Oak Ridge National Laboratory

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Waste Management's New Way of Doing Business

REVIEW

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Oak Ridge National Laboratory is a multiprogram, multipurpose laboratory that conducts research in the physical, chemical, and life sciences; in fusion, fission, and fossil energy; and in energy conservation and other energy-related technologies.

ON THE COVER

These photographs dramatically illustrate the difference between old and new ways of managing waste. See articles in this special issue on waste management and remedial action.

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WASTE MANAGEMENT AND REMEDIAL ACTION

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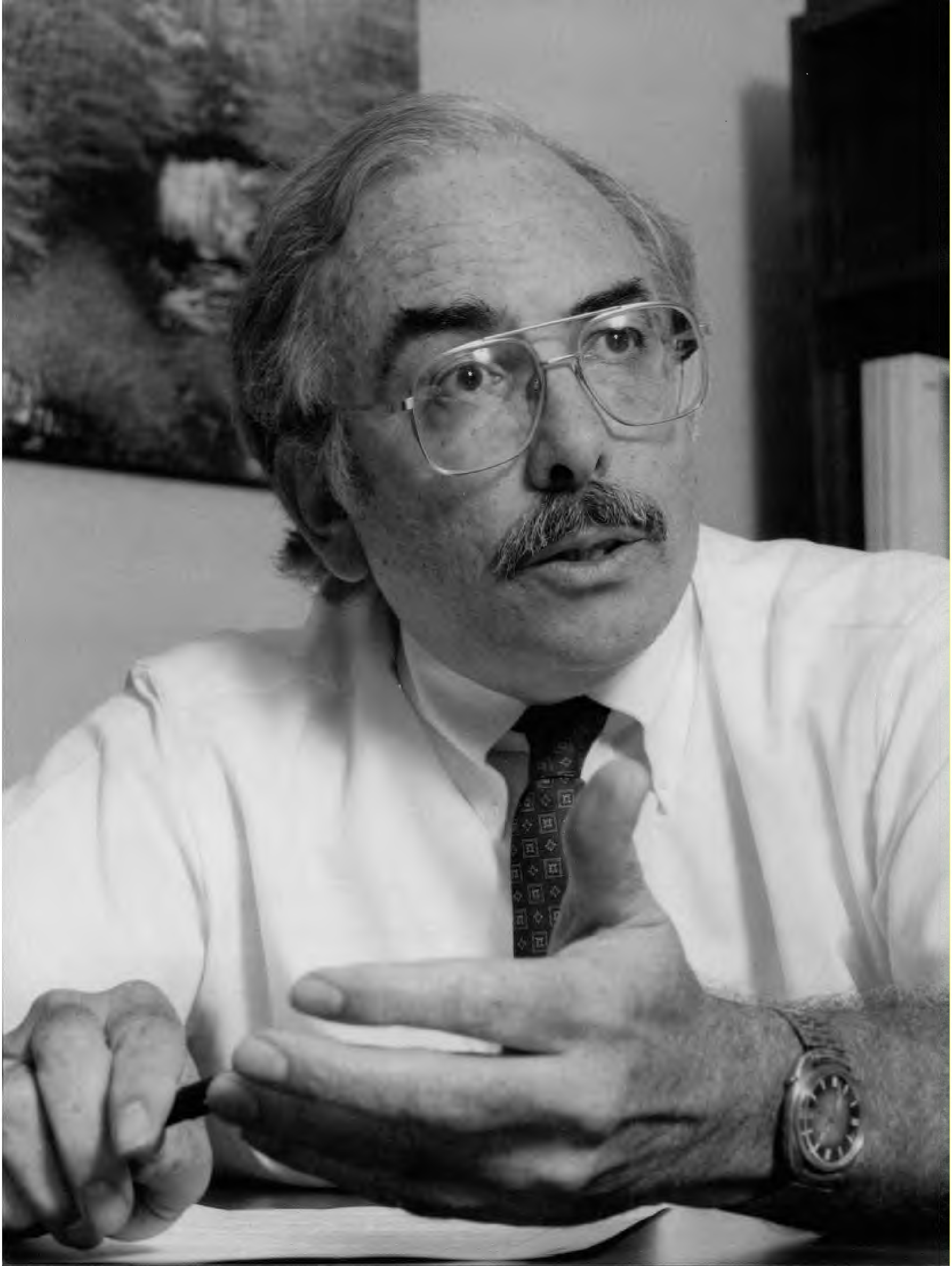


Waste Management—A New Way of Doing Business

*To obtain an overview of waste management at ORNL, the **Review** editors interviewed Tom Row, director of ORNL's Environmental and Health Protection Division.*

How does ORNL's new Environmental and Health Protection Division fit into the waste-management operations and remedial action efforts of the Department of Energy and Martin Marietta Energy Systems, Inc.? How does it interact with regulatory agencies?

The new division was established to bring ORNL's waste-management and remedial action functions together with the environmental compliance monitoring required. Combining these functions has worked well. Before the new division was formed, the process of interaction was inefficient. Consolidating these functions in one division is more efficient and facilitates the achievement of our common goal—to dispose of waste materials in the most environmentally acceptable manner with full protection for the employees involved, as well as the public.

As for working with regulators, we are responsible for developing the pollutant discharge permit applications sent through the line organization to DOE. Once the permits are approved, we have the responsibility for monitoring ORNL's effluents and ensuring that we are in compliance with the discharge limits set by the state of Tennessee and the Environmental Protection Agency.

How has your job changed since you moved from manager of ORNL's Nuclear Waste and Chemical Programs to director of the new Environmental and Health Protection Division?

Consolidating several different operations has required an additional amount of time on the job. The compensation is that I have enjoyed meeting new people and learning about my new responsibilities in the environmental compliance, industrial hygiene, and radiation protection and measurement areas of the division. We have talked about how we can apply new ideas and do the job better. The team I work with is superb; the members are full of enthusiasm and love new challenges. I try to expand the thinking of the group by asking questions that arise as I discuss their work. I don't interact as much with the engineers in the Chemical Technology Division as in the past when I had R&D responsibilities for waste management, but we are still in touch. The communication with other divisions has increased because of my technical safety appraisal responsibilities. My contacts with other plants, central staff, and Oak Ridge Operations are comparable.

What are the responsibilities and goals of the new division?

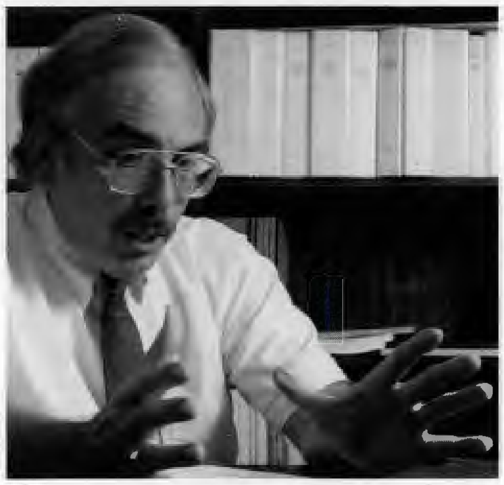
Our division manages the waste generated by operations and R&D activities to ensure the health and safety of all employees. I'm satisfied that we are making a significant effort, using good people to lead the way in achieving state-of-the-art waste management at ORNL. What I want to do in the rest of the division's effort—environmental compliance, radiation protection and measurement, and industrial hygiene—is to put in place the support that encourages a proactive system that addresses R&D and other needs.

"Our division manages the waste generated by operations and R&D activities to ensure the health and safety of all employees."

Are there any new regulations and policies that will affect plans for waste management and remedial actions at ORNL?

The reauthorization of the Price-Anderson Act has changed the world in which I, as a professional manager, can operate. It imposes on me a set of ground rules, the violation of which is a crime punishable by a fine or prison term. I am subject to criminal penalties if I do not manage programs and facilities in a manner acceptable and beneficial to the health and safety of

"Our charge-back policy, plus improvements in the efficiency of our evaporators, have reduced ORNL's concentrated low-level liquid wastes by nearly 80% in recent years."



employees. Previously, there was a corporate "umbrella" that protected me and other employees from such action. As Price-Anderson is now written, I am personally liable and must consider this aspect of my job very seriously. For example, in preparing a proposed budget, I must ask whether our budget requests will bring us in compliance with the law. Being an environmental manager today is a sobering experience because all of us are responsible for sound operations.

How will the new waste-minimization and "charge-back" policies affect current ORNL research and proposals for funding new research?

The waste-minimization activities have been positive for the Laboratory. They encourage personnel to avoid generating a large volume of waste, especially toxic waste. With the charge-back policies, we charge the user (waste generator) for the services required from ORNL's waste disposal facilities. In the past, waste disposal was paid by overhead. Charging disposal costs back to the user instead is a fairer policy, which has been suggested to others and is now being applied in laboratories all over the country. Our charge-back policy, plus improvements in the efficiency of our evaporators, have reduced ORNL's concentrated low-level liquid wastes by nearly 80% in recent years. R&D proposals now include waste disposal costs.

Doesn't this policy discourage needed research—for example, on the health effects of toxic materials—because that research might generate lots of toxic waste?

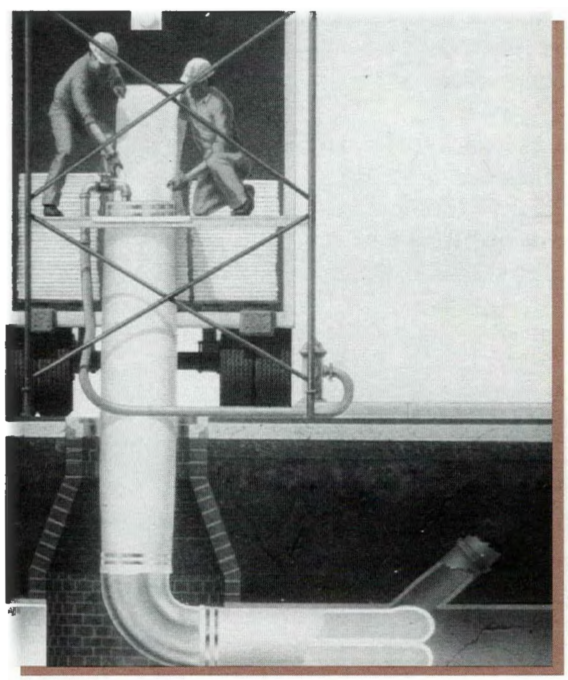
Waste-minimization forces researchers to examine their projects and consider using less-toxic or nonhazardous substitutes to get the answers they need. It's a new mentality, a cultural change. It's true that some good experiments are probably not being done now because of this waste policy, but the overall results, I think, are positive.

Recently, 15 trees in the center of the ORNL complex were cut down because they were

emitting radiation at above-normal levels. They were contaminated with cesium-137 and strontium-90 that leaked into the soil from pipes and tanks storing radioactive wastes disposed of years ago. Is the groundwater in this area also contaminated? Where does this contamination go as it leaves ORNL? What is being done about leaky pipes and tanks?

We certainly received a lot of attention when we cut the trees in the central plant area. The level of contamination was low, but we felt the tree removal was warranted. The tree leaves became radioactive when the root system reached down into the contaminated soil. This was not a surprise, because the region is known to be contaminated. The groundwater 6 to 10 ft deep in this area does encounter contamination.

Most of the water of concern that might leave the site here is recharge water—surface runoff and rain that percolates into the soil and transports some material out of the disposal zone. A representative area is SWSA 4 (a solid waste storage area south of Lagoon Road). Major remediation under way at SWSA 4 has focused on stopping water from flushing through the disposal site and carrying contamination to the creek, which leads to the Clinch River. Dale Huff and other ORNL geohydrologists advised the Laboratory to install an interceptor trench—a French drain—and a surface drain to collect all the recharge water coming from the hillside or else it would go under the road and into the soil. Now we intercept both surface and subsurface runoff, greatly reducing the radioactive material swept into the creek.



Leaks in some of ORNL's process-waste and sewage lines can be stopped using resin-impregnated liners installed by In Situ Form, Inc. (shown here). This process avoids the costly replacement of these leaky components.

The other piece of good news is that we have no evidence that ORNL has contaminated the aquifer used by the local populace as potable well water. The U.S. Geological Survey has studied the water pathways here and found that the water flow tends to resurface into small streams rather than move downward to the aquifer.

Leaky pipes and tanks are the results of this facility being built and rebuilt continuously from 1943 through today. Many of the facilities are over 20 years old. We have three major projects proposed that would replace leaky pipes and tanks in the Bethel Valley, Melton Valley, and Isotopes areas, where we must maintain low-level liquid waste (LLLW) services. Because we cannot afford to replace every pipe and tank, studies were done to assign priority to those that must be replaced. We plan selective replacement in these key areas with doubly contained pipes and tanks having built-in leak detectors.

Some of the process-waste and sewage lines that leak can be renovated with resin-impregnated liners installed by In Situ Form, Inc. This process has saved us millions of dollars by avoiding replacement of these leaky components, which include both steel and vitreous clay pipes.

How much recycling of wastes is ORNL doing? Could we be doing more in recycling the paper, glass, plastics, and metal cans used by employees?

We're doing a good job recycling chemicals by getting our excess chemicals transferred to people who can use them. In terms of general office trash generated by employees, we're probably not doing enough. The tradeoff there is that a significant amount of work remains to be done on better managing our radioactive and hazardous waste, which may have an effect on the health and safety of employees. Recycling our conventional waste, therefore, has lower priority. We dispose of these materials in our on-site landfill. Sorting this waste to allow can and bottle recycling will require a front-end investment. We would have to examine all general trash for possible contamination before it could be released to private firms for recycling. The economics will certainly be a factor in recycling success.

Are there any health hazards associated with emissions from the TSCA Incinerator at Oak Ridge Gaseous Diffusion Plant? Will there be toxic by-products such as dioxin? If so, how will these substances be safely disposed of?

The TSCA Incinerator will not present health hazards. It was designed so that its emissions are not hazardous to the health of employees or neighbors.

Polychlorinated biphenyls from ORNL and other sites are among the materials to be incinerated at the TSCA facility. Aren't the by-products of PCB combustion more toxic than the PCBs themselves?

If the combustion temperature is not correct, dioxin could be produced. Tests have shown that the TSCA Incinerator maintains operating conditions that efficiently destroy the PCBs. System instrumentation will monitor the process closely and automatically shut down the incinerator if correct conditions are not present.

Can you compare some of the old waste management practices and facilities for various types of waste with some of the new ways of handling them?

The Toxic Substances Control Act (TSCA) Incinerator at the Oak Ridge Gaseous Diffusion Plant is one of two DOE incinerators designed to dispose of hazardous wastes that contain radioactive materials (the other is at Los Alamos National Laboratory). About 5% of the wastes to be sent to the TSCA will come from ORNL.

Conventional wastes, such as paper, glass, plastic, metal cans, food scraps

This waste is still handled conventionally. Everything is collected and hauled to the landfill.

Low-level radioactively contaminated solid wastes such as contaminated glass, metals, rags, parts and equipment

Any solid low-level waste used to be minimally identified by record keepers and then loaded into boxes, bags, and cans that were dumped by truck into an unlined trench. Today, we receive drums of identified (pedigreed) radioactive waste and examine each one with a real-time radiography machine

Left:
In the past, bags and boxes of contaminated ORNL wastes were dumped in unlined trenches for burial.

Right:
Now, ORNL wastes are classified and isolated in engineered storage facilities.

to ensure that the material does not contain bottles of liquids or lead bricks or something we should reject. ORNL's divisions are carefully packaging their wastes these days, and we find few packages that should be rejected. The packaged material is further isolated from the environment by loading it into steel cans inside concrete vaults that are placed into buried silos or on a tumulus (concrete) pad having a monitored drainage system.

Liquid low-level wastes

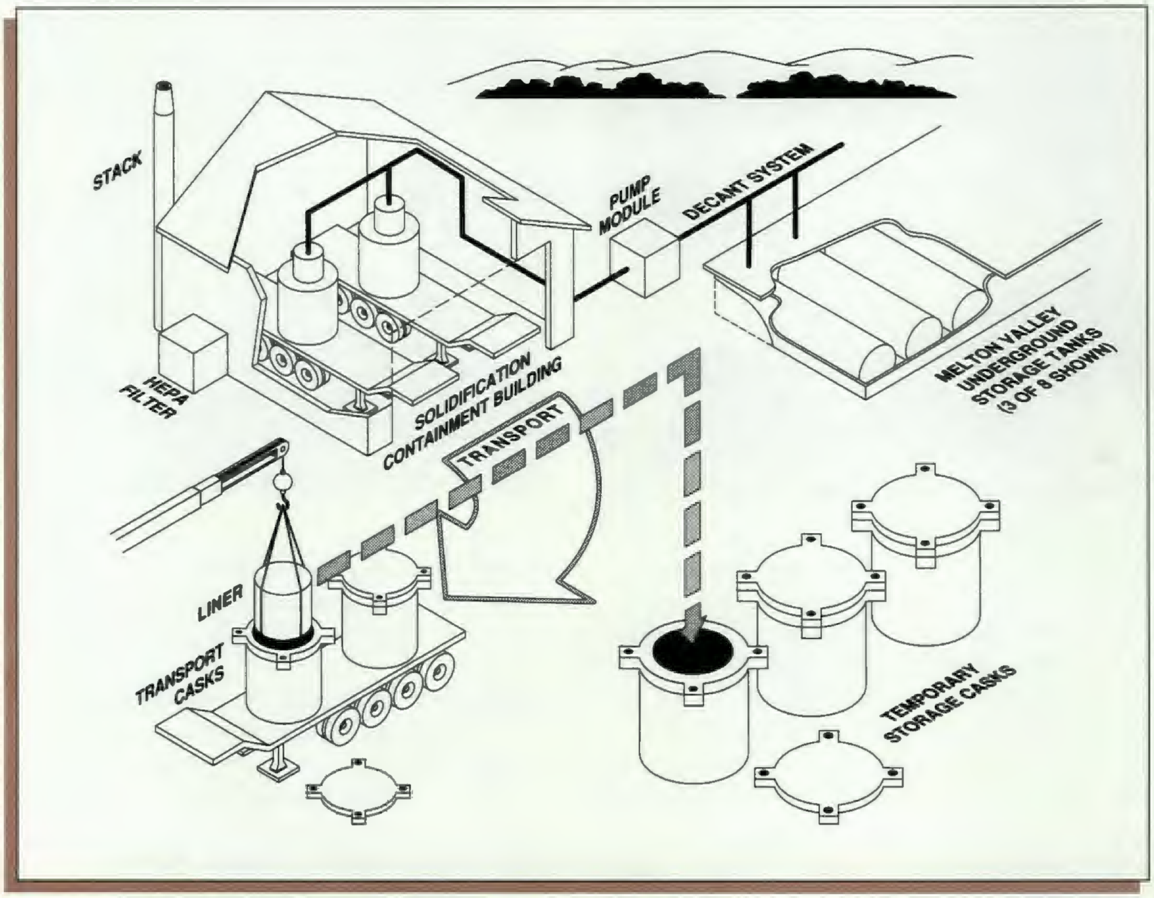
We used to dispose of LLLW using hydrofracture. We mixed the waste in a concrete grout and injected it into an impervious shale bed at a depth of about 1000 ft. Because of changing regulations and documentation and operational problems, we aren't doing that anymore. The cost of our liquid waste treatment has risen from \$1/gal using hydrofracture to between \$30 and \$50/gal for our new approach, which is to solidify and store the waste in aboveground facilities. Our on-site LLLW storage capacity is seriously limited, and we have completed an Emergency Avoidance Solidification Campaign to reduce the volume of LLLW that must be stored. Of course, ORNL's generation of LLLW has been greatly reduced because of our waste minimization efforts—principally through cooperation of the generators and efficiency improvements in the evaporator facility at X-10. Members of my division also work with individual waste generators at ORNL to suggest ways they can reduce the volume and toxicity of the wastes produced. That's a major change in the way we do business.

Spent reactor fuels, fuel reprocessing wastes, and other high-level wastes

Oak Ridge has no high-level wastes, in contrast to Hanford, Idaho, and Savannah River, which operate production reactors and/or reprocess fuel. The work we have done in reprocessing is development work in short-run batches to prove and confirm the validity of reprocessing development activities in years past. Our spent reactor fuels are sent to either Idaho or Savannah River, which have storage facilities for DOE research reactor spent fuels requiring reprocessing.

Transuranic wastes

We have moved from generating transuranic wastes in a reasonably measured and monitored fashion to generating transuranics in a highly monitored, highly examined, certifiable fashion. In quality assurance parlance, we have achieved Level 1 in quality control. The change was brought about by the demands of a repository disposal approach for transuranics—the fact that DOE (working with the state of New Mexico) has established a series of tests for qualifying waste imported into that state for disposal at the Waste Isolation Pilot Plant (WIPP) in Carlsbad. That has been good for us. We now have an on-site device



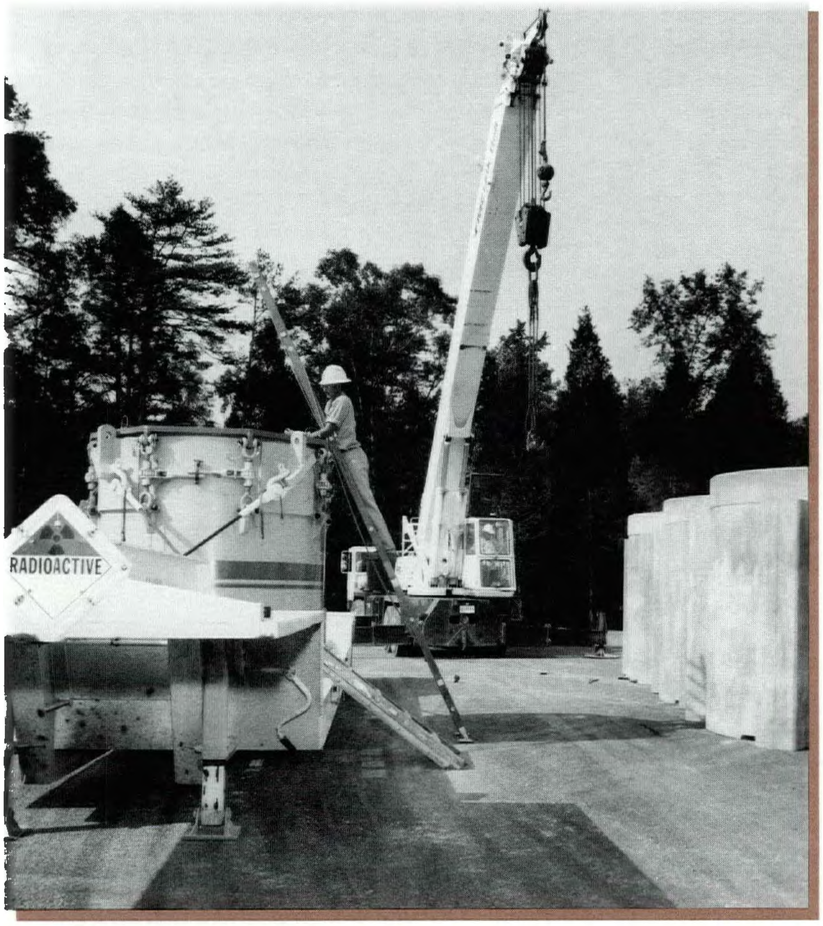
ORNL's Emergency Avoidance Solidification Campaign freed 50,000 gallons of space for R&D waste and for emergency storage.

to measure, nondestructively, the radioactive content of our drums of waste and identify those containing transuranic materials. We also have a device for radiographically examining the contents of each drum. The bonus is that we can also use the same real-time radiographic device, which was developed at Los Alamos National Laboratory, to examine our low-level waste containers. A large facility now in the planning stages—the Waste Handling and Packaging Plant—will process, package, and certify our remote-handled transuranic wastes for final disposal at the WIPP, probably starting in 1996. This plant, for example, will be used to compact glassware, racks, and experimental equipment from hot cells and encapsulate them in concrete-in-steel cylinders for shipment to WIPP.

Like the CEUSP (Consolidated Edison Uranium Solidification Project) waste at ORNL, all our remote-handled transuranic waste has been stored retrievably. The CEUSP material may be considered a special-case waste and will probably be accepted by WIPP for final disposal.

PCBs from electrical equipment, toxic metals such as lead and mercury, and other hazardous chemical wastes

In my opinion, ORNL has an exemplary hazardous waste program. In the past two or three years, we have put forward an extraordinary effort to develop a hazardous chemicals response team that is second to none. This team is A-plus in its operation and receives much positive recognition in our waste management audits. In the old days, I would guess that all hazardous materials were disposed of as industrial trash. The records are sketchy, so little is known about what happened. Now, our waste is disposed of by standard



Workers check tanks used for storing the solidified liquid low-level wastes from ORNL's Emergency Avoidance Solidification Campaign.

will locate and remove all asbestos materials representing a hazard. Currently, however, the industrial hygiene staff is overworked in responding to requests for asbestos investigations, receiving 1200 requests per year. We have an excellent crew in the Plant and Equipment Division who are trained to recognize and report asbestos problems as they find them in their building maintenance activities. This crew provides information to the industrial hygiene crew, who recommend remedial actions. The asbestos inventory will allow us to plan our responses according to a priority of need for removing the asbestos.

What percentage of the ORNL budget is now devoted to waste management and remedial action? How much funding will be required to deal with the Laboratory's waste problems over the next 15 years?

About 15%, or $60 million, of this year's budget is devoted to waste management and remedial action. Nearly $1.4 billion will be required over the next 15 to 20 years to address our environmental legacies and bring our operations up to the desired standards. Oak Ridge ranks fourth—after Hanford, Idaho, and Savannah River—in projected costs. Hanford could spend anywhere from $10 billion to $60 billion for environmental remediation, according to estimates I have seen.

industrial practices: the material is packaged in absorbent material inside drums, which are transferred to a commercial vendor and disposed of in an ORNL-screened licensed hazardous-waste landfill. We visit these disposal sites periodically to reassure ourselves that their operation is at the competence level we demand, because the waste generator is also liable for improper disposal practices. Fortunately this industry is highly regulated, but we still do a quality check on disposal sites for hazardous wastes.

Are there any plans for locating and removing friable asbestos in ORNL's buildings?

We plan to do a full asbestos inventory of Laboratory buildings in the next few years. We

"We operate on the basis of no surprises."

How much of our waste management effort is devoted to handling waste generated at ORNL and how much goes toward handling wastes brought in from other sites?

About 95% of the waste stored here is from our own operations. The rest, such as the CEUSP waste from a New York fuel reprocessing facility, was brought here from other places. We are primarily devoted to managing our own wastes. The TSCA Incinerator will accept materials from all installations managed by DOE's Oak Ridge Operations. The Portsmouth and Paducah gaseous diffusion plants will be large contributors to this incinerator's operation.

What is the Environmental and Health Protection Division's relationship with Tennessee state regulatory authorities and the U.S. Environmental Protection Agency, Region 4?

The DOE Model for Waste Management is a new way of doing business—we first identify the problems and then build something or change the operations to solve the problems. Since 1984, we have devoted an extraordinary amount of time to working with regulators, making sure that they understand and approve of everything that we're trying to do.

We have taken some of the best scientists and placed them in information exchange positions with regulatory people. That approach has paid off handsomely. First, coming out of a contentious environment following the lawsuit of 1983 and revelations about mercury contamination of an Oak Ridge creek and soil as a result of Y-12 weapons activities, we have been able to establish credibility with the regulatory community. They understand that our staff will give them the whole story—the pluses and the minuses. We operate on the basis of "no surprises." If we find a knotty problem, they are the first to know. That credibility allows them to concentrate on evaluating the actual numbers and regulating. This approach has removed the suspicion that usually exists between regulators and the regulated community. It has established on-site a new attitude that does not allow for concealment. We have an open communication policy, a policy of revealing everything that happens before someone asks for information. We operate with a sunshine mentality. All discussions are held in a manner that could be broadcast on local cable TV. We try to foster an environment that will encourage staff to focus attention on problems very early, before they become more difficult to solve.

Which technologies developed in Oak Ridge have proven most useful in currently acceptable waste-management practices?

We have had an excellent technical staff develop cementitious waste forms, or grouts, as a waste management tool. Our technology is currently being used at Hanford for single-shell-tank disposal of their wastes by grouting. We have assisted in the design of Hanford's Transportable Grout Facility and their selection of grout mixtures. The biodegradation process used for waste in the S-3 ponds at the Oak Ridge Y-12 plant was also developed in Oak Ridge.

The geophysical diffraction tomography technique developed by Alan Witten and others in the Energy Division will probably be used to locate hazardous waste in a couple of ORNL sites. Most of our trench closures will involve dynamic compaction of the material in the trenches, followed by capping. Because this process eliminates groundwater and surface water contact with the trench contents, we don't need to know exactly where the waste barrels are. However, some shallow disposal areas at ORNL have such poor records that we may make use of Witten's technique to locate buried solid wastes. For the future, we are developing processing and packaging techniques that will be used at the proposed Waste Handling and Packaging Plant in preparing our TRU wastes for their ultimate disposal in WIPP.

What are the greatest problems ORNL faces in waste management and remedial action? What solutions available today or on the horizon will help to solve these problems?

Our greatest problem is the massive amount of waste management and remedial action that must be carried out at Oak Ridge and at all the DOE sites. The cost of these projects represents a serious problem for the economy of the United States. How are we going to find the money to do all this cleanup work? The challenge to the researchers is to come up with scientific advances or innovative solutions that allow us to do the remedial actions and waste management less expensively.

For example, the in situ vitrification process developed at Pacific Northwest Laboratory and tested at ORNL has successfully isolated radioactive strontium and cesium. We are now considering using this vitrification process for encapsulating some of our underground waste tanks and the contamination around them. What we must work hardest on, in the face of operational costs and deficits and public pressure, is finding the time, money, and good ideas to change the way we manage waste, the way we do business. The questions are: how can we work smarter and how can we get the job done for less money?

Is the urgency to correct problems immediately and to fund remediation a result of real health-threatening contamination or of political and public pressure?

Any time there are problems with the magnitude of the waste problem, such as in the cases of tampering with medication (e.g., cyanide in Tylenol), there is a crisis reaction to fix it immediately, no matter what it costs. If you take time to analyze the risks of the problem and the costs of the solutions, you're susceptible to criticism for not addressing an important issue affecting human health and safety. We've had to make difficult decisions on resource use and do the best we can to identify and rectify our most serious waste problems. First, we had to, in a manner of speaking, plug the holes in the dike. Having eliminated the serious hazards, we're in a transition stage. We must now emphasize working more effectively and come up with new technologies that will do the job cheaper. As citizens, we cannot afford to allow ORNL to do less. ornl

The S-3 ponds at the Y-12 Plant, which have been drained, graded, and paved, once formed a seepage basin for liquid waste containing nitrates, caustic solutions, heavy metals, and organics from plant operations.

The DOE Model

By Bill Adams

Bill Adams is the acting director of the Waste, Environmental, and Emergency Management Division, DOE Oak Ridge Operations Office.

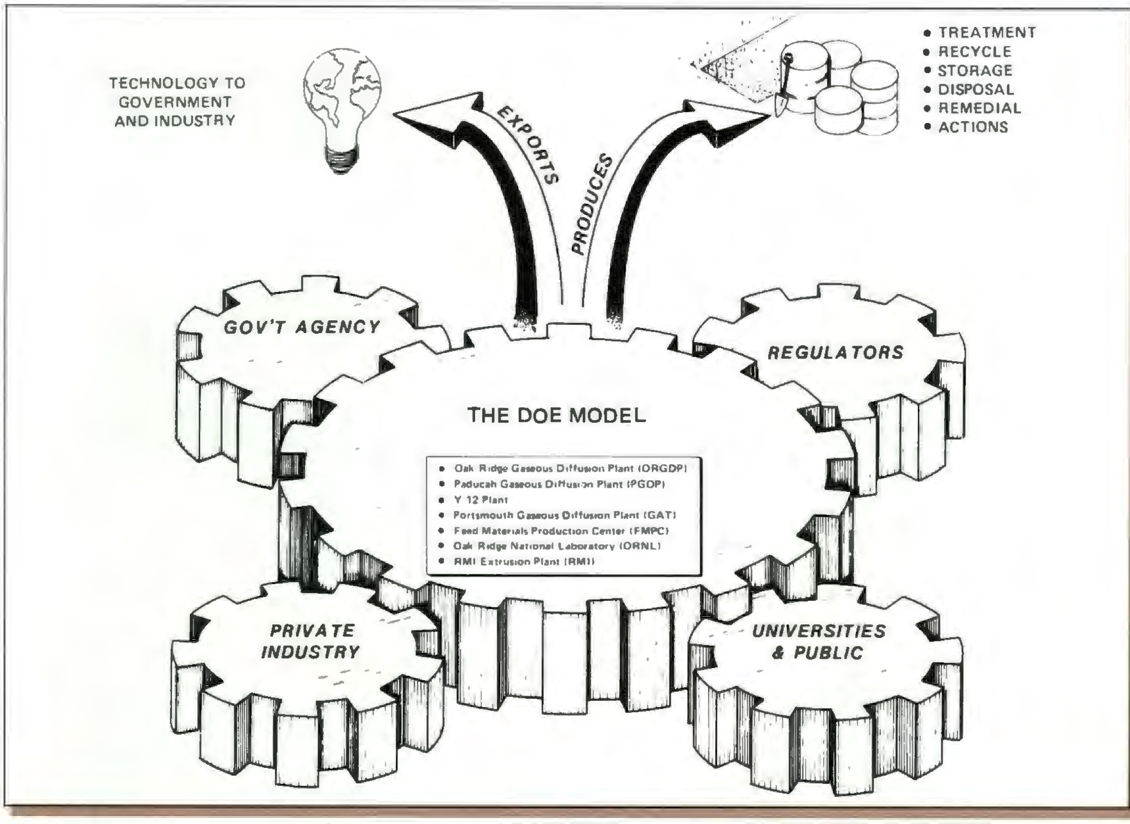
The DOE Model concept represents a new way of managing hazardous, radioactive, and mixed wastes at the facilities managed by the Oak Ridge Operations (ORO) Office for the Department of Energy (DOE). The concept also includes remedial actions on contaminated sites that have resulted from waste practices over the past 45 years at those facilities.

The DOE Model's major objectives are to

- minimize the waste generated, because the most environmentally sound and cost-effective waste management technique is to eliminate all unnecessary generation of waste;
- greatly improve disposal practices at all DOE facilities; and
- develop and demonstrate environmentally acceptable and cost-effective options for remediating contaminated sites that are the result of past waste disposal practices.

ORO is achieving these objectives by actively involving the private sector, regulatory bodies, universities, and other federal agencies in a cooperative effort to help develop waste management solutions. The DOE-ORO facilities will be useful as "laboratories" for developing and demonstrating improved measures and techniques for waste treatment, storage, and disposal and innovative remedial action schemes. Once developed and demonstrated, these measures can

Dumping noncompacted solid wastes in trenches and covering the wastes with soil were typical shallow land burial practices in past years on the Oak Ridge Reservation



The DOE Model represents a new way of dealing with hazardous, radioactive, and mixed wastes at six facilities managed by DOE's Oak Ridge Operations.

be used at other U.S. sites having similar waste management problems and remedial action needs.

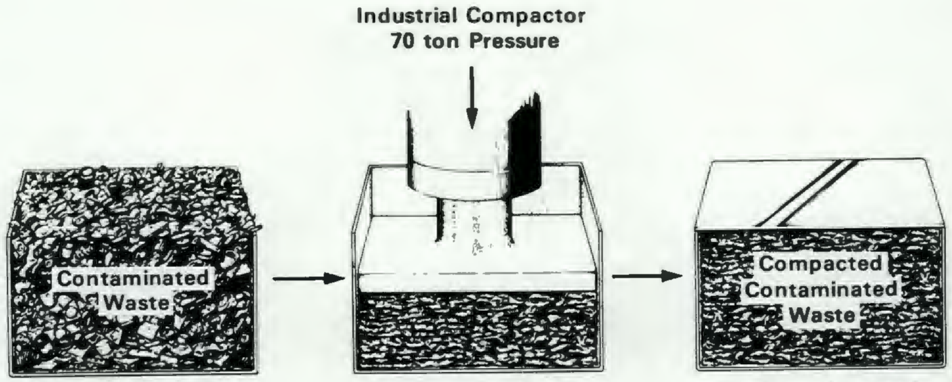
Less Is Better

In the past three years, DOE and ORO contractor facilities have adopted the attitude that "less is better" (see article on "Improving Waste Management Operations" in this issue). DOE has made waste reduction an award fee criterion for all ORO contractors—Oak Ridge National Laboratory, the Oak Ridge Y-12 Plant, Oak Ridge Gaseous Diffusion Plant, Paducah (Kentucky) Gaseous Diffusion Plant, Portsmouth (Ohio) Gaseous Diffusion Plant, and the Feed Materials Production Center in Fernald, Ohio.

Minimizing the generation of waste is *essential*, both to protect the environment and to respond to the new regulations that have so dramatically increased the cost of waste management. For example, meeting the new disposal requirements for solid low-level waste has increased disposal costs during the past 4 years from about $0.50 per cubic foot to more than $40 per cubic foot.

The ORO contractors have implemented charge-back procedures compelling programs and activities that generate waste at DOE facilities to pay for its storage, treatment, and disposal. Our contractors have also made several process changes to minimize waste. Significant reductions have been achieved at the Y-12 and Fernald plants, and ORNL has reduced its liquid low-level radioactive waste disposal requirements by almost 80%. Solid waste generation has also declined 30% at these sites. All ORO facilities have begun separating contaminated trash and metals from uncontaminated materials, simplifying their disposal requirements. In combination, the minimization efforts have produced significant results. DOE will continue to give very high priority to waste minimization by its operating contractors.

Compacting contaminated solid waste is one method ORNL is using to minimize waste disposal requirements.

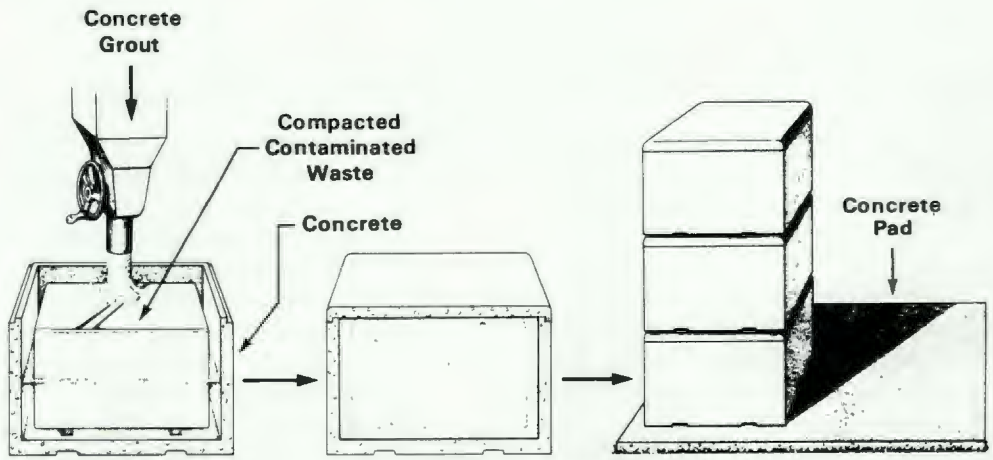


Waste is loaded into metal box (4x4x6 B-25) for first compaction cycle

Additional waste is loaded into box and compacted until box is filled

Filled box is sealed with metal lid

COMPACTION OPERATIONS



The sealed metal box is placed within a concrete overpack box. All void space is filled with grout.

A prefabricated concrete lid is placed on the box after filling with grout.

Completed units are stored by stacking on an environmentally engineered concrete waste storage pad.

OVERPACK AND GROUTING OPERATIONS

Model Participants

The private sector has assumed a vital role in implementing the goals of the DOE Model. In the last four years, about 30 companies have located in the Oak Ridge area to support DOE and its prime contractors in waste management and remedial actions. These firms employ about 2100 persons and have a total operating budget of some $135 million. Scrap decontamination, supercompaction, liquid solidification, biodegradation, waste detoxification, and several in situ fixation processes have been demonstrated by commercial developers at DOE sites. In addition, private-sector efforts in surface impoundment (waste pond) and burial ground closures and site characterizations have been successful.

Regulatory agencies, another important part of the DOE Model team, participate routinely in waste management advisory meetings and regularly scheduled meetings regarding remedial actions at the ORO facilities. DOE and its contractors have broadened communication efforts with regulators in an attempt to avoid "surprises" when they seek approval of proposed waste management actions. The open communication policy is an essential element of our new approach to managing waste problems.

The academic community participates in the achievement of DOE Model goals through research opportunity agreements with the University of Tennessee and Vanderbilt University and through student cooperative work assignments at DOE-ORO facilities. Roane State Community College is filling the need for more and better-trained waste management operations personnel by establishing three new technician training programs in this field, as well as by offering short courses that meet specific waste management training needs in the area. Both Martin Marietta Energy Systems, Inc., staff members and representatives of local waste management companies worked with Roane State in developing these needed programs. Other academic institutions that have been a part of the DOE Model team effort to find solutions to our waste problems include Southern University, Tuskegee University, Knoxville College, and other historically black colleges and universities.

Federal agencies have been extensively involved in the DOE Model activities. The U.S. Geological Survey and the Tennessee Valley Authority have provided support to our remedial actions at ORO sites. DOE's management and operations contractors, primarily Martin Marietta Energy Systems, Inc., also conduct work for other federal agencies (at a level of $60 million per year). Tasks include characterizing waste sites and developing remedial action plans. Recommendations may include in situ biotreatment of groundwater, chemical fixation of sludges, and disposal options for radioactively contaminated materials. Waste minimization techniques that have been used successfully at DOE facilities have also been implemented at Department of Defense sites.

Communicating the information and technology achievements developed through the DOE Model team efforts and transferring these results to other users throughout the United States are two of our most important goals. Toward that end, four successful DOE Model Conferences have been held at Oak Ridge. ornl

"The open communication policy is an essential element of our new approach to managing waste problems."

The Energy Systems Approach

By Lance Mezga

Lance Mezga is manager of the Central Waste Management Office of Energy Systems Environmental and Safety Activities.

Managing the solid wastes produced at DOE installations operated by Martin Marietta Energy Systems, Inc., is a corporate concern that requires considerable attention and significant resources. Should we detoxify, recycle, or burn solid wastes? Bury them on-site or transport them? Which waste treatment schemes and disposal techniques are best suited for particular types of wastes? These are difficult questions and complex issues, but Energy Systems waste managers have devised strategies to address them.

In finding answers to waste management questions, Energy Systems must meet the requirements of a large (and increasing) body of regulations, as set forth in the Resource Conservation and Recovery Act (RCRA), its amendments, and the corresponding Environmental Protection Agency (EPA) and state regulations. In addition, they must abide by DOE's Order 5480.2 (for the management of hazardous and mixed wastes) and Order 5820.2 (for radioactive waste management).

Solid wastes from the various sites managed by Energy Systems can be categorized as (1) conventional sanitary and industrial, (2) radioactive, or (3) hazardous and mixed. Within each of these categories is a wide range of waste forms, including paper, wood, metal, food scraps, ion-exchange resins, fly ash, soils, concrete, asphalt, processing and decontamination solutions, and a variety of discarded chemicals and chemical mixtures. Energy Systems and DOE-ORO have jointly developed solid waste management strategies to comply with the increasingly stringent regulations and to cope with the realization that, given enough time, certain contaminants found in solid wastes likely will migrate from conventional burial sites. Under the new policies, Energy Systems will terminate the use of disposal methods that have resulted in the contamination of soil and water and will develop, demonstrate, and implement waste management concepts that

Solidified waste is stored in metal drums at the Oak Ridge Gaseous Diffusion Plant (ORGDP).

Energy Systems personnel must deal with a wide assortment of wastes, including hazardous chemicals and radioactive materials.

ensure long-term protection of the public health and safety and the environment.

Fundamental to these strategies is the development of multisite waste management programs, including the Low-Level Waste Disposal Development and Demonstration (LLWDDD) Program and the Hazardous Waste Development, Demonstration, and Disposal (HAZWDDD) Program (see articles on pp. 36 and 39, respectively). Working with the Environmental and Safety Activities staff of the Energy Systems Central Waste Management Office, personnel at ORNL and other DOE sites are developing and implementing site-specific waste management systems.

Radioactive Waste Strategy

The multifaceted strategy for handling solid low-level radioactive wastes (LLW) includes waste minimization, disposal in existing burial grounds using new techniques and improved operational methods, interim storage of some wastes, and demonstrations of new technologies that may improve future waste management practices.

The LLWDDD Program addresses two types of concerns:

- Resolving the uncertainties related to the identification, demonstration, and selection of acceptable technologies for LLW management and the certification of LLW to meet treatment, storage, and disposal facility acceptance criteria; and
- Identifying acceptable sites for current and future LLW disposal by determining the availability of DOE-ORO site locations whose soil, geology, and hydrology will isolate the waste for as long as it remains hazardous.

Since the early 1970s, ORGDP has maintained a storage yard for slightly contaminated scrap metal (inset). In September 1983, ORGDP began to clean up the site. By the fall of 1985, the scrap metal had been sorted, reduced in size, and relocated.

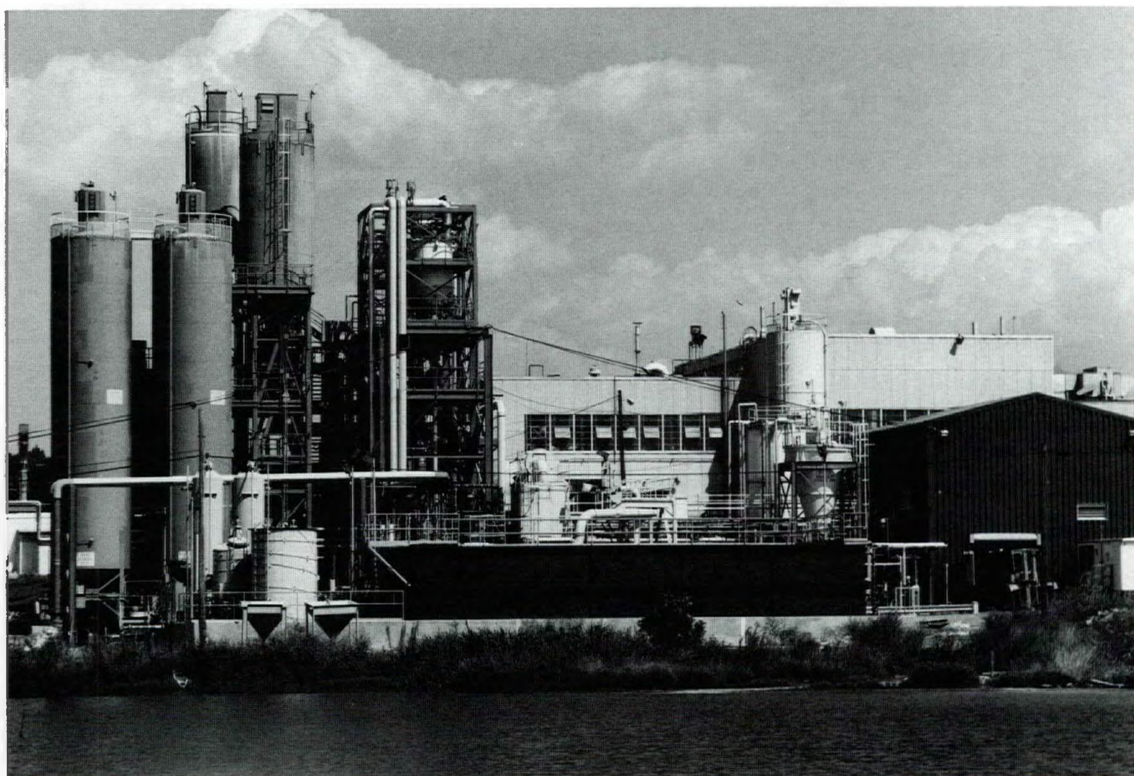
Program personnel also coordinate LLW management activities at the DOE sites managed by Energy Systems and provide assistance in improving waste management operations at existing DOE facilities. For example, LLW from several DOE installations has been placed in interim storage in the unused vaults of the K-25 Building at the Oak Ridge Gaseous Diffusion Plant.

Hazardous Waste Management

The DOE/Energy Systems management strategy for mixed and hazardous wastes generated at DOE installations is designed to ensure that normal operations continue while a waste management technology demonstration and development program is initiated to help resolve current and anticipated problems.

Fundamental aspects of this strategy include:

- Waste minimization (reducing both volume and toxicity);
- Prudent operations for on-site storage, treatment, and disposal of hazardous and mixed wastes;
- Technology demonstrations to allow the selection of the best waste management options; and



The Sludge Treatment Facility at ORGDP has treated more than 1.3 million gallons of sludge containing heavy metals and low-level radioactive materials from two ORGDP ponds. The process mixes the sludge with cement and fly ash, and the resulting grout mixture is given interim storage in metal drums.

- Major efforts to separate and reclassify waste stream components so as to reduce the quantity of materials requiring treatment and handling as hazardous and mixed wastes.

HAZWDDD Program personnel will implement demonstrations of new technologies for the treatment and disposal of hazardous and mixed waste by coordinating surveys to identify and categorize hazardous and mixed waste streams at the various DOE sites, identifying candidate streams for technology demonstrations, selecting acceptable technologies to be demonstrated, and evaluating the demonstration results.

During the next five years, Energy Systems will have major projects under way at all of its DOE sites to improve overall hazardous and mixed-waste management operations. These projects aim to increase storage capacity, reduce waste volume and toxicity, and make liquid waste streams in large volumes as chemically and physically stable as possible. One multisite project, which is now in its final stages of operational checkout and regulatory permitting, is the Toxic Substances Control Act (TSCA) Incineration Facility located at ORGDP. This state-of-the-art treatment facility uses high-temperature incineration and an advanced particulate-removal system to treat numerous types of hazardous wastes (e.g., spent solvents, oils, contaminated soils, and PCBs, or polychlorinated biphenyls, from discarded electrical equipment) without contaminating the environment. Previously, such wastes were stored on-site, because acceptable treatment and disposal methods were not available. The incinerator will eventually accept wastes from all Oak Ridge Operations facilities, including PCB-containing waste oils from ORNL.

Drums of stabilized waste sludge are kept in an aboveground storage yard that meets environmental regulations.

Resolving the Uncertainties

Energy Systems is working to select the best technologies for managing all solid wastes at DOE sites. However, efforts must be made to resolve uncertainties, particularly regarding the handling of mixed wastes. Do acceptable technologies exist for detoxifying hazardous and mixed wastes so that they can be delisted, or reclassified, making them eligible for less costly disposal methods? Which technologies should be used to separate radioactive components from mixed wastes to facilitate their disposal? Mixed wastes are currently stored at each installation, awaiting the resolution of these problems. One concern is that these stored mixed wastes will be delisted, only to be placed back in storage as LLW. Another concern is that future processes implemented to detoxify or separate components of hazardous or mixed wastes may be incompatible with the ultimate disposal options. As part of the overall solid waste management strategy, Energy Systems personnel are examining both on-site and off-site disposal facilities.

Managing Conventional Wastes

Conventional sanitary wastes include those materials that are neither radioactive nor hazardous. Examples are discarded paper, wood, construction debris, and food scraps. Such wastes are suitable and have long been eligible for simple volume reduction by compaction and burial on-site in licensed landfills. However, ensuring the segregation of radioactive and hazardous wastes from these materials has been a concern. Because this problem is also shared by private operators of sanitary landfills, the EPA and state officials may revise their applicable regulations to specify engineered landfill features, such

"Energy Systems is working to select the best technologies for managing all solid wastes at DOE sites."

as liners and leachate collection systems, similar to those now required for RCRA disposal facilities.

Regardless of the DOE site or solid waste category, the problems that must be dealt with and that the DOE–Energy Systems strategies are designed to address are essentially the same—providing ultimate disposal in a manner that will ensure the long-term protection of public health and the environment. ornl

Improving Waste Management Operations

By Tim Myrick, Tom Scanlan, and Cindy Kendrick

Tim Myrick is head of the Waste Management Operations Section of ORNL's Environmental and Health Protection Division.

Managing the radioactive and hazardous wastes generated at Oak Ridge National Laboratory is the responsibility of the Waste Management Operations Program (WMOP), an integral part of ORNL's operations for the past 30 years. Recently, this program has played a key role in the design of new facilities and the implementation of better techniques for managing ORNL's solid, liquid, and gaseous wastes, while protecting the health of employees and the public.

Originally set up to manage only the radioactive waste streams, the program has expanded to include the management of hazardous, mixed (radioactive and hazardous), and normal process and construction wastes. The program is now managed by a section of ORNL's Environmental and Health Protection Division.

ORNL's waste generation differs from that of the typical DOE production facility. Our wide variety of research and development activities generates many forms and types of waste and numerous, small waste streams rather than a few, large ones. According to the most recent annual report on hazardous wastes at ORNL, the Laboratory has ~275 waste streams, mostly discarded laboratory chemicals and process wastes.

Waste Management Facilities

The WMOP operates five major centralized waste collection, treatment, and disposal systems in the Bethel and Melton valleys at ORNL. The WMOP mission also includes defining the need for additional facilities to ensure ORNL's compliance with new regulations, using state-of-the-art waste management techniques to better contain radioactive and toxic materials, and minimizing the generation of liquid radioactive wastes to reduce disposal costs and maintain adequate storage space.

The five waste management facilities, whose estimated worth is about $125 million, provide waste certification and handle slightly radioactive liquid low-level waste (LLLW), liquid process waste, solid radioactive waste, and hazardous waste. The facilities for LLLW include piping and collection tanks, an evaporator for liquid volume reduction, and underground liquid waste storage tanks in Melton Valley. Process waste is collected through underground lines, stored in impoundments, and sampled. If the stored waste meets pollutant discharge limits, it is released to the creek; if not, it is treated before release.

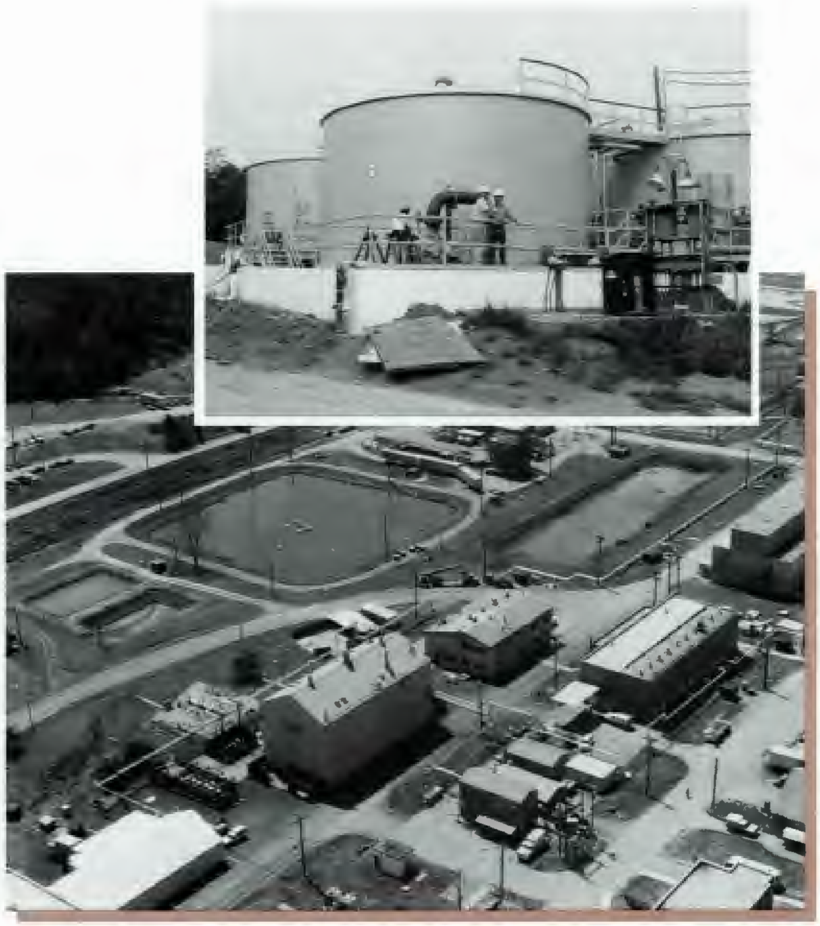
Drums of solid radioactive waste that may contain transuranic (TRU) waste having a low level of radioactivity (contact-handled, or CH) are certified at the Waste Examination and Assay Facility. The certification procedure determines which drums contain only solid low-level waste (LLW) and which ones also contain CH-TRU waste. The CH-TRU wastes are stored retrievably, and the LLW drums are given disposal at Solid Waste Storage Area 6 (SWSA 6) or temporarily stored at the Oak Ridge Gaseous Diffusion Plant (ORGDP). ORNL's hazardous wastes are confined at new hazardous waste storage facilities before shipment to commercial disposal facilities. Construction wastes have been handled at the contractors' landfill for nonhazardous wastes near SWSA 3 off Bethel Valley Road.

Recent major improvements or additions to the WMOP facilities include upgrades to the gaseous waste collection/discharge system and surface water monitoring station improvements on White Oak Creek, Melton Branch, and White Oak Lake. A centralized Waste Operations Control Center was also constructed to allow around-the-clock computer-assisted analysis of system operations.

New Facilities

New major facility construction projects currently planned or under way include a Nonradiological Wastewater Treatment Plant to remove hazardous but nonradioactive components of ORNL process waste streams, a new collection and transfer system for LLLW, a Waste Handling and Packaging Plant to prepare remote-handled TRU waste for off-site shipment to the Waste Isolation Pilot Plant (WIPP) in New Mexico, and a new solid LLW disposal site on the Oak Ridge Reservation (see article on "ORNL's New Environmental Projects," beginning on p. 60 in this issue).

A new Hazardous Waste Management Area is being used for packaging, storing, and shipping hazardous nonradioactive wastes. This area includes three separate storage facilities—one for processing, packaging, and short-term storage of hazardous chemical wastes; one for interim storage of the hazardous wastes that have been packaged for shipment; and a long-term storage area for mixed wastes. These



Surface impoundments such as this for holding ORNL's process waste will be replaced by aboveground tanks (inset) as part of the new Nonradiological Wastewater Treatment Project.

ORNL's new Hazardous Waste Management Area for storing chemically hazardous and radioactive mixed wastes is among the most advanced in the southeastern United States.

Chemicals in laboratories and storerooms that are no longer needed have been donated and redistributed to universities and other agencies.

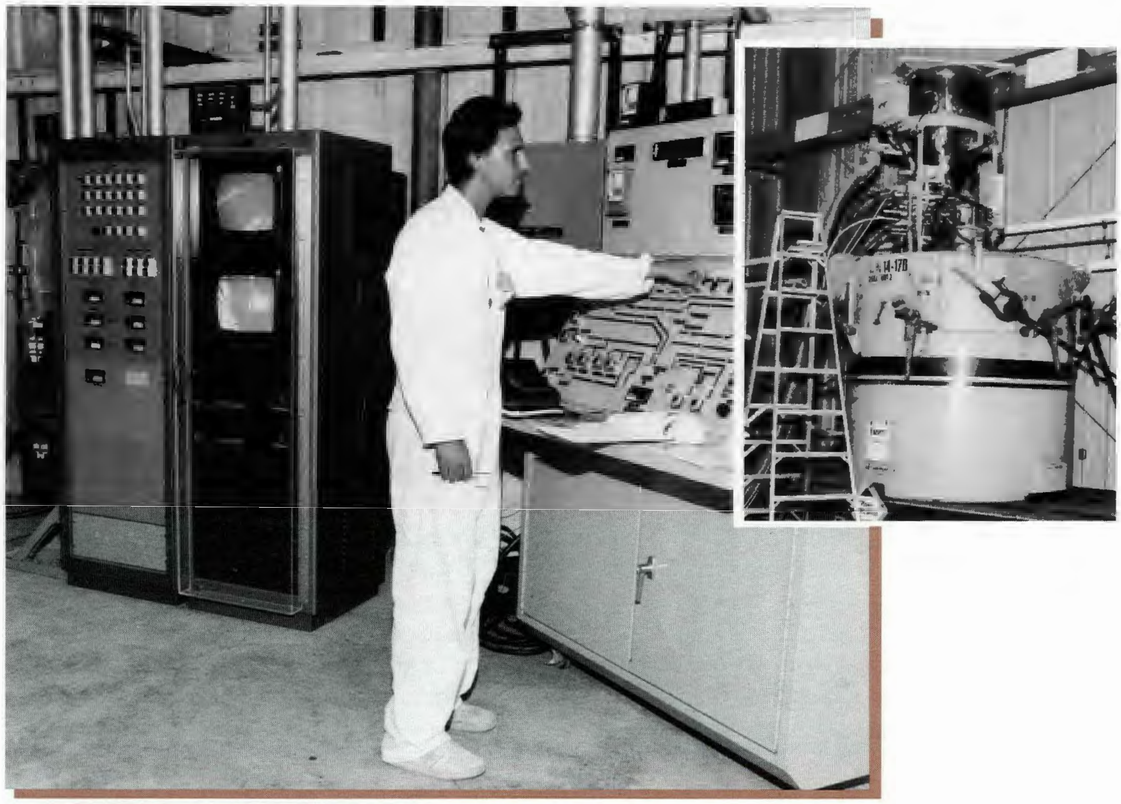
facilities, which have received the required Resource Conservation and Recovery Act (RCRA) permits, represent state-of-the-art hazardous waste management. They are among the most advanced facilities of this type in the southeastern United States.

Waste Minimization

LLLW reduction. About four years ago, ORNL began efforts to reduce the generation of LLLW, because the hydrofracture disposal method had to be discontinued. ORNL is now studying alternative technologies to replace hydrofracture. In the interim, concentrated radioactive liquid wastes must be stored, and our storage space is limited. Reducing the inventory of liquid wastes in storage is essential to allow time for the careful selection of a new disposal method and to provide space for continued waste generation by ORNL research programs.

As a result, policies encouraging waste minimization have been issued by managers of both ORNL and Energy Systems. Additional incentives to minimize waste production are provided by federal regulations and DOE policies and guidelines, as well as the limited disposal options and capacities at ORNL and the increased costs and liabilities associated with waste management.

The rising costs of waste disposal have provided



An employee of LN Technologies with the equipment that solidified liquid low-level waste for the Emergency Avoidance Solidification Campaign. Liquid waste and solids were added through the fillhead (upper right) atop a solidification liner inside a shielded transport cask.

the most effective incentive for waste minimization. Scientists have been highly motivated to reduce their waste generation whenever possible, in order to maximize their use of available funding for research purposes. Waste management must now be included in budgeting for new tasks, which encourages planning to reduce waste generation.

ORNL's waste minimization efforts have achieved marked success. In 1984, the Laboratory established goals for reducing the generation of concentrated LLLW; later, ORNL divisions set individual waste minimization goals and began tracking monthly divisional waste generation. In addition, ORNL's LLLW evaporators were improved, now operating about 300% more efficiently than in 1985.

Besides minimizing the strain on the existing waste management systems, ORNL's approach has decreased its LLLW generation rate by almost 80% in the past four years. For example, generation at the source-points was reduced from 25,000 gallons a week in 1985 to <7000 gallons a week in 1987. Since 1985 this reduction has saved the Laboratory more than $5 million annually in treatment and disposal costs.

Recycling chemicals. A major success of ORNL's waste minimization program has been the redistribution of surplus chemicals, including those discarded during laboratory cleanouts. Instead of disposing of valuable chemicals that are unneeded in certain areas, ORNL has located users in other areas both inside and outside the Laboratory. This type of cooperation among ORNL divisions has dramatically decreased the quantity of usable chemicals destined for disposal.

Unused commercial products constitute ~90% of the waste chemicals collected at ORNL, and nearly a third of the containers are unopened. Since November 1985, more than 70,000 lb (31,750 kg) of unopened chemicals have been donated by ORNL to educational institutions and the Tennessee Department of General Services.

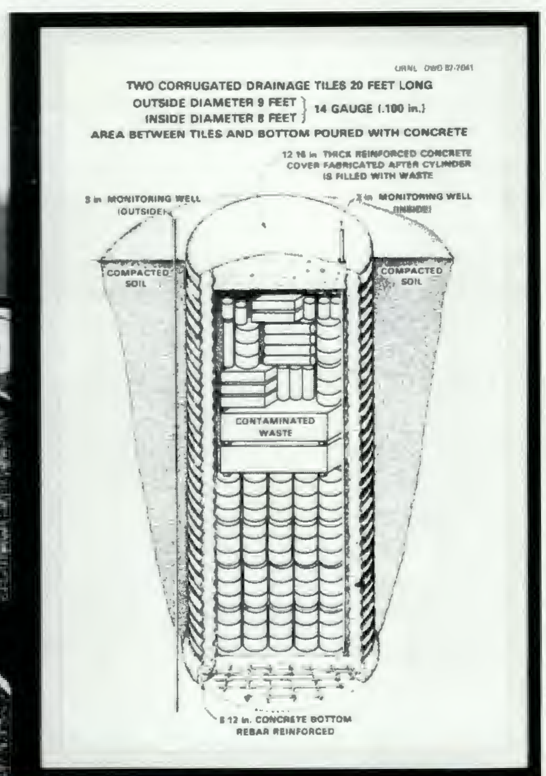
In 1987, however, the central staff of Energy Systems halted this distribution of chemicals to outside organizations. A proposed corporate policy for off-site shipment of hazardous chemicals would allow their continued distribution and would also implement an expanded communication and cooperation system to match excess chemicals at one DOE site with users needing them at another DOE site.

The recycle effort can also save ORNL money by recovering valuable materials that would otherwise be lost. An improved electrolytic separation process for recovering silver from photographic developing solutions was developed here in 1982. The process earned an I•R100 award and was the basis for setting up a silver recovery facility at ORNL. Although the process is extremely efficient, removing 99.99% of the silver from photographic and X-ray solutions, the silver recovery facility has not operated during the past year and a half because of permitting issues and economic considerations. Currently nearly 60,000 gallons of these solutions from the three Oak Ridge plants are sold annually to a local private contractor, Demco, which recovers the silver content. ORNL receives enough revenue from these sales to cover the handling costs.

Emergency Avoidance Solidification Campaign

Another method ORNL used to reduce the inventory of LLLW stored in underground tanks at ORNL was a campaign to decant, solidify, and store the wastes in an aboveground interim storage facility. The Emergency Avoidance Solidification Campaign (EASC), begun in September 1988, freed storage space for nearly 50,000 gallons in ORNL's liquid waste tanks.

A private contractor, LN Technologies, Inc., of Columbia, South Carolina, decanted and solidified a portion of the LLLW stored in the Melton Valley tanks to make this space available for research-produced wastes. The extra space also provides a



ORNL's Solid Waste Storage Area 6 is a demonstration site for the "greater confinement" disposal silo technique for isolating solid low-level waste from the environment.

produced wastes. The extra space also provides a contingency storage area for handling any emergency that might cause the rapid generation of large quantities of LLLW.

The contractor installed and operated a mobile LLLW solidification system placed inside ORNL facilities. The solidified radioactive waste was sealed in concrete liner casks, transported to a specially constructed interim storage area at the new Hydrofracture Facility, and placed inside sturdy concrete storage casks. The solidified waste will be held and monitored by ORNL personnel for up to five years, while DOE determines its final disposal destination.

The LN Technologies staff and equipment left ORNL after completing the waste solidification during an intensive three-month operation. ORNL's solidification facilities were placed in standby condition, awaiting use in future campaigns, should that become necessary.

Advances in Solid Waste Management

ORNL manages three categories of solid wastes: radioactive (including both LLW and TRU wastes); hazardous materials (including mixed wastes and materials defined as hazardous by RCRA); and conventional wastes (nonradioactive and nonhazardous sanitary wastes).

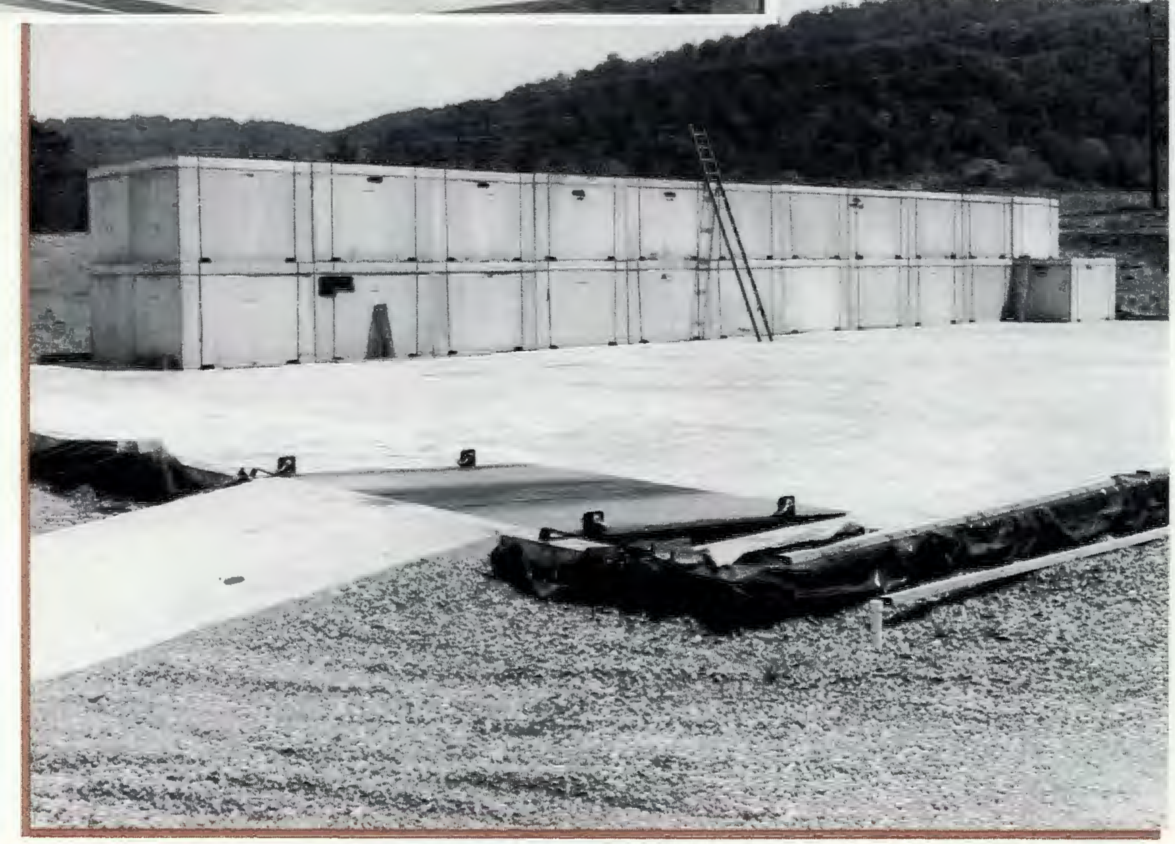
Low-level solid waste. The LLW management strategy adopted by ORNL aims to

- reduce waste generation at all facilities,
- temporarily store wastes at ORGDP to extend the life of existing waste storage facilities,
- demonstrate waste management technologies to gain information about available options, and
- dispose of wastes in existing sites using improved technologies.

This approach will allow time for developing needed new storage facilities and selecting appropriate methods for future disposal. Interim storage of an increasing volume of LLW at ORGDP should help extend the operating lifetime of SWSA 6 at ORNL until the mid-1990s.

TRU waste. Most of our nation's highly radioactive, remote-handled (RH) TRU wastes are from the ORNL Transuranium Processing Plant's past operations. ORNL uses retrievable storage to manage these TRU wastes, because no on-site method or area for permanent disposal has been approved. DOE's *Long-Range Master Plan for Defense Transuranic Waste* has designated the WIPP, a deep geologic repository in New Mexico, as the appropriate permanent disposal facility for RH-TRU waste. Beginning in 1990, drums of less radioactive, contact-handled (CH) TRU waste will be shipped from ORNL to WIPP; in the mid-1990s, RH-TRU waste will be received by the New Mexico repository after WIPP processing.

At the Waste Examination and Assay Facility, Don Coffey loads a drum of contact-handled transuranic (TRU) waste into the passive-active neutron assay detector as part of the waste certification program.



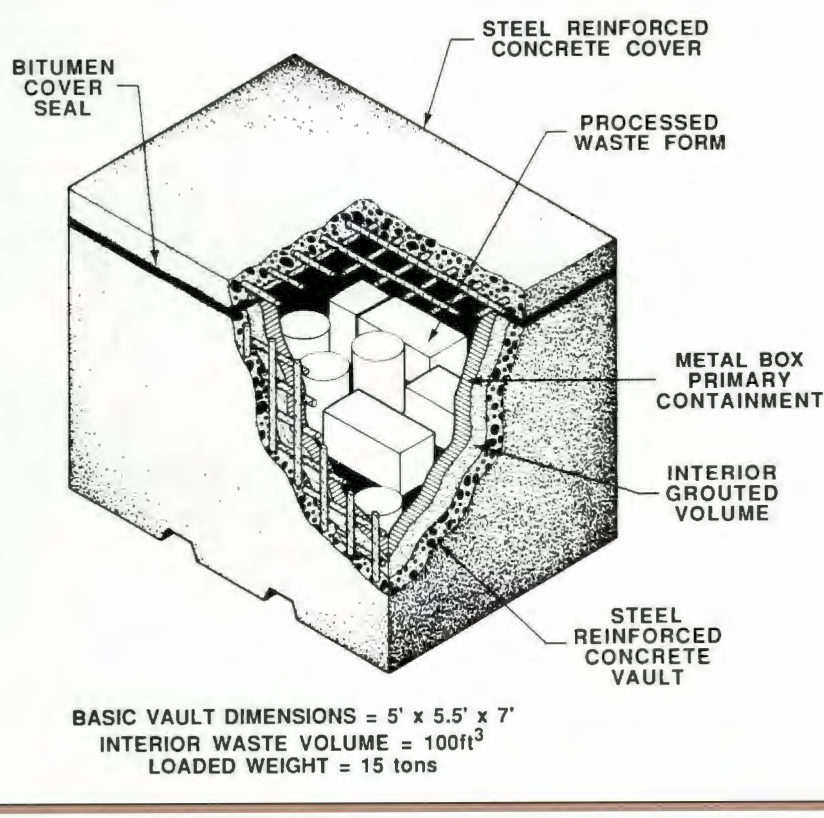
Workers load a vault of solid low-level waste on ORNL's tumulus demonstration pad (insert). At right, 45 vaults loaded on the tumulus pad represent about four months of routine solid low-level waste generation at ORNL.

Hazardous waste. Hazardous waste materials from ORNL's research laboratories and engineering operations are routinely collected, identified, and packaged in appropriate containers to be shipped to EPA-approved treatment and disposal sites or to be stored on-site to await further disposition. Mixed wastes, such as radioactive oils, are being stored indefinitely until regulations are clarified to allow their treatment or disposal by either commercial or on-site facilities such as the Toxic Substances Control Act (TSCA) Incinerator at ORGDP.

Waste certification. Increased documentation is now required on the characteristics of solid wastes packaged for storage or disposal. ORNL has been developing a variety of means to meet these requirements. Stored and newly generated CH-TRU wastes are now being certified in the Waste Examination and Assay Facility (WEAF). A variety of devices there, such as the neutron assay system, the segmented gamma scanner, and the real-time radiography system, are used to measure the neutron and gamma-ray emissions and observe the physical conditions of waste within the TRU packages. Used together, these systems can certify whether a drum of waste should be classified as LLW or TRU waste, which in turn determines whether it can be disposed of on-site or shipped out to the WIPP. ORNL personnel can nondestructively assay 50 drums of CH-TRU waste per week, identifying and quantifying the isotopic content and the total fissile mass. As of March 1988, more than 2300 drums of CH-TRU waste had been assayed in the WEAF.

Technology Demonstrations

A facility to demonstrate the above-grade disposal of solid LLW has been constructed as part of the Low-Level Waste Disposal



The multi-barrier tumulus vault is designed to ensure that solid low-level waste does not contaminate the environment.

"In less than a decade, four new facilities for managing wastes at ORNL will be readied for operation."

Development and Demonstration Program (see article on p. 36). This "tumulus" technology demonstration project seals the LLW in concrete vaults, places the vaults on a grade-level concrete (tumulus) pad in a predetermined stacking arrangement, and ultimately will cover the entire pad with an engineered, multilayered cap (the layers include gravel, sand, compacted clay, geotextile fabric liners, and a bentonite fabric liner). The tumulus pad (105 ft × 65 ft) is constructed of reinforced high-strength concrete and equipped with both surface and below-grade runoff collection systems. Effluents from the pad during the loading period and after facility capping in the mid-1990s will be collected and monitored to ensure waste containment.

The construction of the tumulus facility, the staging and handling of containers, and provisions for drainage and closure will be monitored and evaluated to determine the best approaches and to develop information on the costs, personnel exposure, and environmental protection aspects of these operations. These results will then be used in the design of future disposal sites on the Oak Ridge Reservation.

In another solid waste management demonstration, greater confinement disposal (GCD) silos for solid LLW are being constructed and operated at SWSA 6. These below-grade silos provide multiple waste-containment barriers to prevent releases of radionuclides to the environment. The 8-ft-diam by 20-ft-deep disposal units are constructed of two layers of corrugated steel, separated by concrete fill and sealed on the bottom with a thick concrete layer. Bulk wastes are grouted in the silo space, and the completely filled silo is further capped with concrete for permanent waste isolation.

Outlook

The increasing emphasis on strict compliance with environmental regulations in this country has stimulated a massive effort to upgrade waste management systems and minimize waste generation at all DOE Oak Ridge Operations sites, and much progress has been made. Continued improvement over the next 10 to 15 years will be necessary to bring all current operations into compliance with the applicable DOE orders and with state and federal regulations. In planning ahead, we must also cope with the possibility of radical changes in waste management practices that could be required by future regulations. Advance planning must include improvements in waste certification and operations documentation; better facilities for waste handling, storage, and transport; improved training for waste generators and handlers; and better operation of the waste management systems.

In less than a decade, four new facilities for managing wastes at ORNL will be readied for operation, and new emphases will be placed on planning, training, and quality assurance documentation. We also expect the commercial sector to be increasingly involved in helping ORNL and other federal facilities solve problems in waste management operations. The WMOP first began utilizing outside expertise in the injection well operations for hydrofracture; now commercial vendors are being contracted for routine hazardous waste disposal and for special waste processing operations such as the liquid waste solidification. This involvement of outside vendors in the routine operations of waste management systems can be expected to increase over the coming years.

Contributors Tom Scanlan and Cindy Kendrick work in the Waste Management Operations Section of ORNL's new Environmental and Health Protection Division. Scanlan is head of the Hazardous and Radioactive Waste Management Department. Kendrick is manager of the Waste Management Coordination Office.

Waste Management Technology Center

By Robert Jolley

A major component of the DOE Model for waste management is the Waste Management Technology Center (WMTC), operated and managed by staff members of ORNL's Chemical Technology Division. The WMTC coordinates the activities of a team of engineers and scientists from throughout Martin Marietta Energy Systems, Inc., as they work with experts from universities, private industry, and other government agencies to develop and test solutions to waste management problems at the DOE facilities.

Through the WMTC, existing or newly developed waste management technologies can be demonstrated at appropriate DOE sites in cooperation with the line organizations responsible for solving site-specific waste problems. The Center also evaluates the technical and economic feasibility of these demonstrated technologies and disseminates this information to DOE facilities and other federal agencies, universities, and the private sector.

The WMTC has helped to implement the DOE Model concept by coordinating the expertise of commercial vendors, regulators, and both academic and government researchers to conduct demonstrations of new waste management technologies at the DOE-ORO facilities. Management support is provided through the WMTC for several multisite DOE waste programs. These include the Low-Level Waste Disposal Development and Demonstration Program and the Hazardous Waste Development, Demonstration, and Disposal Program (see the articles that follow in this issue).

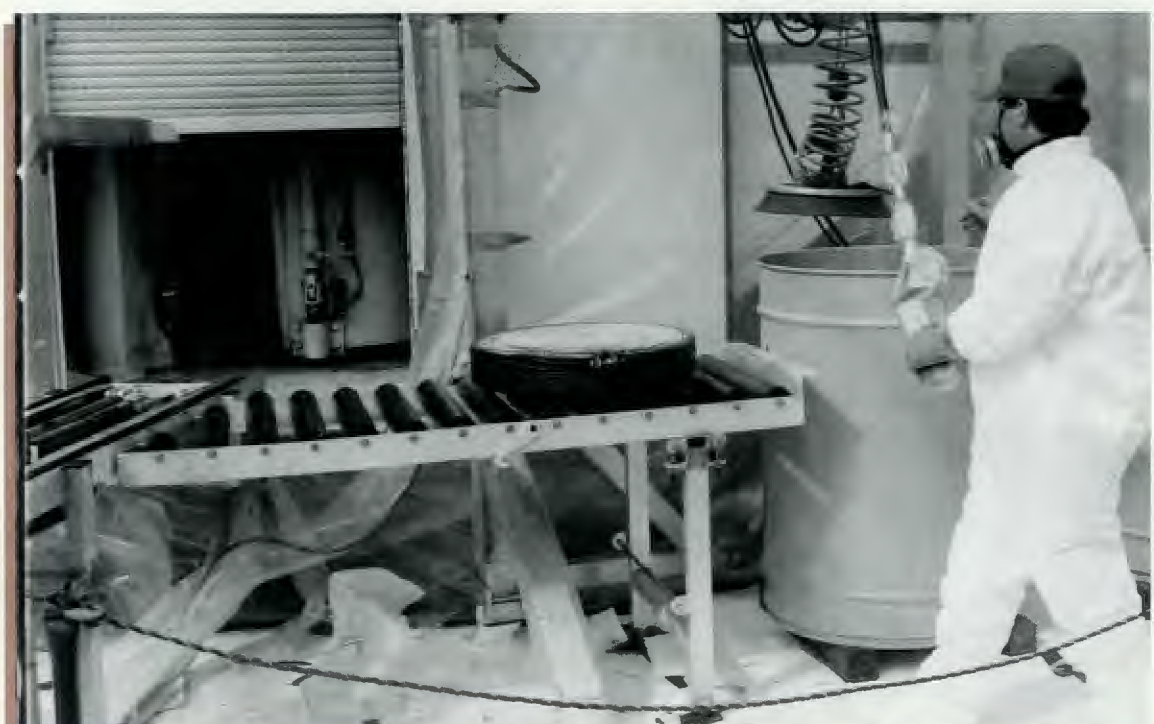
In the two years since its establishment, the WMTC has facilitated several waste management technology demonstrations. The first, a Pyroplasma technology for waste incineration, was done when a private company learned of the DOE Model concept and approached DOE-ORO for assistance in demonstrating their process using DOE waste and facilities. The demonstration was coordinated by the WMTC, which later evaluated the Pyroplasma technology as insufficiently developed for commercial waste applications. Two supercompaction technologies for waste volume reduction have been demonstrated through the WMTC: one for supercompacting baled waste from the Oak Ridge Y-12 Plant and one for supercompacting ORNL low-level waste packaged in drums (see photographs on p. 32).

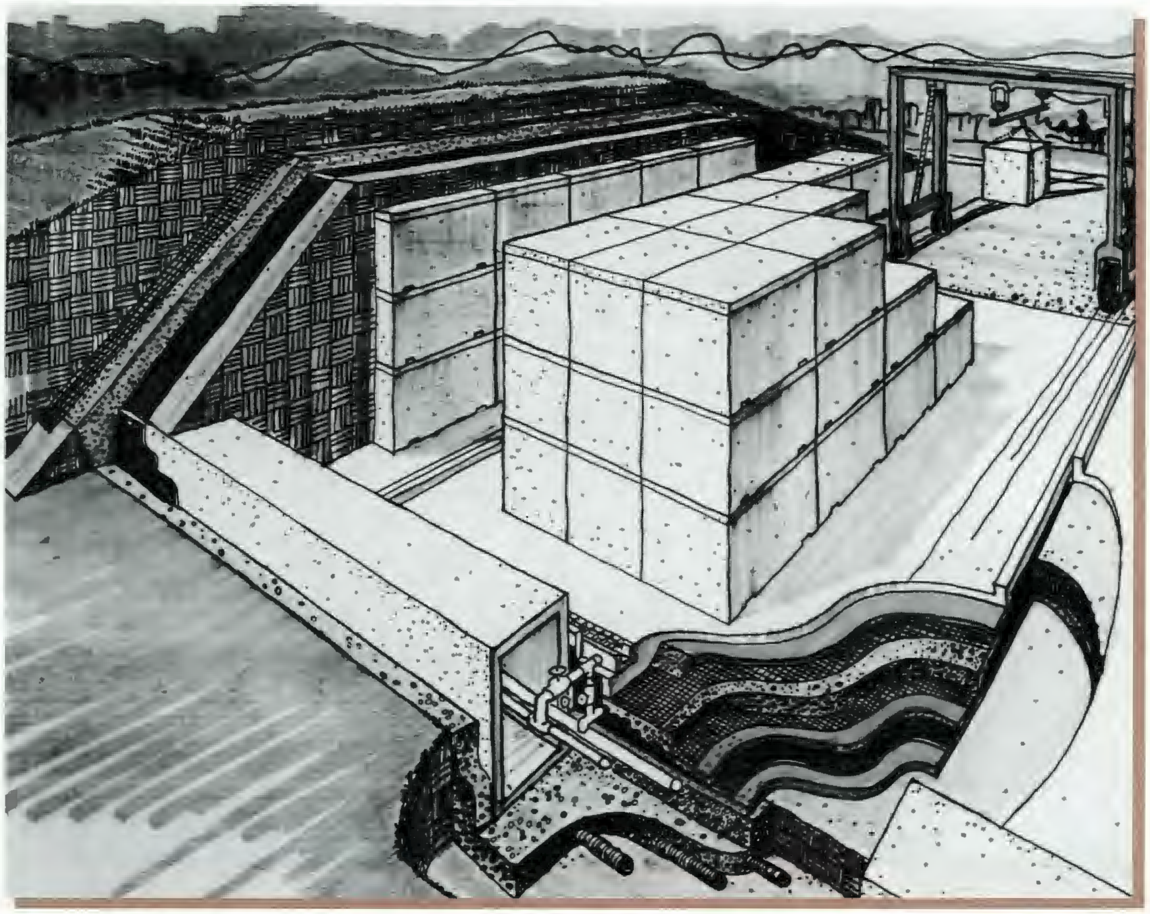
Robert Jolley, a member of the Chemical Technology Division, is acting director of the Waste Management Technology Center.

An ongoing disposal demonstration of the tumulus concept is being coordinated and evaluated by the WMTC. The tumulus concept involves the aboveground storage of securely packaged low-level wastes on a specially engineered concrete (tumulus) pad, followed by the construction of a water-diverting overcap. Wells, drains, and instrumentation are installed around the pad so its performance can be monitored (see photographs on p. 29 and drawing on p. 33). The method has been used for radioactive waste disposal in France, but this is its first U.S. demonstration. The concept is being widely considered for use by various state and regional low-level waste associations.

Private-sector waste isolation technologies are also being demonstrated and evaluated through the WMTC. A large-scale demonstration of a new commercial thermal-extraction process for

These supercompaction demonstrations by Westinghouse (top) and U. S. Ecology showed that barrels containing radioactive low-level solid waste could be compressed to one-fifth their original size.





An artist's conceptual drawing of the WMTC's tumulus demonstration pad shows the multiple layers of leakage protection beneath the pad (lower right) and the multi-layered covering that will be placed over the stacked concrete waste vaults (upper left).

hazardous waste separation was managed by the WMTC in October 1988. This prototype demonstration for DOE's Hazardous Waste Remedial Action Program (HAZWRAP) was conducted at the closed Toll Enrichment Facility of the Oak Ridge Gaseous Diffusion Plant (ORGDP).

WMTC staff members provided project management for the commercial demonstration of a patented X-Trax thermal-separation process for detoxifying heavily contaminated mixed-waste sludges left from Y-12 plant and ORGDP operations. The sludges, ~60% solids by weight, are mixtures of metal-processing wastes that include chromates and dichromates, hydrogen fluoride scrubbing solutions, detergents, mixed organics, and metals. By modifying standard manufactured components, engineers of Chemical Waste Management, Inc. (CWM), of Oakbrook, Illinois, developed the equipment modules and process that were demonstrated at ORGDP by Chem-Nuclear Systems, Inc., of Columbia, South Carolina, a sister company to CWM and also owned by Waste Management, Inc., a multi-billion-dollar international corporation.

In the X-Trax process, the contaminated sludges, soils, or sediments are heated in a concurrent nitrogen gas stream at temperatures up to ~600°F, volatilizing the water and organics and leaving a dry residue containing toxic radioactive and heavy metals. These hazardous and radioactive dry components are stabilized by grouting, which prevents leaching and qualifies the waste for landfill burial. Volatile components are carried by the nitrogen gas stream into a second equipment module, which condenses the off-gases and collects them for separate disposal. A

Babette Phoenix, staff member of the Environmental and Health Protection Division, collects data on the X-Trax thermal-separation process demonstration, which was conducted at ORGDP by Chem-Nuclear Systems.

commercial version of this sludge-treatment unit will be built elsewhere by mid-1989.

The IT Demonstration Project, another thermal-separation process demonstration, was also coordinated in the fall of 1988 by a WMTC project manager from ORNL's Chemical Technology Division. This demonstration, conducted by IT Corporation, is an example of the multiplant, government–private sector cooperation that can be achieved using the DOE Model concept. All five of the DOE-ORO facilities operated by Martin Marietta Energy Systems, Inc., cooperated in funding the IT thermal-separation process demonstration; IT Corporation supplied the equipment and supporting personnel and conducted the demonstration at its local Bear Creek facility. Barrels of soil containing polychlorinated biphenyls (PCBs) and radioactive contaminants were sent from the DOE sites at Portsmouth, Ohio, and Paducah, Kentucky, for the treatment demonstration.

In the IT process, a counter-current nitrogen gas stream moving through a rotating tube dryer removes water and volatile organics from the contaminated soil. The hot vapors (which contain the PCBs, other volatile organic compounds, and water) are then condensed in a cooling unit and collected for high-temperature incineration, chemical treatment, or other disposal. The radioactive and heavy metal contaminants remaining in the dried residue can then be stabilized by grouting and certified for landfill disposal.

As a project for HAZWRAP and the U.S. Air Force, the WMTC is developing an innovative process for immobilization of volatile organic compounds in cement-based grouts. Currently, the only acceptable treatment for soils and sludges containing volatile organics is exhumation followed by incineration—a very expensive treatment ($300 to $600/ton). Our development of a cement-based waste form and an in situ emplacement procedure for sludges contaminated with volatile organic compounds is expected to lower the disposal cost to about $75 to $150/ton. The objectives of this project are to

- determine the technical feasibility and implementation requirements for this treatment and disposal process, and
- establish the quality assurance and quality control procedures needed to ensure that the data generated are technically and logically defensible to the regulators.

Special Projects

In these and other technology demonstration projects during the past three years, the WMTC has assisted DOE and Energy Systems in meeting their commitments to improving waste management practices and environmental conditions here and at other DOE sites. Several series of workshops in waste management areas have been planned and are being coordinated through the WMTC. These workshops on leaching tests, management of uranium-bearing wastes, handling and processing of contaminated soil, and an Environmental Protection Agency–sponsored series on regulatory concerns in waste management, will facilitate information exchange among waste management personnel here and at other DOE sites.

In a recent special project of the HAZWRAP, WMTC staff members developed methodologies for collecting, analyzing, and summarizing data to be used in developing a system-wide waste management scheme for DOE–Defense Program hazardous and mixed wastes. Data for several thousand waste streams of various types were studied, classified, and integrated in the Strategic Alternatives Study. Using readily available personal computer software, the wastes were categorized into treatment groups and incorporated in a flowchart conceptualization that includes a hierarchy of waste management steps from generation to disposal. The successful completion of this enormous task of identifying and characterizing DOE-Defense hazardous and mixed wastes and integrating appropriate treatment and quality assurance information for each waste type through treatment flowsheets for each site will allow DOE and its contractors to adopt and enforce much more comprehensive and effective waste management practices.

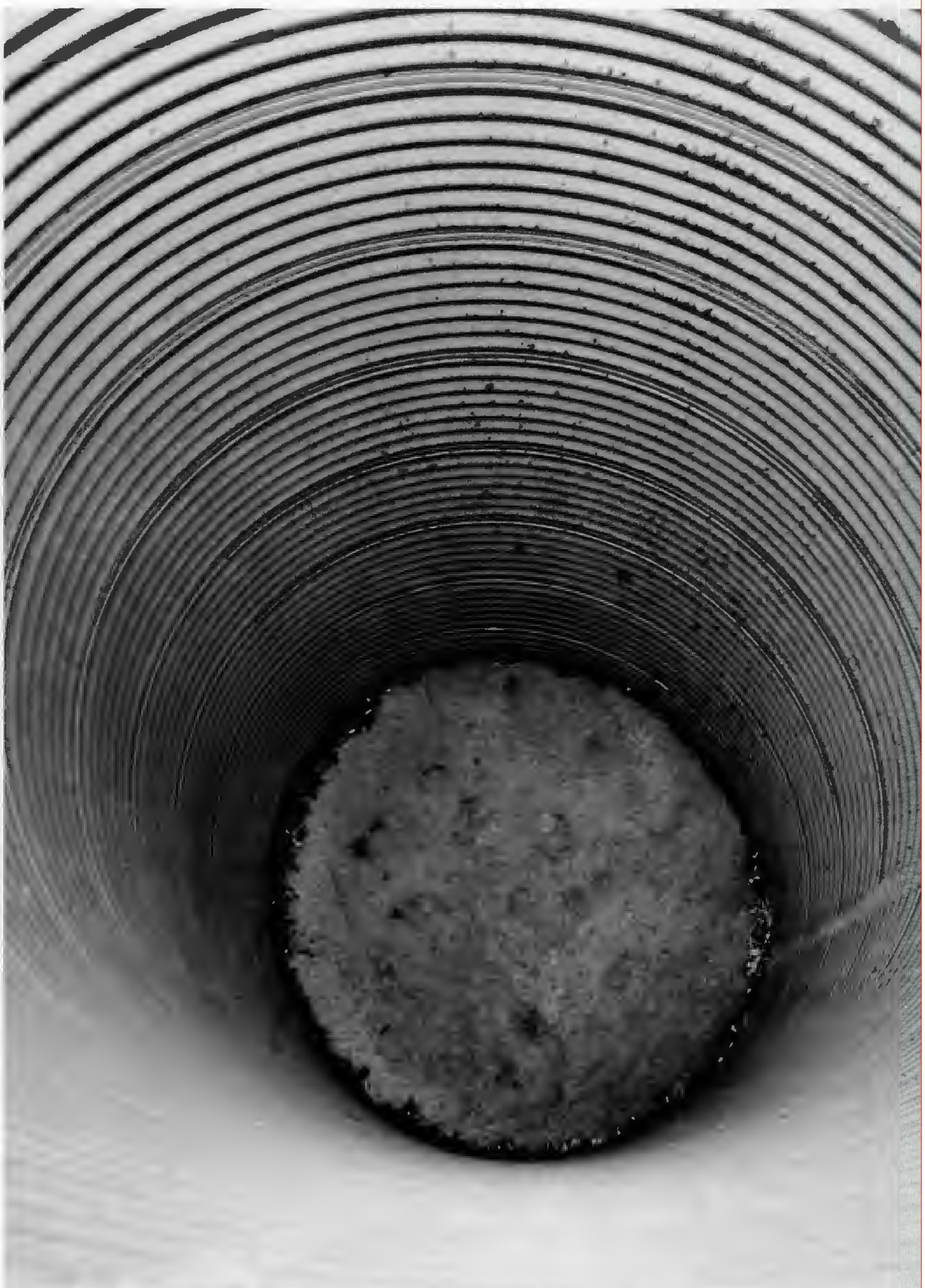
In the activities discussed here and in other projects assigned by DOE or identified by sponsoring agencies as waste management needs, the WMTC will continue to support the DOE Model for waste management. We will also continue to emphasize private-sector involvement in identifying and demonstrating new waste management technologies and to share the information gained from these demonstrations with the participating companies, other federal agencies, and appropriate regulatory bodies. ornl

Low-Level Waste Disposal Development and Demonstration Program

Developing new and improved waste forms and disposal facilities to manage low-level radioactive solid wastes (LLW) generated on the Oak Ridge Reservation is the goal of a new Energy Systems program. The Low-Level Waste Disposal Development and Demonstration (LLWDDD) Program is needed because current disposal capacities are being exhausted, and improved waste management practices are a requirement for continuing operation.

Briefly, the LLWDDD Program was set up to analyze the treatment, storage, and disposal needs of the Oak Ridge Reservation and to provide technical support to meet these needs. Staff members also develop data needed for the environmental impact statement process, demonstrate and assess waste management technologies, and assist in developing new LLW disposal facilities.

The program's plan of action will be based on site-specific LLWDDD implementation plans prepared by each Energy Systems site. These plans will identify the projected volumes of LLW, the required disposal and/or storage capacities, the plans and schedules for new LLW facilities (including waste certification capabilities), and the waste management technology demonstrations needed to support the LLWDDD implementation for each site. The plans will indicate the amount of technical management support that each site needs from the overall LLWDDD Program.



A dramatic interior view of a "greater confinement" disposal silo at SWSA 6.

Above, some of ORNL's solid low-level waste is packaged and placed in metal drums, which are compacted and loaded into an overpack drum. These overpacks are also compacted, transferred to a larger container, and grouted to stabilize the wastes before sealing.

Activities

Beginning in fiscal year (FY) 1986, major efforts were focused on site-characterization studies for Chestnut Ridge, development of waste-stream characterization data, and initiating demonstrations of LLW volume reduction (e.g., by supercompaction), and use of improved waste forms (e.g., through waste immobilization and waste packaging technologies).

In FY 1987, program staff members developed and issued an overall LLWDDD strategy, which defined a new waste classification system and outlined the management requirements for different classes of waste, as needed to begin the design of new LLWDDD disposal facilities planned for construction in 1991. A tumulus pad, based on the French tumulus concept for above-grade disposal of LLW, was built. Modular LLW disposal units were procured, and volume reduction demonstrations were completed. Designs for "greater confinement" disposal systems based on buried silos were developed and evaluated. Waste generation data for FY 1987 at ORNL were added to the LLWDDD data base, and revised estimates were made of waste volumes in the various LLWDDD classes.

During FY 1988, our activities included

- collecting and preparing data for use in environmental impact statements for new LLWDDD facilities,
- continuing the improvement of waste forms,
- developing source-term models and draft waste acceptance criteria for new waste disposal facilities,
- initiating waste certification demonstrations,
- investigating regulatory, programmatic, and technical constraints for off-site shipment to determine the requirements that must be met for this option to be used,
- making evaluations and estimates for new waste disposal facilities, and
- completing and validating models of LLW environmental pathways or routes by which low-level radioactivity from wastes may reach humans.

Plans for the future include a major focus in 1989 on continuing our evaluations of alternative waste forms. We will also work on refinements to the LLWDDD waste acceptance criteria and disposal system designs and initiate demonstrations of large waste treatment, waste certification, and interim long-term storage technologies.

New prototype LLW disposal facilities should be operating on the reservation by September 30, 1991. These facilities could involve a variety of sites and disposal technologies and will represent the best management practices identified for the LLW from three different installations.

Strategy

The waste management strategy developed by the LLWDDD Program is based on waste minimization, segregation, and certification; site-specific pathways analyses; and the selection of sites and technologies to ensure that performance requirements are met. The goal of the strategy is to protect the environment and the public, both now and in the future. Major elements of this strategy have been agreed on by DOE's Oak Ridge Operations Office and the Tennessee Department of Health and Environment, although some specific aspects of both the regulatory requirements and the means to meet these requirements are still being developed. The LLWDDD strategy will use dose-based performance objectives for most program activities and will emphasize interim storage, rather than disposal of LLW, to allow time for new disposal technologies to be developed and demonstrated.

Currently, the LLWDDD Program proposes to use a 10-mrem/year effective radiation dose equivalent as a trigger for remedial action, rather than the 25-mrem/year dose specified in the 10 CFR 61 regulation. This 10 mrem/year dose equivalent will be used as a design basis to compensate for uncertainties in site characterization and to minimize potential future remedial actions. Using this trigger dose of 10 mrem/year, the LLWDDD strategy defines four classes of LLW based on concentrations, half-lives, and leachability characteristics of the materials. Treatment, storage, and disposal proposals for each of these waste categories are also included in the LLWDDD strategy.

Working closely with DOE–ORO and state regulators, the Energy Systems LLWDDD Program has many activities under way to implement this strategy, including site characterization, waste classification and certification, technology demonstration, and new facility development. A cleaner, safer environment should be the ultimate result.—*George Butterworth, manager of the LLWDDD Program and staff member of the Chemical Technology Division.* ornl

Real-time radiography is used to nondestructively examine solid low-level waste packages for noncertified materials, such as this bottle containing free liquid.

Hazardous Waste Development, Demonstration, and Disposal Program

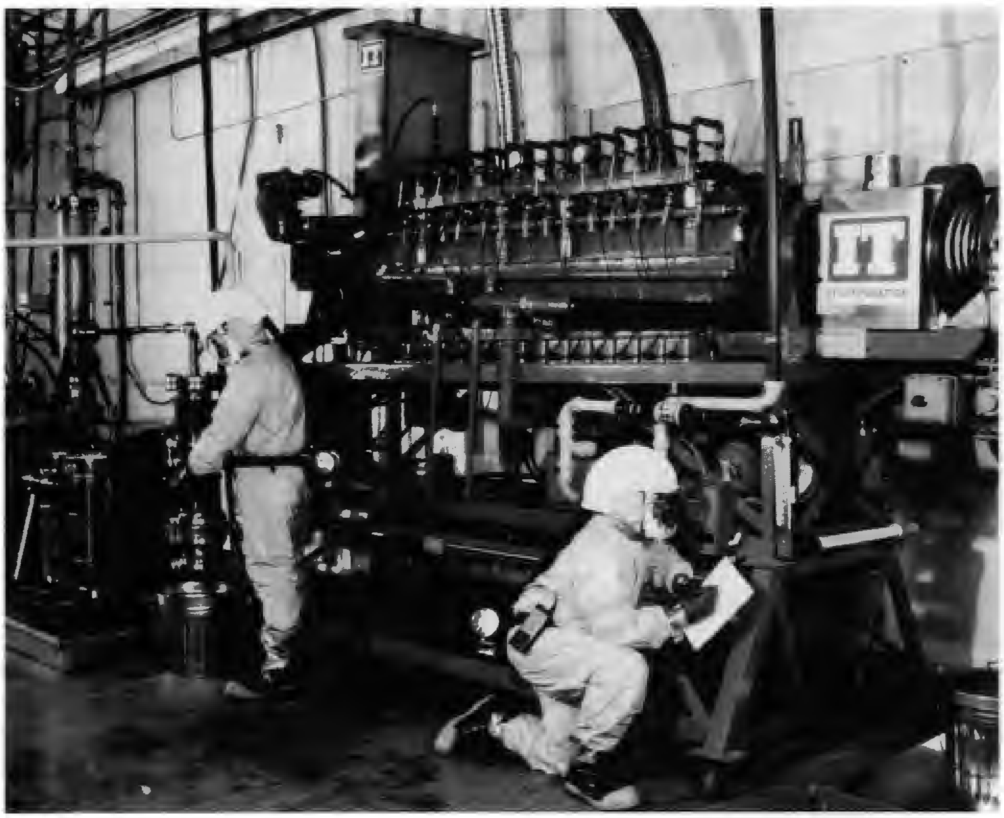
Some chemically hazardous wastes at the five DOE sites managed by Energy Systems have been handled by conventional techniques, but others contain measurable quantities of radionuclides, which compound the difficulties involved in disposal. Because Energy Systems is committed to treating and disposing of all wastes as safely, efficiently, and economically as possible, the Hazardous Waste Development, Demonstration, and Disposal (HAZWDDD) Program was established in 1987 by the Environmental and Safety Activities staff of Energy Systems' Central Waste Management Office to coordinate the development and demonstration of new hazardous waste management technologies.

The HAZWDDD Program is modeled after the Low-Level Waste Disposal Development and Demonstration Program; both programs are administered, under corporate charter, by the Waste Management Technology Center in Oak Ridge.

The HAZWDDD teams at all five Energy Systems sites are identifying technology development and demonstration needs, developing a data base of waste streams (effluents) for all plant sites, and preparing plans to demonstrate various new waste management technologies at several sites. The site plans were consolidated and submitted to the Department of Energy as a corporate program plan by the end of 1988.

A goal of several HAZWDDD demonstration projects now under way is to identify and treat streams that contain mixed (both radioactive and chemical) wastes so that they can be classified as radioactive rather than mixed. Under current regulations, disposal of mixed wastes is much more difficult than disposal of either chemical or radioactive wastes. For example, a small-scale demonstration was conducted in 1988 for removal of PCBs from soil that also contained radioactive components.

Through the HAZWDDD program, Energy Systems aims to bolster DOE's environmental cleanup efforts at government facilities and guide private-sector companies seeking to develop waste management and remediation technologies.—*Phil McGinnis, manager of the HAZWDDD Program and staff member of the Chemical Technology Division.* ornl



The IT Demonstration Project, coordinated by the WMTC and conducted by the IT Corporation, used a thermal-separation process to separate polychlorinated biphenyls (PCBs), heavy metals, and radioactive contaminants from barrels of soil taken at DOE sites in Portsmouth, Ohio, and Paducah, Kentucky.

The Hazardous Waste Technology Program

By Phil McGinnis

Phil McGinnis, a member of the Chemical Technology Division, is manager of the Hazardous Waste Technology Program at ORNL.

During the past 18 months, the Hazardous Waste Technology Program (HWTP) has grown from an idea into a program that manages a dozen different projects and works closely with many divisions at locations throughout the Energy Systems sites. The HWTP has become the "clearinghouse" for hazardous waste technology research and development in the Energy Systems research divisions.

For research sponsors such as the U.S. Air Force, the Navy, or the Environmental Protection Agency (EPA), the HWTP can coordinate a team effort that will harness the necessary technical strengths of the various divisions to solve a particular waste problem. Working across organizational boundaries, the HWTP is responsible for ensuring that waste research results are of high quality and responsive to the sponsors' needs. This integrated approach has proved especially useful in solving hazardous waste problems, which tend to be complex and frequently require the expertise of researchers from several disciplines. The HWTP also handles the business aspects and much of the "red tape" for waste management projects, helping to prepare the often extensive documentation required to allow the sponsored work to be done.

Air Force Projects

The Air Force Engineering and Services Center, at Tyndall Air Force Base (AFB), Florida, sponsors several projects through the HWTP. These include: in situ soil venting to remove spills of hazardous liquids, air stripping with emission controls to remove hazardous volatile compounds, and developing a process for separating uranium from sand.

In situ soil venting. This technology development and demonstration project applies a vacuum to porous soils where a spill of a volatile hazardous material, such as gasoline or trichlorethylene, has occurred. The vacuum vaporizes the material, which can then be recovered or, in some cases, destroyed by the treatment hardware located aboveground. Equipment built for this project at ORNL is being tested at a Hill AFB spill site in Utah. Old jet fuel tanks and the surrounding fuel-contaminated soil were excavated, and soil venting pipes were tunneled through the contaminated soil mound and in the excavation site as it was prepared to receive new tanks (see photos on facing page). The vent pipes will be monitored to evaluate the feasibility, design parameters, and costs of this process, and documentation will be prepared to guide the Air Force in using the technology. David DePaoli and Steve Herbes are the principal investigators for this project. Active support for the work has been provided by personnel at "ORNL West" in Grand Junction, Colorado. Through a subcontract with ORNL, staff and graduate students at Utah State University will provide long-term monitoring of the Utah soil venting demonstration.

Air stripping with emission controls. This project complements the soil-venting effort in addressing spills of hazardous volatile materials. When such spills reach the water table, the contaminated water can be pumped to a surface treatment unit and cleaned by air-stripping to remove the volatile components. In the past, these volatiles were released to the environment. Recent, more-stringent, environmental regulations and the development of new technology have convinced the Air Force that techniques such as centrifugal air stripping and emission controls (catalytic conversion or carbon absorption) should be combined and improved to eliminate the release of such volatiles to the air.

The HWTP coordinated field studies this past summer at an Eglin AFB site near Pensacola, Florida, on soil contaminated by jet fuel spills.

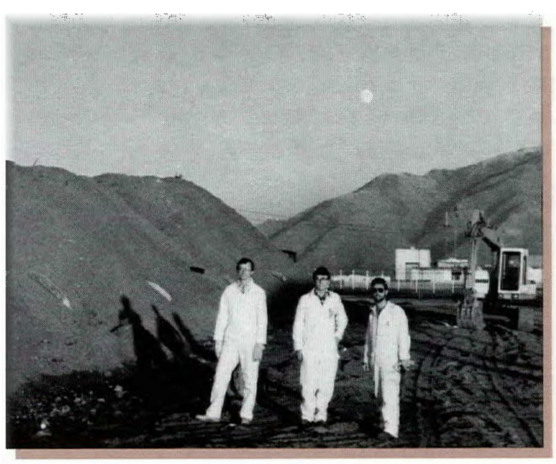
Jim Wilson and Tom Hylton of the Chemical Technology Division (CTD) are the principal investigators of this HWTP project to determine the operational capabilities of an ORNL-designed system that combines available commercial equipment for air stripping and emissions control. They are supported by a team that includes Paul Singh of the Fuel Recycle Division, John Villiers-Fisher and Hal Jennings of CTD, and Pete Counce of the University of Tennessee (UT). The air-stripping assemblage was designed by this team and constructed at ORNL by Plant and Equipment personnel. It was then moved to Florida and reassembled at the contamination site (see photos on next page). The air-stripping operation will be monitored for five months by Wilson and a UT doctoral candidate, Andrew Lucero. Maecorp, an analytical company, has been subcontracted to provide gas-chromatographic analysis of emissions and water samples during this period.

Uranium sand separation. The Air Force has asked the HWTP to solve an unusual waste problem at an Eglin AFB firing range, where armor-piercing shells are fired at targets. The shells contain uranium and, when fired, disintegrate into sand-like particles. Recent EPA regulations require that this sand be removed periodically and handled as low-level waste (LLW). We are investigating techniques for removing the uranium particles from the sand and either recycling the depleted uranium or minimizing its volume to reduce disposal costs. Technologies that are being evaluated for this separation include processes based on the density differences of silica sand and uranium and on paramagnetic techniques (which use highly magnetic fields to separate weakly magnetic substances). Ash Kahn and Bob Wichner of the Engineering Technology Division (ETD) are the principal investigators.

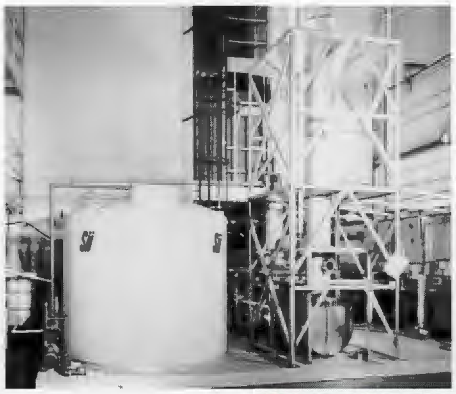
Other DOD Projects

Technology support for several other Department of Defense (DOD) groups, such as the Military Airlift Command (MAC) and the Regional Civil Engineering Office, is being provided at ORNL through the HWTP. An in situ spill treatment combining physical and biological techniques was studied, and the results were reported to the MAC in 1987. Mike Maskarinec of the Analytical Chemistry Division heads an HWTP project to develop analytical methods and instrumentation for use in chemical weapons disposal and on-site spill remediation at the Army's Rocky Mountain Arsenal in Colorado.

Personnel have also analyzed the potential for energy recovery from an incinerator burning



Principal in situ soil venting investigators (left to right) Steve Herbes, of the Environmental Sciences Division, and Dave DePaoli and Hal Jennings, of the Chemical Technology Division, stand beside a mound of contaminated soil excavated from around old jet fuel tanks at a Hill Air Force Base site in Utah. Note soil-venting pipes tunneling through the soil mound and excavation area.



ORNL built this air-stripping equipment, transported it to Florida, and reassembled it to remove volatile components of jet fuel spilled at an Air Force base.

hazardous wastes supplied at least partially from DOD facilities and a companion municipal waste incinerator. Another project for the DOD has been an options study for decommissioning an Air Force nuclear reactor. Technical support staff from both ORNL and ORGDP have reviewed documents for military remedial actions prepared by contractors working for the Department of Energy's national Hazardous Waste Remedial Action Program (HAZWRAP).

Navy Projects

The U.S. Navy is sponsoring R&D in support of waste minimization through the HWTP. Paint-stripping of Navy aircraft generates thousands of gallons of wastewater contaminated with organic stripping agents and heavy metals from the paint. The Naval Energy and Environmental Support Activity group has requested assistance in studies to implement a plastic-pellet blasting paint-removal technique at a Naval Air Station in North Carolina. This technique uses plastic pellets in a type of sand-blasting equipment to remove the paint without damaging the thin skin of the aircraft. ORNL has provided both research and engineering support for these studies. Principal investigator Uri Gat of ETD and engineers Oliver Messner, Joe Arnold, Charles Anderson, and Kathy Kinney, of Energy Systems Engineering, have handled this project.

The HWTP is also helping the Navy to clean wastewaters contaminated with chromium before their release to municipal sewers. Trailer-mounted, reverse-osmosis, chromium-removal equipment (see photo at right) has been built and transported to a Navy Ordnance Station near Louisville, Kentucky. Joe Walker, principal investigator, and technicians Don McTaggart, Judy Butler, John Parrott, and Jim Hewitt (all members of the CTD) are currently demonstrating the equipment in around-the-clock operation on a metal-plating shop waste stream. This technology, which is new to the Navy, builds upon an LLW water-cleanup process that ORNL has been practicing for years.

DOE Projects

DOE is sponsoring several hazardous waste projects through the HWTP. These are primarily funded through the HAZWRAP. The paramagnetic separation of hazardous metals from a substrate such as soil or salt has been tested at ORNL and is now being expanded to a demonstration project. Janet Hoegler, of ETD, is principal investigator of the project. The work is an outgrowth of the coal cleanup work done at ORNL a few years ago.

In another DOE-sponsored effort, several teams of researchers are investigating in situ methods for the destruction of polychlorinated biphenyls (PCBs). The PCB research is discussed in more detail by Terry Donaldson on pp. 44–45.

Another HWTP sponsor in the energy field, the Electric Power Research Institute (EPRI), is funding a study of in situ methylation to remove mercury from sludge at the East Fork Poplar

Creek discharge area of the Y-12 Plant site. In support of this work, DOE is providing funds for Oak Ridge researchers to apply the techniques developed in this study to the mercury remediation efforts at other Oak Ridge sites. Ralph Turner and Jerry Elwood of the Environmental Sciences Division are handling the ORNL portion of this research.

New HWTP work headed by Roger Jenkins, of the Analytical Chemistry Division, will develop rapid field techniques for screening collected environmental samples for contaminants. Because the more costly laboratory analyses could then be performed only on the identified contaminated samples, this development would make remedial site characterization both faster and more economical.

A separate site-characterization project coordinated by the HWTP will provide funds for Jon Nyquist, of the Health and Safety Research Division, to modify the Ultrasonic Ranging and Data System (USRADS) developed at ORNL to accept and transmit geophysical data for locating buried nonradioactive wastes. Nyquist will test the modified USRADS at a DOE facility in Idaho.

Several hazardous waste technology demonstrations are being directed by the Waste Management Technology Center (WMTC) and coordinated through the HWTP. These include the X-Trax thermal-separation process demonstration for treating contaminated sludges, headed by Paul Hollenbeck of the CTD, and the IT thermal-separation process demonstration headed by Mike Morris, also of the CTD (see discussion of both processes on pp. 33–34).

Demonstrations of innovative treatments for contaminated groundwater will be coordinated by Suman Singh and John Kennerly of the CTD, as a WMTC/HWTP project. In another new initiative, Lisa Thompson and Charlene Edwards, of Y-12 Development, will be demonstrating methods for cleaning metal parts with surfactants, rather than the hazardous trichloroethylene that has been used in the past.

We expect a continual expansion of HWTP efforts as the many Oak Ridge technical and support capabilities in hazardous waste management become better known to potential work sponsors. Research divisions here will also continue to develop new waste management proposals. Our role in coordinating these technology development and transfer efforts will benefit DOE and the sponsoring agencies, while providing new ORNL research challenges.

Don McTaggart, a technician for the Chemical Technology Division, uses the reverse-osmosis chromium-removal system designed and built at ORNL to clean wastewaters from a chromium plating process at a Navy Ordnance Station near Louisville, Kentucky.

PCB-Eating Microbes

Contamination of soil by polychlorinated biphenyls (PCBs) is a significant environmental problem on the Oak Ridge Reservation, as it is at many other government and industrial installations. Contaminated soils in the Oak Ridge area include several sites within the burial grounds of the Oak Ridge Y-12 Plant and at least one location along the floodplain of Bear Creek.

Because of their widespread use as dielectric fluids in electrical transformers, PCBs are prevalent in the environment. Even though their manufacture was banned by passage of the Toxic Substances Control Act of 1976, PCBs persist in the environment partly because electrical equipment containing PCBs has been discarded in the past 12 years, releasing the toxins to the soils. Many research efforts are being made to find ways to decontaminate these soils.

Simpler PCBs Biodegradable

Until recently, PCBs were not considered biodegradable. However, it is now known that many of these chlorinated compounds can be degraded biologically and, in some cases, the carbon of PCBs can even be converted by microorganisms to carbon dioxide. The less complex PCBs, containing fewer than four chlorine atoms per molecule, can be degraded biologically under laboratory conditions. It appears likely that compounds containing more chlorine atoms can be degraded as well, although the process may be slower. To date, no technology for in situ PCB biodegradation has been demonstrated in cleaning up an actual contaminated site.

At ORNL, an interdisciplinary team is investigating the technical feasibility of bioremediation of PCB-contaminated soils by stimulating microorganisms naturally present in soil to convert the PCBs to

Dusty Hill, a former ORNL research associate from the University of Tennessee, checks lysimeters used for PCB biodegradation tests on the Bear Creek floodplain.

harmless substances. Team members include professional and technical staff from the Chemical Technology and Environmental Sciences divisions, the University of Tennessee, and the Oak Ridge Research Institute. Funding was obtained through the ORNL Hazardous Waste Technology Program (see article on p. 40 in this issue) from the Department of Energy's Oak Ridge Operations Office, the Hazardous Waste Remedial Action Program, and the environmental compliance program at the Y-12 Plant. This work developed from a recent ORNL Laboratory Director's R&D Fund project dealing with microbial treatment of hazardous wastes.

During the summer and fall of 1987, six in situ lysimeters and two slurry bioreactors were used in testing bioremediation of PCB-contaminated soil from the floodplain of Bear Creek on the Oak Ridge Reservation. The various treatment conditions investigated were: aeration, moisture, nutrients, inoculation with known PCB-degrading microorganisms, and stimulation of the microbial cultures with biphenyl (a nonchlorinated PCB-type compound).

The most promising result of these tests was that indigenous microorganisms (those naturally present) in these contaminated soils were shown to be capable of degrading 4-chlorobiphenyl, a monochlorinated species. Evidence of this degradation included the detection of radiolabeled carbon dioxide produced by microorganisms from radiolabeled biphenyl. Microbial characterization studies using gene probes and signature-lipid analyses confirmed the presence of naturally occurring organisms capable of causing this biodegradation.

Our work also showed evidence of some breakdown of highly chlorinated PCBs under laboratory conditions by microbial cultures isolated from other contaminated soils. We also found that microbial inoculation and incubation of the soils may affect the physico-chemical behavior of the chlorinated biphenyls in the soil, making them more difficult to extract chemically. In other words, the injected microbes seem to alter the PCBs in the soil, making it more difficult for the indigenous microbes to convert them to innocuous materials.

Soil Treatment Helps

The in situ treatment of the soils in lysimeters by aeration and water appeared to stimulate the growth of the indigenous microorganisms, thereby increasing the rate of monochlorinated biphenyl biodegradation in lysimeter soil samples in our laboratory experiments. The effects of changing the concentrations of nutrients, biphenyl, and microorganisms are still unclear because only one condition for each parameter has been tested.

No statistically significant degradation of the preexisting PCB contaminants in the soils was detected in either the field lysimeters or the laboratory slurry bioreactors. However, our experimental results indicate some biodegradation of model compounds and selected PCBs, and our indigenous-microbe characterization studies have encouraged us to continue this work. Experiments are already under way to define the most favorable environmental conditions and microbial cultures for degrading PCBs. Additional lysimeter tests are also being planned.—*Terry Donaldson, Chemical Technology Division* ornl

Radioactive Waste Management R&D

By Allen G. Croff

Allen G. Croff is the director of ORNL's Waste Management Research and Development programs.

ORNL's Waste Management Research and Development (WMR&D) programs include about 40 projects supported by the Department of Energy (DOE), most of which can be classified as radioactive waste management R&D. Much of the work is focused on national needs—that is, not primarily directed toward managing Oak Ridge wastes; however, many of the results could be applied to Oak Ridge sites, including ORNL.

Most of the projects in these programs fit within the categories of applied research (seeking new information about existing systems or materials) and engineering development (proof of principles or use of knowledge identified through research at less-than-operational scale). A few projects are considered to be fundamental research or field implementation (application of complex technologies at operational scale, as in waste management technology demonstrations).

Within DOE, the primary sponsor of WMR&D at ORNL is the Office of Civilian Radioactive Waste Management (OCRWM). This office is responsible for transporting, storing, and ultimately disposing of the spent fuel produced by civilian nuclear reactors and the high-level waste produced by defense plants, such as the Savannah River and Hanford facilities. These efforts are funded by a \$0.001/kWh tax on the electricity generated by the civilian nuclear reactors or equivalent payments by the defense plants. Another important sponsor is DOE's Office of Nuclear Energy, whose responsibilities include identification and cleanup of residues from the processing of (1) uranium ores, typically in the western United States, and (2) highly concentrated, naturally occurring radionuclides (e.g., radium, thorium) from the Manhattan Project. Other important sponsors include DOE's Office of Defense Programs and Office of Environment and Health.

Additional WMR&D projects are discussed in other articles in this issue (e.g., "Hazardous Waste Technology Program"; "Waste Management Technology Center"; "Grouts Solve Disposal Problems"; "Low-Level Waste Disposal Development and Demonstration Program"; and "Hazardous Waste Development, Demonstration, and Disposal Program").

The work discussed here includes

- identifying and characterizing sedimentary rocks for potential use in disposing of high-level wastes;
- conducting sensitivity and uncertainty analyses for predicting the long-term reliability of waste repositories;
- testing transportation casks for radioactive materials;
- integrating the transportation, temporary storage, and permanent disposal of radioactive wastes into a smoothly operating system;

- maintaining an Integrated Data Base to track annual inventories and projected amounts of radioactive wastes in the United States; and

- surveying radioactive properties in the western states.

Study of Sedimentary Rocks

For over two decades, ORNL has supported DOE's efforts to permanently isolate high-level waste (HLW), including spent fuel. Before 1978, ORNL had the lead responsibility for the national program to develop a permanent repository—a mined cavern 600 to 1200 m underground to be filled with waste and permanently backfilled and sealed. ORNL researchers studied the feasibility of burying HLW in the abandoned salt mines near Lyons, Kansas. However, after the withdrawal of Union Carbide Corporation, ORNL's operating contractor at the time, from this area in 1978, ORNL had very little involvement until passage of the Nuclear Waste Policy Act in 1982.

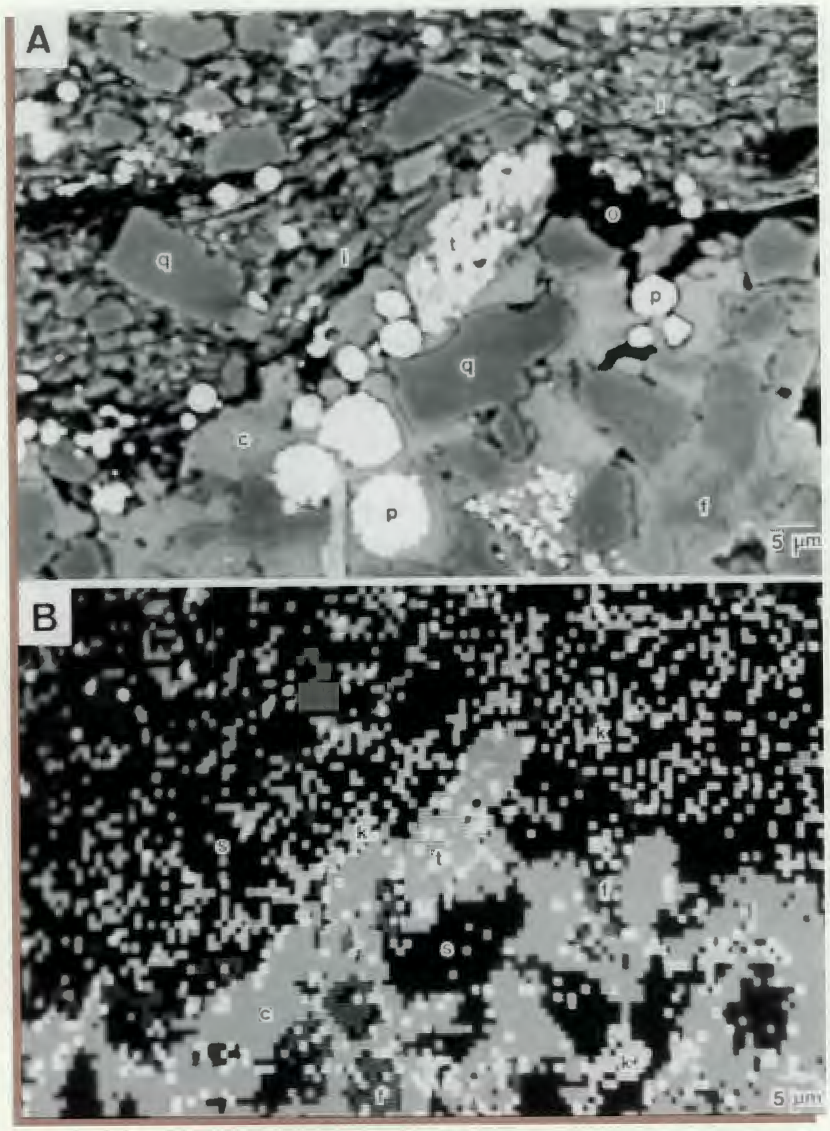
This act provided a new structure and impetus for efforts to establish HLW repositories. The terms of the act allowed for new initiatives in the national program, and ORNL successfully proposed a study of sedimentary rocks—those laid down at the bottom of primordial seas—as potential for a repository. After nearly a year of work evaluating five sedimentary rock types, the argillaceous shales and clays were determined to be best suited for a repository. These have been the focus of recent experimental studies. East Tennessee rock formations are included among the carbonates and shales studied by the ORNL group.

Further study of shale will better define its intrinsic properties and allow its precise evaluation as a potential host medium for a proposed HLW repository. Four representative "end member" shales that are relatively abundant in the conterminous United States have been identified. Hydrology tests have been done to characterize the flow of water through these shales, and their geochemical and mechanical properties are being investigated.

Hydrology. Using highly specialized equipment and assisted by personnel from DOE's Lawrence Berkeley Laboratory, we measured the hydraulic conductivity of shale—its resistance to the passage of water. Because of the extremely low hydraulic conductivities of shales, instrument improvements had to be made to obtain accurate results. Subcontractors for ORNL and Martin Marietta Energy Systems, Inc., have also been involved in modeling the flow of water through rocks such as shale. These laminar rocks are composed of many thin, parallel layers and may contain closed or sealed fractures. Most shale samples have two distinct hydraulic conductivities: one parallel to the bedding plane and another (typically lower) perpendicular to it.

Geochemistry. Studies to characterize the geochemical aspects of shales have been conducted by ORNL's Environmental Sciences and Chemistry divisions. One such study evaluates the extent to which the movement of radioactive species in groundwater would be retarded by interactions (sorption) with shales. Because of its clay content, shale has an outstanding ability to retard most radionuclides, allowing them to decay to innocuous levels before they reach the accessible environment. Another study is attempting to determine the dissolved mineral content of groundwaters typically found in shale formations; however, data are sparse because shales at repository depths contain little water. These data are used in computer models developed to predict the composition of unperturbed water and, once satisfactory results are obtained, can be used to predict the behavior of radionuclide species dissolved in groundwater.

Because shales are so "tight" with respect to groundwater movement, the greatest potential for the rapid travel of groundwater containing radionuclides is believed to be through fractures introduced during deposition or subsequent deformation, even though such fractures have generally been sealed eons ago by plastic deformation (of the overlying rock) or deposition of minerals from flowing groundwater. The geochemical aspect of this work will characterize the minerals deposited in the fractures to determine when the deposition occurred (thus, how long the formation has been stable) and the susceptibility of the fracture to future groundwater flow.



The mineralogical diversity of Chattanoga shale is shown in the electron micrograph (A), and a computer-generated elemental distribution map of the same area is shown below it. Potassium (k) represents the minerals illite and feldspar; silicon (s) represents quartz; iron (f) represents pyrite; calcium (c) represents calcite; and titanium (t) represents a titanium-bearing mineral.

Rock mechanics. Studies are under way by an ORNL/Energy Systems subcontractor having highly specialized equipment to measure shale parameters (e.g., unconfined compressive strength, Poisson's ratio, modulus of elasticity) related to shale's ability to maintain a mined opening and the potential for shale deformation after closure of a repository. Because the wastes to be emplaced in the repository will generate heat and raise the rock temperature by as much as 200°C, the mechanical properties of shale must be measured as a function of temperature. Additionally, thermal properties such as the heat capacity, thermal conductivity, and coefficient of thermal expansion must be measured to permit making accurate predictions of heat transfer and rock deformation.

Beyond these determinations of intrinsic rock properties, researchers of the Chemical Technology Division have subjected scale models of mined openings in shale samples to pressures simulating the overburden to observe deformation rates. These experiments, which typically last weeks to months and may extend to years, have demonstrated that the deformation behavior of shales is nonlinear with time and temperature—that is, the size and shape changes of openings in shales are not proportional to the increases in time and temperature.

Sensitivity and Uncertainty Analysis

The repository to be built and operated by DOE will be licensed by the Nuclear Regulatory Commission (NRC) under specific regulations based on general standards established by the Environmental Protection Agency. Compliance with these regulations and standards must be demonstrated by predicting the performance of the repository after closure for periods up to 100,000 years. Because experimental demonstration of repository performance over these periods is clearly impossible, predictions must rely on calculational models (e.g., groundwater flow at the repository site and waste package degradation) based on scientific knowledge and geologic history. In using models that depend upon uncertain and variable data (e.g., hydrological properties of the rock or the waste package corrosion rates), the key issues are identification of the data that most affect the model predictions and quantification of the uncertainties in these predictions arising from the data uncertainties (e.g., groundwater travel time to the accessible environment, waste package lifetime).

However, because the computational models are complex and expensive to run and use a large amount of data, the identification of the most sensitive data and the calculation of the uncertainties can become very expensive and even prohibitive using traditional statistical approaches that depend upon numerous (often thousands) of model reruns. Researchers in ORNL's Engineering Physics and Mathematics Division and in the Energy Systems Computing and Telecommunications Division have developed an approach for calculating data sensitivities and model result uncertainties that is far more cost efficient than the normal statistical approaches.

The basic concept in their approach takes advantage of the fact that these computational models consist of systems of equations that can be analytically differentiated. By calculating the first derivatives of the results of interest with respect to the data, the effect of the data upon the results can be quantified. Furthermore, multiplication of these derivatives by the ratio of the input value to the result value defines a unitless quantity, referred to as a sensitivity value, which allows direct comparison among data (comparison of derivatives does not account for the fact that the data can have different units).

For more than 20 years, "sensitivity analysis" methods have been developed to efficiently calculate derivatives. These methods have been known to require orders of magnitude less computational effort than the many model reruns required for direct pertubation of the data or statistical regression analysis.

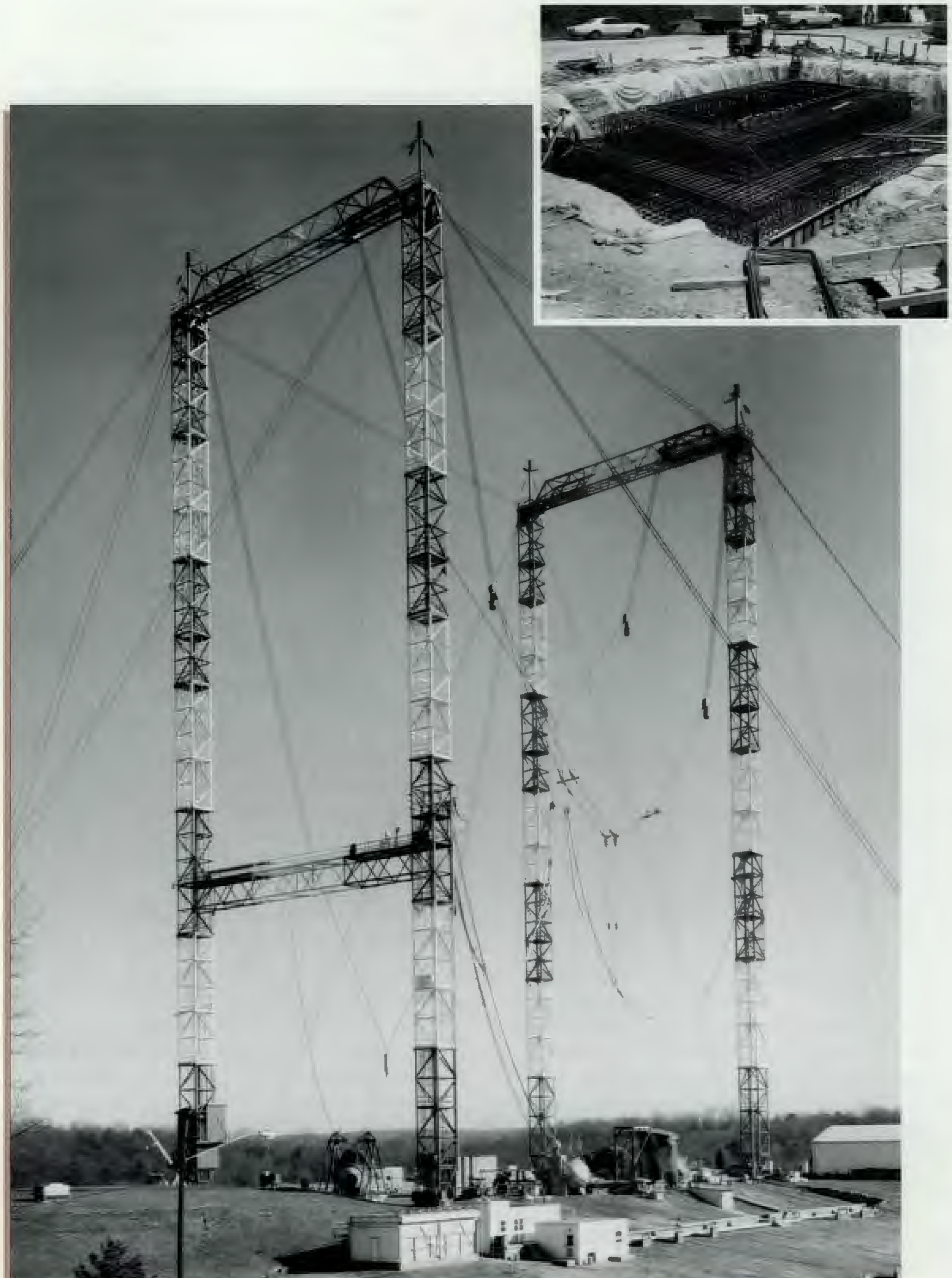
However, these methods require that the original model equations be painstakingly differentiated one by one and that additional lines of computer coding be added for calculating the needed derivatives. The effort required to implement these methods into existing computer models was most often viewed as prohibitive. To circumvent this prohibitive task and thus take advantage of the existing sensitivity methods, a computer compiler was developed that compiles existing FORTRAN models and automatically adds the capability to calculate derivatives of interest in addition to the normal model results.

Two automated systems, called GRESS and ADGEN, have been tested and verified on computer models of interest to both the national repository and low-level waste programs. As an example, the ORNL-developed PRESTO-II code for calculating the dose to man from shallow-trench burial of low-level solid waste was compiled with ADGEN, and sensitivities of the dose to over 3000 input data values were calculated at a cost of only 52 times that of the reference model. In comparison, EPA recently spent a year determining a thousand sensitivities by rerunning the model a thousand times.

Finally, the researchers have developed a method, referred to as deterministic uncertainty analysis (DUA), to use the derivative information for calculation of the model result uncertainties. The use of the derivative information results in a more nearly accurate CDF using only two model runs, compared to 50 model runs in the Monte Carlo analysis.

For large models having many data values, this reduction in the number of model runs, even taking into account the computation of derivatives, leads to a substantial reduction in computer cost. The GRESS, ADGEN, and DUA software are currently being used in repository performance assessment within the waste management research community. This project is also noteworthy because it was one of the first in the United States to meet the stringent quality assurance requirements of the OCRWM repository program. This program uses the same nationally recognized QA standard (NQA-1) as does ORNL, but the implementation of its provisions for the repository program is much more intense and, therefore, difficult to meet.

"Another study is attempting to determine the dissolved mineral content of groundwaters typically found in shale formations."



These towers of the TSF have been fitted with cables and special instrumentation for drop-testing of waste transportation casks. The inset shows the heavy reinforcement of the concrete pad on which the casks are dropped during testing.

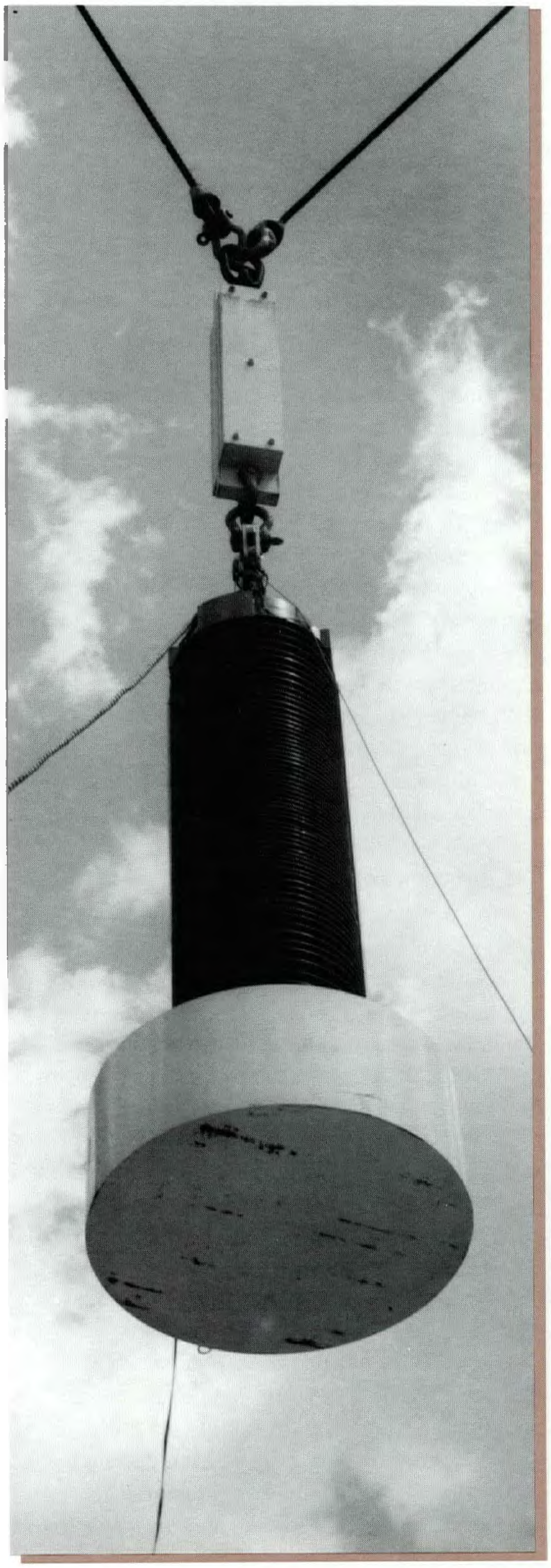
Testing Transportation Casks

Spent nuclear fuel and HLW will be transported from producer sites (nuclear power plants and defense plants) possibly to intermediate destinations (e.g., storage sites) and eventually to DOE's repository for final internment. Because these materials are highly radioactive and hazardous, they will be shipped in special casks—massive, high-integrity containers that must meet very stringent state and federal requirements. To ensure that these criteria are met, the NRC has issued regulations requiring each cask design to pass specific tests before it can be certified (licensed) for use. These drop, fire, and leakage tests are designed to demonstrate that a cask will remain intact under various accident conditions that might occur during shipment.

Because of its Tower Shielding Facility (TSF), ORNL is uniquely qualified to perform these drop tests. The TSF has four 300-ft-tall towers that were once used to test various radiation shielding materials. After the shielding tests ceased, ORNL staff members in the Chemical Technology, Engineering, and Operations divisions adapted it for use in cask testing. During the past 12 years, only two of the four towers have been used for drop testing (see photo at left).

In the drop tests, each cask is maintained in its least-favorable orientation (generally, to achieve corner impact), lifted to a specified height, and dropped on an unyielding surface (thick steel plates atop reinforced concrete). All parts of the test must be carried out reliably; the cask must be fully instrumented to record accelerations, deformations, etc.; the test should be photographed, videotaped, and otherwise monitored to provide the information necessary to analyze the cask's performance. The casks being dropped in these tests can weigh anywhere from several hundred kilograms to 100 t, depending on the cask design and whether a full-scale test is required.

During the next few years, this facility is expected to have considerable use in the testing of new casks being designed for transporting highly radioactive spent fuel, the less-hazardous radioactive wastes produced by the defense plants, and hazardous chemicals from various producers.



Each cask is maintained in its least-favorable impact orientation during drop testing.

Work is under way to expand the TSF into a comprehensive Cask Testing Complex, including facilities for thermal and leak testing. The complex will be developed as a DOE user facility, making it available to a variety of clients.

Systems Integration

"The Nuclear Waste Policy Act of 1982 fundamentally altered the scope of DOE's repository program."

The Nuclear Waste Policy Act of 1982 fundamentally altered the scope of DOE's repository program. Before the Act, DOE was responsible only for siting, licensing, constructing, and operating the repository. However, the Act also requires DOE to accept title to nuclear waste at the sites that produce it (e.g., reactor sites). DOE also has the responsibility of transporting the waste and possibly storing it in a monitored retrievable storage (MRS) facility prior to repository construction. Such a multifaceted scope requires DOE to ensure that the functions of the system (transportation, storage, and repository) will work together smoothly and that all facilities use consistent design and construction criteria, assumptions, and data. Toward this end, DOE has created a systems integration function, and ORNL has a lead role in this area.

Logistics modeling. Some of the work dealing with criteria, assumptions, methods, and data is novel and interesting. One group, which includes members of the Chemical Technology and Energy divisions and subcontractors, is responsible for developing a state-of-the-art computer program to model the movement of spent fuel through the DOE/OCRWM system. The program will be able to model a facility or operation at any desired level of detail based on the input data (as opposed to encoding the model in a programming language such as FORTRAN) and track individual fuel assemblies or HLW canisters, taking into account their individual characteristics.

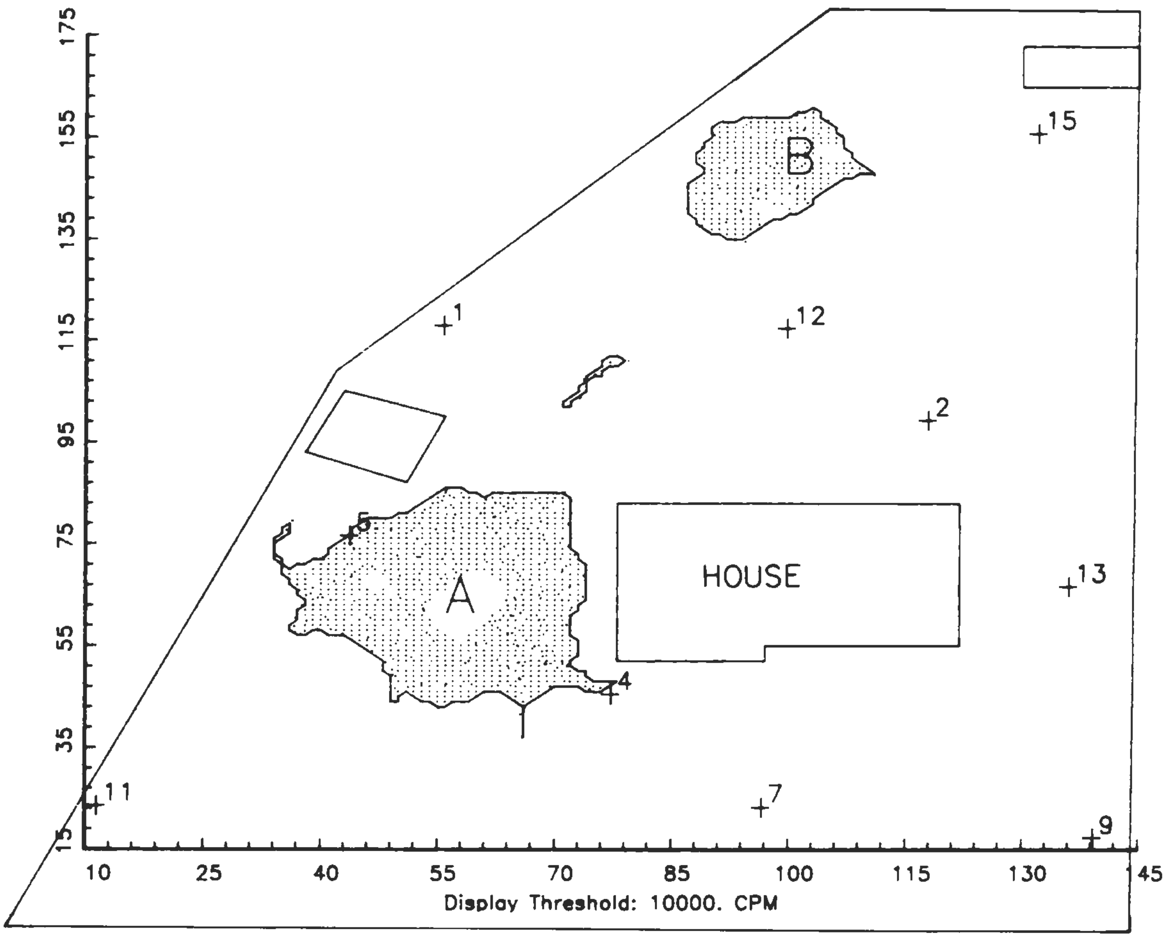
The initial use of this code is expected to be in system design and trade-off studies to ensure appropriate dimensions of facilities. Later, this program will probably be supplemented with additional modules and will become the central software used for dispatching and controlling the progress of shipping casks.

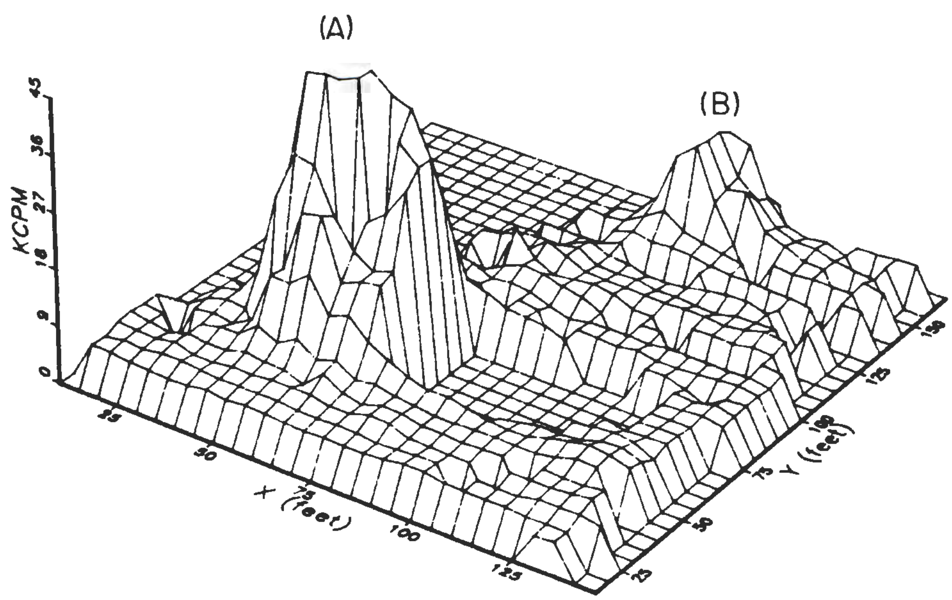
System modeling support. To ensure that consistent and acceptable computer programs are available to the many contractors and subcontractors working for the OCRWM, the work participants have been surveyed to identify and evaluate the computer codes being used. Codes in functional categories generally applicable to multiple elements of the OCRWM system (e.g., radiation shielding analysis codes are used by transportation, repository, and storage groups) are assessed to determine which is preferred for OCRWM use. Recommendations identify the preferred code and specify the extent to which it requires enhancement and validation. The preferred codes will then be upgraded to meet OCRWM needs and validated to show that they yield acceptable results.

The validation is part of the quality assurance process, and its major goal is to demonstrate that the computer code is accurate. This is currently being done with the ORIGEN2 code, used to predict the radionuclide composition of spent nuclear fuels. The only defensible way to do this is to obtain samples of the spent fuels, identify and quantify their radionuclide compositions, and compare the experimental results with ORIGEN2 calculation results. This work must be done in remotely operated hot-cells because of the intense radioactivity of the spent fuel. A relatively high degree of accuracy in the analyses is required. Samples of spent fuel have recently been received from Pacific Northwest Laboratory, and the experimental measurements are currently under way.

The results of this entire process are expected to be formally documented and used as a basis for an early petition to the NRC to agree that the code and its results, within specified limits, are acceptable for use by OCRWM. This concurrence will provide early assurance to DOE, the NRC, and the public that this aspect of the work is acceptable and will expedite the licensing of the OCRWM system components. The codes, when approved, will be made available to our contractors through ORNL's Radiation Shielding Information Center to ensure their widespread use.

USRADS DATA ANALYSIS





This computerized data analysis of an USRADS survey done on private property in Grand Junction, Colorado, shows both the location and radioactivity of the imported uranium mill tailings.

"Each winter, ORNL issues a call for updated information to all parties believed to have radioactive wastes."

Integrated Data Base

Several years ago, DOE recognized the need for a consistent, centralized, data base of management-level information on all U.S. radioactive wastes. To meet this need, the Integrated Data Base (IDB) was developed. This thriving program has been supported by three separate DOE offices since its inception, producing updated annual reports summarizing the inventories of radioactive wastes and projections of future U.S. waste production. The IDB includes waste types ranging from the barely radioactive mill tailings in the western states (residues from processing uranium ores) to highly radioactive spent reactor fuels and HLW. Wastes from Department of Defense activities, civilian nuclear reactors, industries (e.g., smoke detector manufacturers), and institutions (e.g., hospitals) are included in the compilation. The data constitute a basis for DOE and other federal agencies to use in establishing radioactive waste management policies and planning their implementation.

Acquiring data for the IDB is a complex, lengthy process, because the wastes exist in many locations and under the jurisdiction of many different DOE operations offices and operating contractors. Each winter, ORNL issues a call for updated information to all parties believed to have radioactive wastes. At the same time, work begins to establish the bases to be used in waste projections (e.g., the number of operating nuclear reactors in future years). The IDB staff members then begin to organize and evaluate the information. Ensuring that the data are complete and accurate and that the definitions used are consistent and fully understood may require follow-up telephone calls and meetings with the data-contributing organizations. After months of information gathering, the IDB staff sends the organized and evaluated data back to the originating sites for final verification and approval. Upon approval, the data are summarized by waste type, formatted, and published.

We expect that the scope of the IDB will be expanded to include mixed (containing both radioactive and hazardous chemical constituents) wastes and, eventually, hazardous chemical wastes—providing a complete picture of existing and projected U.S. wastes.

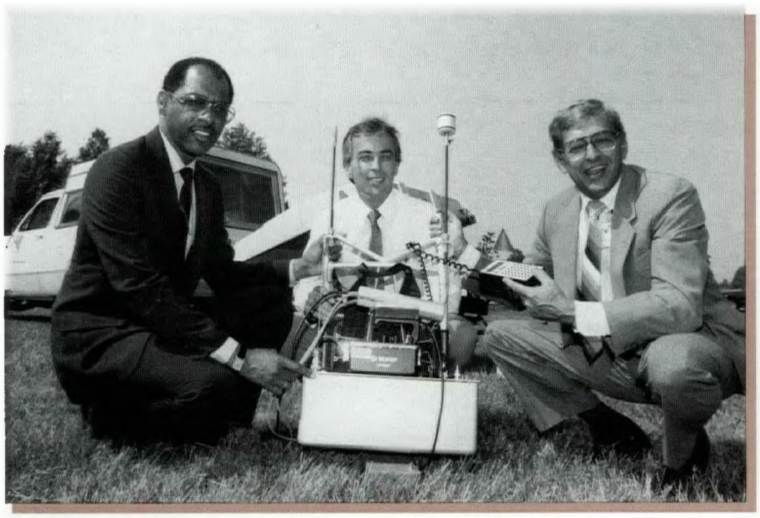
Radiological Surveys

The Uranium Mill Tailings Radiation Control Act of 1978 mandates that inactive mill tailings piles and associated properties be cleaned up or made safe for habitation. Uranium ores typically contain about 0.25% uranium. Thus, after a mill has chemically separated the uranium, about 99.75% of the material has no economic value and is relegated to the large tailings piles found in the western United States. Disposing of the huge volumes of these sand-like materials was a problem for the uranium mill operators. Consequently, for years they gave the tailings away to be used as aggregate in mortar, fill material in yards and sand in children's sandboxes.

Increasingly stringent regulations led to the determination that some of the uranium decay products in the tailings (primarily radium-226 and radon-222) posed a possible hazard to human health, and their location and removal was necessary. Because of the give-away policies of the past, these tailings were widely distributed over thousands of unidentified sites. Thus, an inclusion survey project was initiated to identify locations of the tailings and to determine which individual properties should be included in a program to remove the materials. About five years ago, personnel in ORNL's Health and Safety Research and Instrumentation and Controls divisions became involved in the survey. The scope and potential cost of surveying over 10,000 properties by (1) repeatedly walking the properties, (2) recording approximate locations and radiation readings, (3) transcribing the readings to computers at a home base, (4) analyzing the results, and (5) returning to survey sites, if necessary, was mind-boggling. ORNL scientists offered an alternative solution: the Ultrasonic Ranging and Data System (USRADS) (see article in the ORNL *Review*, Number Two, 1988).

Briefly, ultrasound is transmitted from a surveyor's position to as many as 15 perimeter receiving stations located around a property. Radiofrequency (RF) transmission signals from

Using USRADS, Kathy Dickerson conducts a radiological survey of a property as Doug Pickering checks the data displayed on the microcomputer.



The ORNL-developed USRADS was recently licensed by Martin Marietta Energy Systems, Inc., to Chemrad Corporation. Participating in the negotiations were, from left, Sammie Harris, a director of the Energy Systems Office of Technology Applications; Charles Flynn, Chemrad president; and Bill Carpenter, Energy Systems vice president of Technology Applications.

the surveyor's backpack initiate the start time of the ultrasound as it leaves the surveyor's location, and an RF stop signal is sent from each perimeter receiving station as it hears the ultrasound. A microcomputer nearby is equipped with receivers for the RF start and stop signals. The surveyor's location is calculated (with an accuracy of within 15 cm) each second by a computerized triangulation method using the ultrasound time-of-flight. In addition, the exposure rate of detected radiation is transmitted from the surveyor to the computer each second, enabling the computer to correlate the surveyor's exact position with the radiation data collected.

USRADS has benefited the survey program in many ways. First, the surveyor can see the survey results immediately on the computer screen, eliminating the need for return visits. Second, the positional information is automatically correlated with the radiation readings. In addition, feeding the information directly from the measuring instruments to the computer has eliminated the time and errors involved in manual transcription. It is conservatively estimated that the USRADS survey system has saved our government millions of dollars.

The survey aspect of the program is now winding down because most of the properties have been surveyed; only difficult-to-locate properties remain unsurveyed. In addition to its application in the uranium mill tailings survey, the USRADS technology has been used recently in the Formerly Utilized Sites Remedial Action Program, a DOE effort to identify properties in the eastern United States that have been contaminated by residues from the processing of naturally occurring radioactive materials during the Manhattan District era. USRADS has also been used locally to aid in locating radioactively contaminated areas.

For the program and staff, a transition from radiological to hazardous site survey and characterization using the USRADS technology is anticipated. In the near term, this will involve developing small, reliable chemical "sniffers" that perform the same function as the radiation detector in the existing USRADS system. The chemical industry is already showing interest in the commercial potential of USRADS; in 1988 Energy Systems licensed USRADS to the Chemrad Corporation. Program activities may extend beyond surveying to more completely characterizing site contamination, perhaps including the preparation of remediation plans.

Conclusions

ORNL's R&D programs can be expected to play a large role in future waste management activities, particularly if DOE's concept of better managing the wastes currently produced and cleaning up the contamination left from past abuses is widely accepted and receives congressional funding. The task of removing or rendering innocuous the hazardous constituents of wastes is difficult because of the waste volumes, the number of sites, and the variety of waste types and concentrations involved. ORNL's waste management R&D goals are to develop solutions to waste management problems that have not been solved, as well as more cost-effective approaches to waste problems that have been considered too large and too expensive to solve. ornl

Grouts Solve Disposal Problems

By Earl McDaniel

Earl McDaniel is organizer of a new Engineered Waste Form Program for the Waste Management Technology Center.

Mafia gangsters have often been credited with using cement to "dispose of" their rivals. Could these notorious felons have inspired a new waste management technique? Although engineers in ORNL's Chemical Technology Division deny any connection with the underworld organization, they have developed a technology for disposing of radioactive wastes by immobilizing materials in a cement-based grout.

Originally developed for the permanent disposal of high-level radioactive waste, in 1982 the grout technology attracted the attention of program manager Joe Wetch of Rockwell Hanford Operations (RHO), the Department of Energy's contractor for waste management operations at Hanford, Washington. Wetch believed the grout technology might be used to dispose of some highly radioactive nuclear fuel reprocessing waste streams (effluents) at Hanford. In 1982, RHO contracted with the engineer developers at ORNL to investigate the feasibility of grout immobilization for Redox and Purex process sludges.

ORNL Helped Hanford

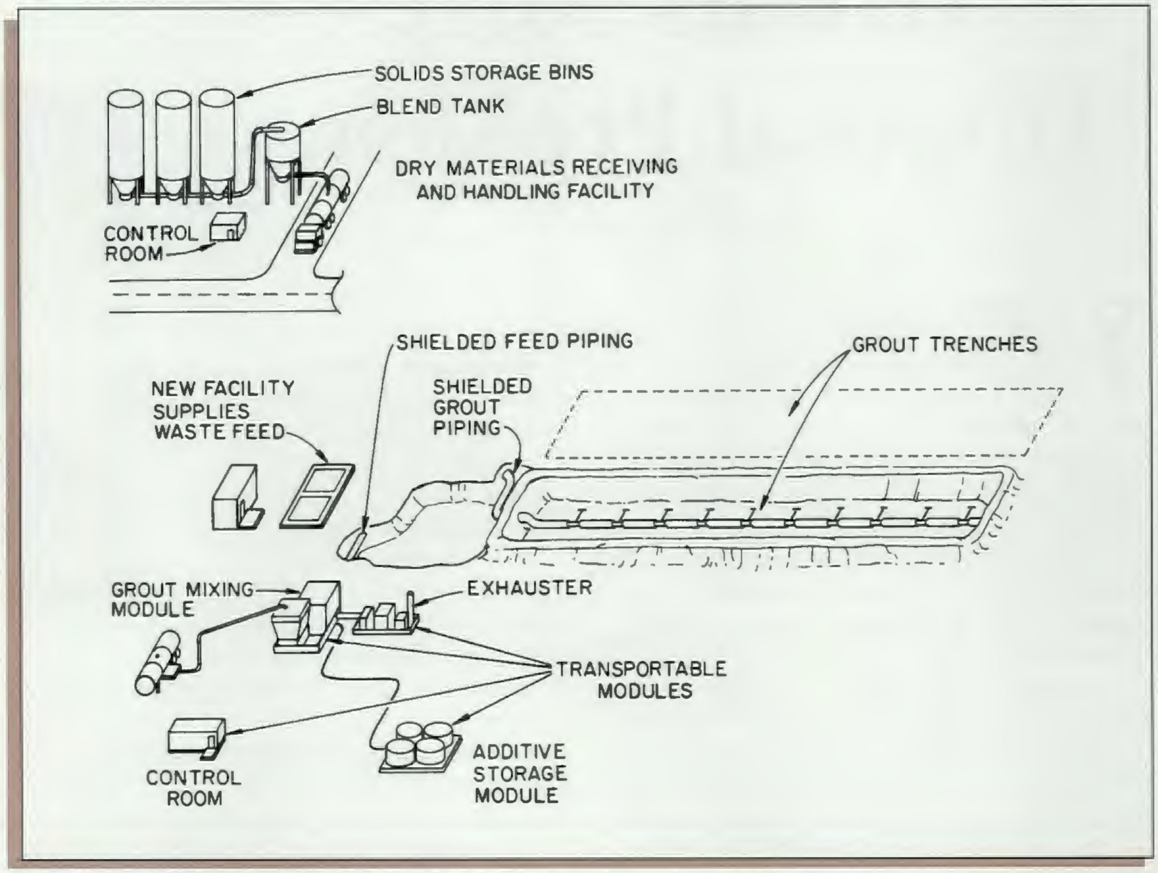
ORNL engineers soon found, and convinced RHO officials, that the grouting method was more suitable for disposing of Hanford's low-level liquid wastes (LLLW). After evaluating several other technologies for handling the permanent disposal of LLLW, RHO managers decided that grout solidification using transportable equipment was the preferred option. It offered greater cost benefits and more flexibility and had less-demanding engineering requirements than any alternative developed technology for disposing of LLLW in an environmentally sound manner.

As a result of this decision, ORNL was given a large role in developing RHO's Transportable Grout Facility, including giving assistance in plant design, process development, waste-form testing, and grout formulation research. The funding for these support efforts increased to $1.1 million in FY 1986, as RHO's plans changed from building a demonstration facility to building an operating grout production plant.

Grout is simply a mixture of cementitious materials and water (or other liquid), proportioned to be pourable or pumpable without separation of the constituents. ORNL and RHO engineers plan to use stored LLLW as the liquid portion of the grout mixture. As the grout hardens, these wastes will be immobilized in a stable, easier-to-handle, solid form. The grout formula used for the Hanford wastes calls for Portland cement as the binder, fly ash for retaining the radioactive strontium and as a cement extender, and Attapulgite-150 drilling clay as a suspending agent. In some cases, Indian Pottery clay will be used to retain radioactive cesium, and blends containing blast furnace slag will immobilize technetium-containing wastes. The distinctive dry solids formulations for each type of Hanford LLLW stream were developed by Chemical Technology Division engineers at ORNL. Each formula is specially tailored to maximize waste loading and minimize costs, while accommodating some modest variability in the waste composition.

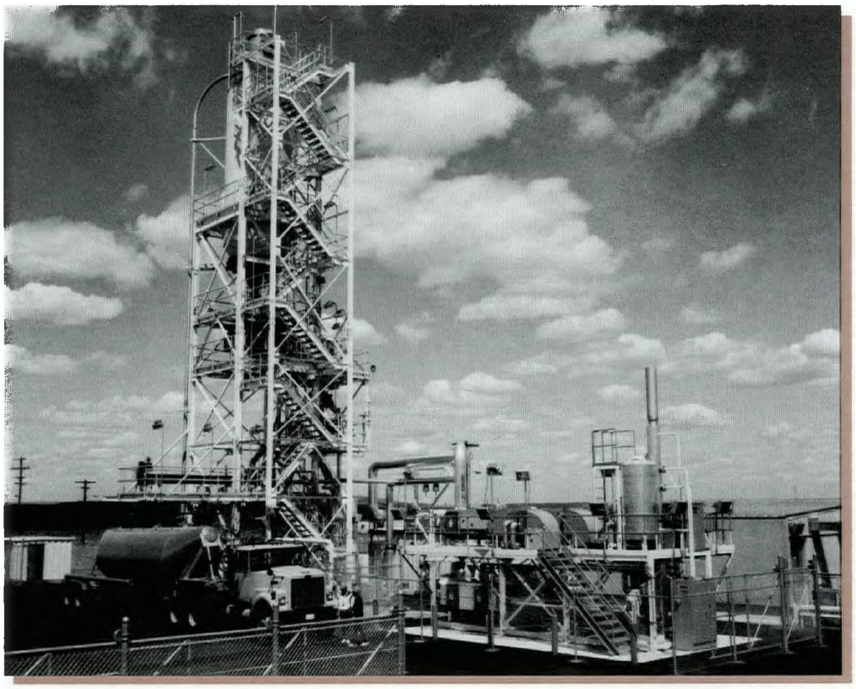
Transportable Grout Facility

In mid-1987, Westinghouse Electric Corporation assumed the contractor responsibilities for



The Transportable Grout Facility (TGF), an engineered storage facility for low-level liquid wastes in cementitious forms called grouts, includes a Dry Materials Receiving and Handling Facility and the Transportable Grout Equipment. Not shown are the near-surface disposal vaults, recently built to replace the grout trenches (shown here) for storing the immobilized waste.

The TGF control room has state-of-the-art equipment for waste management operations and monitoring.



Waste solids are delivered by truck from a blending facility to the dry-solids bin (behind the tower here) for storage.

waste management operations at Hanford, but the grout immobilization project (and ORNL's involvement in it) have continued unchanged. The Hanford grout production and disposal system will have three major components: a feed tank that holds 1 million gallons (3.8 million liters), a Dry Materials Receiving and Handling Facility (DMRHF), and the Transportable Grout Equipment (TGE). The combination of the DMRHF and TGE, called the Transportable Grout Facility (TGF), forms the heart of the waste disposal system (see figure on p. 58). A near-surface disposal vault has been built to receive the immobilized waste.

All grout formulations and disposal components have been designed to meet regulatory requirements, within a wide safety margin. Personnel at Battelle Pacific Northwest Laboratory (PNL) will also verify the grout formulas and perform environmental assessments for the project. They will investigate the potential for human exposure to the waste that might result from natural events (e.g., climatic changes, seismic activity, biotic transport, or wind erosion) or from human activities (e.g., drilling, excavation, or irrigation) around a buried grout monolith. They will also model potential disposal events, such as failure of the monolith from thermal or pressure excursions.

PNL's preliminary results indicate that grouted wastes from decontamination and fuel-basin filter solutions and cladding removal will perform adequately over the long term. Groundwater contamination from leaching would result in doses that are 30 million times lower than the average annual dose from exposure to naturally occurring radiation, and in no case would acute radiation effects in humans occur.

ORNL engineers have provided support to the Hanford TGF in engineering, formulation development, performance assessment, and analytical capability development. The TGF will operate on a campaign basis. Each campaign will immobilize 2 million gallons of LLLW in grout during a period of three to five weeks. At this rate, 4 to 6 million gallons (15 to 23 million liters) of liquid waste can be disposed of annually. ORNL will provide start-up assistance and continue a reduced level of support for the Hanford TGF in formulation development, verification, and consultation through the remainder of this decade. ornl

ORNL's New Environmental Projects

By Sid du Mont

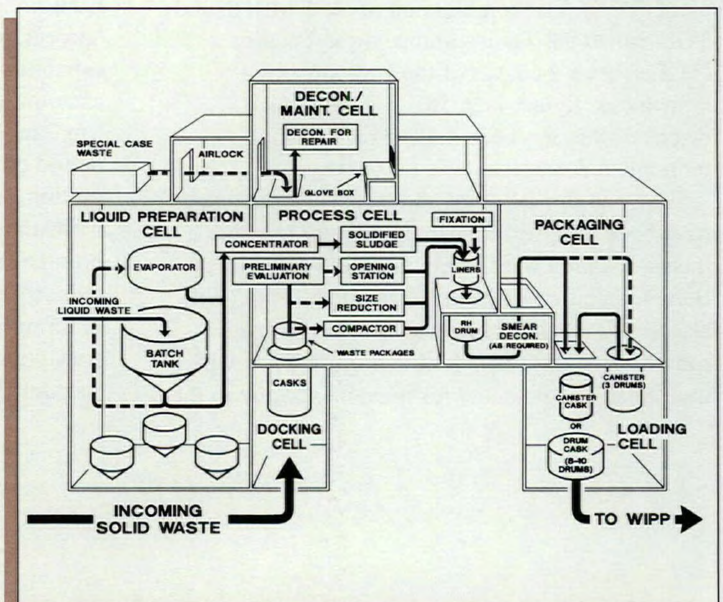
Sid du Mont is head of the Environmental Projects Section of the Environmental and Health Protection Division.

To comply with policies and regulations of the Department of Energy, the Environmental Protection Agency (EPA), and the state of Tennessee, ORNL is planning numerous projects ranging from "general plant projects" (costing up to $1.2 million) to major "line-item projects." Major line-item facilities are planned for (1) highly radioactive solid and liquid wastes containing elements heavier than uranium [transuranic wastes (TRU)], (2) liquid wastes having a low level of radioactivity, and (3) process wastewater classified as nonradioactive.

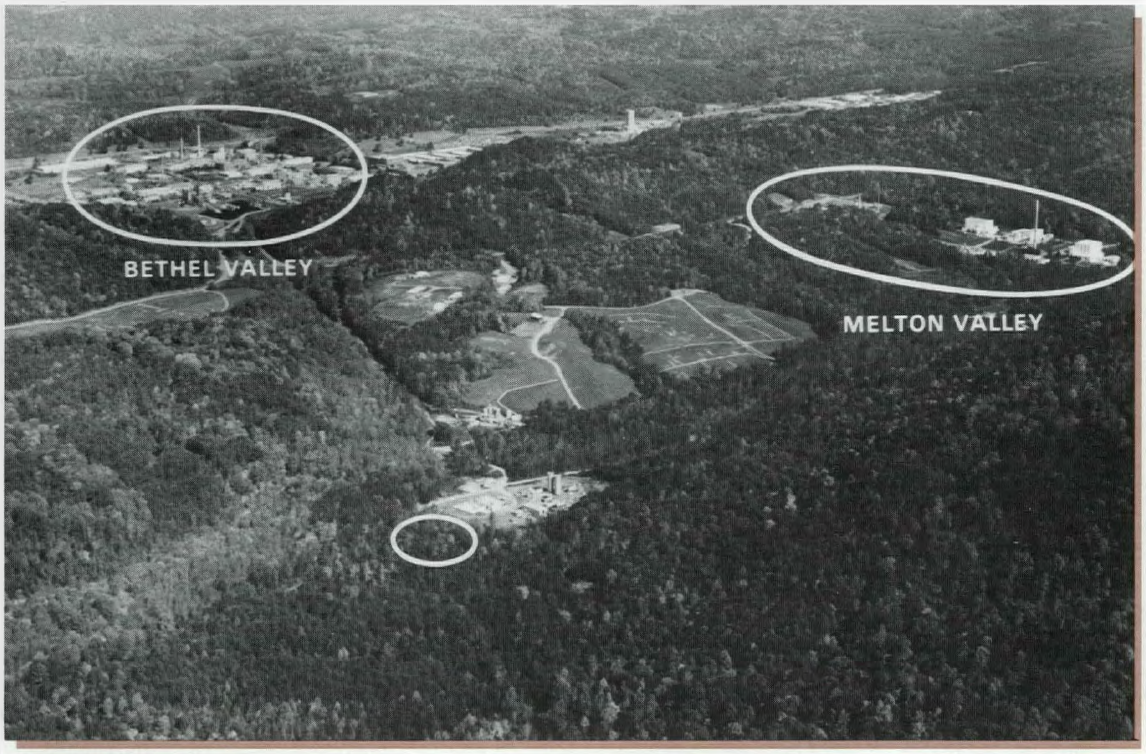
Waste Handling and Packaging Plant

ORNL's High Flux Isotope Reactor (HFIR) produces important radioisotopes for industry, medicine, and research, and the Radiochemical Engineering Development Center (REDC) prepares and packages these radioisotopes for shipment to users. The TRU wastes produced by these operations—wastes containing >100 nanocuries per gram—are classified as contact-handled (CH) and remote-handled (RH). CH-TRU waste, which emits radioactivity ≤ 200 millirems per hour (mrem/h) at the surface of the container, is stored at ORNL in drums and will be shipped in the 1990s for final disposal at DOE's Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. RH-TRU waste, which generates higher penetrating radiation (>200 mrem/h at contact), contains plutonium, californium, and other transuranic isotopes that generate high-energy neutrons and gamma rays. RH-TRU must be remotely processed and packaged before shipment off-site for disposal at the WIPP. Since 1970, the RH-TRU wastes at ORNL have been stored to allow retrieval for the required processing and disposal. Other DOE facilities in Idaho, New Mexico, and Washington also have been storing RH-TRU wastes to facilitate their retrieval.

ORNL and the national TRU Program have proposed the Waste Handling and Packaging Plant (WHPP) to process and package RH-TRU wastes retrieved from DOE sites for shipment to the WIPP. About 90% (~1300 m^3) of DOE's RH-TRU waste inventory is stored on-site at ORNL. It is estimated that another 1000 m^3 of such waste will be generated at DOE facilities during the next 25 years. The proposed WHPP would use several unique processes that are being developed at



Schematic of the Waste Handling and Packaging Plant.



ORNL's transuranic wastes are generated by the High Flux Isotope Reactor at Bethel Valley and the Radiochemical Engineering Development Center at the Melton Valley site. Current plans are to transfer the remote-handled transuranic wastes to the proposed Waste Handling and Packaging Plant circled at lower center.

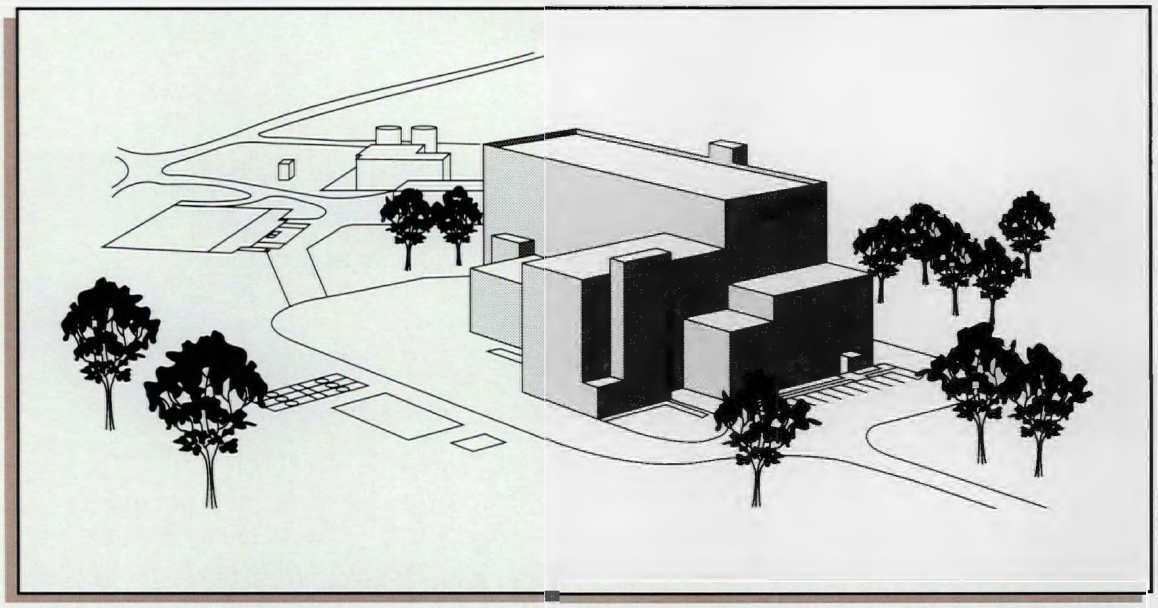
ORNL and other facilities specifically to prepare all of these wastes for final disposal at the WIPP.

At ORNL, solid RH-TRU waste has been placed in interim storage in concrete casks in underground trenches. More recently, the casks have been stored in concrete bunkers (see photo on p. 44) to further facilitate retrieval. RH-TRU waste sludges have been stored in several on-site tank farms.

Typical RH-TRU solid waste from the REDC hot cells includes contaminated items such as paper, cloth, glass, plastic, rubber, metal cans, equipment racks, and ventilation filters. TRU sludge consists mainly of a highly alkaline sodium nitrate precipitate containing significant TRU components, fission products, and little or no organics.

According to current plans, the WHPP would solidify liquids and sludges, yielding a product that meets waste acceptance criteria for disposal at WIPP. Packages of solid waste would be manipulated remotely in process cells and examined by real-time radiography and neutron assay to determine the processing needed for certification. Other processes would be available to solidify free liquids, immobilize loose particulates, and neutralize corrosive materials. Processed wastes would be loaded into liners in the process cell and then transferred to drums, which, in turn, would be placed in special shipping casks or canisters for shipment to WIPP.

The WHPP is scheduled to be funded in the FY 1992 budget as a congressionally authorized capital project. This would allow the facility to become operational by 1999. Conceptual design is now being done by the Engineering Division under the guidance of the Environmental Projects Section of ORNL's Environmental and Health



Artist's conception of the proposed Waste Handling and Packaging Plant.

Protection Division. Development work is focused in the Chemical Technology Division under the guidance of the TRU Waste Program. The development work is also being supported by the Engineering, Fusion Energy, Fuel Recycle, and other divisions. Completion of the development tasks will provide the basis for a detailed design of the WHPP by 1991. The total design, procurement, and construction costs for the WHPP are estimated to be about $130 million.

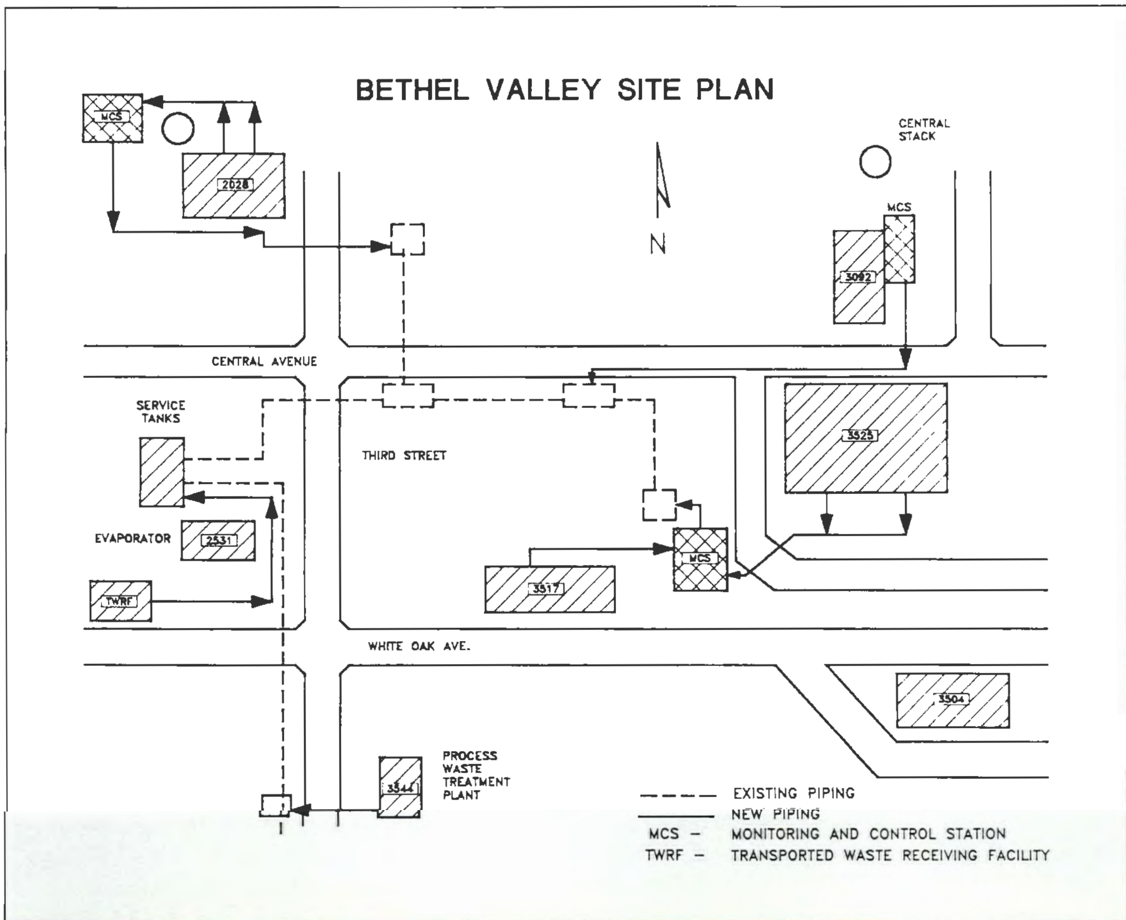
Liquid LLW-CAT System

In response to the Resource Conservation and Recovery Act, the EPA has published regulations defining underground storage tank requirements for wastes classified as either hazardous or toxic. In 1985, ORNL began formal planning for a series of large projects to improve its liquid low-level waste collection and transfer (liquid LLW-CAT) systems. Some of these projects are already under way to correct such problems as leakage of liquid LLW from old deteriorating pipes and tanks into the ground, from which it could migrate into groundwater or to surface streams.

Proven industry standards for containment, leak detection, and materials technologies are being employed in the new system to ensure the safe transfer and collection of liquid LLW within the Laboratory. Guidelines that regulate these projects require all underground tanks and ancillary systems (such as piping) to be doubly contained. Monitoring is also required to ensure the continuing integrity of both the primary and secondary containment systems.

A Transported Waste Receiving Facility (TWRF) is included in the proposed $35-million Bethel Valley Liquid LLW-CAT Upgrade Project. (see drawing on p. 63). The TWRF will be designed to receive bottled and tanked liquid LLW from various generators at ORNL.

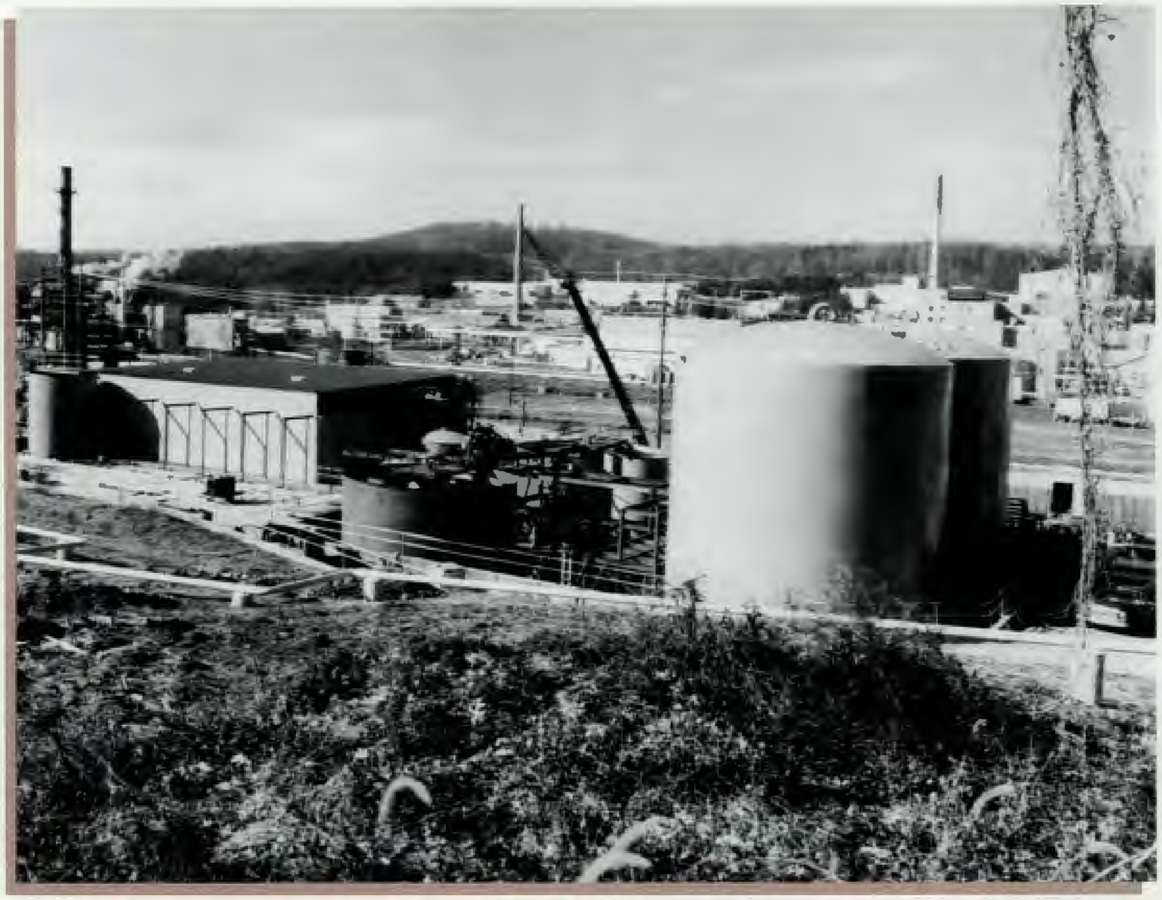
The project will provide a CAT system for the liquid LLW generators within Bethel Valley to replace portions of the existing system, which have reached the end of their design life. The new system will control all access to the central collection system, which will allow better monitoring of waste production and better management of the new waste "charge-back" system. It should also encourage waste volume reduction by individual generators. As part of the upgrading process, existing collection tanks will be isolated, and maintenance and surveillance measures will be instituted to prepare them for final decontamination and decommissioning under ORNL's Remedial Action Program.



ORNL has planned a series of projects to improve its liquid low-level waste collection and transfer systems. The planned projects, some of which are shown in this Bethel Valley Site Plan, will help correct problems such as leakage of the waste into the ground.

The planned system improvements and liquid LLW-CAT upgrade projects should result in considerable savings by reducing the need to maintain current systems. A second liquid LLW-CAT project, now in the conceptual design phase, will address the needs of waste generators and systems located in ORNL's main isotopes area. A third liquid LLW-CAT project, scheduled to begin the conceptual design phase in FY 1989, will handle Melton Valley liquid LLW collection and transfer needs.

These two 350,000-gallon tanks in Bethel Valley will collect process wastes from ORNL for transfer to the adjacent Nonradiological Waste Treatment Project.



The ORNL Nonradiological Waste Treatment Project includes two storage tanks (right), a clarifier (center) to remove metals from wastewater, and a building for process equipment and the control system (left).

Nonradiological Wastewater Treatment Project

The Clean Water Act requires that all discharges to the nation's waters meet water quality standards or be treated before discharge by the "best available technology." ORNL's process wastewater contains diverse discharges from a variety of research operations and requires more complex handling and processing than the few well-characterized waste streams of a typical industrial complex. To lower the potential toxicity of this wastewater and to meet environmental regulations, ORNL has proposed an $18-million Nonradiological Wastewater Treatment Project (NRWTP) to modify existing process systems and collect and treat process wastewater using the best available technology. The major components of the NRWTP are the new treatment plant, collection system, transfer lines, and process control system. During 1988, the NRWTP collection system, consisting of four 100,000-gallon tanks in Melton Valley (near the HFIR), two 350,000-gallon tanks in Bethel Valley (near the new treatment plant), and four wastewater pumping stations, were constructed to replace surface impoundments, which will be filled and removed from service.

The NRWTP started with a detailed characterization of the flows and contaminants of ORNL's process wastewater. Based on this information, proposed treatment schemes were prepared and tested to verify flowsheets and provide engineering data to aid in more detailed system design. Wastewater samples were taken as near the source as possible, to eliminate dilution effects, and the streams were categorized according to contaminants of concern (e.g., heavy metals and organics). This detailed characterization information served as the basis of the conceptual flowsheets for the project.

A comprehensive computerized data base of the known wastewater sources was prepared and then reviewed by personnel from the various ORNL divisions to ensure its completeness and accuracy. The major sources of wastewater include drainage from various laboratories (chemistry, physics, electronics, biology, environmental sciences, and metallurgy), process wastewaters pretreated for removal of radionuclides, steam plant boiler blowdown, and aqueous streams from several radiochemical processing facilities and reactor operations. ORNL's Operations Division is providing flow data from several past seasons to aid in designing an efficient new collection system that will replace the existing surface impoundments with pumping stations and tank farms.

The new NRWTP treatment plant now under construction will treat the segregated process wastewater to remove organics only or both metals and organics, depending on the wastewater source and characteristics. A modern instrumentation and control setup will operate the collection and treatment system, as well as monitor the quality of the treated water to ensure that it is "clean" enough for discharge.

Makeup water demineralizers at the HFIR, Oak Ridge Research Reactor, and Bulk Shielding Facility were also replaced as part of the wastewater system upgrade.

The Chemical Technology and Engineering divisions planned and performed studies simulating the treatment of ORNL nonradiological process wastewaters by schemes proposed for the NRWTP. Results of these treatability studies indicated that the proposed discharge limits could be achieved using the selected treatment technologies.

When completed, the treatment facility will remove metals, organics, and suspended solids and adjust the water's acidity level (pH) to meet the limits specified by ORNL's National Pollution Discharge Elimination System (NPDES) permit. The average design flow rate for the new facility is 500 gal/min, and its water treatment scheme uses chemical precipitation and pressure filtration for the removal of heavy metals, air stripping for the removal of volatile organics, and activated carbon for the removal of nonvolatile organics and mercury. A filter press will dewater the sludges produced from the precipitation of heavy metals.

As part of the permitting process for the treatment plant, Federal Facility Compliance Agreement Milestones were established for ORNL by the EPA and the Tennessee Department of Health and Environment. The collection system was completed in November of 1988; construction of the treatment plant is to be completed at the end of September 1989. By March 31, 1990, the treatment facility will be operating to attain the wastewater treatment required by the NPDES permit, ensuring that ORNL has the best wastewater quality achievable with currently available technology. ornl

"A modern instrumentation and control setup will operate the collection and treatment system."

Remedial Actions for ORNL's Environment

By Lanny Bates and John Trabalka

Lanny Bates is manager of ORNL's Remedial Action Program and head of the Remedial Action Section of the Environmental and Health Protection Division.

The Graphite Reactor at ORNL (photo at right) was built in 1943 as a pilot plant for producing small amounts of plutonium as part of the World War II Manhattan Project. Over its 20 years of operation, it produced neutrons for experiments and radioisotopes for medical, industrial, and research uses as ORNL expanded. It also produced radioactive waste that was buried on-site. The Graphite Reactor is now a remedial action site, along with many of its contemporaries, including the surface impoundments (lower left in photo) and underground waste storage tanks (many of which are under the two open areas opposite the old coal-fired steam plant in the center of the photograph).

Ironically, the offices of ORNL's Remedial Action Program (RAP) are now located in renovated space within the original Graphite Reactor building. This program is responsible for the implementation of an extensive environmental remediation and facility decommissioning effort focused on cleaning up the results of past ORNL operations. Remedial action at ORNL is expected to cost more than $1 billion and to require more than 20 years for completion.

45-Year Legacy

After 45 years of operation involving the development and use of nuclear materials and technologies, ORNL has accumulated a variety of contaminated sites, facilities, and wastes that require attention. The legacy includes inactive facilities, research areas, and waste management areas contaminated with a wide variety of liquid and solid wastes, primarily radioactive liquid and solid materials, but also mixed wastes in which radioactivity is the principal hazard.

The major sources of ORNL's contaminated wastes have been radioisotope production, research reactors, hot cells and pilot plants (for chemical separations or fuel reprocessing), research laboratories (physical, chemical, and biological), accelerators, and analytical laboratories. Solid wastes from other sites contributed a large fraction of both the material and the radioactivity buried in ORNL's solid waste storage areas (SWSAs) from 1955 to 1963. During that period, ORNL served as the Southern Regional Burial Ground of the Atomic Energy Commission.

Wartime waste management practices at the Oak Ridge facilities were crude by current standards and were influenced by the urgency of the Manhattan Project, the anticipated temporary nature of ORNL's role, and the lack of experience in dealing with radioactive wastes. In later years, waste management has been limited by the unpredictability of the federal budgeting process and the lack of a complete understanding of how ORNL's wastes would behave in the settings where they were emplaced or released. Thus, it is not surprising that a legacy of environmental contamination exists at ORNL or that information on waste inventories at individual sites is often incomplete.

For example, several sites are known or believed to contain buried transuranic (TRU) wastes; however, the exact locations of these wastes in the large (2.8- to 14-ha) SWSAs are highly uncertain. Radionuclide inventories for these sites appear to be dominated by fission products such as strontium-90 and cesium-137, tritium, and activation products such as cobalt-60, rather than by uranium or transuranium elements. Knowing the identity and amounts of all wastes present, including the hazardous chemicals, is important for developing the appropriate site stabilization strategies.

Only recently have we fully realized that our waste management technology is seriously limited in its ability to overcome the unfavorable environmental conditions (high seasonal rainfall, shallow

The ORNL Graphite Reactor (large building on the right with stack), which was prominent in plutonium production for the Manhattan Project, was still a major feature at the X-10 site in this 1947 photograph.

groundwater table, elevated levels of calcium and magnesium in water, complex hydrogeology) of the ORNL site for waste disposal. Although local soil minerals have excellent sorptive properties for some radionuclides, such as cesium-137, the unfavorable environment, as well as some past waste disposal practices, make it difficult to properly manage important waste contaminants such as tritium and strontium-90 locally. Fortunately, despite such handicaps, the activities at ORNL do not appear to have resulted in significant exposures of the off-site public to hazardous materials.

Following a 1984 federal court decision, the Department of Energy (DOE) and ORNL clearly became subject to new environmental and waste management laws administered by the Environmental Protection Agency (EPA). ORNL's RAP was set up to make a comprehensive effort to meet these new regulatory requirements and to ensure adequate protection of on-site workers, the public, and the environment by providing appropriate corrective measures at more than 100 contaminated sites. The RAP's structured schedule includes site characterization, surveillance and maintenance, technology development and demonstration, alternative option assessments, interim corrective action, and, eventually, site closure for the contaminated areas.

Because of the diversity of past ORNL operations and the magnitude and scope of the RAP, funding support is provided by several DOE

Environmental contamination from cesium-137, one of ORNL's prominent fission wastes, is shown as count-rate isopleths on this photo obtained during a September 1986 aerial survey.

sources: the Environmental Compliance Program in the Office of Energy Research; Surplus Facilities Management Program (SFMP) in the Office of Nuclear Energy; and Office of Defense Programs Activities such as Defense Facilities Decommissioning Program, Environmental Restoration Program, Interim Waste Operations Program, and Transuranic Waste Program.

The ultimate goal of closure or decommissioning of the stabilized RAP sites is long-term containment for most wastes, requiring only periodic monitoring and minimal maintenance to ensure protection of human health and the environment. Most realizable stabilization options for the ORNL sites leave the contaminants in situ but isolated by physical, chemical, or (more typically) hydrologic measures. The very low risks to off-site residents posed by current releases from ORNL sites, along with the need to balance these risks against the danger of exposure for workers implementing remedial actions and the cost differentials for various remedial options, all strongly favor in situ stabilization of the waste over contaminant removal and external disposal. However, in situ stabilization is likely to be effective for only a limited period, and the permanent isolation of TRU or uranium wastes cannot be ensured using existing state-of-the-art techniques.

One potential approach to this problem at ORNL is to design primarily for in situ decay and control (an institutional control period of

100 years or more) of intermediate-level wastes such as tritium, strontium-90, and cesium-137. Passive measures designed to provide greater long-term confinement could be exercised at sites contaminated with TRU wastes or high concentrations of hazardous constituents. An example of such a measure is in situ vitrification—using an electric current to melt the wastes, along with the surrounding soil and contaminating materials, into a leach-resistant glass block. This approach would provide time to evaluate the effectiveness of environmental processes and passive remedial measures in controlling the migration of long-lived materials. It would also allow time for developing the new technologies needed for more permanent site stabilization and would at least postpone the need for more expensive exhumation and disposal actions.

Regulatory Climate Changes

In situ vitrification is an appropriate corrective measure at some of ORNL's contaminated waste sites.

We are experiencing a period of unprecedented change in the national policy toward waste management. The ongoing attempts by Congress to define, and by federal and state agencies to implement, the policy changes have resulted in an evolving regulatory environment within which major issues remain unresolved.

Although the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); Resource Conservation and Recovery Act (RCRA); Superfund Amendments and Reauthorization Act (SARA); and Toxic Substances Control Act (TSCA) provide the principal legal stimuli for undertaking corrective measures, the environmental and human health protection standards derived from the amended Atomic Energy Act of 1954 (AEA), Clean Air Act (CAA), Clean Water Act (CWA), and Safe Drinking Water Act (SDWA) primarily determine the rigor of the response required to protect human health and the environment. For major federal environmental actions, the National Environmental Policy Act (NEPA) defines the process by which decisions are made and implemented, but its applicability to RCRA and CERCLA remedial actions is unclear, as is the current status of CERCLA-SARA at ORNL.

Beginning in 1986, the EPA elected to enforce principal regulatory requirements for remedial actions through its RCRA authority rather than its CERCLA authority. Additional RCRA requirements covering SWSA 6 and 33 underground waste storage tanks, as well as SDWA requirements applicable to the hydrofracture sites, were also added in 1986. In addition many operational facilities, such as waste collection tanks and storage facilities for hazardous and mixed waste, are potentially subject to these regulations and may require corrective action through ORNL's separate Environmental Projects Program. (Ironically, it now appears that CERCLA-SARA requirements will be superimposed on the existing RCRA requirements through EPA's decision to place the entire DOE Oak Ridge Reservation, including off-site contaminated areas, on the National Priorities List for the Superfund.)

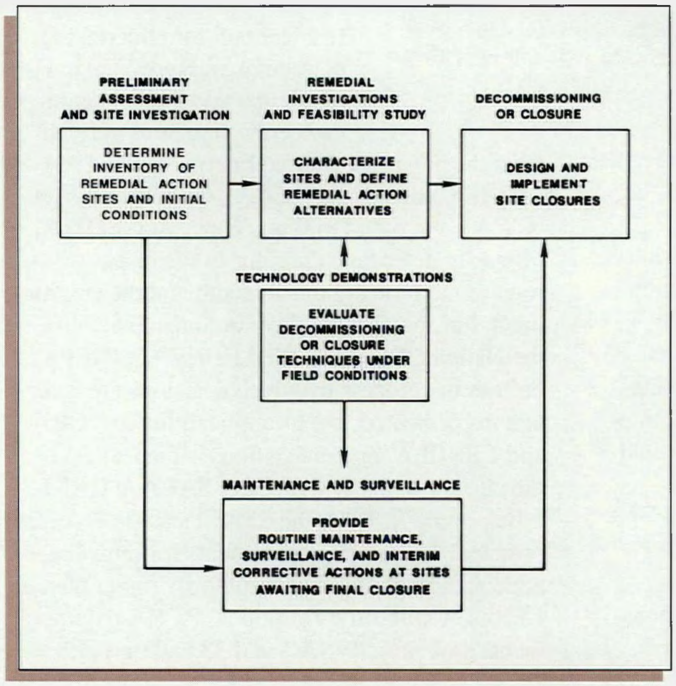
EPA's proposed enforcement of the RCRA Sect. 3004(u) provisions involves a series of steps similar to those required by the CERCLA-SARA that provide the basis for determining the extent of contamination problems and the scope of needed corrective actions. Because of the large number of sites to be considered and the hydrogeologic complexity of the ORNL area, it became apparent that treating potential remediation sites individually in the new regulatory framework would result in an unmanageable situation. Thus, the strategy is now oriented toward Waste Area Groupings (WAGs), which are generally defined by watersheds that contain contiguous and similar remedial action sites.

ORNL RAP sites can be placed within 20 such groupings, each representing distinct small drainage areas within which similar contaminants were introduced. (One exception is WAG 10, which contains the underground injection wells and grout sheets from hydrofracture operations; however, these sites are unique and are located within the same hydrogeologic setting.) In some cases, hydrologic interaction has occurred among the sites within a WAG, making individual sites hydrologically inseparable. The use of area groupings allows perimeter monitoring of both groundwater and surface water and a remedial response that is protective of human health and the environment in an appropriate time period.

Remedial Action Approaches

The first steps of our phased RAP (see flowchart below) are (1) the establishment of a regulatory-approved inventory of sites (and WAGs) to be evaluated for future remedial actions and (2) a preliminary characterization of conditions at these sites, including the development of a comprehensive RCRA groundwater monitoring program.

For each site in the RAP inventory, a detailed characterization and assessment of site conditions and the potential for environmental and health impacts must be performed. The conceptual diagram on p. 72 shows an exposure analysis associated with a hypothetical contaminated site. Each WAG must be evaluated individually, and in each case all potential pathways to humans must be identified for contaminants that might migrate to the surface or reach water supply wells from the underground contamination zone. Interim control must be established at each inventoried site through maintenance, surveillance, and any corrective actions required to ensure



This flowsheet illustrates ORNL's phased approach to Remedial Action Program implementation.

adequate protection of human health and the environment until final site disposition has been achieved.

The characterization and assessment process includes an evaluation of alternatives for accomplishing any corrective actions needed. These alternatives to decommissioning or closure will be screened for their applicability to ORNL's environmental and waste management conditions, and field-scale technology demonstrations will be performed, when necessary, prior to full-scale implementation.

RAP Phases

The RAP at ORNL is being carried out through six major operational phases (see flowchart at left):

- **Site assessment** for the RAP is an ongoing process, but the preliminary environmental surveys were completed and submitted to regulatory authorities in 1987. Supplemental information is developed through follow-up investigations as needed. The basic groundwater monitoring network is being put in place and should be completed for the principal inventoried WAGs by FY 1990. Studies of groundwater contamination associated with sources in ORNL's main plant area are being conducted. Comprehensive, long-term geohydrologic studies at ORNL and biological monitoring of the White Oak Creek system are also under way.

- **Remedial investigations and feasibility studies** will be the largest RAP activity area during the next few years. Initiated in 1986, the task is of such magnitude that a major support team of contractors, guided by ORNL technical staff and the preliminary site characterization data, has been engaged to carry out the investigations according to regulatory-approved priorities and schedules. Detailed studies will be prepared for each WAG, and any interim corrective actions needed to protect human health and the environment at specific sites within the WAG will be identified for early implementation.

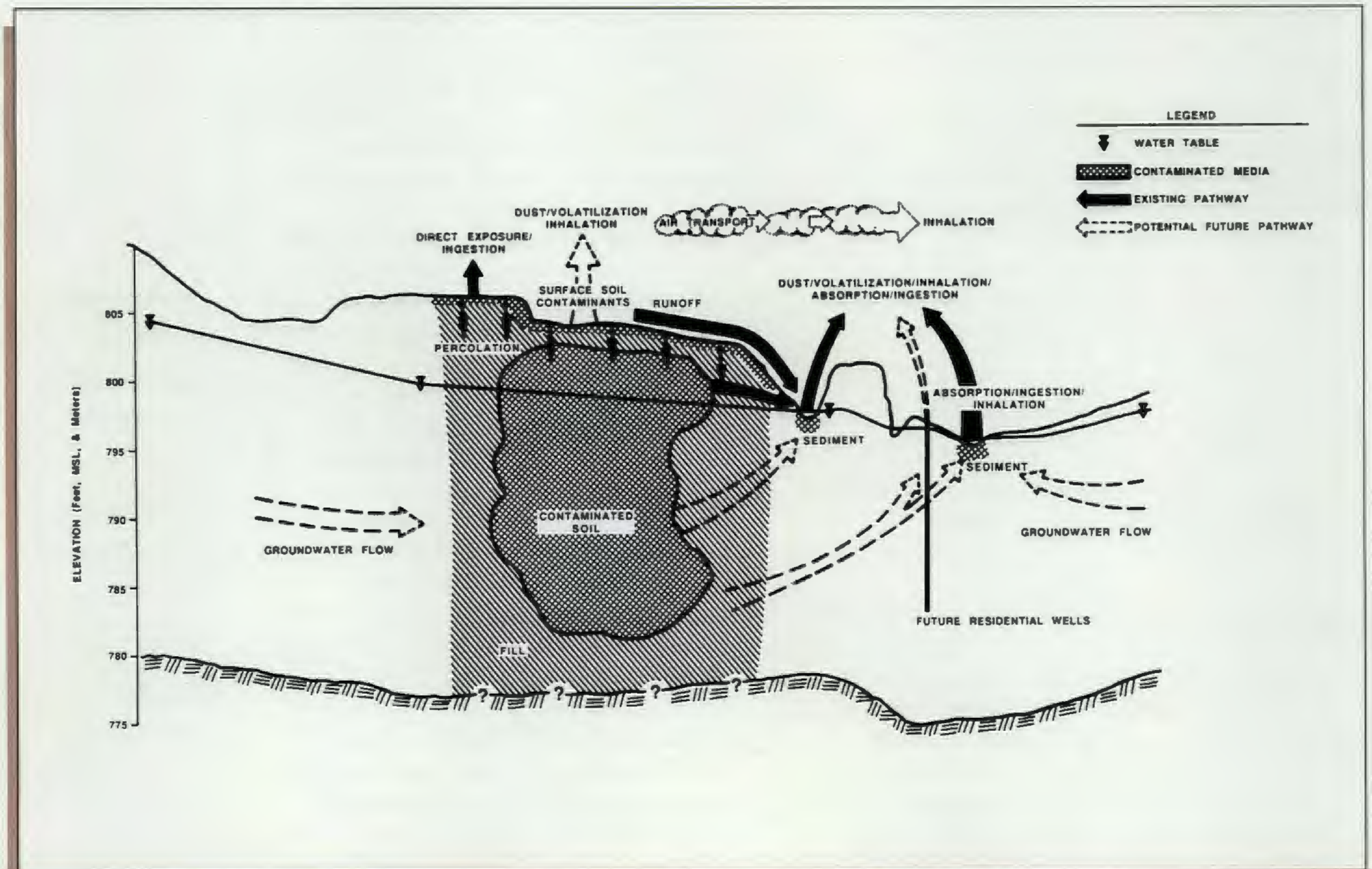
  All of the WAG studies will be integrated into feasibility studies for ORNL, currently scheduled for completion during the 1990s. These reports will provide a comprehensive listing of the need, extent, priority, and timing for future remedial actions at ORNL.

- **Technology demonstrations** of alternative remedial action options will be conducted and evaluated on a schedule compatible with future decommissioning, closure, or corrective action needs. After initial screening for general applicability to ORNL environmental and waste management conditions, the identified technologies will be assessed through field-scale demonstrations at specific sites prior to full-scale implementation. A companion effort will involve comprehensive evaluations of past corrective actions undertaken at several sites, such as the water-diversion systems constructed for SWSAs 4 and 6.

- **Maintenance and surveillance plans** to meet the needs of the wide variety of ORNL remediation sites have been prepared and will be updated periodically. Criteria for the acceptance of new RAP sites (as facilities are closed or new contamination sources are identified) are also being developed.

- **Site decommissioning or closure** will focus on the ultimate long-term RAP containment of residual contaminants, bringing each site to a permanently stabilized state requiring only minimal monitoring and maintenance. Decommissioning or closure will be implemented according to priorities and schedules negotiated with regulatory authorities. The magnitude of the effort for long-term management of ORNL's RAP sites can be only roughly approximated, because site-characterization information is still preliminary. For some sites (e.g., those containing TRU wastes), our current technological limitations make achievement of the ultimate RAP objective problematic. The RCRA regulatory requirements mandate early decommissioning and closure of SWSA 6 and of

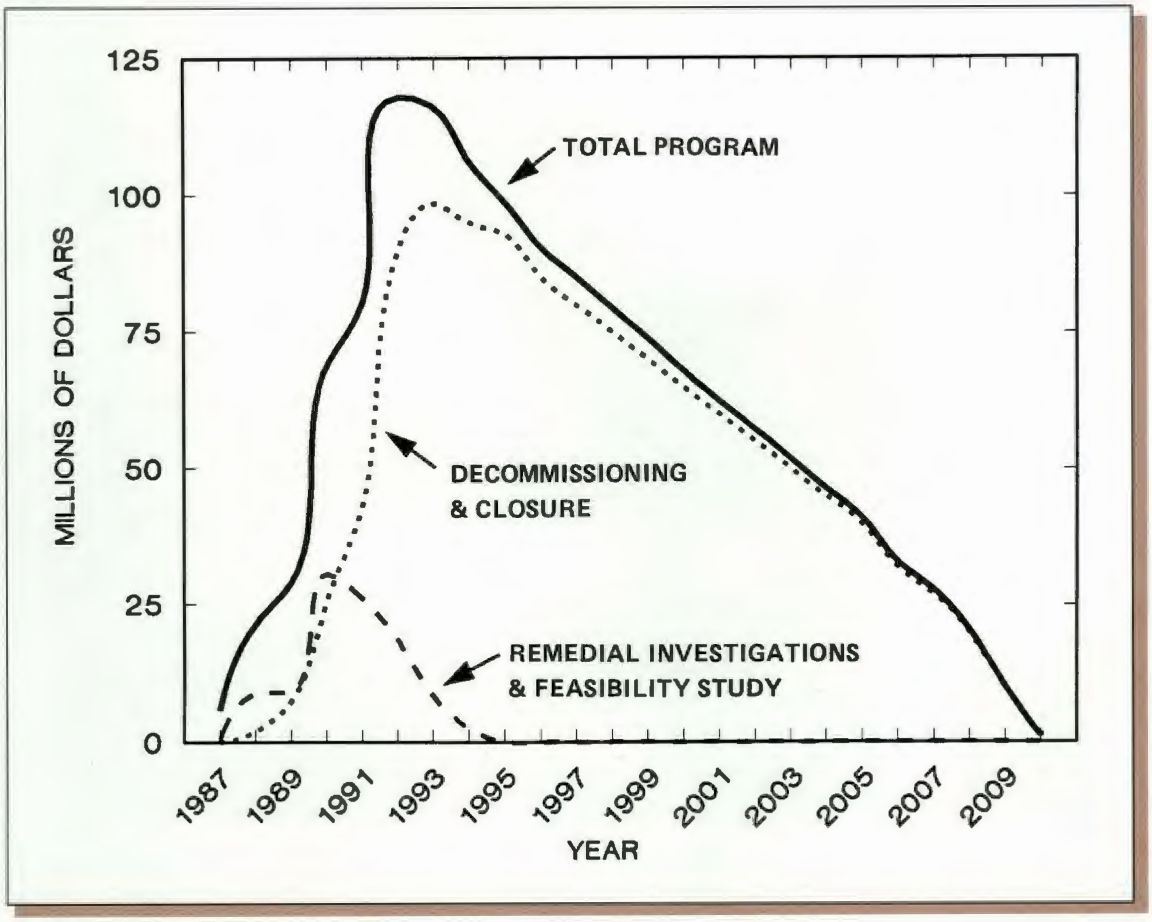
"Studies of groundwater contamination associated with sources in ORNL's main plant area are being conducted."



Each inventoried RAP site is characterized individually to identify all potential pathways by which contaminants might reach humans.

the 33 inactive underground liquid low-level waste (LLLW) storage tanks. In addition, plugging and abandonment of the hydrofracture injection and observation wells, as well as the groundwater monitoring wells that penetrate the hydrofracture injection zone, are likely to receive separate attention in response to SDWA regulations. Plans and schedules for these activities are the subject of current discussions with regulatory representatives from both the EPA and the state of Tennessee. The costs of these combined activities needed to ensure regulatory compliance are estimated at $100 million to $300 million over the next five years (see figure on facing page), which poses a significant problem for both DOE and ORNL in the currently tight budgeting climate.

Remedial Action Program support activities must ensure that any releases of hazardous materials from ORNL sites are maintained within acceptable limits, while optimally apportioning the limited resources for corrective action among the many remedial action sites. In addition to management and data base support for the program, this phase will provide input to the overall RAP strategy through (1) integration and synthesis of information from the first five RAP phases; (2) analyses of institutional, regulatory, and technical issues; (3) development of site closure criteria; and (4) maintaining an interface with EPA and Tennessee state regulatory authorities and with national DOE remediation programs.



These are the estimated RAP expenditures needed to ensure environmental regulations compliance during the next 20 years at ORNL—a significant budgetary concern.

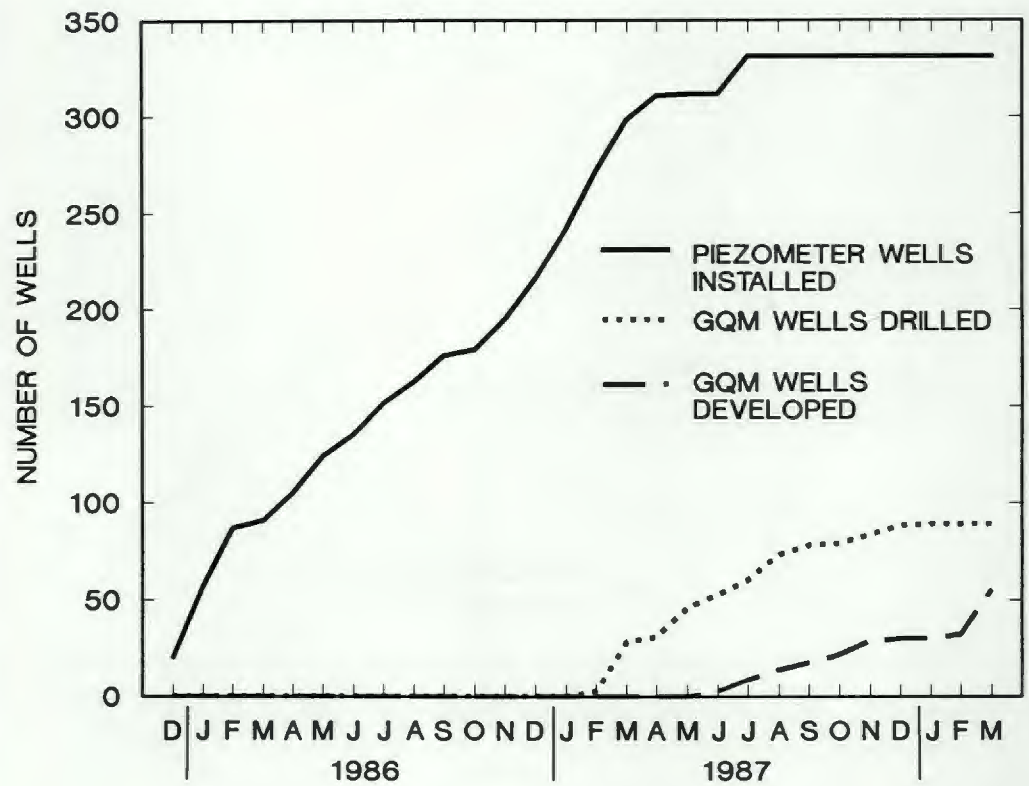
Progress Report

The RAP is moving aggressively toward meeting the goals and defining the solutions for ORNL's numerous environmental problems. The existing conditions and geohydrology of the contaminated sites must be thoroughly understood as a first step toward effective remedial action. To provide this information, a substantial groundwater monitoring well installation program has been under way since 1985 (see figure on p. 74), establishing both low-cost piezometer, or exploratory, wells and the more expensive groundwater quality monitoring wells used to ensure regulatory compliance. Well installation was temporarily suspended in 1988 to allow development of a clearing facility for well drilling equipment and to resolve funding problems.

During FY 1988, plans for a sampling campaign were developed and implemented to further characterize the contents of 33 inactive underground LLLW storage tanks for possibly hazardous constituents. Alternatives for closure of these tanks range from removal and processing of the contents and subsequent excavation of the tank to in situ stabilization of the tank and its contents. Depending on results of the sampling campaign, actual closure operations could begin by 1992, with estimated costs ranging from $50 million to $250 million.

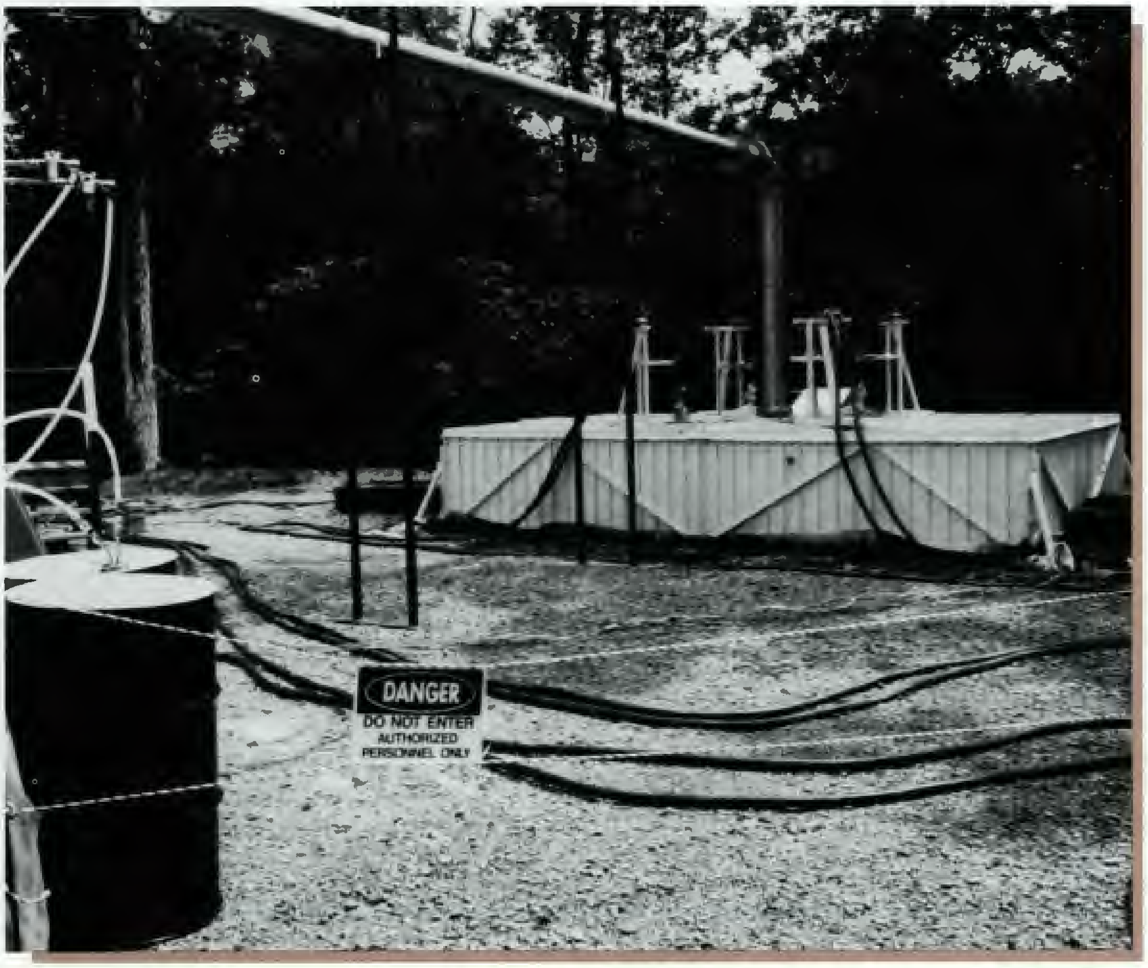
The disposal of lead and scintillation vials (classified as hazardous materials) in the currently active burial ground, SWSA 6, resulted in the implementation of a statutory deadline of November 8, 1988, as prescribed by RCRA, for closure of selected areas there. Closure of these portions

The RAP has established an extensive system of exploratory (piezometer) and groundwater quality monitoring (GQM) wells since 1987.



of SWSA 6 has been a top priority of the RAP. The challenge of conducting closure activities in conjunction with continued radioactive waste disposals to support ORNL operations has resulted in our development of a unique approach—interim closure—that was approved by the regulating agencies. This approach includes the installation of thick plastic sheeting (rather than multilayer earthen caps) to cover the designated portions of SWSA 6, accompanied by the necessary drainage control measures. Covering these areas reduces the risk of continued releases, yet allows our characterization efforts for the total SWSA 6 to be completed before starting substantial remediation.

Major activities are also under way in the demonstration of technologies to support remedial action decisions. In particular, the test area for remedial actions located in SWSA 6 will be used for the demonstration of waste trench stabilization and closure techniques, including dynamic compaction, in situ grouting, and capping. During the summer of 1987, a demonstration of in situ vitrification (ISV) was conducted by ORNL and Pacific Northwest Laboratory on a one-third-scale model of an old seepage trench (demonstration equipment is shown in the photo on facing page). The demonstration proved that the process can be successfully applied to ORNL's specific conditions. ISV processes are being further evaluated



This in situ vitrification equipment was demonstrated near ORNL SWSA 4.

for potential use in the ultimate remediation of ORNL's waste pits and trenches as well as for closure of ORNL's inactive underground waste storage tanks.

Challenges in the future management of remedial actions at ORNL are numerous. Substantial resource commitments will be required from DOE for at least the next 20 years, if these challenges are to be met. The expenditure projections shown on p. 73 are those estimated for complete compliance with environmental regulations. Continual reprioritization of planned activities to reflect new understanding and negotiations toward achievable solutions that are acceptable to the regulatory agencies will remain essential elements of the program.

John Trabalka, a member of the Environmental Sciences Division, is technical assistant to the manager of the Remedial Action Program. ornl

QA in Waste Management

By Jim Dumont

Bethel Valley Project manager Cal Pepper (second from left) discusses QA plans with Quality Department members (from left) Alison Weisbin, Martha Woody, and Jim Dumont, who manages the Environmental and Health Protection Division's Quality Assurance Program.

The late U.S. Secretary of Commerce, Malcolm Baldridge, noted that in the area of quality assurance (QA) ". . .the challenge is to create an organizational environment that fosters creativity, productivity, and quality. . . ." Striving to meet this challenge, ORNL's Environmental and Health Protection Division is dedicated to maintaining high standards in our management of nuclear and chemical wastes. Our standards are those of the *Quality Assurance Program Requirements for Nuclear Facilities* (NQA-1), published by the American Society of Mechanical Engineers and the American Nuclear Standards Institute.

Briefly stated, our objectives are to develop, implement, and maintain practices to ensure that ORNL's waste management activities are

- conducted with the highest regard for the health and safety of plant personnel and the surrounding population,
- designed and executed for both the short- and long-term protection of the environment, and
- in compliance with all applicable state and federal regulations.

The QA program at ORNL provides a framework of practices and procedures to assure both management and line organization that quality issues, environmental protection, and human health and safety factors have been incorporated in design, construction, and operation activities. Teamwork is the key ingredient. A team including both project management and Quality Department staff members evaluates each phase of every waste-management project at ORNL for present or potential risks. Working together, the team then develops and documents plans and procedures to mitigate identified risks.

A recent successful example of this teamwork approach is the Bethel Valley Low-Level Liquid Waste (LLLW) Collection and Transfer System. This project was initiated to upgrade existing LLLW-handling facilities at ORNL. When completed, it will provide new underground LLLW pipeline service to five major sources, a new facility to receive LLLW transported via bulk tanker trailers or bottles, and means to transfer waste from the storage facility to the existing ORNL LLLW processing system.

To ensure the highest quality standards in all aspects of this work, we worked with a team that included the project manager, Cal Pepper of the Chemical Technology Division; Martha Woody of the Quality Department; and the engineering project manager, Don Haberkost. This team worked out a QA Plan for the Bethel Valley project that addresses materials standards, construction quality, operational training, and monitoring and compliance issues.

QA success stories are by nature undramatic—records of the accidents that did *not* happen, equipment that did *not* fail, and remedial actions that were *not* necessary. Another QA "success story " at ORNL was the recent Emergency Avoidance Solidification Campaign (EASC). This project decanted and solidified ~50,000 gallons of LLLW from underground Melton Valley Storage Tanks. The LLLW was solidifed by a commercial vendor, using a cement solidification process recently demonstrated as part of the Remedial Action Program. A second commercial vendor transported the solidified waste to a storage area at ORNL.

Both commercial vendors involved in the EASC had approved QA plans. ORNL's Quality Department has appointed a special EASC vendor-interface manager to coordinate and monitor the project's QA activities. A team that included project manager Tim Myrick and facilities operator Chris Scott of the Environmental and Health Protection Division, engineering project manager Tom Monk of the Energy Systems Engineering Division, project engineer Robin Schultz of the Chemical Technology Division, and Rick Forbes of ORNL's Quality Department developed a comprehensive QA plan for the project activities that were handled by ORNL's Waste Management Operations personnel.

Although no one enjoys the paperwork, our experiences have shown that careful, ongoing documentation and recordkeeping are essential. This is particularly true as ORNL and other government facilities participate more often in complex joint projects, such as the EASC, that involve interdisciplinary project teams and multiple commercial vendors. Documentation is needed for work elements ranging from very strict specifications for equipment or facility design to the QA inspection schedules and the training that is set up to meet operational requirements. For some waste management activities, regulations require that dual sets of records be kept in separate locations for the lifetime of the project—sometimes up to 300 years. To ensure that project activities continue to comply with all standards and requirements, periodic QA audits are conducted, findings reported, and corrective actions taken when necessary. The QA process is a strenuous yet flexible means of managing the multiple demands placed on our waste management systems. We have made costly mistakes in the past, and we have learned there is no substitute for the satisfaction and confidence gained from knowing that the best possible methods have been applied to ensure the success of any waste management endeavor ornl

"There is no substitute for the satisfaction and confidence gained from knowing that the best possible methods have been applied to ensure the success of any waste management endeavor."

Loss of Coolant: ORNL's Role in a Key Reactor Safety Experiment

By John Cleveland

In October 1988, Oak Ridge National Laboratory participated in a landmark safety test at a high-temperature gas-cooled reactor (HTGR) in the Federal Republic of Germany (FRG). The 46-MW(t), 15-MW(e) Arbeitsgemeinschaft Versuchs Reaktor (AVR) in Jülich was subjected to a simulated loss-of-coolant accident (LOCA), a very severe occurrence in which the coolant escapes from the reactor core and no emergency system provides coolant flow to the core. The test, which demonstrated the inherently safe response of this reactor to a LOCA, marked the first time that a reactor has been intentionally subjected to loss-of-coolant conditions.

As a member of ORNL's Engineering Technology Division and a long-time advocate of such a test, I had the opportunity to work with AVR staff in preparing the test plan and in jointly performing the analyses needed to obtain the license to conduct the test. I was present at the AVR in October to review planning and preparation for the test, to assist in data evaluation, and to obtain test results for further analysis and examination in the United States.

A New Approach

To ensure safe operation, designers of light-water reactors (LWRs) have adopted a "defense-in-depth" approach, relying on multiple redundant pumps, valves, pipes, and control systems. These components are arrayed so that each has at least one backup, and particularly critical systems have multiple levels of backup—for example, as many as three standby diesel generators to provide emergency electrical power. This complex and expensive redundancy is necessary because in normal operation the temperature of the uranium dioxide reactor fuel is far greater than the melting point of the Zircaloy metal tubes in which it is encased. That's no problem when the tubes are properly cooled, but if the coolant water should boil away or flow away through a broken pipe, the Zircaloy tubes would melt in about a minute without emergency cooling.

The AVR LOCA test was performed to demonstrate that inherent characteristics of small HTGRs enable them to withstand highly unlikely LOCA conditions in which no emergency backup system provides gas coolant to the core. We wanted to show that, although the core would heat up, temperatures would not even come close to dangerous levels that would lead to fuel failure and a consequent release of radioactivity.

This test was especially important to U.S. and FRG programs for HTGR development, because it demonstrated a fundamentally different approach to ensuring the safe and economical generation of electricity using nuclear power. This new approach is to design the reactor system to rely primarily on inherent characteristics to ensure safety, thus reducing the number and complexity of active engineered systems needed. New and larger designs called modular high-temperature gas-cooled reactors (MHTGRs), which are based on the same inherent safety principles, are being developed in both countries. In the United States, the Department of Energy is currently developing a new 350-MW(t), 135-MW(e) MHTGR.

Inherent Safety Features

The inherent safety features incorporated into these reactors are

- an inert coolant (helium) that will not react with the fuel or its coatings under any circumstances [at high temperatures, water coolant will react with Zircaloy to produce explosive hydrogen gas—an interaction that contributed to the severity of the accident at Three Mile Island-2 (TMI-2) and may have had a role in the Chernobyl accident];

The empty core of the AVR (left) was later loaded with graphite pebbles containing refractory-coated particles of nuclear fuel. (Photo courtesy of AVR.)

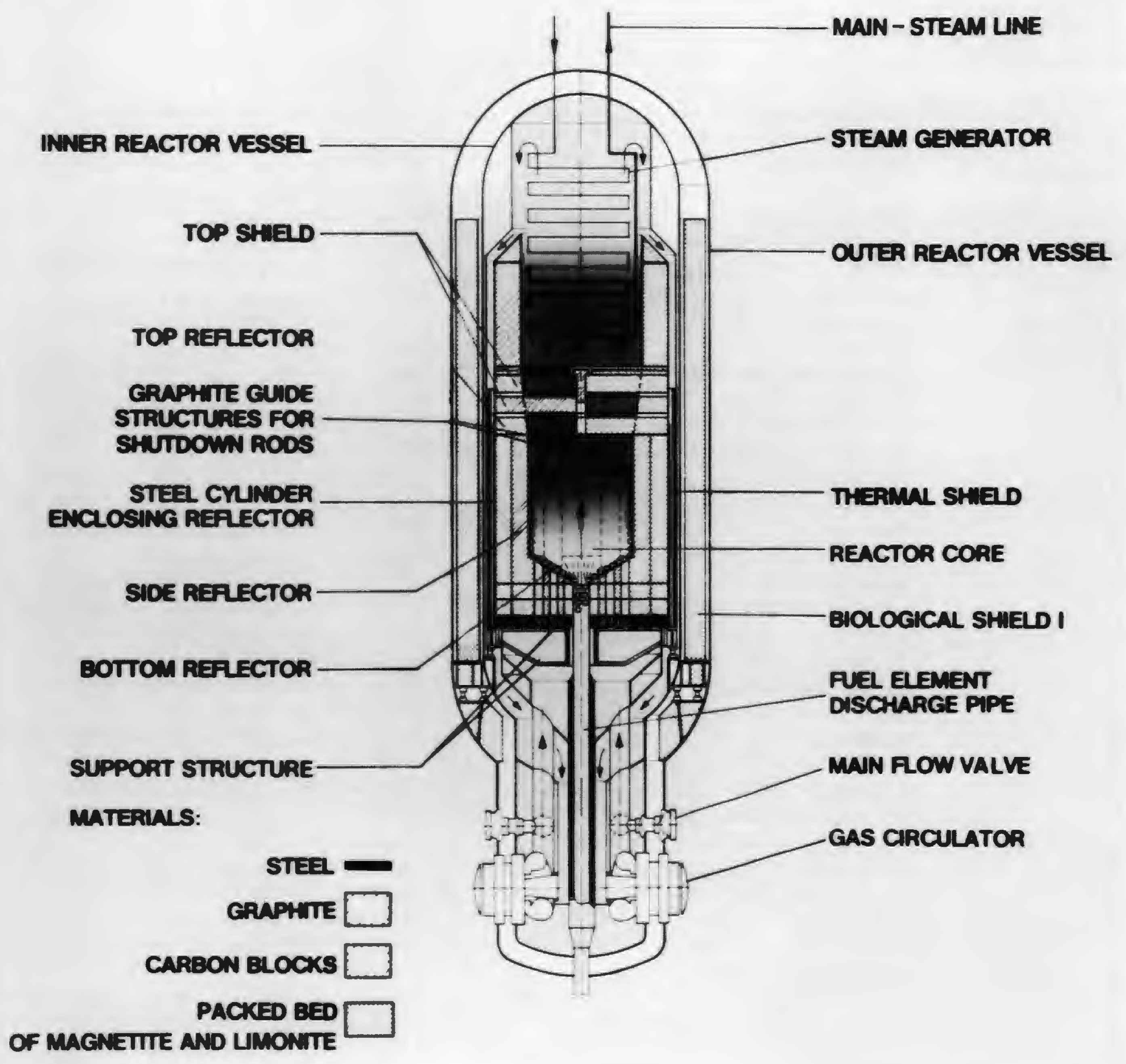
In the control room, AVR staff operate the high-temperature gas-cooled reactor during the planned "loss-of-coolant accident." (Photo courtesy of AVR.)

- refractory-coated particle fuel that is capable of withstanding temperatures higher than would be reached in any conceivable accident condition [no failure of the refractory coatings occurs if the fuel temperature is maintained below 1600 to1800°C];
- a negative temperature coefficient of reactivity that shuts down the nuclear fission chain reaction as temperatures increase (this feature is incorporated into all U.S. commercial reactors);
- a low power density and a high heat capacity of the fuel, leading to very slow transient response (change in temperature with time);
- the ability to passively dissipate decay heat from the core.

In the AVR "pebble-bed" reactor (see schematic on p. 81), the core is fueled with about 100,000 billiard-ball-size graphite pebbles each of which contains thousands of refractory-coated fuel particles designed to retain fission products at high temperatures. Fuel particles of this type are also used in the U.S. MHTGR, where they are bonded together into graphite fuel rods and contained in large hexagonal graphite fuel element blocks. In normal operation of the AVR, helium is circulated through the core to transport heat to a steam generator, which powers a turbogenerator to produce electricity. Refueling is done on-line by adding fuel pebbles to the top of the core and withdrawing spent fuel pebbles from the bottom. A graphite reflector returns neutrons to the reactor core. Four protrusions in the reflector, shown in the photo (p. 78), are called reflector noses and have channels through which the AVR's four control rods move.

ORNL and LOCA Test

ORNL's involvement in the test was possible under an agreement between the two countries to cooperate in gas-cooled reactor development. In


MAIN - STEAM LINE
INNER REACTOR VESSEL
STEAM GENERATOR
TOP SHIELD
OUTER REACTOR VESSEL
TOP REFLECTOR
GRAPHITE GUIDE STRUCTURES FOR SHUTDOWN RODS
STEEL CYLINDER ENCLOSING REFLECTOR
THERMAL SHIELD
REACTOR CORE
SIDE REFLECTOR
BIOLOGICAL SHIELD I
BOTTOM REFLECTOR
FUEL ELEMENT DISCHARGE PIPE
SUPPORT STRUCTURE
MAIN FLOW VALVE
MATERIALS:
GAS CIRCULATOR
STEEL
GRAPHITE
CARBON BLOCKS
PACKED BED OF MAGNETITE AND LIMONITE

"ORNL made significant contributions to the development of the LOCA test plan."

1984, ORNL established a cooperative effort with Kernforschungsanlage (KFA) and AVR staff in reactor physics, thermofluid dynamics, and safety. Analyses performed at ORNL showed that a LOCA demonstration could be conducted without causing reactor fuel damage. In 1987, the cooperation was expanded to include detailed planning and analysis for the LOCA test and other reactor physics and fission product behavior tests. This cooperative program includes ORNL and General Atomics of the United States as well as AVR and KFA. The AVR test data are being used in the United States to help validate computational methods used for MHTGR design and licensing.

ORNL made significant contributions to the development of the LOCA test plan. Also as part of the licensing procedure, joint analyses performed by ORNL and AVR predicted that reactor temperatures would not reach—or even come near—conditions potentially damaging to the fuel.

The test was planned to create conditions that would exist if the LOCA occurred when the reactor was operating at full power. In such a case, the plant protection system would respond by inserting control rods to shut down, or "scram," the reactor, thereby stopping the nuclear fission chain reaction in the core and slowing the generation of heat. Even without scram, fission would stop because of the negative temperature coefficient of reactivity. In either event, however, the decay of radioactive fission products in the core would continue to generate heat. Although the heat generation rate would decrease after scram, the core temperatures would rise unless cooling continues. In fact, decay heat resulted in partial melting of the TMI-2 core when its cooling was interrupted.

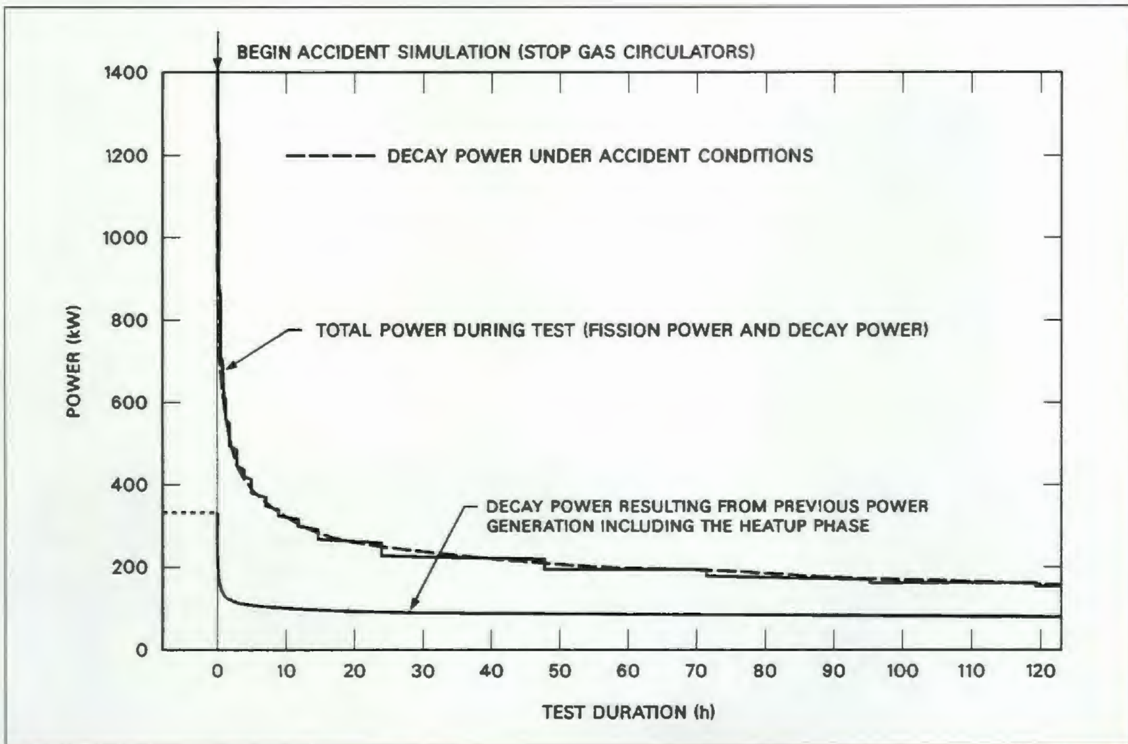
The AVR was not designed so that the helium could be removed rapidly for the test. To remove the coolant by normal depressurization (pumping it into storage tanks) requires over three days. During this time the decay heat generation rate would decrease to levels much lower than would exist immediately following an actual rapid LOCA, making a test at these conditions unrealistic and uninteresting.

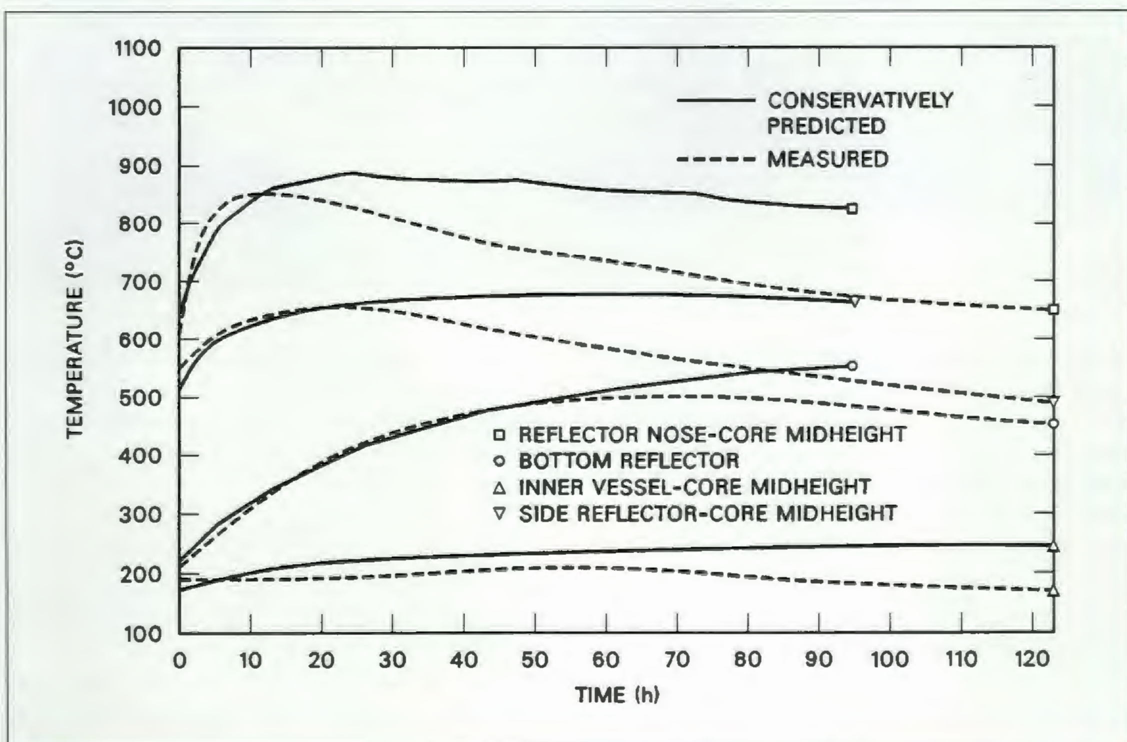
Thus, a test plan was devised to establish normal, full-power, steady-state, operating temperatures after depressurizing the reactor, and then, during the "accident" phase of the test, to generate nuclear fission power (heat) to equal the levels of decay power that would exist in a rapid LOCA. Since the heat input into the core during the test was the same as it would be under actual accident conditions, the measured temperature response was the same as it would be during a real accident.

The test followed a normal shutdown and depressurization; then the core was taken critical and heated with fission power. Normal operating temperatures were established using the gas circulators to move helium through the core (at atmospheric pressure) to the steam generator. To start the LOCA, the coolant flow was halted (the system was already depressurized) by stopping the gas circulators, and the operators controlled fission power generation to predetermined levels so that the total power was equal to accident levels of decay power (see figure on p. 83).

The LOCA test lasted for five days and, except for the need to prepare for other scheduled tests, could have continued indefinitely. During the test, core temperatures increased for nearly 14 h and then began a gradual and continual decrease as heat dissipated from the core by natural convection, conduction, and heat radiation to the water-cooled steam generator and through the reactor vessel wall. Maximum temperatures measured in the reflector noses, the reflector, and the reactor vessel during the test were lower than the conservative predictions made by AVR and ORNL for the licensing process. Test results are compared with conservative AVR/ORNL predictions (in the figure on p. 83).

Core temperatures were recorded using special monitoring elements that had been loaded into the core a few months before the experiment. Monitoring elements are graphite pebbles having the same size as normal fuel pebbles. Each monitor element contains 20 quartz capsules with wires of various metal alloys, whose melting temperatures range from about 650 to 1300°C. Following discharge from the core, the monitoring elements will be X-rayed, and the highest temperature





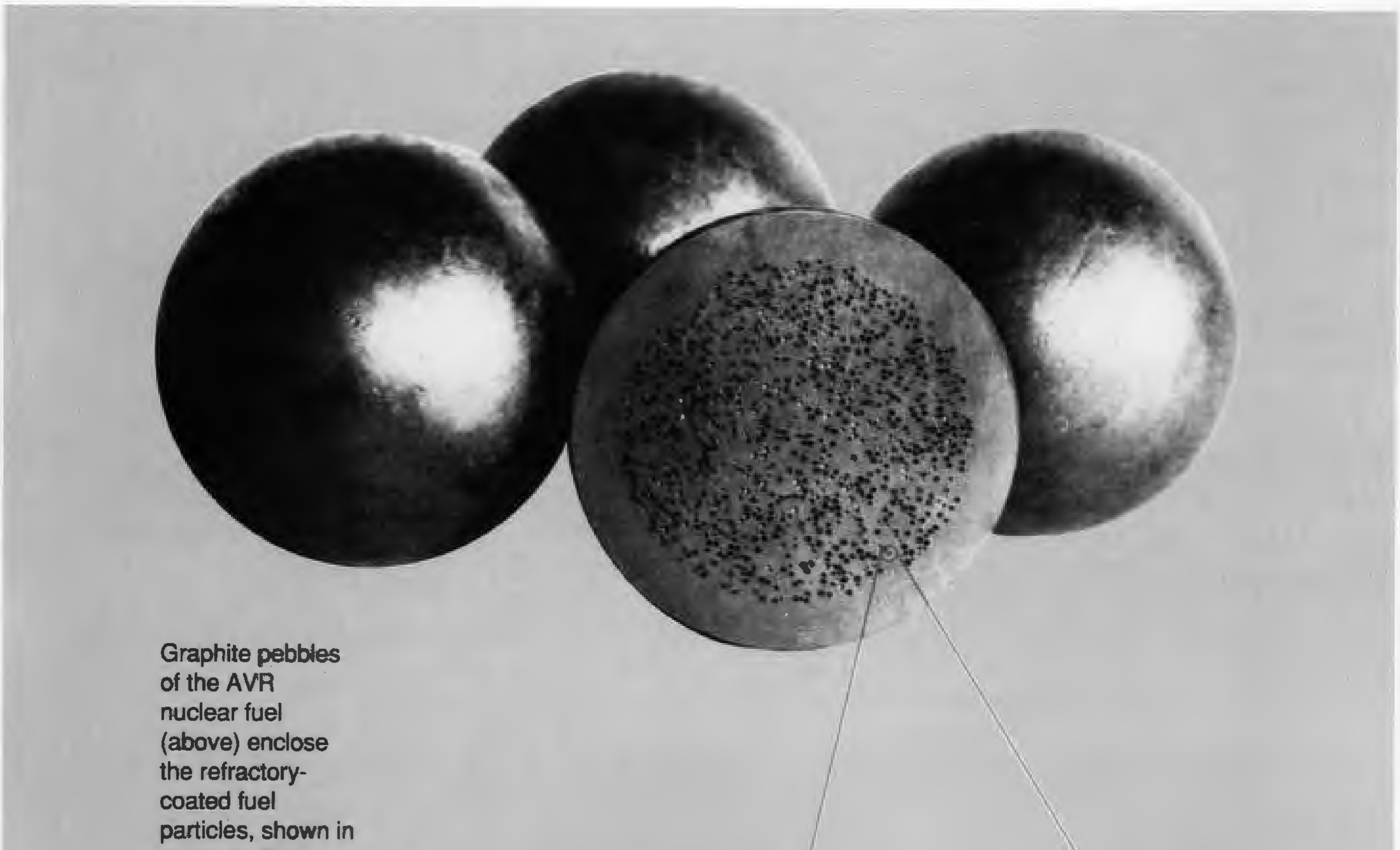
Fission power was used to simulate accident levels of decay power. (Figure courtesy of AVR.)

Because of its inherent safety characteristics, the AVR (shown here)—a high-temperature, gas-cooled reactor—survived a simulated worst-case accident without damage.

reached by each element will be indicated by the number of melted wires. This technique will give information about the maximum temperatures at various locations in the core. Based on AVR-ORNL analytical predictions, we expect maximum temperatures of about 1100°C—several hundreds of degrees less than the level at which the refractory-coated fuel particles begin to fail and release significant radioactivity.

In this AVR test, most of the heat was removed from the system by the water circulating through the steam generator. Under similar accident conditions in the MHTGR, heat removal would be completely passive—that is, the heat would dissipate from the core through the reactor vessel to panels cooled by natural air circulation and then to the environment.

The AVR test results also confirmed that the HTGR core becomes less reactive as its temperature increases. This effect was easily seen, since controlled fission was used to generate the desired core power after the LOCA test began. The amount of control rod motion required to maintain core criticality, coupled with the temperature



Graphite pebbles of the AVR nuclear fuel (above) enclose the refractory-coated fuel particles, shown in cutaway view below. (Photo courtesy of AVR.)

measurements, provided information regarding the temperature coefficient. This self-limiting feature was previously demonstrated in a series of AVR tests in the 1970s, during which the flow of coolant was simply stopped (but the coolant itself was not removed), and reactor shutdown occurred without insertion of the control rods.

TV Coverage

A crew from the Chedd-Angier Production Company, producer of the "Nova" TV series for the Public Broadcasting Service (PBS), recorded activities before and during the test. Chedd-Angier is producing a documentary entitled "Energy and the Environment," which will present several solution-oriented stories from around the world that emphasize various approaches to reducing our dependence on fossil fuels and the resulting negative impacts on the environment. The series will examine energy conservation, renewable energy resources, cleaner and more efficient combustion of conventional fuels, and inherently safe nuclear power. The documentary will be part of the PBS series, "State of the World" and will be shown in the United States and other parts of the world in the fall of 1989.

Chedd-Angier believes that the most dramatic way to present the concept of inherently safe nuclear technology to a general audience is to show activities on the scene in the control room while the LOCA test was being conducted. The television crew understood before the test that the accident proceeds slowly without much excitement. However, Chedd-Angier maintained that this very fact would present a startling reality to most viewers.

In summary, the test at the AVR showed the importance of inherent safety features for a LOCA, demonstrating that inherent safety is a reality, not just a computer prediction. Experience gained through the AVR LOCA test will be useful in testing the MHTGRs of the future. This demonstration that inherent safety features enable a reactor to survive a loss-of-coolant accident without damage should instill public confidence in this fundamentally new approach to safe and economical nuclear power. ornl

Biographical Sketch

John C. Cleveland has been a development staff member in ORNL's Engineering Technology Division since 1974. He manages cooperative programs with the Federal Republic of Germany involving the AVR tests and gas-cooled reactor safety research. He has worked on reactor design, performance, and safety analyses for a variety of reactor types including both commercial and space reactors. He holds a master's degree in physics from Virginia Polytechnic Institute and State University. In 1979 to 1980 he was a guest scientist at Kernforschungsanlage in Jülich, where he worked on the AVR and performed safety analyses on advanced gas-cooled and liquid metal reactors that have been constructed in the Federal Republic of Germany. Here, Cleveland (center) explains the results of the AVR-LOCA test to John Jones, Jr. (left), director of ORNL's Reactor Programs, and Frank Homan, technical director of Gas-Cooled Reactor Programs.

RE: Awards & Appointments

Stan Milora

Tuan Vo Dinh

P. C. Srivastava

Fred C. Hartman, Samuel H. Liu, and **Philip B. Thompson** have been named Corporate Fellows of Martin Marietta Energy Systems, Inc.

Alex Zucker, former ORNL acting director, has been appointed associate director for Nuclear and Engineering Technologies. He replaces **J. Robert Merriman,** who has assumed the position of vice president for AVLIS and Work for Others Programs for Energy Systems.

Charles A. Hall, former vice president for Engineering at Martin Marietta Corporation, has been appointed vice president for Technical Operations at Energy Systems. He replaces George Jasny, who retired.

Jackson B. Richard has been named director of Reactor Operations at ORNL, reporting to Energy Systems President Clyde C. Hopkins.

William D. Burch, Felix C. Difilippo, and **Ward W. Engle** have been named Fellows of the American Nuclear Society.

Bill R. Appleton, Lynn A. Boatner, and **Sheldon Datz** have been elected Fellows of the American Association for the Advancement of Science.

Jim Ball has been appointed a member of DOE's Nuclear Science Advisory Committee and has been elected vice chairman of the Division of Nuclear Physics of the American Physical Society.

Stanley L. Milora has received the 1988 Albert Nerkern Award from the American Vacuum Society for his "outstanding achievements in developing and applying unique and creative fueling systems for fusion devices."

Emily D. Copenhaver has been named to the Executive Committee of the Training Resources and Data Exchange (TRADE), which is managed by Oak Ridge Associated Universities for DOE.

F. F. (Russ) Knapp, Jr., has been appointed to the three-member U.S. editorial board of the nuclear medicine journal, *NucCompact—European/American Communications in Nuclear Medicine*.

R. D. Hatcher, an ORNL–University of Tennessee Distinguished Scientist, has received the first Distinguished Service Award of the Geological Society of America.

R. V. O'Neill and **W. R. Emanuel** have been appointed to ad hoc panels to review proposals for the Earth Observing System for the National Aeronautics and Space Administration. (Sometime in the 1990s, NASA will loft this platform of remote-sensing devices into orbit around the earth's poles.)

Steven E. Lindberg has been elected chairman of the U.S. National Atmospheric Deposition Program and National Trends Network.

George E. Taylor, Jr., has been appointed to the editorial board of the *Journal of Environmental Quality*.

V. R. Tolbert has been named treasurer of the North American Benthological Society.

Tuan Vo Dinh received a Gold Medal Award from the New York Society for Applied Spectroscopy at a special award symposium organized to honor him for his contributions to the advancement of spectroscopy in analytical, environmental, and biophysical chemistry. He also has been appointed a topical editor (spectroscopy) of the new international journal *Polycyclic Aromatic Compounds*.

Robert B. Shelton has been appointed associate director of ORNL's Energy Division.

P. C. Srivastava has been invited to serve on the Developmental Therapeutics Contracts Review Committee of the National Cancer Institute.

R. J. Luxmoore has been elected a fellow of the Soil Science Society of America.

Five ORNL/Energy Systems staff members received the International Metallographic Society's Pierre Jacquet Medal and the ASM International's Francis R. Lucas Award. They are researchers **Lynn A. Boatner, Stan A. David, Gerald M. Marsh,** and **John M. Vitek** and graphic artist **Allison Barcomb-Baldwin.**

P. J. Mulholland has been appointed to serve on the Advisory Committee of the National Science Foundation's Long-Term Ecological Reserve at the Coweeta Hydrologic Laboratory.

Richard F. Wood has received the Federal Republic of Germany's Senior U.S. Distinguished Scientist Award from that country's Alexander von Humboldt Foundation.

Francis B. K. Kam has received the Award of Merit of the American Society for Testing and Materials (ASTM) for his meritorious service to ASTM Committee E-10 on Nuclear Technology Applications during the development of standards related to nuclear radiation metrology.

Karen L. Von Damm has been named an advisor to the National Oceanic and Atmospheric Administration VENTS Program.

Carolyn Hunsaker has been elected secretary of the Association for Women in Science.

Robert I. Van Hook has been appointed ORNL's representative on the Great Smoky Mountains National Park Long-Term Ecological Research and Monitoring Program Cooperating Institutions Committee. He also has been named leader of a planning group to define ORNL's research contributions to global environmental issues.

Stephen H. Stow has been named to the Education Advisory Committee of the American Geological Institute and has been appointed chairman of the Membership Committee of the Geological Society of America. He has also been appointed to the National Academy of Sciences–National Research Council Geoscience Panel on Professional Community: Education and Manpower and to the Commission on Professionals in Science and Technology, a participating organization in the American Association for the Advancement of Science.

R. E. Swaja and **S. Yeh** received an Editor's Award for their paper, "Potential Problems with Using Sphere Ratios To Determine Neutron Albedo Dosimetry Correction Factors," in Volume 4 of *Radiation Protection Management*.

George E. Taylor, Jr., has been named a member of the Clean Air Scientific Advisory Committee of the Science Advisory Board of the U.S. Environmental Protection Agency.

Fred C. Hartman has been elected to the Executive Committee of the Division of Biological Chemistry of the American Chemical Society.

The International Metallographic Society and the American Society of Metals International have established The DuBose-Crouse Award in honor of **Carus K. DuBose** and **Robert S. Crouse,** because they were the only two individuals to chair the International Metallographic Contest during the first 20 years of its 21-year existence.

G. Daniel Robbins has been appointed director of Administrative Services for Energy Systems. In this new capacity, he will be responsible for three divisions, including the Graphics Division, headed by **T. Wes Robinson**; the Information Services Division, headed by **Nancy P. Norton**; and the Publications Division, headed by **Donna S. Griffith**. Norton and Griffith are the first women to head Energy Systems divisions.

JoEllen M. Meredith has been named director of ORNL's Personnel Division. She is the second woman to head an ORNL division.

Charles C. Coutant has been named manager of the Exploratory Studies Program in ORNL's Program Planning and Analysis Office.

Thomas H. Row has been named director of the new Environmental and Health Protection Division, which combines activities of the former Environmental Compliance and Health Protection Division, the Operations Division, and the Nuclear and Chemical Waste Program Office. **L. E. McNeese** has been appointed associate division director for environmental corrective actions and operations, and **J. H. Swanks** is now associate division director for environmental compliance and health protection for the new division. **Lanny D. Bates** is manager of the Remedial Action Program of ORNL's Nuclear and Chemical Waste Programs and head of the Remedial Action Section of the Environmental and Health Protection Division

Dick Wood

JoEllen Meredith

Steve Stow

RE: Books

The Economic Feasibility of Recycling: A Case Study of Plastic Wastes

T. Randall Curlee, Praeger Publishers, New York 1986 (203 pages)

Reviewed by Carolyn Krause, *ORNL Review* editor

Most ORNL staff members pondering the problems of waste management are considering hazardous or radioactive waste. However, economist Randall Curlee of ORNL's Energy Division has studied the economics of recycling plastic waste, a growing portion of conventional trash. Such recycling has been proposed to reduce the landfill space required for burying plastic waste and to eliminate the possibility of hazardous emissions from burning plastics in incinerators.

Plastic waste, which includes such common objects as hamburger packages, coffee cups, and grocery bags, makes up 7.3% of municipal waste in the United States. Other components of domestic refuse include cardboard and paper (18.6%), yard wastes (17.1%), food (17%), magazines and newspapers (11.1%), soil (8%), glass (7.9%), metal cans and foils (5.3%), and diapers (3.6%). Reusing rather than disposing of these materials could prove attractive as concerns about the health effects of incineration mount and as the costs of landfill disposal spiral.

In August 1988, the U.S. Environmental Protection Agency formulated new regulations that compel operators of municipal landfills to monitor hazardous wastes and methane gas; ban discharge of harmful wastes into groundwater; and strengthen controls on rodents, insects, fire, and odor. According to the September 5, 1988, issue of *Time* magazine, any of the 6000 American municipal landfills could be closed if they fail to meet these regulations by 1991. EPA estimates that its landfill rules will increase the nation's annual garbage-disposal costs (now $5 billion) by $900 million a year.

In his book, Curlee first examines the economics of recycling plastic waste. His cost data, unfortunately, are several years old—representative of an era when landfill disposal costs were lower but rising. Overall, Curlee presents an excellent, though slightly repetitious, overview of the complex technological, economic, and institutional issues involved in recycling plastic waste. He gives plastic waste volume projections, compares recycling and disposal costs, and discusses the incentives for (and barriers to) recycling in selected business sectors, such as electrical and electronics equipment manufacturers, automobile shredder operations, and beverage container production.

"One advantage of tertiary and quaternary recycling over primary and secondary recycling is that the plastics can be used without separating them from other municipal waste."

The book has an impact. The last time I poured a cola from a plastic bottle and tossed it in the trash, I felt a twinge of guilt in sending that plastic bottle to the local landfill instead of to someplace where it could be converted to fiber for stuffing pillows, ski jackets, and sleeping bags.

Curlee's book makes it clear that recycling plastic waste is a more complicated technical operation than recycling paper, glass, and metals. One reason is that the many organic resins used in plastics (e.g., thermoplastics, thermosets, and polyurethane foams) vary significantly in their chemical and physical properties. There are also four different types of plastic recycling: primary (processing the waste into a product having characteristics similar to those of the original); secondary (processing that yields characteristics inferior to those of the original product—for example, making drain pipes and construction materials from thermoplastics); tertiary (recovering basic chemicals and fuels from waste resins); and quaternary (retrieving only the heat content of plastics through incineration).

One advantage of tertiary and quaternary recycling over primary and secondary recycling is that the plastics can be used without separating them from other municipal waste. A disadvantage of quaternary recycling, according to some (but not all) experts, is that the toxic by-products from plastic incineration (e.g., hydrochloric acid from incinerating polyvinyl chloride) may threaten human health or damage the environment. In addition, burning excessive amounts of plastic waste could generate too much heat and clog a conventional incinerator.

Conventional trash destined for disposal in the Y-12 Plant sanitary landfill is now packaged in nondegradable color-coded plastic bags as a means of tracking the trash volume generated by various plant operations. The information may be useful for future waste minimization efforts.

The economic and institutional issues of plastic waste recycling, writes Curlee, can be as complex as the technical issues. For example, a private firm may decide to try recycling plastic wastes because it is potentially less costly than disposal. However, the firm may not produce enough plastic waste or have a large enough market for the technology to be economically viable. Whether members of the private sector decide to recycle or dispose of plastics will be affected by a multitude of economic and institutional incentives and barriers.

Curlee recommends that the government encourage recycling through positive actions, not just by making disposal more costly—a policy which, he points out, "will promote open dumping." Positive actions in this area might include subsidizing recycle operations, supporting the development of less costly tertiary and quaternary recycling processes, and purchasing recycled plastic products. He urges that plastic waste be separated from other municipal waste at the consumer level. A local example of the kind of positive action Curlee advocates is the recent move in Johnson City, Tennessee, to provide free household garbage pickup to homeowners who presort the paper, metal, glass, and plastic trash into separate containers.

Some believe sorting trash at home is likely to meet resistance (although a survey of Johnson City homeowners indicates that free garbage pickup is a successful motivator). The city of San Jose, California, has a large, successful recycling program in which 180,000 households separate glass, metal, and newspapers from their garbage; but the residents have balked at separating plastic pop bottles.

"Curlee notes that nondegradable plastics may be good for landfills because they provide structure and prevent subsidence when landfills are closed."

A current related issue, not discussed in this book but covered recently by *Science* and *Time* magazines, is the trend toward manufacturing biodegradable plastics containing cornstarch. Landfill bacteria will consume the starch, causing the plastic to disintegrate in four to seven years and conserving landfill space. According to an article, "There's (Plastic) Gold in Them Thar Landfills," in the July 22, 1988, issue of *Science*, state and local legislators in some areas are now mandating that plastic containers be made of materials that sunlight or bacteria can break down. However, the growing use of such degradable plastics "could pose problems for emerging plastic recycling operations" because degradable plastics cannot be easily recycled. Replacing nondegradable with degradable plastics in landfills in the future may also have drawbacks. Curlee notes that nondegradable plastics may be good for landfills because they provide structure and prevent subsidence when landfills are closed.

Though no longer current, Curlee's book is still a very readable, reliable source of information about the technical and economic issues of plastic waste recycling. One of the many facts I learned from this book is that ORNL—through its Energy Conversion and Utilization Technologies Program managed by the Metals and Ceramics Division—has done research on developing processes to make composite materials from clean, shredded automobile residue mixed with plastic binders. The resultant material could be used to make floor coverings, drainage gutters, flower pots, and particle board.

Because plastic recycling continues to be a hotly debated issue, Curlee's book should be updated and retitled *The Economic Feasibility of Plastic Recycling* (the current book has no mention of plastic on the spine because the word is not part of the main title). To make the book more attractive to readers, photographs of plastic recycling operations, feedstocks, and products of recycled plastic waste should be included. Perhaps it would be fitting to put on the cover a drawing of a plastic pop bottle floating in a stream (a waste stream?), carrying a message that says "Recycle me."

National Environmental Policy Act (NEPA) Process

Keshava S. Murthy, CRC Press, Inc., Boca Raton, Florida, 1988. (215 pages)

Reviewed by Carolyn Krause, *Review* editor

Those ORNL researchers and other staff members involved in the preparation of environmental impact statements and assessments to satisfy NEPA regulations should find this book a useful guide. Chapter topics include (1) environmental statutes such as NEPA, the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act, and the Safe Drinking Water Act; (2) technical aspects of statutes, standards, and regulations, including those dealing with limits on the discharge of polluted water and the emissions of lead, sulfur oxides, particulate matter, carbon monoxide, ozone, and nitrogen dioxide; (3) the NEPA process itself; (4) methods for writing environmental documents; (5) selection of control technologies for compliance with regulations (e.g., scrubbers, flue gas desulfurization technology, fluidized-bed combustion technology, electrostatic precipitators, and high-efficiency particulate air filters); (6) NEPA and the Nuclear Waste Policy Act (the text mentions the proposed Monitored Retrievable Storage facility); (7) keeping records of decisions; and (8) empathizing with the public. The book ends with answers to common questions about the NEPA process. Altogether it is a handy reference for anyone in the environmental business, including waste managers. ornl

Roof Research Center Dedicated

DOE's Roof Research Center, a user facility at ORNL, will meet the need for research on roof performance and for participation by industry in roof research. It will also provide a way to make research results available to users. So said John Berg, DOE's principal deputy assistant secretary of Energy Conservation and Renewable Energy at the recent dedication of the Roof Research Center. The center is operated by ORNL's Energy Division and is partly supported by the roofing industry.

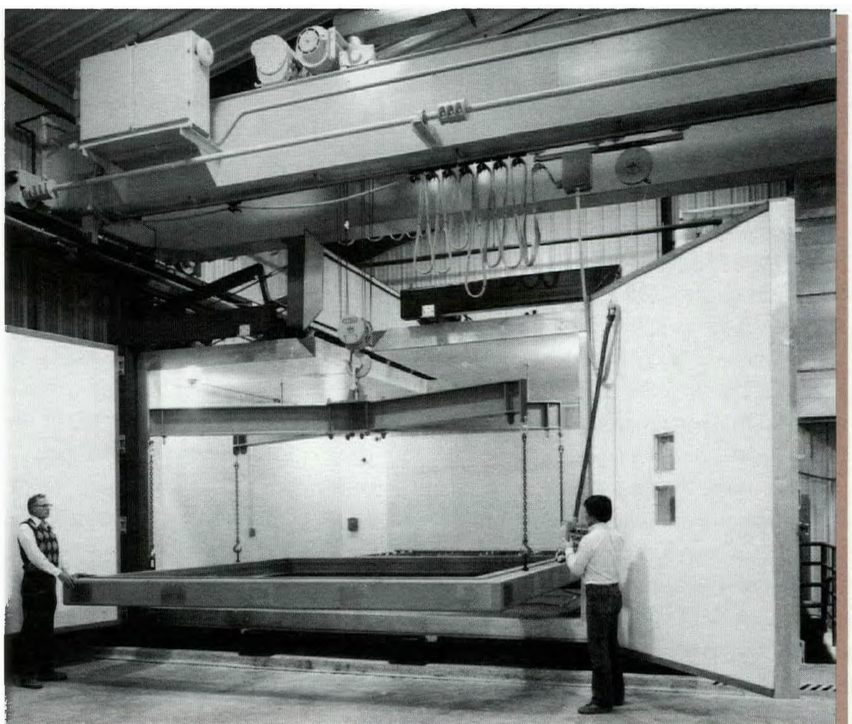
The $2.8 million user facility was conceived out of the need to improve the thermal efficiency of low-slope roofs and attic systems while maintaining durability and long service life, all at competitive prices. Industrial and ORNL researchers at the Roof Research Center will study the effects of moisture, temperature, and other variables on roofing systems, including insulations used to retain heat in buildings in winter and reflective coatings used to keep heat out in summer.

"We need your cooperation and we need your bucks," Berg told representatives of 66 industrial organizations present at the dedication. "We need you on the team. DOE and U.S. taxpayers are the quarterback and industry is the fullback. If we don't have your support, we will be dropped back for a heck of a loss."

Marlin Potteiger, president of the National Roofing Contractors Association, said that the Roof Research Center would bring a "new level of scientific excellence" to the understanding of roof systems through the collection of experimental data, the performance of mathematical analysis, and the development of models.

Roger Bengtson, vice president and general manager of the Roofing Systems Division of Manville Corporation, said that industry "looks forward to getting the facts" about the performance of different roofing materials and systems under a variety of conditions.

The dedication ceremony was held on September 14 at Building 3144, near the Graphite Reactor. The speakers representing ORNL were Bill Fulkerson, Energy Division director, and Murray Rosenthal, associate director for Advanced Energy Systems. Following the ceremony, a technical symposium on "Mathematical Modeling of Roof Systems" was held off-site in Oak Ridge.



Dick Huntley and Phil Childs load a roof section on the diagnostic platform at the Roof Research Center.

Large Coil Task Issues Final Report

"One new effort will be to develop motors using super-conducting materials."

The 232-page final report on the international Large Coil Task (LCT) was completed at the Laboratory in July 1988. It summarizes 10 years of activities and the findings of the 18-month test of six superconducting magnet coils at ORNL. After review comments by the foreign participants in this fusion project were addressed, the report was published in September 1988 as a special issue of the international journal, *Fusion Engineering and Design* (Vol. 7, Nos. 1 and 2).

The report concluded that

- The limits of coil operability exceeded the design points by substantial margins.
- Satisfactory stability of much larger tokamak magnets should be achievable through use of the design procedures tested in the LCT.
- Findings suggest that forced-flow cooling of the superconducting material with helium should be preferable to immersing the coils in a helium bath.
- The effective international collaboration in cooperative design and production and integration of large-scale, advanced components portends success in larger international ventures in fusion and other technologies.

The report noted that air leaking into the helium was the most important problem in the operation of the LCT facility at ORNL. In terms of research results, the niobium-titanium superconductor in five coils performed as well as expected but the current-carrying ability of the niobium-tin superconductor in a U.S. magnet fell short of expectations because of scattered imperfections along the coil, apparently resulting from "problems in conductor production."

The LCT experiment, which ended in early September 1987, marked the first time that four countries—the United States, Federal Republic of Germany, Japan, and Switzerland—have contributed different versions of the same equipment to a fusion hardware experiment and collaborated in tests to evaluate equipment performance, reliability, and economics.

At ORNL, the seven-person staff of the Large Coil Task group has returned to the Magnetics and Superconductivity Section under the leadership of Martin S. Lubell. (Paul Haubenreich, former Large Coil Task manager, went to Vienna, Austria, to serve as International Thermonuclear Experimental Reactor Council secretary for the International Atomic Energy Agency.) Lubell's group is picking up where it left off on some pre-LCT research and seeking new projects requiring its expertise in superconductivity. R&D work on enhancing the performance of forced-flow, cable-in-conduit conductors at higher fields and higher current densities will be continued. One new effort will be to develop motors using superconducting materials, a collaborative effort involving researchers from ORNL's Applied Technology, Energy, and Fusion Energy divisions. Another area of interest is the development of magnetic energy storage for excess electricity produced by electric utilities.

ORNL Probes Leaking Cesium-137 Capsules

After a five-month effort to find the cause of cesium-137 leakage from one or more of the 252 stainless steel capsules used by a Decatur, Georgia, company to sterilize medical supplies, chemists and engineers in ORNL's Chemical Technology Division found a deformed capsule that leaked radioactivity.

A group of researchers led by Eugene Newman have applied various techniques to identify the leaking capsule in the storage pool at the facility. In November 1988, Jim Snider and a group of engineers developed a "pressure-cycle leak detection system," a device that can apply pressure to test six capsules at a time. When the suspect bulging capsule was isolated from the storage pool, the activity level of the pool decreased; at the same time, the activity of the test system water in contact with the capsule increased, providing more evidence that the deformed capsule was the source of the leak.

The capsules containing the radioactive cesium were fabricated by DOE's facilities at the Hanford Reservation in Washington state. About 50,000 Ci of cesium-137, a by-product from recycling of Department of Defense nuclear reactor fuel, was sealed in each stainless steel capsule, which was then enclosed in an outer stainless steel container. Only about 4 Ci of this radioactivity was leaked into the storage pool, and none escaped the facility. These doubly contained capsules were leased to users by DOE's Isotope Sales, Lease, and Loan Program. The cesium isotope is used in medical applications, to fuel remote power sources, and to sterilize materials such as food, wastes, or medical products.

Radiation Sterilizers, Inc. (RSI), located in Decatur and in Westerville, Ohio, leased these capsules from DOE, housing them in buildings where the capsules are stored in a pool of water for radiation shielding (just as spent fuel elements are stored in a swimming-pool reactor). Periodically the capsules, each about 3 in. in diameter and 21 in. long, were lifted out of the pool to sterilize medical supplies that passed through the radiation field on a conveyor line.

On June 8, 1988, RSI reported abnormal radiation readings in the facility, indicating leakage of cesium-137 from one or more of the capsules. The DOE Operations Office was asked to handle the investigation to determine the source and cause of the leakage.

Because it has both the required hot-cell facilities and personnel experienced in handling radioactive materials, ORNL was asked to assist in all phases of the effort to identify the leaking capsules, transport them safely to Oak Ridge, and conduct metallurgical examinations to determine the mechanism of capsule failure.

Staff members from ORNL's Chemical Technology Division, working with staff members from Westinghouse Hanford and Pacific Northwest Laboratory (PNL), have headed the efforts to identify, remove, package, and transport the leaking capsules to ORNL for examination to determine the cause of leakage. Plant and Equipment Division personnel fabricated the special equipment used to identify which of the 252 capsules was the source of the radiation leakage. Staff members of the Instrumentation and Controls, Metals and Ceramics, Analytical Chemistry, and Environmental and Health Protection divisions of ORNL and Energy Systems' Engineering Division have also been involved in work for the project both in Oak Ridge and Decatur.

Underwater cameras, weighing techniques, and ultrasonic instruments used at the Decatur facility last summer failed to positively identify the leak source. Twenty-nine capsules were considered suspect because of exterior surface deposits, which could be signs of corrosion.

A heavily stained capsule was removed, packaged, and transported to ORNL on August 17 for exhaustive testing in the Chemical Technology Division's hot cells. Two additional capsules that showed indications of internal liquid were shipped to ORNL on September 16 for testing.

The new leak detection system was constructed at ORNL and moved to Decatur last September so that the capsules could be tested, in batches of six, under conditions more like those encountered in RSI's operations. Using this new equipment, a swollen and leaking capsule was found on November 29. On December 2, another bulging, but not leaking, capsule was identified. This capsule had been previously examined and was not, at that time, deformed.

By December 20, the ORNL team had completed examinations of all remaining capsules at RSI. The two bulging capsules were transported to ORNL for exhaustive testing and analysis. The tests have already revealed that the bulge on one leaking capsule increased its diameter in that area by 0.220 in. A gamma scan showed that the cesium compound is present in the annular space of both capsules, indicating that the inner containment in both capsules failed. Scientists here speculate that solid-solid phase transitions in the cesium, which result in a 15% density change, could be a contributing factor to the leakage. Tests on the capsules are far from completed and will continue for several months. In the interim, cesium contamination at the Decatur facility is being removed.

"Only about 4 Ci of this radioactivity was leaked into the storage pool, and none escaped the facility."

Air Monitoring Data Available

Quarterly air monitoring data from DOE's Oak Ridge facilities are now available to area residents in notebooks located at three Oak Ridge sites—the Scarboro Community Center, the American Museum of Science and Energy, and the Oak Ridge Public Library. ORNL staff routinely analyze the data from three community air monitoring stations and others in the region to compare emissions from DOE facilities with allowable limits specified by federal and state regulations. In addition to current monitoring data, the notebooks contain general information on DOE's environmental monitoring program, comparison charts and graphs, and a glossary of pertinent terms used in the notebooks.

Accelerator Sets World Record

The tandem electrostatic particle accelerator at ORNL's Holifield Heavy Ion Research Facility (HHIRF) recently set a world record and exceeded its design voltage by accelerating a beam of charged particles with a 25.5-million-volt terminal potential.

In September 1988, the 25-million-volt machine accelerated nickel ions at a terminal potential at least 5 million volts higher than that of any other tandem accelerator facility. In addition, the ORNL accelerator surpassed its own design voltage by a half million volts.

The recent increase in terminal voltage was made possible by an improved acceleration tube design developed jointly by researchers from ORNL and the National Electrostatics Corporation. The beam energies at the HHIRF today are about 60% higher than were available when the accelerator first operated in 1982. The increased energies will permit experiments on a larger number of heavy-ion species.

The accelerator, a tool for basic research on nuclear structure and nuclear reactions, is the largest of its type in this country. It is housed in ORNL's landmark concrete tower near the swan pond on Bethel Valley Road.

Vibroseis System Acquired by ORNL/UT

The Environmental Sciences Division at ORNL and the Department of Geological Sciences at the University of Tennessee have jointly acquired a state-of-the-art seismological system known as Vibroseis. The system houses seismological testing equipment in two large trucks and is used to conduct highly refined studies of the earth's crust.

Originally developed by the petroleum industry to detect large oil and gas reserves without expensive drilling, the system will be used by ORNL and UT researchers in studying earthquakes and in assessing disposal sites for radioactive and hazardous wastes.

RE: Take a Number

By V. R. R. Uppuluri

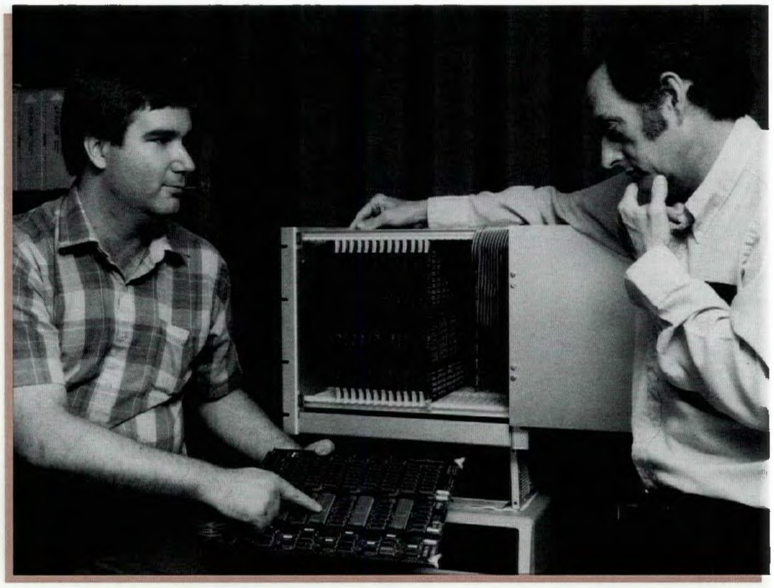
Means and Standard Deviations as Integers

The mean of *n* numbers is the sum of these numbers divided by *n*. The variance of *n* numbers is the mean of the squares of deviations from the mean, and the standard deviation is the positive square root of the variance. It has been shown that the mean and standard deviation of any set of *seven* consecutive integers are both integers. Recently, Jim Delany, of San Luis Obispo, California, asked whether this property is shared by any other sets of consecutive integers. Home computer hobbyists are invited to try to answer Delany's question.

Sums and Products as Reversals

The integers 47 and 2 have an interesting property: their sum ($47 + 2 = 49$) is the reversal of their product ($47 \times 2 = 94$). Similarly, the sum of the integers 24 and 3 ($24 + 3 = 27$) is the reversal of their product ($24 \times 3 = 72$). The integers 9 and 9 have the same property: $9 + 9 = 18$ and $9 \times 9 = 81$.

Two Oak Ridge Innovations Win R&D 100 Awards



Philip L. Butler (left) and John D. Allen, Jr., of ORNL's Instrumentation and Controls Division, developed a decision-making parallel computer called OPSNET.

Two Oak Ridge developments—a decision-making computer and an X-ray device for analyzing materials—were selected as among the top 100 new technology advances in 1988 by the editors of *Research & Development* magazine.

The OPSNET Parallel Computer developed by ORNL researchers is expected to have applications in organic chemical synthesis, medical diagnosis, robotics, and other processes using artificial intelligence. The other development, the High-Resolution X-Ray Microprobe, was done by staff members of the Oak Ridge Y-12 Plant. It can be used to analyze heterogeneous materials, evaluate microelectronic or corrosion protection films, and determine elemental distributions in biological or geological specimens.

These R&D 100 Award winners are selected from among thousands of U.S. scientific and engineering achievements on the basis of their importance, uniqueness, and usefulness.

OPSNET

OPSNET, a new, extensible, fault-tolerant parallel computer developed at ORNL to execute the popular OPS5 "expert" system language, has achieved significant performance gains over conventional computer architectures—and at a fraction of the cost of other parallel machines. Previously, uses of expert systems for real-time process control have been limited by slow execution speeds, even when very powerful mainframe computers are used.

Computer-based expert systems are being employed increasingly to emulate the decision-making processes of human experts in fields ranging from organic chemical synthesis to medical diagnosis to intelligent robot control. OPSNET captures some of the parallelism inherent in such expert system programs. It was developed especially to execute, rapidly and directly, programs written in OPS5—one of the oldest and best-established computer expert-system languages.

The machine's central feature is a network bus over which a host processor broadcasts messages to a set (any number) of parallel rule processors. Existing prototype computer systems use a host and 64 parallel processors or, in a smaller package, a host and 8 processors.

Complex expert-system programs often contain several thousand production rules expressed as "if-then" statements. Each production rule must be evaluated by the computer before it arrives at a decision. The computer searches for rules that have conditions matching the current state of system memory. OPSNET was designed to execute this rule-matching in parallel for expert systems written in OPS5.

OPSNET can be extended indefinitely by plugging in additional processors without any reprogramming. Among other advantages, it can run existing expert systems written in OPS5, also without any reprogramming; it can be made inherently fault tolerant; and it provides parallel processing of expert systems at a fraction of the cost of other parallel machines.

Developers of OPSNET are Philip L. Butler and John D. Allen, Jr., of ORNL's Instrumentation and Controls Division.

X-Ray Microprobe

The high-resolution X-ray microprobe, known as HRXRP-5, is an advanced analytical device developed at the Y-12 Plant. It produces color-enhanced images showing the distribution of elements in metals, ceramics, composites, and biological and geological specimens. The instrument was developed for nondestructive, high-resolution microanalysis of materials having heterogeneous structures and compositions.

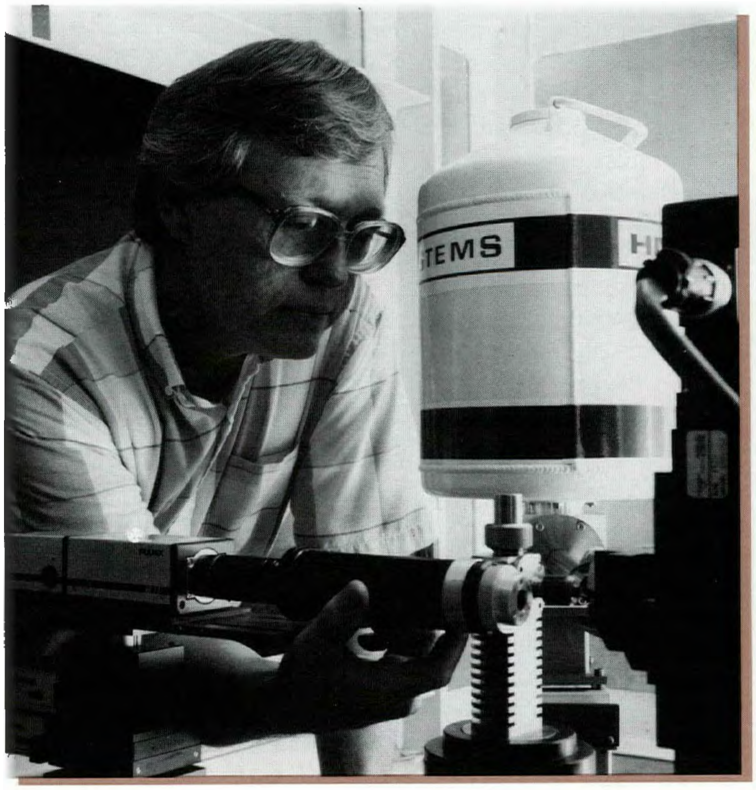
Using an intense, highly collimated X-ray beam as a fluorescence probe, a typical analysis is carried out in air with little or no sample preparation. Analysis time is fast enough to maintain a high sample throughput, and since no vacuum chamber is required, relatively large specimens can be analyzed. The beam impinging on the sample surface causes specific elemental fluorescence to occur. Fluorescent X rays are captured with a solid-state detector and separated by energy level to uniquely identify each element present in the sample. A spatial resolution of about 5 µm is obtained routinely.

The analysis is repeated up to 40,000 times for each sample, by translating the sample in a grid pattern normal to the incident X-ray beam. Elemental spatial distributions are displayed on a graphics work station as gray-scale or color-coded topographic images. Unique features permitting rapid, high-resolution analysis include a high-brilliance, 22-W X-ray tube (with a 10-µm focal spot), combined with a tightly coupled collimation system that uses extremely fine-bore glass-capillary tubing.

The principal applications of HRXRP-5 for engineered materials are in the evaluation of failure modes, identification and mapping of impurity inclusions, and verification of elemental distributions. The system also can be used to verify the integrity of multiple films used in microelectronic or corrosion-protection applications and as a film-thickness gauge for plated, vapor-coated, or ion-coated specimens.

Developers are Donald A. Carpenter, Roger L. Lawson, Mark A. Taylor, Gary M. Haney, and Karl Z. Morgan, all of the Y-12 Plant Development Division.

This year's two awards make a total of 62 won by the Oak Ridge facilities since 1967; 45 were



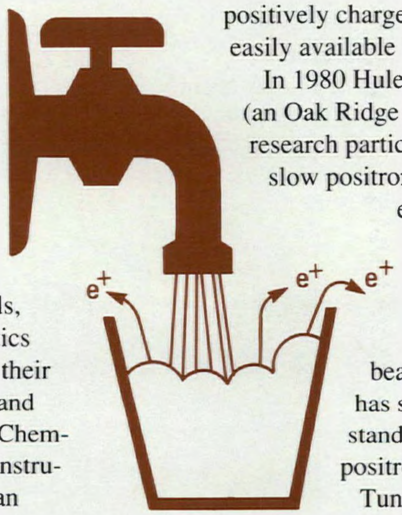
Donald A. Carpenter and his research team at the Y-12 Plant have produced a high-resolution X-ray microprobe that shows the distributions of elements in many materials.

received in the last 10 years. Thirty-five percent of the R&D 100 Awards presented in 1988 were given to Department of Energy facilities, including ORNL and the Y-12 Plant.

New Positron Source at ORNL

A positron source—probably the most practical and versatile of its kind in the world—has been constructed and installed at the Oak Ridge Electron Linear Accelerator (ORELA) at ORNL. The source, which has produced a beam of 1.1×10^8 slow positrons per second, has applications in analytical chemistry, chemical physics, materials characterization, and the biological sciences.

The positron source facility is the result of joint efforts by the Analytical Chemistry, Instrumentation and Controls, and Engineering Physics and Mathematics divisions. To complete the project with their limited funding, developers Les Hulett and Dave Donohue, of ORNL's Analytical Chemistry Division, and T. A. Lewis, of the Instrumentation and Controls Division, took an informal, flexible approach. They did their own design, improvised, and worked closely with individual crafts and procurement personnel. In addition, low-cost assistance was obtained from workers at the Anderson County Sheltered Workshop, who wrapped the target room solenoid with the required 1500 ft of aluminum wire, strung with 60,000 ceramic insulating beads.



The "positron spigot" can be turned on at any time for ORNL research.

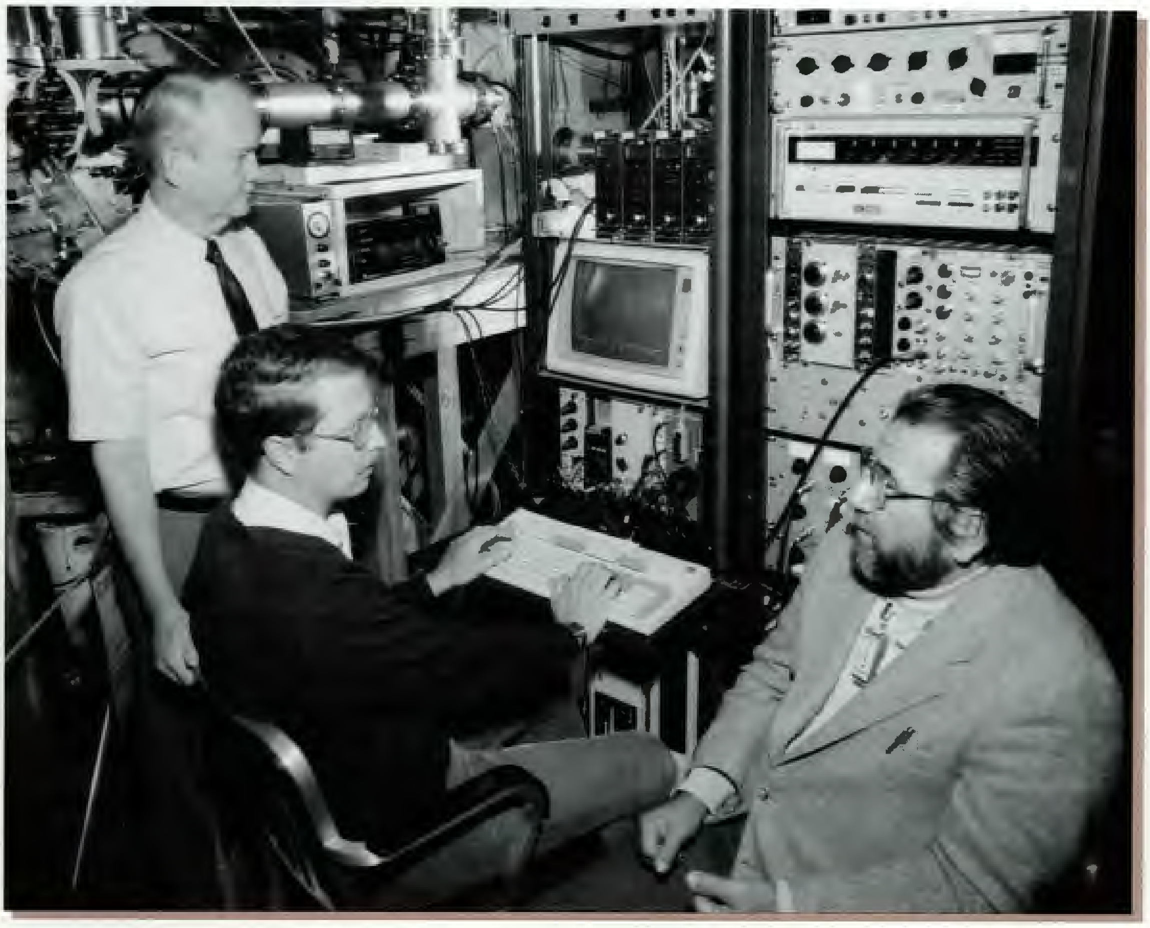
Recycled energy. Hulett calls the new source a "positron spigot," because it can easily be turned on or off at any time, unlike other positron sources in this country. The source is also unique in using the previously wasted energy of gamma rays that are scattered beyond the ORELA's tantalum target during electron bombardment. Because the gamma energy is a by-product of neutron production, using this energy for the positron source makes its operating costs negligible. It also provides a much higher positron production than is possible at other positron sources in the United States. Unlike the ORNL source, Hulett says, positron facilities at other institutions are rather cumbersome to use and require special funding and operating schedules.

Positron research at ORNL began about 10 years ago, after Hulett and John Dale of the Analytical Chemistry Division received internal funding when the project was deemed suitable for ORNL "seed money." One goal of the effort was to produce beams of monoenergetic positrons—elementary particles that may be thought of as positively charged electrons—which were not easily available for research at the time.

In 1980 Hulett, Dale, and Subra Pendyala (an Oak Ridge Associated Universities research participant having experience with slow positrons) developed a highly efficient tungsten moderator for converting fast positrons with various undefined energies to the desired monoenergetic positron beams. The tungsten moderator has since been adopted as a standard by essentially every other positron group in the world.

Tungsten is also an efficient initiator of positron formation from gamma rays. In 1930, American physicist Carl D. Anderson first discovered the formation of positron-electron pairs from gamma ray bombardment of target materials. This "landmark effect" in physics, which vindicated Albert Einstein's prediction that energy and matter are equivalent, is the principle on which the ORELA positron source facility operates.

The positron source in ORELA consists of thin tungsten plates mounted in an evacuated housing behind the primary tantalum target for producing neutron beams. A 150-MV electron beam strikes the tantalum, generating intense pulses of gamma rays that photoeject neutrons. The neutrons are channeled into flight paths for neutron physics



T. A. Lewis (left), Dave Donohue, and Les Hulett discuss data acquired from an experiment using ORNL's new positron source at the Oak Ridge Electron Linear Accelerator. A beam line for the slow positrons is in the upper left corner.

research. About 15% of the gamma energy produced in the tantalum bombardment escapes unused, however, as forward-scatter. This formerly wasted radiation is now intercepted by the tungsten plates of the positron source facility and converted to matter in the form of positron-electron pairs. Great care was taken in the design of the facility to ensure that the positron apparatus is clear of all the neutron flight paths.

Initially, the positrons are very energetic, but within about a picosecond, a large portion of them are thermalized (cooled to a low energy level). The positrons that are thermalized near the surface of the tungsten moderators are ejected at a uniform energy level of about 2.7 eV. A negatively charged extraction tube in front of the moderator receives the slow positrons as they emerge, focusing and accelerating them down the tube axis through the magnetic field of a coaxially wound solenoid. The magnetic field maintains the positrons in spiral trajectories and prevents their collision with the tube walls while they travel to a shielded experiment room about 10 m from the ORELA target.

In the planning stages, there was great concern over possible worker exposure to scattered neutrons during delivery of the positron beams. Kirk Dickens and Larry Weston, of the Engineering Physics and Mathematics Division, supplied neutron flux data, and Ron Mledkodaj, of the Environmental and Health Protection Division, helped to devise a shielding scheme for the facility that results in a neutron dose below ordinary background levels.

"Positrons are . . . useful for probing super-conductors."

Positron-lifetime spectroscopy. Why bother experimenting with the ephemeral positrons when electrons are so much easier to produce? Positrons have exactly the same mass as electrons and an electrical charge of the same magnitude but of opposite sign. Because of their opposite charges, electrons and positrons are strongly attracted to each other. However, it is a fatal attraction, because the newly formed pairs quickly "annihilate," producing gamma rays. Hulett explains, "Positrons can act as 'tagged electrons' for many applications. When they are injected in matter, they are thermalized about as fast as electrons. But because they are opposite in charge, they maintain their identity after thermalization, unlike electrons. Although positrons are eventually annihilated, we can determine their positions and energy environment by measuring the energy of the gamma rays emitted during the annihilation. Thus, from a spectroscopist's viewpoint, positrons 'live' longer than electrons."

"Although positrons disappear very quickly, their 'lifetime' is long on the scale of atomic and molecular processes. Our ability to detect their locations and movements make them valuable particles for probing defects in solids and for determining electronic structure," states Hulett.

Brian Annis, of the Chemistry Division, plans to use positron-lifetime spectroscopy as a probe for voids in materials and the free-volume content of polystyrene and other plastics. When positrons enter plastics, they remain in open sites a long time, because few electrons exist there. Thus, a delay in gamma-ray detection from a sample bombarded with positrons indicates the presence of voids and free-volume areas.

Positrons are also useful for probing superconductors. Positron-lifetime spectroscopy is known to be sensitive to atomic vacancies in high-temperature superconducting oxides, but probably not to the oxygen vacancies believed to induce superconductivity. Although the mechanism is not completely understood, it seems likely that the technique detects cation vacancies that occur because the materials have a poorly defined crystal structure. The types of vacancies detected are dependent on the specimen preparation. Positron spectroscopy will undoubtedly become a useful quality-control tool for the production of uniform high-temperature superconductors.

Positron-ionization mass spectroscopy. Another application for the positron source is in mass spectroscopy. Dave Donohue, Scott McLuckey, and Gary Glish, all of the Analytical Chemistry Division, plan to study large biological molecules by using positrons to produce low-energy molecular ions. Because positrons and electrons annihilate each other, a positron impinging on a molecule should remove one of the molecule's electrons, producing a positively charged ion of low energy that can be detected by mass spectroscopy. Most other methods for ionizing molecules involve bombarding them with electrons, photons, or ions, leaving them in a high-energy state; such excited molecules usually fragment in complicated patterns. The ORNL chemists hope to achieve low-energy molecular states with no fragmentation—or fragmentation along simple, predictable lines.

Positron microscopy. About five years ago, Hulett, Dale, and Pendyala published their ideas on the design, advantages, and resolution capabilities of a new type of microscopy based on the re-emission of slow positrons. Researchers at Brandeis University and the University of Michigan adopted the Oak Ridge idea and recently developed the world's first positron microscope (the Oak Ridge contribution in this area was acknowledged in an article in the November 1988 issue of *Physics Today*).

ORNL, however, has the capability of developing an even more powerful positron microscope, because the positron source facility here produces 1000 times more positrons per second than other U. S. sources. Such a microscope might be used to selectively alter DNA and obtain information about individual genes. Positron microscopy, as well as positron-lifetime spectroscopy and positron-ionization mass spectroscopy, are likely to be important applications of ORNL's new positron source. ornl

RE: Technology Transfer

Triple-Effect Chiller Licensed to Trane

Bob DeVault shows a computer model of the triple-effect absorption chiller he invented. The gas-fired heat pump was designed for cooling large buildings.

Energy Systems has signed a licensing agreement with Trane Company giving it exclusive rights to manufacture and market a large, highly efficient, gas-fired absorption chiller for cooling large commercial buildings. Trane Company, a division of American Standard, Inc., is a leading manufacturer of heat pumps.

The cooling device, recently patented as a "triple-effect absorption chiller using two refrigeration circuits," was invented by Robert C. DeVault of ORNL's Energy Division. Its development promises to make the United States more competitive with the Japanese in marketing gas-fired air-conditioning equipment for hospitals, skyscrapers, and other large buildings.

In the 1970s, the United States dominated the absorption cooling market. However, the Japanese captured the market during the 1980s and now sell ten times as many absorption chillers as the United States. DeVault's development, funded by DOE's Building Equipment Research Division, may help turn this situation around.

"The triple-effect absorption chiller offers several advantages," says DOE program manager John Ryan. "Compared to other types of heat pumps for cooling, it uses less energy, costs less money to operate, and is potentially less expensive to manufacture."

The new ORNL gas-fired chiller has a great efficiency advantage over conventional air-conditioning equipment, such as motor-driven heat pumps, and uses 30 to 60% less primary energy than the best existing double-effect absorption chiller marketed by the Japanese.

Primary energy is the fuel energy consumed—at gas-fired and nuclear power stations, for example—to produce electricity. Because some of this energy is lost during the production and transmission of electric current, electrically operated heat pumps are less efficient users of the basic fuel energy than heat pumps run directly by natural gas.

Gas-fired chillers offer benefits to both gas and electric utilities, since the gas utilities often have excess capacity during the summer months when electric utilities have difficulties meeting the peak demands caused by air conditioning.

Another advantage of the ORNL chiller is that it does not use ozone-destroying coolants. Conventional chilling equipment generally uses chlorofluorocarbons, such as Freon, which have been shown to reduce the ozone concentration in the upper atmosphere. Lower ozone levels allow more ultraviolet light to reach the earth, increasing the number of skin cancer cases.

The gas-fired absorption heat pump differs from a conventional, motor-driven, electric heat pump in the way it recompresses the vaporized refrigerant. The refrigerant in an electric heat

"This is the first royalty-bearing license for a nuclear medicine technology developed at ORNL."

pump, which transfers heat from outside to inside for space heating or from inside to outside for air conditioning, is recompressed by a motor-driven compressor.

In an absorption heat pump, the refrigerant is recompressed chemically, as it dissolves in an absorbent fluid, and is recovered by boiling out of the absorbent at a higher pressure. Only an external heat source is needed to operate the absorption heat pump—to boil the refrigerant out of the absorbent—so it can be run on natural gas.

Using DOE funds, ORNL has contracted with a number of industrial firms to develop advanced absorption heat pumps through the Building Equipment Research Program of the Energy Division. Three advanced cycles are being developed by industrial subcontractors under the direction of DeVault, who is technical program manager for the Absorption Heat Pump Program in the Energy Division's Efficiency and Renewables Research Section. Devault's invention has, thus far, proven more efficient than any of the advanced cycles developed by the subcontractors.

Wyle Laboratories Gains License

Energy Systems has granted Wyle Laboratories of El Segundo, California, a license to market an ORNL-developed method that detects deterioration and other problems in motor-driven systems by analyzing current flow through the electric motors.

The ORNL development, the Motor Current Signature Analysis technique, is based on the discovery that current flowing through an electric motor provides useful information about the condition of the motor-driven equipment.

The load on an electric motor changes constantly, reacting to conditions within the system the motor is driving. By establishing the load "signature" of a properly functioning system, this technique can make load comparisons to determine whether similar systems are operating properly.

The technology, which includes a customized signal-conditioning device and associated analytical technique, was developed by David M. Eissenberg and Howard D. Haynes of ORNL's Engineering Technology Division. They did this work as part of the Nuclear Regulatory Commission's Nuclear Plant Aging Research Program to assess the effects of aging on motor-operated valves used in the safety systems of nuclear power plants.

Wyle Laboratories intends to manufacture and market the diagnostic technique to the commercial nuclear power industry through its offices in Huntsville, Alabama. The company will also sell and service related equipment and perform diagnostic testing of the equipment when required.

Nuclear Medicine Technology Licensed to Du Pont

Energy Systems has granted a license to E. I. du Pont de Nemours and Company for an ORNL nuclear medicine technology that may help physicians detect cancer in its early stages.

The technology involves the synthesis of a new chemical compound known as iodophenylmaleimide, which can be attached to antibodies that seek out tumors. By using specialized cameras to detect radioactive iodine in the compound, physicians can locate tumors at an early stage of development.

Studies conducted at ORNL and the University of Michigan show that the compound enables antibodies to retain radioactive iodine much longer than do existing agents, keeping it from concentrating in the thyroid gland, where it might increase a patient's risk of cancer. (For more information on this technology, see "New Radiolabel - ling Technique May Aid Early Cancer Detection," in the Number One 1988 issue of the *Review*).

"This is the first royalty-bearing license for a nuclear medicine technology developed at ORNL," said William W. Carpenter, Technology Applications vice president for Energy Systems. "The agreement enables Du Pont to supply the compound to research institutions across the country."

A group of ORNL researchers, led by Prem C. Srivastava of the Nuclear Medicine Group in the Health and Safety Research Division, designed and synthesized the compound. Du Pont will market the compound through its Medical Products Department in Boston. ornl

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NEXT ISSUE

Steve Pennycook's success in obtaining improved images of the atomic structure of high-temperature superconducting material is one of the highlights of the State of the Laboratory address.