing the chloride in the pipes to react with the cesium in the soil. "There's naturally a little bit of chloride in the soil in the form of salt (sodium chloride)," says Spalding, "but not enough to volatilize very much cesium. It turns out that PVC pipes are an excellent source of chloride." Future ISV tests will employ other types of plastic pipe.

Laboratory tests confirmed that what began as an ISV problem was also a potential solution to the difficult task of loosening cesium's tenacious grip on the soil. In fact, when cesium-137–contaminated soil was mixed with chloride and heated to between 800 and 1000°C for at least two hours, 99% or more of the radioisotope was removed.

Of course, this shake-and-bake decontamination process takes a toll on the soil. "It's kind of like crushed brick when we're finished," Spalding admits, "But it's clean, and its alkalinity and high mineral content would probably make it a good fertilizer for other uncontaminated soil."

Despite the technology's remarkable success in decontaminating soil in the laboratory, Spalding and Jacobs have taken the technology about as far as they can and are planning to refocus their efforts on ISV. "We did this research to explain the cesium releases during the ISV process, and we've shown that, as a decontamination process, it has all the desirable features. We hope there's someone out there who wants to develop it and demonstrate that it is a realistic technology in field tests."—*Jim Pearce*

On-Site Tests for PCB Contamination

A much less expensive test for detecting toxic polychlorinated biphenyls (PCBs) in environmental samples has been developed at ORNL. This simplified "spot test" can be performed at one-tenth the cost of the conventional laboratory method because it provides almost immediate results at the site of the PCB contamination. As a result, sample transport to the laboratory, costly laboratory procedures, and extra work time are eliminated.

The newly developed and patented test uses strips of chemically treated paper that glow if exposed to PCBs and then excited by a certain light. The tests, based on room-temperature phosphorescence (RTP) and enhanced photoluminescence (EPL), were developed by Tuan Vo-Dinh, leader of the Advanced Monitoring Development Group in ORNL's Health Sciences Research Division. Vo-Dinh has developed several applications using RTP, including spot tests for other pollutants. Other researchers involved in the projects included Anjahi Pal, Lorna Ramirez, Wendi Watts, Lisa Ford, and Jean Pierre Alarie.

PCBs were manufactured in the United States from 1929 to 1977 for various uses, including electrical equipment, hydraulic fluids, and lubricants for industrial equipment. Through such products, PCBs entered the environment.

The disposal of PCBs was not regulated until the late 1970s, when studies started to show that these toxic compounds do not degrade readily in

When cesium-137–contaminated soil was mixed with chloride and heated, 99% of the radio-isotope was removed.

This simplified "spot test" can be performed at one-tenth the cost of the conventional laboratory method because it provides almost immediate results at the site of the PCB contamination.

Tuan Vo-Dinh demonstrates the simplified PCB spot test. The newly developed test uses strips of chemically treated paper that glow when exposed to ultraviolet light if the liquid sample coating the strip is contaminated with PCBs.

the environment and can cause adverse health effects. "PCB contamination is now one of the environment's most pressing global issues," Vo-Dinh says.

In the new test, a sample of material is applied to a paper test strip coated with special chemicals and then ultraviolet (UV) light is shone on it. If PCBs are present in the sample, the PCB molecules on the test strip retain the UV energy, interact with the chemicals, and glow. Such UV analysis has become increasingly popular in recent years. Examples of other spot tests that rely on luminescence and fluorescence include UV-reactive threads woven into currency to provide a means for identifying counterfeit bills or amusement park handstamps that show up only under UV light.

Previous phosphorescence tests relied on frozen samples because ordinary molecular movement in a room-temperature sample would dissipate UV energy and prevent the sample from glowing. Vo-Dinh's RTP and EPL methods use chemicals that stimulate light emission from the test strip, making it glow if PCBs are present.

This development was sponsored by DOE's Office of Environmental Technology Development and Office of Health and Environmental Research and by the Environmental Protection Agency's Environmental Monitoring Systems Laboratory at Las Vegas, Nevada.—*Travis Parman*

ORNL Physicists Find New Laser-Based Optical Effect

ORNL physicists have discovered a new laser-based optical effect, a phenomenon of light's interaction with matter, that provides an entirely new principle for several uses of laser technology.

The discovery, published in the June 1993 edition of *Physical Review Letters*, could lead to measurement methods tens to hundreds of times more accurate than those currently used for measuring gas concentrations in mixtures. The effect also could be used in enriching materials with rare isotopes by relatively inexpensive lasers instead of traditional mass spectrometry. Another application could be laser control of certain chemical reactions, creating a "laser-induced catalyst."

"What we have done is reveal new ways in which the characteristic emissions and absorptions of light by atoms and molecules can be greatly modified," says W. Ray Garrett, a senior research scientist in ORNL's Health Sciences Research Division.

Garrett explains that normal emissions occur in characteristic, sharply defined "colors," or spectra, that distinctly identify the chemical species that are present. "Until now, scientists could do little to change these emitted colors, although color shifts have been observed in the stars. But the newly discovered effect can, with proper laser setup, produce big changes in the emissions," he says.

When the laser beam strikes and excites a gas sample in a particular type of excitation mode, a shift in wavelength (change in color) is observed in the reemitted light for the specific chemical being analyzed. The amount of this color change, which is easily measured, provides researchers with an accurate analysis of the sample because it is directly and linearly proportional to the concentration of the gas species being measured and independent of the intensity of the exciting laser.

The phenomenon is free of the normal masking effects of other gases present, revealing the presence and concentration of a given chemical, independent of other components in the sample. "That advantage over existing technology," Garrett says, "could greatly improve accuracy during remote measurement of chemical concentrations in a vapor plume from an exhaust vent, smokestack, or leaky container." Experimental results have been obtained for metal vapors and for noble gases in exact agreement with theoretical predictions.

Garrett says the underlying physics of the discovery at ORNL is "part of the burgeoning field of nonlinear optics," a field that embraces a variety of effects associated with the interaction of high-intensity laser light with matter in all of its forms—gases, liquids, solids, and plasmas.—*Brian Daly*

ORNL Scientists Win Three R&D 100 Awards

R&D magazine has cited three ORNL inventions among 1993's top 100 new technologies, bringing the total R&D 100 awards for Martin Marietta Energy Systems, Inc., to 82. Oak Ridge is still first among all DOE sites in the total number of R&D 100 awards.

The Energy Systems developers who have received a 1993 R&D 100 Award are Francois G. Pin of ORNL's Engineering Physics and Mathematics Division and Stephen M. Killough of the Robotics and Process Systems Division, for a new means of locomotion for wheeled vehicles; Peter Mazur, a cryobiologist in ORNL's Biology Division, for a new technique for deep-freezing fruit fly embryos for genetic research; and John Googin and Ben Davis, both of the Y-12 Plant, William Huxtable of Energy Systems' Central Engineering Services, and Alicia Compere and Bill Griffith, both of ORNL's Chemistry Division, for a new way to degrade chlorine bleach in industrial process streams.

New means of locomotion for wheeled vehicles. So often, an invention's success is a consequence of its elegant simplicity. So it is with the Omnidirectional Holonomic Platform (OHP). This new technology, developed by ORNL's Francois Pin and Stephen Killough, promises big improvements for wheeled devices such as motorized wheelchairs, factory and plant equipment, robots, and even household vacuum cleaners.

Conventional wheeled vehicles can't move in all directions from a given starting position while simultaneously rotating—a capability arising from a property known as holonomy. The OHP can do this. For this reason, some manufacturers say it may displace their existing wheel technology because it is much more efficient and dexterous.

Despite its weighty name, the OHP's basic structure and function are elementary. Its parts are easy to manufacture and assemble, yielding a readily accessible, low-cost item.

"This is not a complicated piece of equipment," says Pin, leader of the Autonomous Robotic Systems Group in ORNL's Engineering Physics and Mathematics Division. "That's what is so beautiful about it and what makes it so widely applicable."

For devices such as motorized wheelchairs, the virtue of holonomic motion will offer unprecedented mobility. Starts and stops for

Conventional wheeled vehicles can't move in all directions from a given starting position while simultaneously rotating.

Francois Pin and Stephen Killough demonstrate the Omnidirectional Holonomic Platform, which promises big improvements for wheeled devices such as motorized wheelchairs, factory and plant equipment, robots, and even household vacuum cleaners. The ORNL device can do what conventional wheeled vehicles are unable to do—move in all directions from a starting position while spinning.

The first applications of the OHP may be for autonomous robots used for inspecting crowded and reach-restricted spaces in factories and plants.

changing direction will be eliminated, and getting into tight quarters will be easier. Similarly, on the factory floor, transport vehicles such as forklifts and wheeled carts stand to gain exceptional dexterity, saving both time and trouble.

The platform is a disk approximately a meter (3 feet) in diameter that sits on a Y-shaped rolling system. Unique wheel assemblies and their individual motors make up the three arms of the "Y." The wheels have very little hub area with an almost completely spherical rolling surface. In appearance, they resemble croquet balls that have had an inch sliced off each side. Each arm of the Y-shaped rolling system has a set of two wheels that are either side-by-side (perpendicular to the arm) or end-to-end (in line with the arm) and at 90° angles to one another. This clever configuration allows the whole contraption to move about holonomically.

"This is the big advantage of this type of system," says Killough. "It offers exceptional mobility and precision." Until now, nobody has been able to devise a wheeled platform or conveyor-type system to master this movement without using wheels that require steering.

The OHP owes its deftness to the 90° angle wheel assemblies and the innovative computer technology developed at ORNL that controls them. "We didn't reinvent the wheel," Pin says, "We found a smart way of controlling several of them."

By appropriately combining the speed of the three motors that drive the wheels, the computer's program controls the platform and permits its unique means of locomotion. It can be teleoperated using a joystick control, or it can move about autonomously using sensors to avoid obstacles.

The first applications of the OHP may be for autonomous robots used for inspecting crowded and reach-restricted spaces in factories and plants. "Robotics manufacturers with whom we have spoken see this as an attractive alternative to the current wheel technology, particularly when simultaneous rotational and translational motions (in a straight line) of the robot are required," Pin says.

"We can instantly take off in a new direction or spin around without stopping to steer the wheels," Killough adds, "and can maneuver very precisely in a minimal amount of space."

Other promising applications include autonomous transport vehicles in warehouses, outdoor vehicles, construction equipment, and maybe even home vacuum cleaners. Groupings of the wheel assemblies (when pointed up) could serve as an improved conveyor belt on which objects can be smoothly transported, manipulated for precise machining, and loaded as cargo where

minimal shear or strain on the object being carried is desired.

Research on the OHP was supported by DOE's Office of Basic Energy Sciences and was carried out in ORNL's Center for Engineering Systems Advanced Research.

Freezing fruit flies for future research. Millions of dollars could be saved each year through use of a new technique for deep-freezing fruit fly embryos for genetic research, developed by ORNL biologists Peter Mazur in cooperation with University of Chicago scientists.

The new method can preserve embryos for an estimated 1000 years and hatch 20% of the thawed embryos into fertile adult flies. Attempts to freeze, thaw, and hatch fruit flies had been unsuccessful before 1990.

Mazur, a Martin Marietta Energy Systems Corporate Fellow and senior staff biologist in ORNL's Biology Division, says that cryopreservation—preservation through the use of extremely low temperatures—also could reduce research costs and ensure a more genetically consistent stock of the flies for future study.

Biologist Kenneth Cole reaches into a box containing 40,000 fruit flies as biologist Peter Mazur looks on. Mazur has made a breakthrough by freezing, thawing, and hatching fruit fly embryos.

"As it stands now, thousands of genetic strains of fruit flies must be maintained through constant breeding about every two weeks," Mazur says. "That runs into millions of dollars each year and poses the risk of not being able to maintain a stock that is genetically pure over time."

Since the early 1900s, geneticists have been enthusiastic about the fruit fly's usefulness for research. Because of its genetic likeness to the human genome (the whole of an organism's genetic information), the fly's genome has been listed as one of the five most significant genomes to be sequenced as part of the worldwide Human Genome Project. Sequencing involves identifying and putting into sequential order the genetic building blocks of DNA at the most fundamental level.

The *Drosophila* fly (scientific name for the fruit fly) has several attractive qualities: It flourishes in a laboratory setting, its chromosomes are often large enough in size to be easily seen through a microscope even at the larval stage, and, particularly appealing to geneticists, it has only a 10-day life cycle.

"This short lifespan makes it relatively easy to study genetic mutations throughout many generations," Mazur explains. However, he adds,

The new method can preserve embryos for an estimated 1000 years and hatch 20% of the thawed embryos into fertile adult flies.

the drawback to such a short lifetime is the need to constantly breed the flies to maintain sufficient laboratory stocks—an expensive and risky proposition.

Maintaining a single stock costs roughly $200 a year, and 10,000 to 30,000 different genetic stocks are now being maintained. The major risk is "genetic drift"—spontaneous changes in the organism's genetic blueprint that can occur from generation to generation. "And," says Mazur, "there always exists the possibility of flies being incorrectly labeled. Such mistakes could contaminate the stock."

Compounding the ordeal of keeping thousands of stocks of fruit flies is the frustrating fact that only about 20% of them are in use at any given time. The remaining 80% must be maintained, though, because they are either a testament of past research or the topic of future studies.

Given 15,000 stocks of fruit flies, cryogenic preservation of the 80% not in use could save a conservatively estimated $2.4 million a year. The amount rises to $6 million per year if all 30,000 stocks were frozen.

For decades, scientists have searched in vain for an effective method for deep-freezing fruit fly embryos without damaging them, but the eggs' high sensitivity to cold has foiled most every attempt. The eggs also are shrouded in a protective, waxy membrane that resists water and other solutions used in the cryogenic process.

"Peter Steponkus was actually the first to achieve some amount of success in 1990 in preserving *Drosophila* cryogenically," Mazur says, pointing out that the Cornell University scientist's research laid the foundation for successful cryopreservation of the organism.

But on average, only about 0.5% of Steponkus' cryopreserved embryos were able to develop into adult fruit flies (see photo above). Mazur's 20% recovery rate represents a 40-fold improvement. Steponkus has recently reported still further improvement.

Mazur and his ORNL research team, in consultation with *Drosophila* expert Anthony P. Mahowald at the University of Chicago, identified critical steps in the freeze-thaw process to realize the impressive results.

When the eggs are about an hour old, the researchers wash them, then put them in a bath of cool water overnight to slow their growth rate. The next morning, they remove the eggs from the cool-water bath and then use bleach, alcohol, and a gasoline-like liquid called heptane to remove the two membranes that coat the eggs.

Once the coating has been removed and the embryos are permeable, a solution of ethylene glycol is introduced into the cells of the eggs. "The ethylene glycol is similar to a concentrated form of antifreeze," Mazur says. It is used to protect the embryos from fatally freezing when they are plunged into a thermos of liquid nitrogen slush.

In an instant, the embryos are frozen at about –205°C. The ethylene glycol, instead of crystallizing like ice, vitrifies into a glasslike substance, and the eggs are preserved.

"This rapid freezing actually outraces the chilling effect that normally would kill the eggs," Mazur says. "When we thaw the embryos, we have to do it at an equally rapid pace."

Mazur's work was initially funded by the National Science Foundation (NSF). He is now continuing to study cryopreservation techniques for mosquitoes through the support of NSF and DOE's Office of Health and Environmental Research.

Breaking down bleach in waste streams. Martin Marietta Energy Systems researchers have invented a new way to break down hypochlorite, or chlorine bleach, in industrial waste streams. The new method is environmentally safe, and it costs less and is more effective than currently available chemical methods.

Chlorine ranks eighth in production among manufactured chemicals worldwide. It is used to make plastics, pharmaceuticals, paper, and agricultural products and to disinfect swimming pools, cooling towers, and drinking water.

Hypochlorite is a by-product or waste of many industrial and environmental processes that use chlorine.

To meet environmental standards, industrial firms making chlorine or chlorine-containing products must filter escaping chlorine gas through a caustic scrubber. This treatment produces sodium hypochlorite (NaOCl), which can kill fish and other aquatic life when discharged to lakes and rivers.

Energy Systems developers of a new way to degrade chlorine bleach in industrial process streams are, from left, John Googin, Bill Griffith, Ben Davis, Alicia Compere, and William Huxtable.

Researchers have invented a new way to break down chlorine bleach in industrial waste streams.

The new hypochlorite degradation process, patented by DOE, was invented by researchers from ORNL and the Y-12 Plant. The process was originally developed to break down sodium hypochlorite in Y-12 Plant waste streams. The waste hypochlorite was produced by scrubber treatment of chlorine released in the electrolytic separation of lithium from chlorine in the feed material, lithium chloride. This material has been used in the production of lithium metal for nuclear weapons.

(The hypochlorite treatment process is not used at the Y-12 Plant because of a beneficial arrangement in which waste liquids containing sodium hypochlorite are loaded in tanks in Oak Ridge and delivered by truck to a Knoxville sewage plant. This facility uses the waste as a source of chlorine for sewage treatment. However, the new process is an alternative solution.)

R&D Solutions, a company based in Oak Ridge, obtained a license for the process from DOE. The catalyst used in the process is manufactured for R&D Solutions by United Catalyst, Inc., of Louisville, Kentucky. Personnel from Martin Marietta, R&D Solutions, and United Catalyst received an R&D 100 Award for the chlorine removal technology. Besides Energy Systems researchers Googin, Davis, Huxtable, Compere, and Griffith, other winners were Chet Thornton of ORNL's Plant and Equipment Division, who is president of R&D Solutions, and other ORNL staff members who also work for R&D Solutions—Bob Walker of the Health Sciences Research Division, Arnold Beal of the Instrumentation and Controls Division, Deborah Davidson of the Chemical Technology Division, and Scott Beck of the Plant and Equipment Division.

According to R&D Solutions, the new process can reduce 26,500 parts per million (ppm) of chlorine bleach in a waste stream to less than 0.1 ppm in minutes. Using a catalyst invented by Compere, Griffith, and Huxtable, the process simply converts a toxic waste stream containing chlorine bleach into a harmless one containing recyclable oxygen and salt. Furthermore, the catalyst lasts for many months before becoming inactive, compared to just a few days with others.—*Wayne Scarbrough and Carolyn Kraus*

ORNL Robot Licensed to REMOTEC, Inc.

Traditional robots with wheels or tank-like tracks can't climb vertically-oriented pipes or make sharp turns. The PNEU-WORM does so with dexterity.

Don Box (right) of ORNL holds the PNEU-WORM robot he invented to help inspect pipe interiors. Checking it is Howard Harvey, vice president of REMOTEC, Inc., a robotics manufacturer in Oak Ridge. Energy Systems recently signed a licensing agreement with REMOTEC, granting the robotics firm the right to manufacture and market the ORNL robot.

An Oak Ridge firm may soon be manufacturing and marketing an ORNL-developed robot that can easily inspect pipes for leaks, obstructions, and corrosion. Martin Marietta Energy Systems, Inc., has signed a licensing agreement that grants commercial rights to the patented robotics technology to REMOTEC, Inc., a robotics manufacturer based in Oak Ridge.

Don Box, a development engineer in ORNL's Chemical Technology Division, invented a robot now called PNEU-WORM that can more easily move around the insides of pipelines, tanks, and other tight places that require inspection. REMOTEC officials say the robot's design and action offers unprecedented inspection capabilities for difficult-to-access areas.

Common to industrial plants and municipalities are thousands of feet of pipeline that periodically requires inspection. The ducts of commercial air-conditioning systems are also subject to inspection, but like many pipelines, they may be too small to accommodate workers.

Box has considerable experience inspecting pipelines and underground tanks at the Laboratory. Realizing that existing robots as well as humans have problems maneuvering in these cramped areas, he invented the new robot.

"Traditional robots with wheels or tank-like tracks can't climb vertically oriented pipes or make sharp turns," Box explains. "PNEU-WORM does so with dexterity that is amazingly true to its namesake."

Its "head" and "tail" are metal disks, each fitted with an inflatable bladder around its circumference like an inner tube on a bicycle wheel. Three flexible rubber hoses that act as bellows connect the disks and serve as the Inchworm's "body." Two inexpensive pumps

provide air pressure and vacuum to the bladders and hoses. Air lines are bound together in a single umbilical cord that trails the unit as it explores pipelines.

For the unit to go forward, the tail bladder is pressurized so it expands to grip the wall of the pipe while the head bladder remains deflated. When air pressure is applied to the three connecting "body" hoses, the head is pushed forward (or upward) through the pipe. Next, the head bladder is inflated to grip the pipe, the tail bladder is deflated to release its grip, and the hoses are vacuumed, drawing the tail forward.

Repeating this sequence sends the robot crawling through the pipe in a motion reminiscent of an inchworm. To make a 90° turn, two of the "body" hoses are vacuumed while the third is pressurized, causing the device to turn in the direction of the vacuumed hoses.

Box's demonstration model is about 0.3 meters (1 foot) long and 10 centimeters (4 inches) in diameter. It moves through pipes at a rate of about 9 meters (30 feet) per minute.

Tiny lights and a miniature high-definition camera in the robot's headpiece allow the operator to monitor what's ahead in the pipeline and to easily spot leaks, obstructions, or corrosion. PNEU-WORM can be operated using switches that control each function, or it can take commands from joystick-controlled computer software.

"And there are many possibilities with regard to what can be added to the unit based on specific needs," Box said. For instance, sensors can be added to detect the properties of liquids or air in a pipeline, and added tubing or collection scoops can be used to draw samples for laboratory analysis."

John White, REMOTEC's founder and president, calls the partnership with Energy Systems a perfect match. "We know there's a market for PNEU-WORM," he says. "It's very cleverly designed, it's been patented, and we're in the business of robots," he says. REMOTEC officials said they foresee an increase in employment to make production of the PNEU-WORM robot possible. They expect to add personnel for marketing and production and for field representatives.

REMOTEC robots were used to gather unexploded ordnance following Operation Desert Storm and are popular among many big-city police departments for use with bomb squads and hostage crises. REMOTEC is a subsidiary of Westinghouse Electric Corporation.

The first commercial uses for PNEU-WORM, says REMOTEC Vice President Howard Harvey, may be for inspecting pipelines at nuclear power plants. "But any other type of pipeline is applicable," he says. "We have several ideas for making it even more universal."

The robot was even used by ORNL environmental scientists to explore abandoned kingfisher nests. Kingfishers are birds that build their nests in muddy river banks. The invention earned Box the 1992 International Inventor's Forum Award for robotics.—*Wayne Scarbrough*

The first commercial uses for PNEU-WORM may be for inspecting pipelines at nuclear power plants.

Radon Detectors Sense Uranium Contamination

Like fleas on a dog, uranium and plutonium can be present on a surface and yet be difficult to detect. These hazardous elements can lurk on irregular surfaces, in wall cracks and crevices between floor tiles, inside pipes and tubes, under tight-fitting furnishings, and at or below soil surfaces.

At ORNL researchers are modifying and evaluating commercially available radon detectors for use in mapping uranium and plutonium concentrations in soils and on building surfaces, such as floors, ceilings, walls, and window ledges.

"Use of these detectors is being evaluated as a potential low-cost alternative to conventional radiation surveys," says Richard Gammage, who is leading the effort at ORNL. The work is being done under cooperative research and development agreements (CRADAs) between Martin Marietta Energy Systems, Inc., and two manufacturers of different types of radon detectors.

The two CRADAs involve personnel from the Measurement Systems Research Group (led by Gammage) in ORNL's Health Sciences Research Division. The two manufacturers of two different types of radon detectors are Rad

One approach to detecting radioactive contamination in inaccessible places is to use commercial plastic detectors of indoor radon.

Dick Gammage records Kevin Meyer's readings of electret detector voltages from an electrometer during field studies at the Nevada Test Site. The plastic detectors (the small black cylinders in the photograph) measure alpha emissions from plutonium-contaminated soil. The work is being done as part of a CRADA with Rad Elec, Inc.

Elec, Inc., of Frederick, Maryland, manufacturer of electret ionization chambers, and Landauer, Inc., of Glenwood, Illinois, manufacturer of alpha-track detectors.

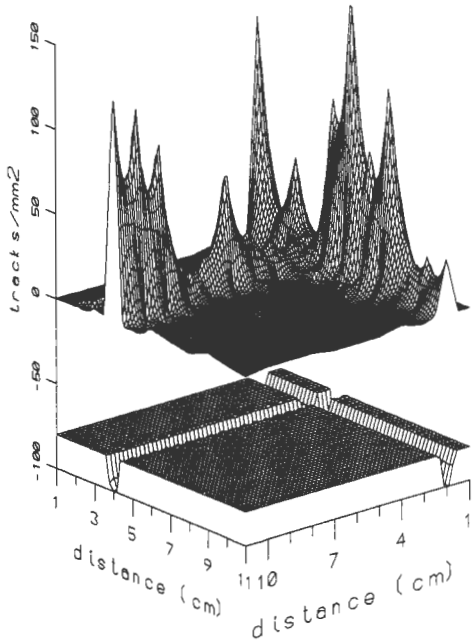
CRADAs are designed to foster cooperative research between industry and government laboratories by offering private firms advantageous rights to patents and other intellectual property from the joint research, trade-secret-like protection of joint data, and streamlined government approval of the agreement. The chief goal of CRADAs is to improve the nation's competitive position in the world marketplace.

One approach to detecting radioactive contamination in inaccessible places is to use commercial plastic detectors of indoor radon. Available as disks or thin sheets that can easily be held between the index finger and thumb, they are inexpensive, simple, and able to detect alpha particles, the radiation given off by the decay products of radon as well as by fissionable uranium and plutonium. Detectors made of thin plastic sheets are particularly attractive because they can be cut into pieces of various sizes and shapes to make them fit into tight or inaccessible places.

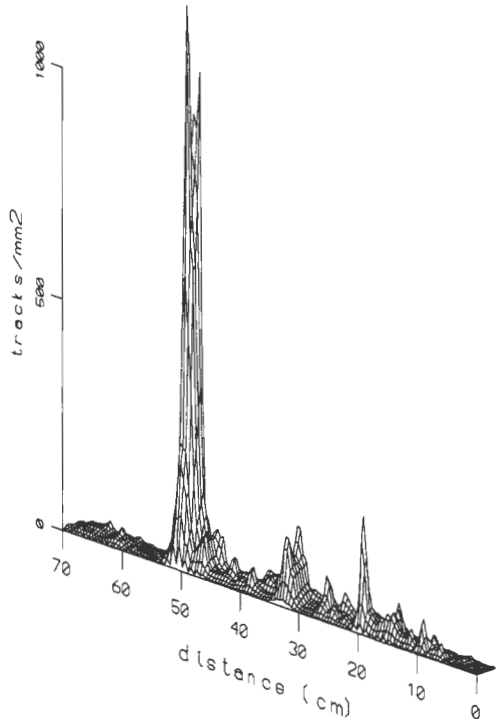
Rad Elec's electret ionization chamber operates on the principle that ions are formed in air by the presence of alpha particles. The device consists of a disk of charged Teflon attached to a chamber made of conducting plastic, creating a simple, passive ionization chamber. The static charge on the electret detector attracts the negatively charged ions generated by alpha particles entering the chamber volume. The collected ions reduce the disk surface charge.

The change in the disk surface charge before and after the detector was deployed is determined by comparing surface voltage measurements using a hand-held electrometer. Because the voltage change is proportional to the number of alpha particles in the chamber volume during the exposure time, it indicates the concentration of surface alpha emitters in that location.

Gammage, Kevin Meyer, Charles Dudney, and other ORNL researchers have shown that a number of Rad Elec's electret ionization chambers deployed on a large site can be used to generate a map of relative uranium contamination in soil. They demonstrated this capability recently on a field 240 meters by 540 meters that is contaminated with low levels of uranium at the Fernald Environmental Management Project in Ohio. Similar demonstrations have been carried out at a Nevada Test Site area that is



Damage tracks in plastic radon detectors plotted on a three-dimensional graph show relative alpha contamination on a tile floor and in the crevices between the tiles.



Damage tracks in plastic radon detectors plotted on a three-dimensional graph show relative alpha contamination along a narrow difficult-to-access ledge.

Alpha-track detectors can be cut or formed to suit a particular use.

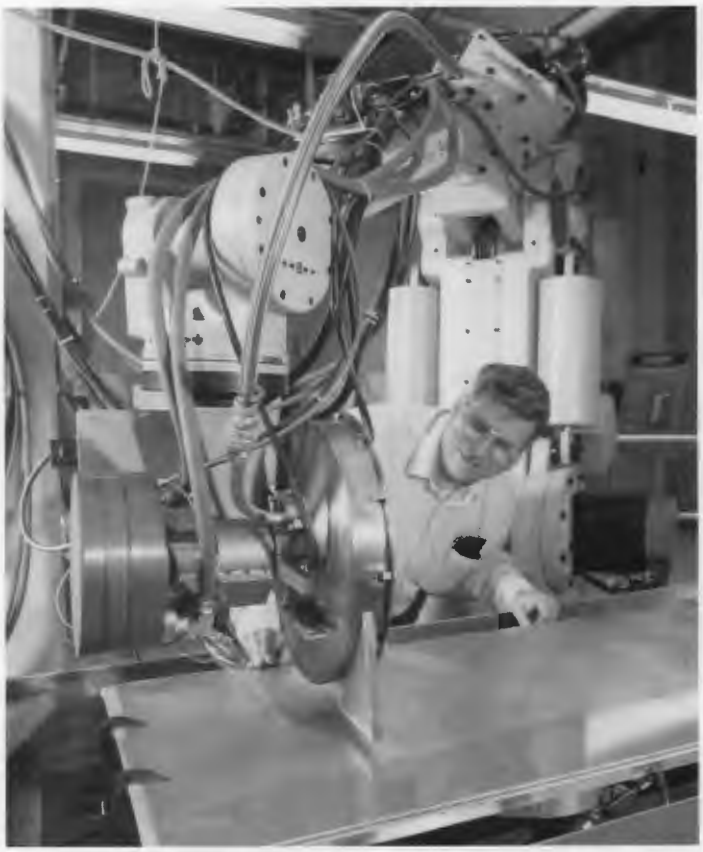
contaminated with isotopes of plutonium and americium. The purposes of these in situ measurements are to demonstrate the field screening capabilities of plastic radon detectors at contaminated sites and to verify the effectiveness of remediation efforts.

The ORNL researchers also have tested alpha-track detectors made by Landauer, Inc., for measuring uranium and plutonium concentrations in soils and on building surfaces. Each detector consists of a clear plastic sheet about 1 millimeter thick. When struck by alpha particles, localized microscopic damage forms in the crystalline structure of the plastic. When etched in an appropriate caustic solution, these defects in the chemical bonds, or tracks, become visible as etch pits. These pits can be counted under an optical microscope for use in calculating alpha particle track density.

Such alpha-track detectors can be cut or formed to suit a particular use. In 1993 at the Nevada Test Site, ORNL researchers drove wooden stakes into the ground, forming narrow holes 20 centimeters (8 inches) deep. Then they inserted long narrow strips of the plastic material into the holes to obtain a depth profile of plutonium contamination before cleanup. The same procedure will be used after cleanup to verify that the plutonium levels have been reduced to environmentally acceptable levels.

These detectors were also used to measure transuranic contamination along narrow ledges and in crevices between vinyl floor tiles under a glove box at ORNL. By using a computer to plot the number of damage tracks on three-dimensional graphs, the ORNL researchers could pinpoint the most radioactive spots in these inaccessible places (see graphs above).

The advantage of ORNL's cryoblasting technique for cleaning surfaces is that it does not leave a waste stream requiring additional cleanup.



Chris Foster checks the robot-compatible cryoblaster that he and Paul Fisher are developing for stripping paint from military aircraft. The device consists of a centrifugal accelerator that blasts dry-ice pellets (through the triangular unit) against a metal panel to remove paint. Energy Systems has licensed the technology to Cryogenic Applications F, Inc., of which Foster is president.

In addition to soils, floor tiles, outdoor loading docks and other concrete areas, ORNL researchers will be testing alpha-track detectors for measuring alpha contamination at the Oak Ridge K-25 Site, particularly in less accessible areas such as piping; valves; diffusers; gas compressors; and electrical, ventilation, and cooling systems. Targets for measurement at ORNL will include the Molten Salt Reactor and the storage tanks and transfer canal of the Graphite Reactor. It is hoped that this simple approach will "sniff" out hidden radioactive contamination more effectively than combing a dog's fur for fleas.—*Carolyn Krause*

Frozen Gas Pellet Blasting Licensed

An ORNL scientist who developed a technology for refueling experimental fusion energy devices and then adapted it for cleaning surfaces has received the right to manufacture and sell it for profit.

Energy Systems has signed a licensing agreement with Cryogenic Applications F, Inc., of Clinton, Tennessee, whose president is ORNL's Christopher A. Foster. The Clinton company has been granted the right to further develop and market an environmentally safe ORNL technology for surface cleaning. Specifically, it will be used to remove paint and radioactive contamination from surfaces by blasting them with pellets of frozen gases. The cleaning technology may replace the practice of washing parts with chlorine-containing solvents, which pollute groundwater and destroy Earth's protective ozone layer.

ORNL scientists Foster and Paul Fisher developed the cryoblasting process in conjunction with the Y-12 Plant. They are conducting a project for the U.S. Air Force at the Warner Robins Air Logistics Center (at Robins Air Force Base in Georgia) to develop a robot-compatible cryoblaster for stripping paint from military aircraft. Paint is removed so metal parts can be inspected for cracks and corrosion to determine if they can be placed back into service. As staff scientists with ORNL's Fusion Energy Division, Foster and Fisher hope to demonstrate to the Air Force that their cryoblasting process for stripping paint from aircraft is potentially faster, more efficient, and cleaner than other techniques.

A nonexclusive patent license agreement has also been made with Alpheus Cleaning Technologies Corporation of Rancho Cucamonga,

California, for commercial use of the cryoblasting process technologies.

The licensed technologies include a method of freezing carbon dioxide and argon gases into pellets and a pellet-blasting centrifugal accelerator with an improved rotor and housing. Foster originally developed a centrifugal accelerator to fire pellets of frozen hydrogen gases (deuterium and tritium) into hydrogen plasmas to refuel fusion devices. One such centrifugal injector, which uses a high-speed wheel to accelerate the frozen pellets before injecting them into the plasma center, is used to refuel the Tore Supra tokamak in France.

"The advantage of the cryoblasting technique over conventional techniques for cleaning surfaces is that it does not leave a waste stream requiring additional cleanup," Foster says. "In cryoblasting, the frozen pellets evaporate into harmless gases, and the contaminants freed from the surface can be sucked from the air by vacuum systems with high-efficiency particulate absorbent filters."

The usual procedure for removing aircraft paint has been to bathe the planes in methylene chloride. Because use of this solvent is being discouraged by the Environmental Protection Agency, ORNL-developed centrifugal technology for blasting carbon dioxide, or dry ice, pellets may be useful to the Air Force and similar customers.

"A paint-stripping technology that uses compressed air to propel dry ice pellets is on the market," Foster says. "But our technology strips paint at a higher rate."

Cryoblasting also may replace sandblasting because it doesn't leave a sand-contaminated waste stream. At the Y-12 Plant, cryoblasting using argon pellets is being developed as a replacement for iron-bead blasting for removing oxides from metal surfaces. Because it is inert, argon will not react with reactive metals. Unlike the iron beads, the argon pellets evaporate into the air and do not add to the solid waste stream.

Larry Dickens of Energy Systems' Office of Technology Transfer negotiated the nonexclusive patent license agreement with Cryogenic Applications F.

Lessons Learned from SEMATECH project

ORNL researchers have helped forge a tool for etching circuits on computer chips in collaboration with researchers from the University of Cincinnati (UC) and SEMATECH, a nationwide technology consortium of 11 semiconductor manufacturing companies headquartered in Austin, Texas. Development of the tool has resulted in improvements in two companies' products and provided valuable lessons, including an understanding of why no U.S.-manufactured etch tool based on this work is on the market.

ORNL researchers have helped forge a tool for etching circuits on computer chips.

The purpose of this project was to help continue the astounding advances in performance and capability of digital electronic systems and the very large-scale integrated circuits on which they depend. As a result of these advances, integrated circuits have become, in turn, large scale, very large scale, and now even ultralarge scale. Increasing numbers of circuits are being built into silicon chips, making computers more compact, faster, and able to store greater amounts of information.

For example, the 8-megahertz, 16-bit systems with 64-kilobyte memory chips in Apple Macintosh computers of the early 1980s have been replaced by 40-megahertz, 32-bit systems with 4-megabyte chips. The pace of this advance is expected to continue for at least another decade.

At the heart of this revolution is the ability to economically manufacture the devices that make up these complex circuits in ever-smaller dimensions. The transistors in today's integrated circuits measure 0.5 to 1 micron (millionth of a meter), but the goal is to reduce those dimensions to less than a quarter micron—smaller than the wavelength of blue light. Because tools that can produce these small dimensions do not exist, they must be developed to turn 8-inch wafers of silicon into tens of billions of transistors.

ORNL recently completed the first of several projects that are contributing to the development of needed processes and tools for manufacturing microchips. Researchers working in semiconductor manufacturing are in the Fusion

The SEMATECH project has had commercial and technological success.

Energy, Solid State, and Instrumentation and Controls divisions, among others. Their task is to work with the semiconductor industry to help the United States become more competitive in the world market for computer chips.

The first project, begun in 1989 with SEMATECH and UC, was announced in an Oak Ridge ceremony in which the late Robert Noyce, co-inventor of the microchip and then SEMATECH chief executive officer, presented then Senator Albert Gore, Jr. (now vice president of the United States) with one of the first silicon wafers produced by SEMATECH. The project began after SEMATECH approached ORNL and UC with a proposal to combine the organizations' expertise to produce a silicon etch tool that could create circuit devices as small as a third of a micron.

ORNL's Fusion Energy Division had long been developing and using electron cyclotron resonance (ECR) heating for producing and heating plasmas in magnetic fusion devices. In 1987, in conjunction with the Solid State Division, it had begun a project supported by the Director's R&D Fund to adapt this technology to deposition of thin films. Tom Mantei of UC had also been applying this technique to materials processing.

Mantei, SEMATECH researchers, Lee Berry of ORNL's Fusion Energy Division, and Steve Gorbatkin of ORNL's Solid State Division worked together for two years on this project. In that time they developed a tool for heating and controlling plasmas (ions and electrons in a hot gas) to etch circuits in silicon wafers. They and their SEMATECH colleagues assembled three processing systems, each worth about $500,000; evaluated three different systems configurations; and in their research produced etch results that were competitive with the world's best. However, the project was unsuccessful in getting an American vendor to use the research results to develop a commercial chip-processing tool.

The project did have commercial success from the standpoint of two small businesses that were involved in it. ASTeX of Woburn, Massachusetts, supplied the microwave, magnet, and plasma chamber components for the research etch tool, and Plasma Quest of Richardson, Texas, added controls, wafer handling, and vacuum and process gas systems. Both companies are selling components and systems that have been improved as a result of the project's research.

The project also has had technological success in that its results have been used by Berry, Gorbatkin, Gary Henkel, Rob Rhoades, and others in the Solid State and Fusion Energy divisions in their work with IBM under a cooperative research and development agreement (CRADA). The goal of this CRADA is to find ways to deposit conducting films that connect devices in an integrated circuit.

What lessons have been learned from the SEMATECH project? According to Berry, "First, we learned that meeting a schedule is more important in the commercial world than in the research world. Unless we got our results out in time for a U.S. vendor to get a product on the market before its competitors, the market for our product would likely be lost. The drive to meet real objectives on time sparked a spirited effort by the industry-laboratory-university team that may have resembled the way it was in the old Manhattan Project days at Oak Ridge."

Second, research priorities were focused on a marketable product. "We expected that research on interesting problems that did not move the project forward was inappropriate," Berry says. "We did very little work in areas that would have improved our ability to develop successive generations of etch tools. The surprise was that taking risks in the hope of improving the schedule was encouraged."

Gorbatkin notes that the approach to experimentation was different in the project than it is in many research studies. "Often, variables are systematically manipulated individually, with all others held constant, to gain an understanding of a physical process," he says. "In the SEMATECH project, we conducted experiments in which more than one variable changed from run to run. A statistical approach was emphasized in determining the most efficient method of achieving the desired results. To guide us, a statistician was assigned to the project, and we were given courses in experiment design and

analysis. Industry may well be the leader in the use of systematic, statistically based, experimental techniques."

The third lesson, Berry says, is the importance of industry pull—recognizing a need for a product and choosing the technology that will make the product competitive. "It was unanimously agreed by U.S. semiconductor companies that advanced etch technology is needed," he explains, "but it was not agreed that the etch tool should be based on ECR technology. Foreign companies were already introducing ECR tools, and, even if a U.S. tool could be produced and put on the market at about the same time, it would look too much like the foreign products to have a competitive edge. Thus, U.S. companies adopted the strategy of developing an etch tool based on a different technology—inductively driven plasma sources—instead of commercializing the ECR technology developed in the SEMATECH project."

What did industry learn from ORNL? "We believe we demonstrated that we could successfully work as a team with industry and university collaborators in a tightly focused, applied project," Gorbatkin says. "Our work maintained a high standard of excellence and drew on a broad range of skills from across the Laboratory. This belief is validated by current ORNL projects in semiconductor manufacturing."

ORNL in CRADA with General Motors

Energy Systems, Inc., has entered into a CRADA with the AC Rochester Division of General Motors Corporation to improve vehicle emission-control catalysts and systems for conventional and alternative-fuel vehicles.

Researchers at ORNL will develop materials and manufacturing processes that will help General Motors meet more stringent emission standards requiring improved catalyst efficiency and longer usage.

Under the joint agreement, emission-control catalysts and systems will be developed to help General Motors further improve vehicle fuel economy and alternative fuel capabilities, making the United States less dependent upon foreign oil.

Another objective of the agreement is to reduce the company's use of precious metals such as platinum, palladium, and rhodium, which also should reduce dependence on foreign sources.

Researchers will use sophisticated spectrographic techniques to study mechanisms that cause emission-control catalysts to become ineffective. ORNL engineers will conduct tests to evaluate new catalysts using flow reactors and multicylinder engines and exhaust systems that include catalytic converters provided by AC Rochester. Engines already have been sent to Oak Ridge by General Motors. Final road tests will be performed by General Motors.

AC Rochester is the world's largest manufacturer of automotive catalytic converters, and ORNL has a strong reputation in materials research, coupled with engineering research experience in automotive fuels and engines.

The CRADA, which is expected to achieve desired results by October 1995, is being funded by DOE's Office of Industrial Technologies, Advanced Industrial Concepts Division, and the Office of Transportation Technologies.

ORNL will develop materials and manufacturing processes that will help General Motors meet more stringent emission standards.

Supercomputing Program Picks Three More Schools in Tennessee

Three more high schools from Tennessee have been selected by DOE to participate in an ongoing supercomputing program.

The program, "Adventures in Supercomputing" (AiS), is designed to cultivate the interest of women, minority, and disadvantaged high school students in the subjects of science, mathematics, and computing. DOE funds the program, which is implemented at host sites, including ORNL, Ames Laboratory, Sandia National Laboratories, Colorado State University, and the University of Alabama, Huntsville.

ORNL's Adventures in Supercomputing program aims to make science, mathematics, and computing more exciting for both students and their teachers.

"The program is very refreshing. It gives the teachers a way to get out of the 'same ole, same ole' teaching routine."

The AiS selection board in Tennessee picked Humboldt High School, Loretto High School, and Maplewood Comprehensive High School to join the 12 Tennessee schools already participating in the program.

Participating schools from the East Tennessee area include: Clinton High School, Horace Maynard High School, and Wartburg Central High School.

More than 70 schools from the five respective host states will be active in the program during the 1994-95 school year.

Requirements must be met before a school is eligible to apply. The application must be from a public school located within one of the five host states. The school must include at least some of the grades 9 through 12. A team of at least two teachers, including one science teacher, must participate. To involve students earlier, only middle schools that feed into already-participating high schools will be targeted next year.

The program provides each school with curriculum materials, high-speed network capabilities, supercomputing resources, continuing technical support, and computing equipment. Each school has access to a sophisticated computer network.

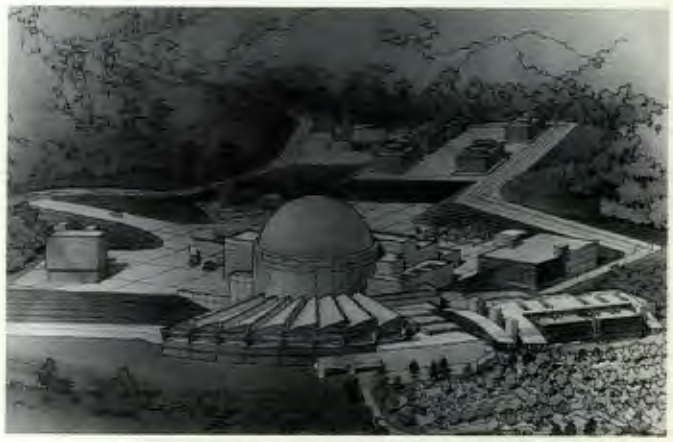
The program recommends that teachers establish a new course in computational science and supercomputing in the school or that they integrate the AiS curriculum material into existing science and mathematics classes, making the subjects more exciting for students.

"The program is very refreshing. It gives the teachers a way to get out of the 'same ole, same ole' teaching routine," Barbara Summers, AiS coordinator for ORNL, says.

The faculty team from each Tennessee school takes part in an intensive Summer Institute, scheduled for June 12–24, 1994, at ORNL. At the Institute, teachers will prepare to guide students in programming solutions to scientific problems. The Institute provides teachers with instructional materials for presenting introductory concepts in high-performance computing, scientific visualization software, and examples of the use of computational tools in modeling scientific problems. Teachers also develop a course outline and a course time line to help implement the AiS program at their schools.

During the school year, on-line communications among teachers, students, scientists, and college faculty help prevent the teachers from becoming isolated after they return to school. Newsletters, bulletin boards, and electronic mail facilitate this communication. Technical support personnel are available to troubleshoot hardware, software, and networking problems.—*Amy L. Jones*

NEXT ISSUE



The future benefits of the Advanced Neutron Source, a research reactor proposed for ORNL, are explored. A special section is devoted to ANS history, reactor technology developments, and medical and industrial applications.

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