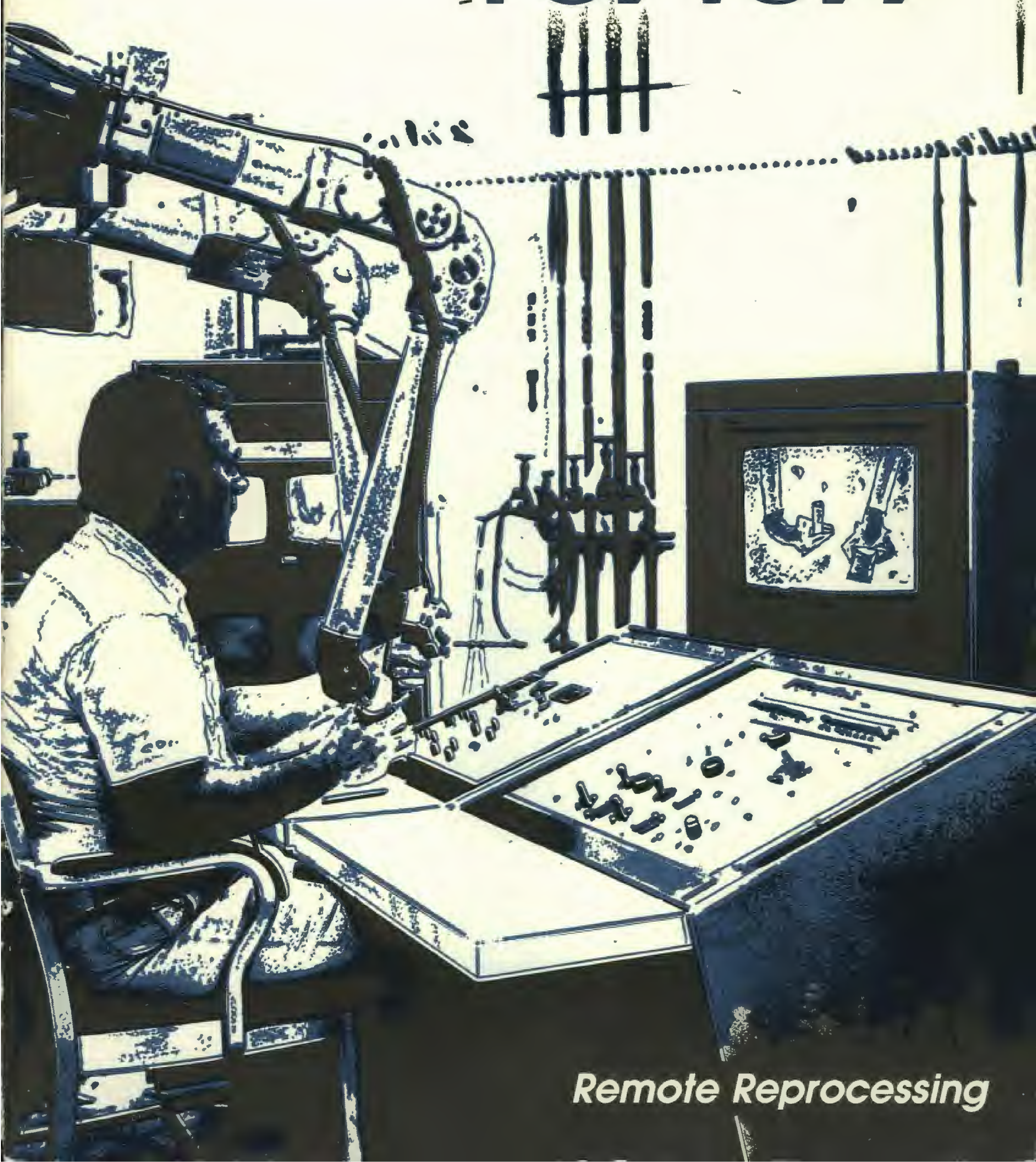
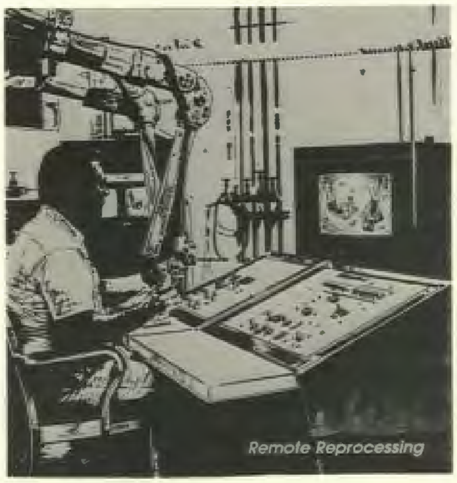
Winter 1983

Oak Ridge National Laboratory review



Remote Reprocessing



***THE COVER:** Don Spangler demonstrates the remote operation of manipulators to run or repair simulated fuel reprocessing equipment. ORNL is a world leader in the development of remote maintenance techniques.* *See the article on p. 15.*

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DEPARTMENTS

OAK RIDGE NATIONAL LABORATORY

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Howard Adler came to the Biology Division in 1956 from Cornell University, where he received his B.S., M.S., and Ph.D. degrees in microbiology. Except for a period of seven and a half years, he has devoted most of his time to research as a division staff member. From 1969 to 1975, Adler served as director of the Biology Division. He next spent a year on loan to the Institute for Energy Analysis of Oak Ridge Associated Universities, where he worked on approaches to setting radiation exposure standards. He has long been involved with the University of Tennessee. He was one of the university's Ford Foundation professors in the 1960s and is active in the Graduate School of Biomedical Sciences.

A Novel Way to Grow Anaerobic Bacteria

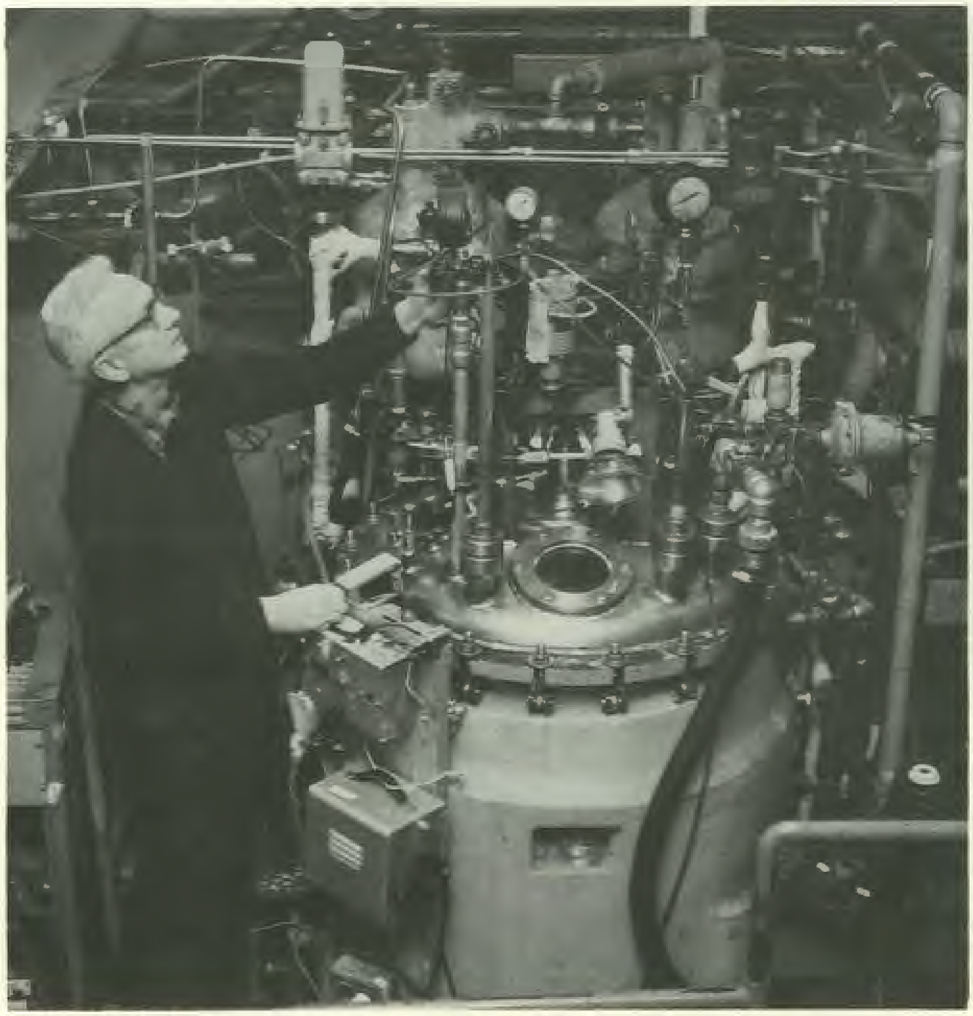
By HOWARD ADLER

Most organisms require oxygen to live. An important group of bacteria, however, cannot survive in the presence of even small amounts of molecular oxygen. Known as anaerobes, these bacteria are found in a variety of natural environments. Some of them cause infections such as gangrene and tetanus in humans and animals. Others produce useful fuels and chemicals such as hydrogen, methane, butanol, ethanol, and acetone.

Although these organisms have long been studied and used in a variety of ways, our detailed knowledge of them is limited. This limited understanding is partially because the techniques currently available for removing oxygen from the environments in which anaerobes are grown and manipulated are difficult and sometimes inefficient. Before scientists can fully appreciate the role of anaerobes in the natural environment and can hope to apply sophisticated techniques such as gene splicing and other genetic manipulations to them, it must be possible to grow them conveniently and readily in the laboratory.

We in ORNL's Biology Division have recently taken an unusual approach to solving this problem. Our results to date are exciting and hold promise for our understanding the basic biology of anaerobes, for early detection of some human diseases, and for more efficient production of some fuels and other chemicals.

Our current work on the growth of anaerobes has its roots in some basic radiation microbiology studies



The bacterium Escherichia coli *is shown at a magnification of 10,000x in this scanning electron micrograph (courtesy of Jim Dumont, ORNL Biology Division).* E. coli *bacteria are commonly found in human intestines.*

Ed Phares makes adjustments in the large fermenter used to grow bacteria, such as E. coli, *for oxygen-removal experiments that hasten the growth of anaerobic bacteria.*

initiated in the Biology Division in the early 1960s. At that time, we were studying the effects of ionizing radiation on the bacterium *Escherichia coli*. This organism, which is not an anaerobe, grows well in the presence or absence of oxygen. We were working with mutant strains that, after exposure to radiation, retained the ability to grow but could no longer divide. We were trying to explain the curious observation that such cells recovered the ability to divide if they were incubated in the presence of certain other bacteria.

The phenomenon did not seem to require direct contact between the irradiated cells and the "neighbor" cells. For a long time, we thought that some low-molecular-weight material must be leaking from the neighbor cells and stimulating the division process in the irradiated cells, but we could never produce solid evidence for this postulated material.

The problem became even more difficult when, in the early 1970s, we found that a particulate fraction derived from the neighbor cells was responsible for stimulating division. The particulate material, while clearly too large to migrate through the solid bacteriological media in which the irradiated bacterial cells were growing, somehow induced division. This sort of "action at a distance" was so intriguing that we continued to hammer away at the phenomenon.

By the late 1970s, we had purified the active particulate fraction and determined that it was derived from the innermost membrane of the complex envelope that encloses bacterial cells. This membrane, the cytoplasmic membrane, contains several enzymes and is important in many of the biochemical transformations carried out in bacterial cells. Initially, we could not see how any of the activities known to be present in the cytoplasmic membrane could possibly account for the ability of the membrane fraction to promote cell division.

Particles Gulp Oxygen

A break came in 1979 when we observed that the amount of particulate fraction required to promote division was directly related to the amount of oxygen present in the medium in which the irradiated cells and the fraction were incubated. In other words, if we flushed most of the oxygen out

Mary Long works with apparatus associated with the fermenter pilot plant for growing bacteria.

of the system, we found that smaller amounts of particulate fraction could still do the job of promoting cell division. These observations led us to suspect that the particulate fraction was partly promoting division by removing oxygen from the growth environment. This assumption has proven to be the case and helps explain the puzzling "action at a distance." We do not yet know, however, why removing oxygen promotes cell division; consequently, we are continuing to work to better understand this phenomenon.

Our studies of the ability of the membrane fraction to stimulate division in irradiated cells and remove oxygen involved many quantitative determinations. We first took measurements of the rate and extent to which oxygen could be removed from both solid and liquid bacteriological media. We then determined that our oxygen-consuming system compared favorably to the best chemical or physical methods available. Based on the work of other investigators, we were quite certain that the membranes removed oxygen because they contained a system of enzymes (the cytochrome system) which transferred hydrogen atoms from various medium components to oxygen, thereby producing water. Our own experiments strongly supported this idea.

About this time, for reasons that are still not entirely clear to me, I began to think about the possibility that membrane fragments might be a valuable way of removing oxygen from bacteriological media designed to support the growth of anaerobes. Perhaps it was because I had become a member of ORNL's committee for planning research projects in biotechnology, a field in which anaerobic bacteria figure prominently. Whatever the reason, the use of membrane fractions to remove oxygen seemed to have several advantageous features that might make it a preferred alternative to currently available methods.

Competitive Techniques

Most current techniques employ strong nonspecific chemical reducing agents or oxygen-free gases to sweep oxygen out of bacteriological media. These techniques, which are sometimes combined, are not problem-free. Because chemical agents are often toxic, they can be added in only limited amounts. Their toxicity probably results from the tendency of these agents to react with components of the medium other than oxygen and even to penetrate the bacteria and react with important cell constituents. Treatment with oxygen-free gases also has limitations. When liquid media are sparged with such agents, foaming and evaporation can present problems. If solid media are exposed to oxygen-free gases, the diffusion of oxygen from the solid into the gas phase is usually a slow and inefficient process.

In contrast to these agents, we found that membrane fractions are nontoxic and that they remove oxygen equally well from liquid and solid media. The expectation that membrane fractions would be nontoxic was based on our observation that they specifically reduce oxygen to water in the medium and that the membrane particles are too large to penetrate the bacterial cells. Furthermore, in natural environments, anaerobes are accustomed to growing in the presence of membranes—both their own and those of surrounding cells.

Membrane fractions remove oxygen by a catalytic process; therefore, they can be used in small quantities and remain available and active if the system is repeatedly exposed to oxygen. The membrane preparations can be stored in the frozen state for many months and, after they are added to media, remain active for several days at 37°C. They can also survive short exposure to temperatures of 60°C and above. The most likely reason for this unusual stability is that the enzymes involved in the oxygen-reducing reaction are protected by enclosure in the membrane particles.

Do Membranes Work?

Do membranes really stimulate growth of anaerobic bacteria? Before we could answer this question, we had to solve one technical problem: how to sterilize the membrane fragments. The usual technique for sterilizing components of bacteriological media—exposing them to pressurized steam at 120°C—was clearly not possible in the case of the membranes. Such a treatment would undoubtedly destroy the enzymes crucial to the oxygen-reducing reaction. Fortunately, we were able to develop methods of filtering the membrane fraction to exclude any contaminating organisms. We then were in a position to see if the membranes really worked.

Over the past two years, we have used the membranes to grow 18 different species of anaerobic bacteria representing 8 different genera. We have conducted experiments in both liquid and solid media. All organisms tested have grown well in the presence of the membrane fraction; indeed, some of them have grown much better than in conventional anaerobic media.

One implication of these tests is the possibility of early and sensitive detection of certain diseases. For example, members of the genera *Bacteroides* and *Peptostreptococcus*, which are involved in infections of soft tissues in humans and animals, grow rapidly and luxuriantly in membrane-containing liquid media. As a result, their presence in a clinical specimen could be detected earlier and more reliably than by the use of currently available techniques.

Most organisms can be grown in the presence of the membrane fraction without recourse to oxygen-free containers and without the need for special precautions to exclude oxygen during media preparation. For some species, we have developed simple techniques that allow us to clone organisms from single cells in solid media without incubation in anaerobic containers. This basic experiment in microbiology is difficult to perform with anaerobes using conventional approaches.

New Directions

Where does all this lead? In many directions, we think. First, the ability to grow clinically important anaerobes conveniently and rapidly should lead to improvement in our ability to diagnose and treat certain human and animal diseases. This aspect of the work, although potentially important, is not a proper subject for our research at the Laboratory. We are attempting to pursue it as a separate venture, which may prove to be an interesting experiment in technology transfer.

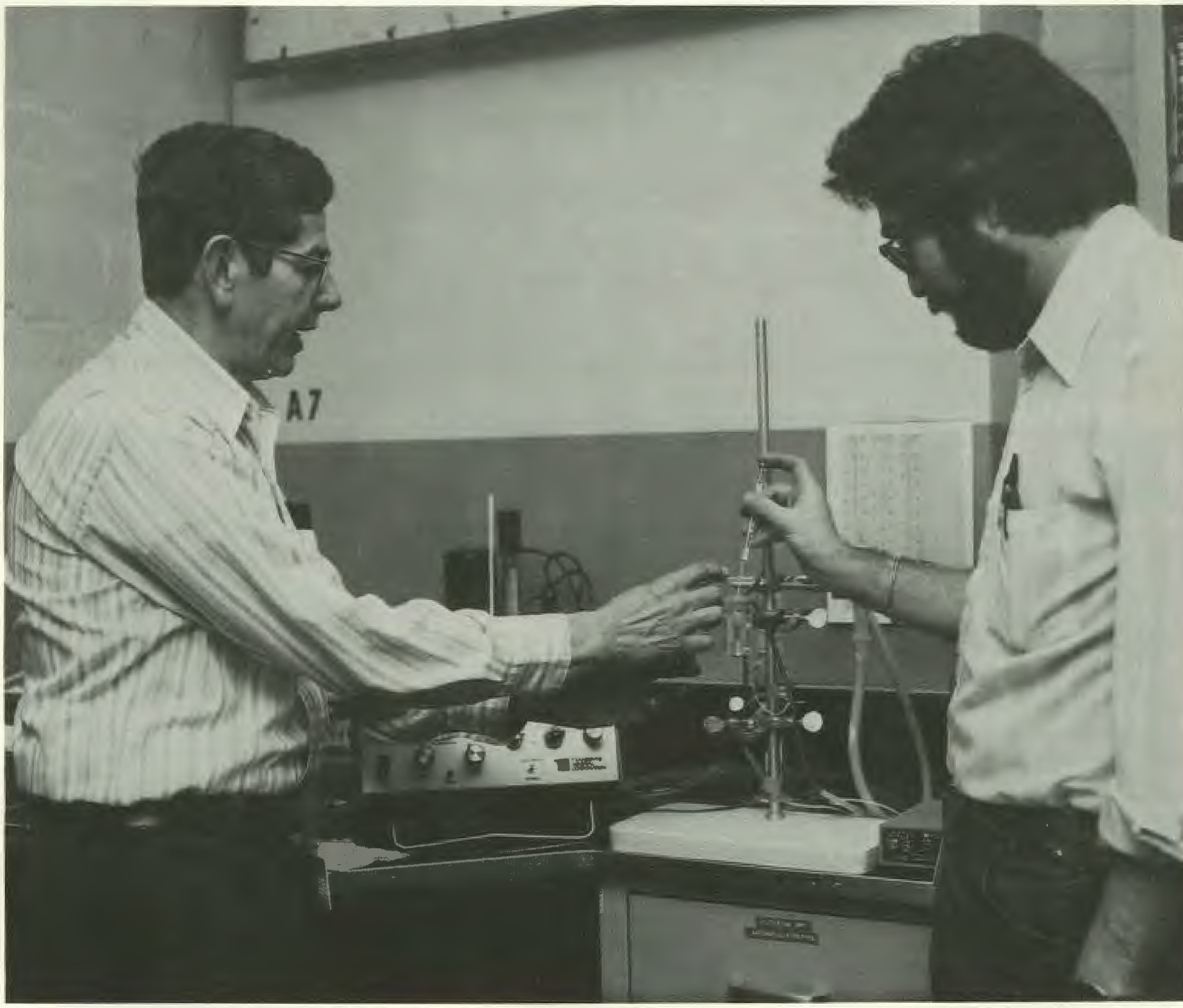
Second, we expect that our new techniques will allow us to perform more sophisticated experiments with anaerobes in fields where they are used to manufacture chemicals such as fuels, solvents, and chemical intermediates.

Many genetic manipulation techniques developed for oxygen-tolerant species may become, with some modification, applicable to anaerobic organisms in biotechnology. For example, we have just developed a technique based on the use of membrane fragments that should allow us to select, with high sensitivity, butanol-resistant mutants of the butanol-producing organism *Clostridium acetobutylicum*. It is generally believed that the growth and fermentative activity of this organism is inhibited by the butanol it produces. A butanol-resistant mutant might be able to produce higher concentrations of desirable end products such as acetone, ethanol, butanol, and hydrogen than are currently achieved.

We have also used our membrane-based techniques to perform experiments in which genetic material (DNA) has been transferred into the anaerobe *Clostridium butyricum* from the aerobic bacterium *Bacillus subtilis*. In these preliminary experiments, a gene that controls resistance to the antibiotic streptomycin was transferred and the *Clostridium butyricum* cells became resistant to the antibiotic. The transfer of genes between organisms is a powerful tool in the construction of strains with specific, desirable properties.

Finally, several unexplored applications undoubtedly exist for this oxygen-removing system. In any situation in which one wants to remove oxygen from a system that is basically aqueous, the membrane fraction may prove useful. One process that comes to mind is the purification of oxygen-sensitive components from biological sources.

Many enzymatic proteins, for example, are inactivated by contact with oxygen after they are removed from cells. For this reason, reduc-



Howard Adler and Richard Machanoff measure the dissolved oxygen concentration in bacteriological media.

ing agents are often added during the isolation and purification procedure. These agents are not always effective in removing oxygen and sometimes react with the protein being purified. Membrane fractions may prove to be more desirable for the purification of enzymatic proteins because the membrane material is particulate and, therefore, could be readily removed by high-speed centrifugation. I am optimistic that new uses for the membrane fraction will appear as we and others continue to explore the system.

As in the case with any project that spans many years, several people have made major contributions. Alicia Carrasco, a visitor from Santiago, Chile, made significant contributions during her 18 months in our laboratory. James Gill, a Ph.D. candidate in our group, worked on important aspects of the problem for his thesis. Weldon Crow, now in the Metals and Ceramics Division, also contributed heavily to the work over the past four years.

When we began our studies on the effects of radiation on cell division in bacteria 25 years ago, I never could have predicted that we would come up with a novel way of growing anaerobic bacteria. In all honesty, I could not have predicted this possibility even three years ago. Today, I still hesitate to predict the future of this work in any detail, but I am optimistic that new, unexpected uses will be found for particulate membranes. ornl

awards and appointments

Ray Wymer has been named director of the Chemical Technology Division, replacing **Don Ferguson**, who has been appointed technical advisor to Don Trauger, Associate Director for Nuclear and Engineering Technologies at ORNL.

Dennis C. Parzyck is the new director of ORNL's Industrial Safety and Applied Health Physics Division. He succeeds **John Auxier**, who has taken a position as chief of nuclear sciences at Evaluation Research Corporation in Oak Ridge.

The U.S. Department of Energy has presented four 1982 Materials Science Awards to members of ORNL's Solid State Division and Metals and Ceramics Division. **Ralph Coltman** and **Charles Klabunde** received an award for "significant implication for energy technology" for their work on the effect of neutron irradiation on the magnetoresistivity of copper for fusion reactor magnets. **Herbert Mook** and three researchers from Argonne National Laboratory received an award for "outstanding scientific accomplishment" for their work on the coexistence of superconductivity and magnetism in a single crystal of erbium rhodium boride. **Cabel B. Finch**, **Charles S. Yust**, **G. Wayne Clark**, **Carl J. McHargue**, and **Victor J. Tennery** received an award for "significant implication for energy technology" for their research on processing and properties of dense, fine-grained titanium diboride ceramics. And **Sam Faulkner**, **Malcolm Stocks**, and **William H. Butler** received an award for "outstanding sustained research" for their development of the modern theory of metallic alloys.

C. M. Haaland is an advisor to Scientific Committee 63 of the National Council on Radiation Protection and Measurements.

Wes Robinson, recently appointed head of the Publications and Visual Arts Section of ORNL's Information Division, was elected president of the East Tennessee Chapter of the Society for Technical Communication. Other ORNL officers are **Ralph Sharpe**, first vice-president, and **Carolyn Krause**, secretary.

R. B. Braid is chairman of the Publications Committee of the International Association for Impact Assessment.

Elizabeth S. Von Halle has been elected to a three-year term on the Council of the Environmental Mutagen Society.

Wilson Pitt is now program manager for ORNL's Radioactive Waste Process Development Program.

C. W. White was elected vice-president of the Materials Research Society for 1983. During the society's 1982 annual meeting, **Lynn Boatner** and **Bill Appleton** were elected to the Program Committee, and Boatner was elected chairman of Corporate Affiliate Committee.

The American Nuclear Society has presented a Certificate of Appreciation to **Philip T. Perdue** for outstanding service in connection with the ANS exhibit, "Our Radioactive World," at the 1982 World's Fair.

Gene Goodwin has been elected a Fellow of the American Society for Metals.

Jagdish Narayan and **G. Malcolm Stocks** have been elected Fellows of the American Physical Society.

Dave Reichle is now a member of the Board of Directors of the Nature Conservancy.

Allen Solomon has been appointed to the Governing Council of the American Quaternary Association.

Phil Sklad has been appointed to the Education Committee of the Electron Microscopy Society.

K. L. Daniels, M. P. Farrell, J. C. Goyert, and **R. H. Strand** received the Best Paper Award from the Biometrics/ Applied Statistics Section at the recent Sixth SAS Users Group international meeting in San Francisco.

In the Engineering Technology Division, three new section heads have been named: **Jim Corum**, Structural Mechanics Section; **Grady Whitman**, Pressure Vessel Technology Section; and **John E. Jones, Jr.**, Engineering Analysis Section, replacing Irv Spiewak, who has retired.

At the 1982 International Metallographic Exhibit, sponsored by the International Metallographic Society and the American Society for Metals, **Vivian Baylor**, **C. W. Houck**, and **Kaye Russell** placed second in the Optical Microscopy Class, and **Calvin White** and **Ray Padgett** placed first in the Unique and Unusual Techniques Class.

Conrad Chester is an associate member of the Advisory Board of the Federal Emergency Management Agency. He is also a member of the Technical Advisory Committee of the Science and Education Research Grants Program of the U.S. Department of Agriculture.

Hank Shugart is a member of the Board of Editors of the Ecological Society of America.

Don Jared has been named Southeast regional coordinator of the Federal Laboratory Consortium.

J.W. Roddy has been named technical assistant to Donald B. Trauger, Associate Director for Nuclear and Engineering Technologies.

Marshall Adams and **Webb Van Winkle** have been named associate editors for *Transactions of the American Fisheries Society.*

Stan Auerbach has been appointed a member of the Commission on Physical Sciences, Mathematics, and Resources of the National Research Council.

Robert W. McClung has been appointed to serve on the Honor Lecturer Subcommittee of the Board of Directors of the American Society for Nondestructive Testing.

William Corwin was elected secretary of the Task Group on Nonstandard Subsized Specimens for Irradiated Testing of the American Society for Testing and Materials.

James H. Smith has been elected to the Board of Directors of the American Society for Nondestructive Testing.

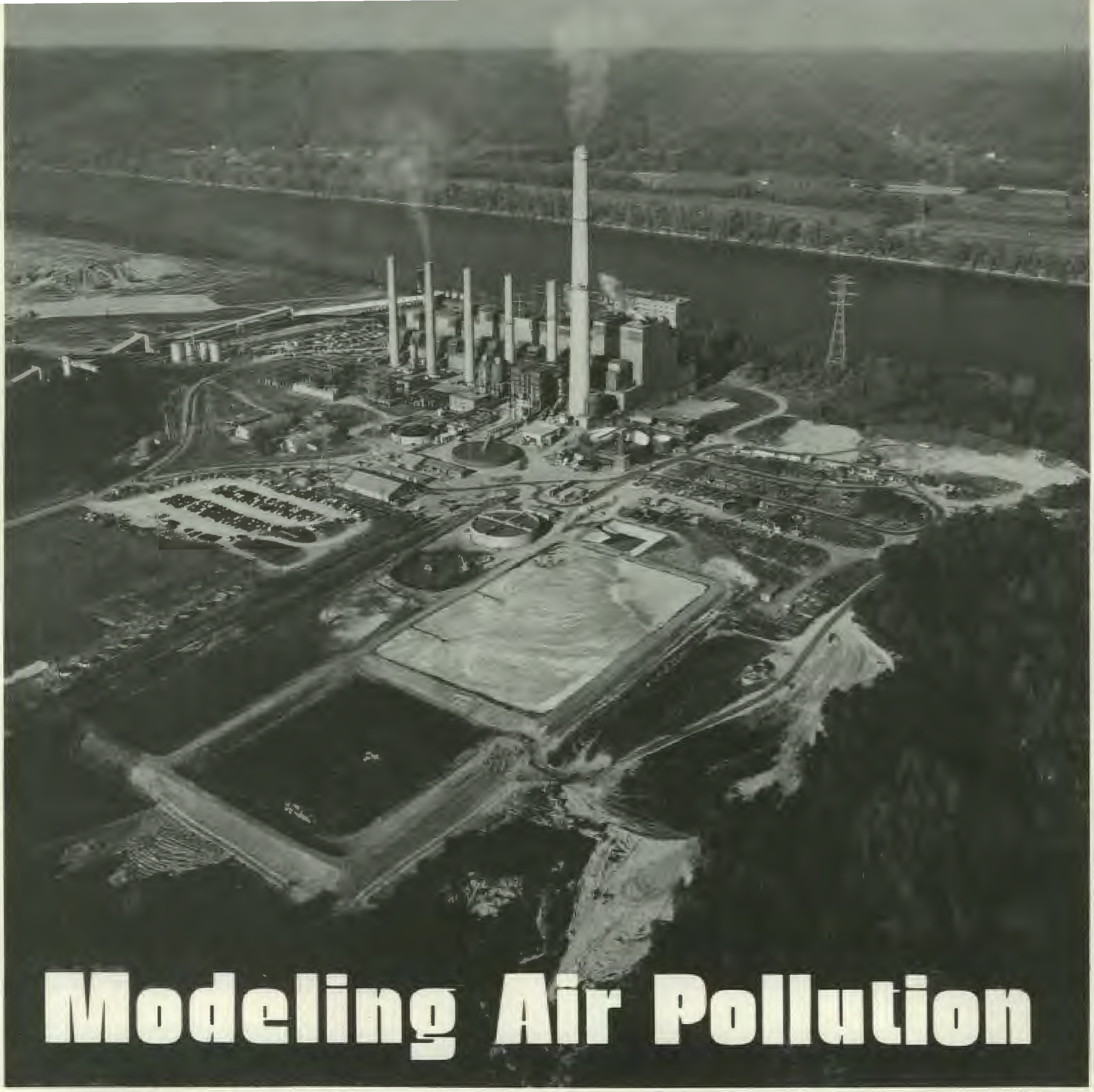
Robert J. Gray received the Outstanding Speaker Award for 1982 from the York, Pennsylvania, chapter of the American Society for Metals.

Jim Mason has been appointed secretary of the American National Standards Institute's Office Systems Committee and has been asked to participate in the work of ANSI's Committee on Computer Languages for Processing Text and the Graphic Communication Association's Committee on Generic Coding of Text.

National Laboratories and the Energy Sciences

Excerpts from Alex Zucker's responses in April 1982 to questions from members of the Subcommittee on Energy Development and Applications, Committee on Science and Technology of the U.S. House of Representatives, are presented below. The ORNL Associate Director for the Physical Sciences, who had testified at a subcommittee hearing on March 25, 1982, responded this way to a question on the role of the national laboratories in DOE's basic energy sciences (BES) program.

"One role of BES programs in the national laboratories is to provide a synergism between science and technology which advances the science, identifies areas for scientific inquiry, and provides insights and data for the solution of technical problems. The establishment and operation of large, user-oriented facilities available to university and industrial communities in the United States is a second role. . . . In many areas of science, large facilities are becoming increasingly essential to advance a discipline. . . . A third role of the Laboratories has to do with. . .[the fact that the] Department of Energy must maintain large-scale or long-term continuing research and create an institution which will have both a corporate memory and clear sense of purpose for this research. . . . National laboratories are able to carry out long-term basic research investigations without loss of quality and vitality. A fourth important characteristic of the multipurpose laboratories is the ability of the Department of Energy to access this community and, in times of crisis, call on it to provide information rapidly or solve problems that appear crucial and that require a significant effort in one or more scientific disciplines."



Modeling Air Pollution

by ALAN WITTEN

Coal-burning industries and utilities face a dilemma. To comply with the dictates of the president and Congress in the late 1970s, industries and utilities switched from burning imported oil and scarce supplies of natural gas to using more abundant coal as a fuel. By converting to coal, however, they often have contributed to region-wide violations of federal and state environmental laws that govern air quality and restrict emissions from industrial sources. Thus, in order to comply with national environmental as well as energy policies, they have to face the possibility of investing in expensive pollution control equipment.

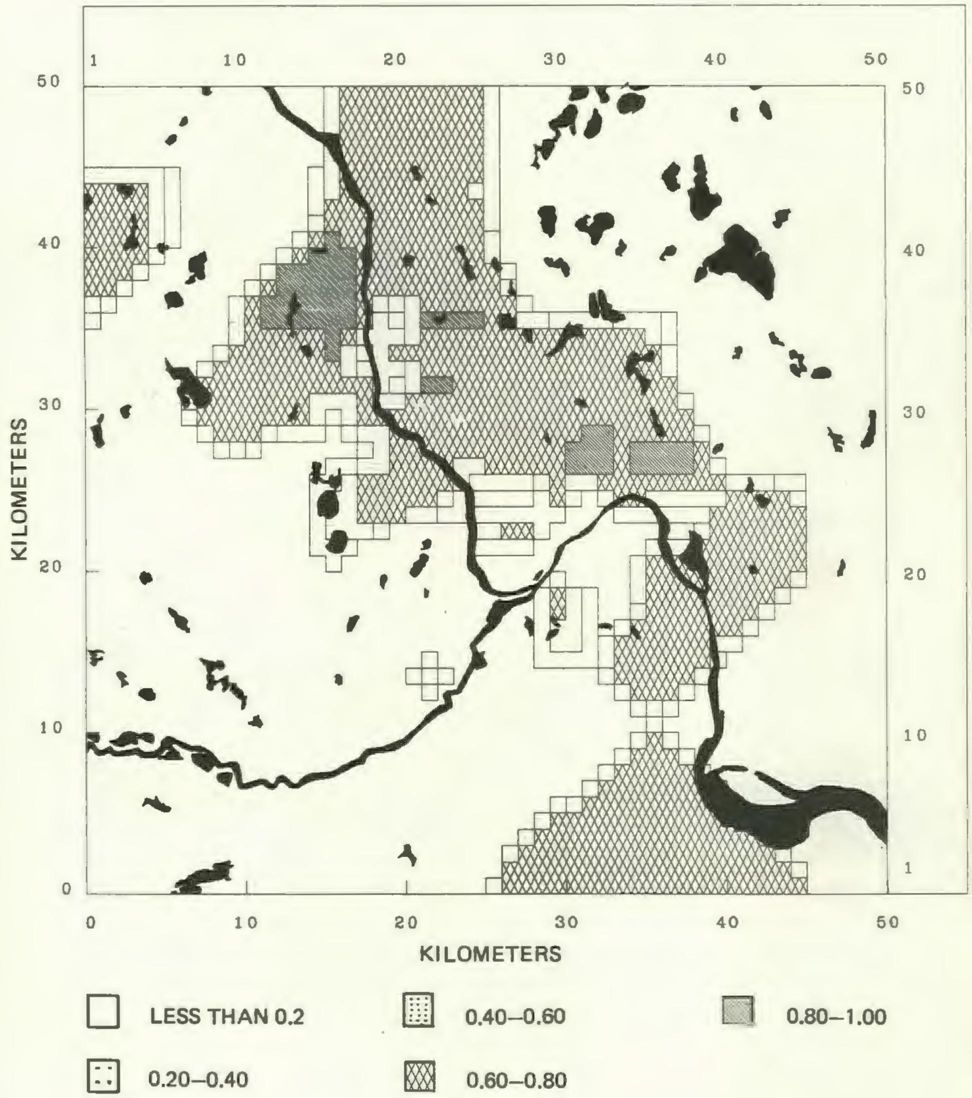
It may not be necessary, however, for all new coal-burning power plants in a given region to install pollution controls, because controls on only a few plants might keep a region in compliance with environmental limits. But a predictive tool is needed to determine how much more air pollution is likely to result as new power plants go into operation. Such a tool should also indicate how many of the new plants need pollution controls.

Aerial view of Louisville Gas and Electric Company's Cane Run Station, a coal-fired power plant. (Photo courtesy of Louisville Gas and Electric Company).

Alan Witten (second from right) joined the ORNL staff in 1975 as a member of the Engineering Technology Division. A year later, he transferred to the Energy Division, where he now leads the Applied Physical Sciences Group. A native of Massachusetts, he holds a Ph.D. degree in mechanical engineering from the University of Rochester in New York. His research interests include environmental fluid dynamics, and he writes here of the stochastic air pollution models that were developed under his leadership. These mathematical models have been used by ORNL scientists in three divisions and by the Tennessee Valley Authority. Here, Witten discusses air pollution modeling with his colleagues, from left, Don Hunsaker, Frank Kornegay, and Ed Long. In the background is the Bull Run Steam Plant.

At ORNL, we have developed mathematical models that could help utilities and the nine regional offices of the U.S. Environmental Protection Agency (EPA) to determine the probability that total emissions from existing and proposed coal-fired plants in a given region would violate EPA air quality standards. This information can provide guidance in deciding how many new coal-fired power plants should add equipment to reduce emissions to keep the region in compliance.

One EPA standard of particular interest is the limit on emissions of sulfur oxides, including sulfur dioxide (SO_2), a well-known environmental and health hazard. Our model can aid in predicting the probability that SO_2 emissions in a given region will violate environmental limits one or more times during the year. By extension, information provided by the model can be used to assess the health risks from long-term industrial emissions. John Krummel of the Environmental Sciences Division and Charles Gilmore of the Energy Division have used the model to estimate levels of sulfur dioxide on



This map shows the spatial distribution of probability (in %) of violating air quality standards in the Minneapolis–St. Paul area. Grid cells are 1 km square.

landscapes from emissions from proposed synthetic fuels and coal-fired plants. From this information can be estimated damage to crops and other vegetation.

In addition, our model can evaluate the effectiveness of pollution control strategies such as flue gas desulfurization (FGD) controls which restrict emissions of sulfur oxides. And it can predict how many coal-burning facilities in a region need emission controls to ensure that an EPA region will not exceed SO_2 limits.

We have already shown that our model can be useful in providing guidance to a region in meeting air quality regulations. We recently looked at the effect of converting 30 oil-burning plants in the New York City region to coal-fired plants. We found that the probability that such a conversion would violate EPA air quality limits is 100%. We also determined that, if sulfur-removing emission controls were placed on just five of the 30 facilities, the New York City region would be brought into compliance with the EPA limit.

In a study of eastern Massachusetts, we found that imposing controls on the Salem Harbor coal-burning plant would mitigate local but not regional air quality problems. We determined that controls on the Brayton plant alone would be more useful for bringing the region in compliance.

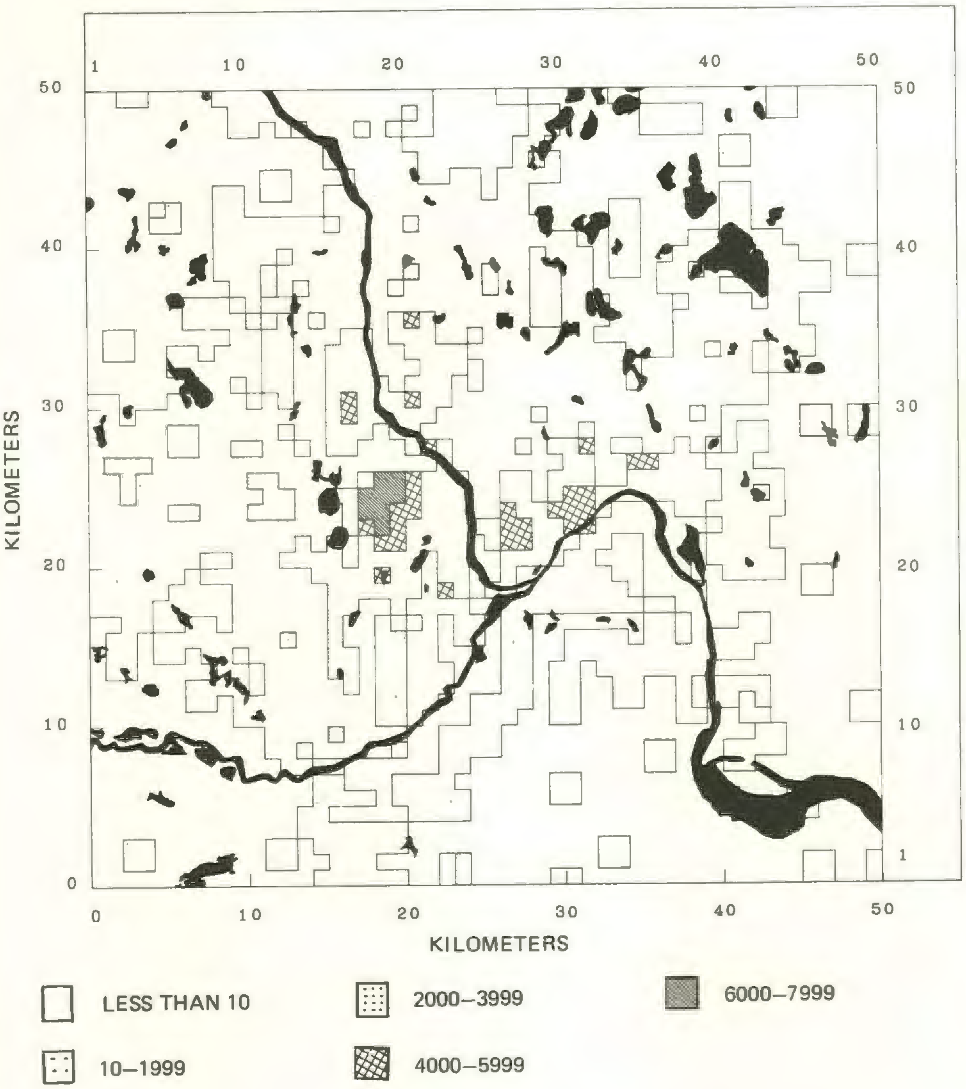
The most ambitious application of our stochastic air quality models has been a study of the implications of changing air quality regulations to explicitly account for emissions variability, as will be discussed below.

Stochastic Models

The rates at which air pollutants are emitted from coal-fired power plants may fluctuate from day to day because of the variability in the composition of the feed coal and in plant operations. One way to incorporate this variability is to treat the emission rate as a random variable (as a stochastic process). By determining the probability that a certain emission rate will occur under specific conditions, we should be able to calculate the probability that a certain ground-level concentration of a given pollutant will result.

Frank Kornegay and I, both members of ORNL's Energy Division, along with Ed Long of the Computer Sciences Division, have developed stochastic models which address the variability in sulfur dioxide emissions from coal-fired power plants. By treating power plant emissions as random, these models simulate the effect of emission variability on the ground-level concentrations of sulfur dioxide in the environment.

Our models will predict the probability of exceeding a specified ground-level sulfur dioxide concentration at selected points of concern once and only once, or two or more



Distribution of population in the Minneapolis-St. Paul area. By overlaying the computer-generated probability map (left) on this distribution map, one can establish level of exposure as a function of population exposed.

times during a one-year period. In addition, the models are useful in assessing acute health effects.

Stochastic air quality models require greater input information than do the more conventional deterministic models currently used for air quality assessments by EPA, utilities, and others. Deterministic models use a design emission rate, while stochastic models require a description of the range of emission rates expected to be encountered and the probability of these emission rates occurring (probability distribution). Such information is not developed as part of a power plant design and consequently poses a problem in the implementation of stochastic models for plants not yet in operation.

In order to make stochastic models more useful tools for preoperational assessment of pollutant emissions, Donald Hunsaker of the Energy Division worked with us in performing statistical analyses of SO_2 emissions from operating coal-fired power plants. He analyzed extensive data from three units of the Louisville Gas and Electric Company's Cane Run power plant in Louisville, Kentucky.

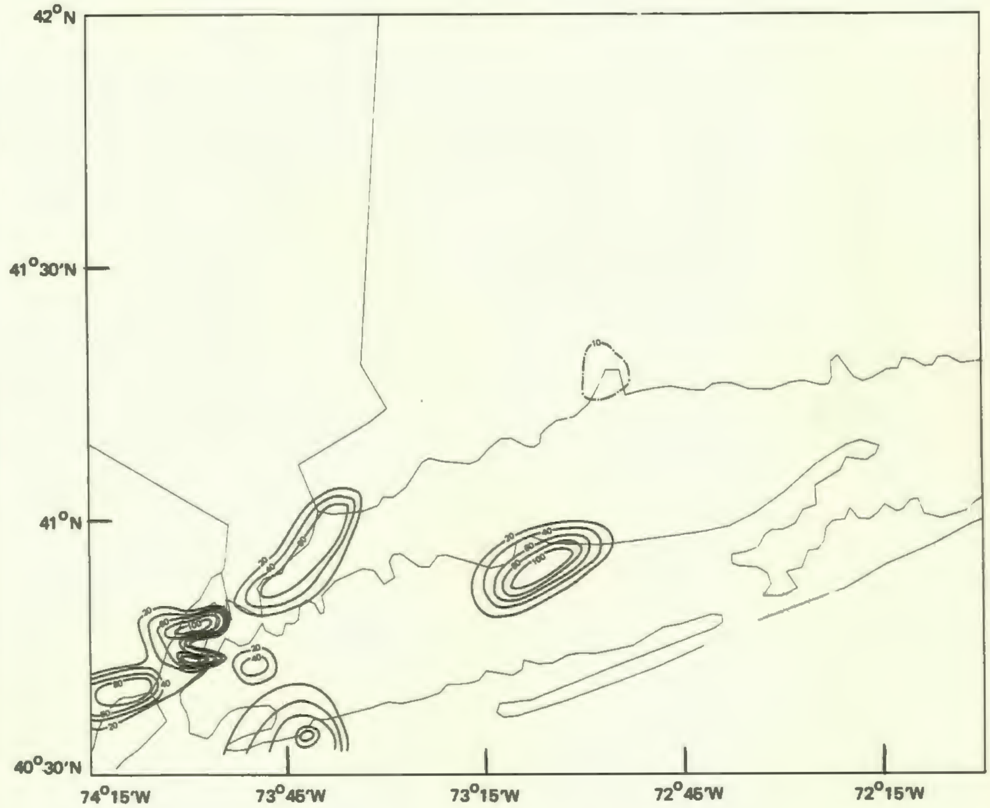
Recent analyses of data on SO_2 emissions from power plants suggest that emissions from coal-fired power plants can be represented by a bell-shaped curve using a logarithmic scale. This distribution of probability as a function of emission rate is called a log-normal probability distribution. Hunsaker's quantitative analysis of the Cane Run data supported this finding and, as a result, a log-normal distribution was adopted for the stochastic air quality models.

For such a probability distribution, emissions statistics can well be described by the mean emission rate and by some measure of the variability in emissions, such as the standard deviation. Available emissions statistics revealed that emissions from power plants not equipped with FGD systems varied much more than did those from power plants without FGD systems. (For plants operating without FGD systems, the emission rate standard deviation ranged from 7 to 10% of the mean emission rate. For power plants operating with FGD systems, the ratio of emission rate standard deviation to mean emission rate ranged from 25 to 40%.) Hunsaker and I concluded from these findings that FGD systems tend to exaggerate the variations in sulfur dioxide concentrations leaving the boiler, thus multiplying the variations (not the SO_2 emissions) by a factor of three. Therefore, plants equipped with FGD systems must be modeled differently from those without such systems.

Rule Change Implications

EPA currently uses fixed limits for air quality standards. The agency's regulations specify that all new coal-fired plants, except for

This example of a computer-generated graphic used to evaluate regional pollution control strategies shows contours of probability (%) of violating air quality standards.



those burning coal with a very low sulfur content, must reduce SO_2 emissions in some manner. The predicted ground-level concentration of SO_2 must be less than a specified value, regardless of the sulfur content of the coal being burned. These regulations require facilities to meet specified levels of emission reduction at all times; thus the utilities must have backups in their pollution reduction systems in case of system failures. This requirement increases their costs.

Regulations based on a stochastic approach, on the other hand, could be more flexible; they would take into account sulfur content of coal, boiler and pollution-control efficiencies, and other factors that determine how likely a utility is to meet air quality regulations—or to violate them.

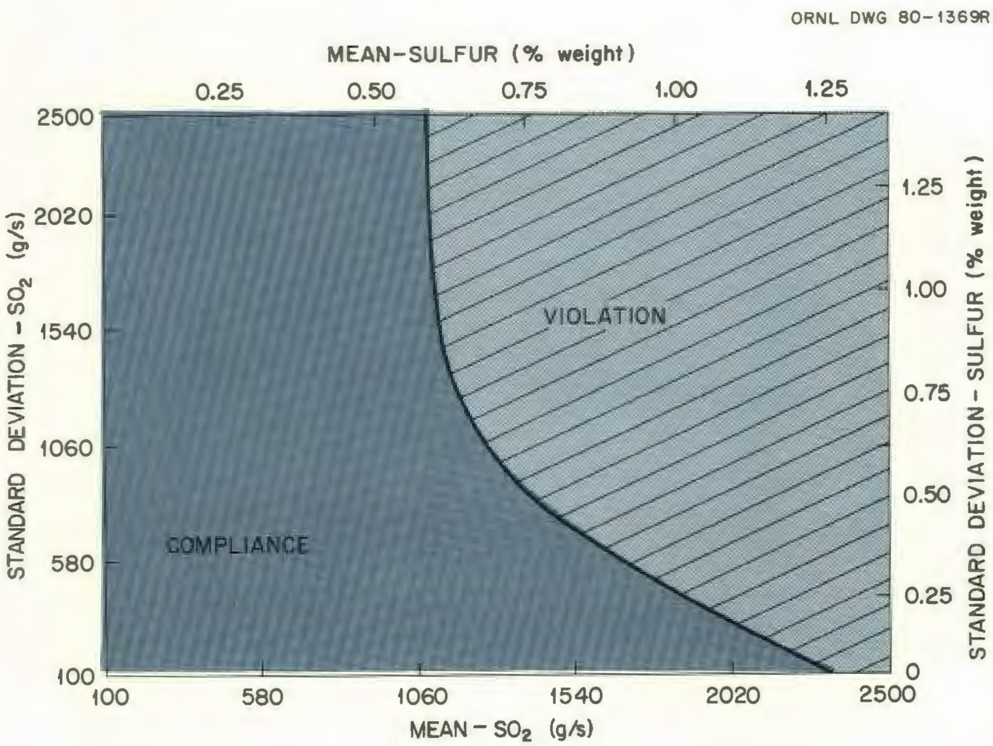
In this approach, state regulatory agencies or EPA could specify a violation probability that could not be exceeded by the utility. For example, the agency might permit a violation probability of 10% per year, meaning in theory that the utility would be allowed to violate the EPA standard only once in 10 years. The utility, in turn, could determine the best method of staying within the allowed probability.

In 1980 Frank Kornegay and I introduced the concept of a compliance map. This map defines a relationship among power plant design, plant operation, type of coal used, and an allowable range of air quality impacts. Plant design, operations, and coal type determine plant emission statistics. By applying our stochastic model, we can relate these emission statistics (mean and standard deviation) to the probability of violating an air quality standard. Any combination of emission rate mean and standard deviation which lies in the compliance region of this map will result in an allowably small probability of violating air quality standards.

In this study, we selected alternative power plant scenarios—plant designs or operating procedures prohibited by existing air quality regulations but permitted by hypothetical probabilistic regulations. One alternative plant design, for example, would incorporate more efficient pollution-control technology without backup systems.

We selected specific power plant scenarios that offer economic advantages when compared with similar power plant scenarios (base cases) which would satisfy current air quality regulations. Plant capital and operating costs were developed for the base cases and alternative scenarios, and the relative cost differences were compared to changes in health effects. These health effects analyses were performed by Phil Walsh and Elaine Zeighami of ORNL's Health and Safety Research Division. Using available health effects data, Walsh and Zeighami developed a relationship between the probability of exceeding certain ground-level SO_2 concentrations and the probability of observing increased health effects.

To further assess the implications of changing air quality regulations, we selected Minneapolis–St. Paul as a typical urban-rural area. Using actual zoning and land use patterns, we located five hypothetical power plants operating under the alternative scenarios. Using the actual population distribution and actual ambient SO_2 concentrations, we predicted air quality and health effects. These predictions were com-



Compliance map defining the range of power plant emission statistics allowed under hypothetical probabilistic air quality regulations.

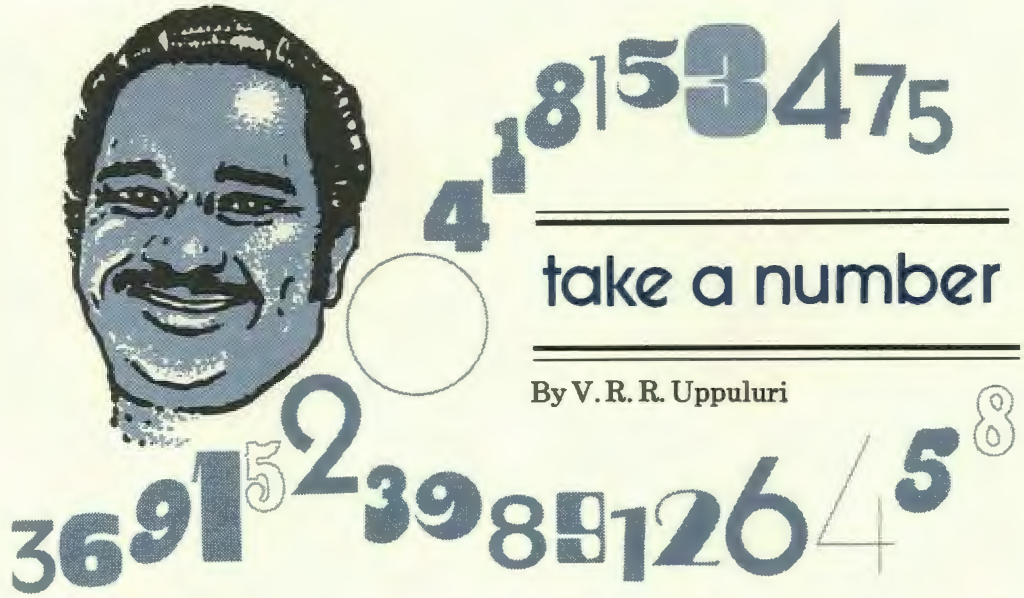
pared with similar predictions made for the five hypothetical plants designed to meet current regulations.

The results of our study suggest that probability-based air quality regulations could reduce utilities' capital and operating costs without significant changes in health effects. Utilities could install more-efficient pollution control systems without the need for backup systems. The elimination of these backup systems would reduce the utilities' costs by 2% or more. The more efficient technology, in turn, would permit utilities to purchase cheaper, more readily available coal with a higher sulfur content. This flexibility in choice of fuel could offer further savings by reducing coal transportation costs.

Besides reducing costs, the alternative scenarios considered in this study would also reduce long-term concentrations of sulfur dioxide in the atmosphere. Wide-scale switching to more efficient FGD technology could reduce long-term SO_2 emissions by 10% or more. (Persistent concentrations of SO_2 have been linked to acid rain, which is believed to damage vegetation, lake ecosystems, and building structures.) Despite the potential benefit of reducing atmospheric SO_2 concentrations without causing significant health-effects changes, this alternative method of preserving air quality is not allowed under current EPA rules.

Instead of the current fixed limits, we think that it makes more sense for EPA to use violation probabilities that account for variability in pollutant emissions. If this were the case, utilities would have significantly greater flexibility in plant design, operating procedures, and fuel selection. They would save money and would lessen their sulfur dioxide emissions.

Further study may confirm that probability-based air quality regulations such as those we favor would offer utilities and industries economic incentives to reduce air pollution.



take a number

By V. R. R. Uppuluri

Different Expectations

In the context of probability theory, the notion of "expectation" is a difficult concept. Historically, French gamblers seem to have used expectations heavily in games of chance. Rather than relying on simple probabilities, the gamblers continually evaluated their prospects and strategies in light of each new win or loss. Expectation is a matter of perception or perspective; however, individual expectations may be different even in the same problem, as shown in the following illustration discussed by David Hemenway in the May 1982 issue of *Mathematics Magazine*.

Most colleges and universities advertise their "average class size," yet most students find themselves in larger classes most of the time. For instance, if there are 100 students to be divided into four classes, administrators assume that the average class size is 25; this average is based on the assumption that the probability that a student will be in any class is 1/4. In practice, however, this assumption does not hold true. The class sizes often are far from equal; when the class sizes are unequal, the "average class size"—the size most students usually find themselves in—is always larger than 25.

More specifically, if the class sizes turn out to be A, B, C, and D, the expected class size is given by $(A^2 + B^2 + C^2 + D^2)/(A + B + C + D)$. For example, if the class sizes are 10, 20, 30, and 40, the expected class size is 30, not 25. And of the 100 students, 70 are in a class of 30 or more. That is the reason most students find themselves in larger classes most of the time.

Unusual Numbers

The number 81 is the square of the sum of its digits:

$$81 = (8+1)^2 . \qquad (1)$$

No other two-digit number has this property.

The four-digit number 2025 has a similar property:

$$2025 = (20+25)^2 . \qquad (2)$$

Only two other four-digit numbers, namely 3025 and 9801, respectively, exhibit this property:

$$3025 = (30+25)^2 . \qquad (3)$$

$$9801 = (98+1)^2 . \qquad (4)$$

Fuel Reprocessing: A Futuristic Look

Sparks fly as laser beams slice away at simulated fuel elements in a test of the new laser disassembly system in the Fuel Recycle Division.

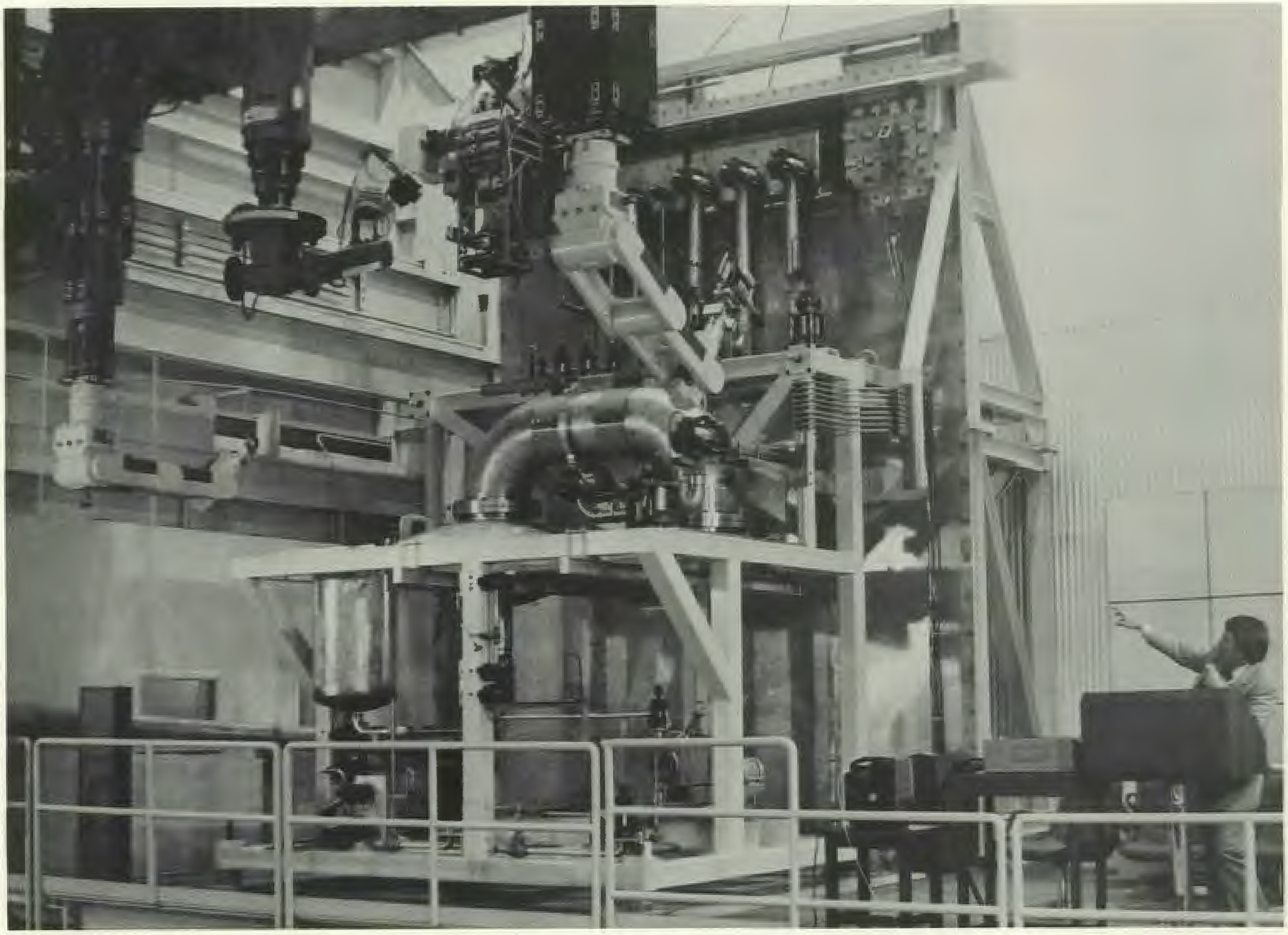
When the Integrated Equipment Test facility was dedicated at ORNL on June 22, 1982, those present were offered a glimpse of a technology which will be used in the next generation of commercial nuclear fuel reprocessing plants. Tomorrow's commercial technology will incorporate many advances beyond those developed in the 1950s and 1960s. Reprocessing plants will have lasers, computers, television cameras and monitors, remotely controlled mechanical arms and robotlike manipulators, and a battery-driven vehicle that moves from station to station to sample process liquids containing uranium and plutonium.

In fuel reprocessing plants envisioned for the future, uranium and plutonium are extracted from the spent fuel of breeder and light-water reactors for reuse in nuclear power plants. Lasers are used to remove the extra hardware on breeder fuel-rod bundles, mainly hexagonal ducts and inlet nozzles. Then the bundles of 3.7-m (12-ft) metal rods are sent to the mechanical shear to be sliced into pins the size of cigarette butts. The pins then go to the continuous rotary dissolver, where the uranium and plutonium are dissolved out of the metal cladding by hot nitric acid.

An immiscible organic solvent (tributyl phosphate in the Purex process developed years ago at ORNL) is contacted with the dissolved fuel solution to extract the unused uranium and plutonium from the solution. Over 99% of the radioactive fission products are left behind as waste in the nitric acid solution. The organic solvent is then treated to remove the uranium and plutonium and to separate them from each other. In the case of breeder fuel, the solution can be converted chemically to mixed oxide fuels containing 25% plutonium and 75% uranium. This material is fabricated into pellets, the final product that can fuel breeder reactors. When fuel from light water reactors is reprocessed, the uranium-235 that is separated out can also be sent to gaseous diffusion facilities for further enrichment and preparation as new reactor fuel.

The solvent extraction facility of the future will, as now, be operated remotely to avoid exposing workers to the high levels of radiation typical of reprocessing work. The facility of the future, however, will be computer controlled to minimize operator time and error. By viewing closed-circuit TV monitors and handling master-slave manipulators and other remote maintenance tools, technicians will be able to remotely operate or repair reprocessing equipment such as motors, pumps, tanks, rotary dissolvers, shears, or laser disassembly systems.

This is the first in a series of two articles on nuclear fuel reprocessing. The second article, to appear in the Spring 1983 issue, will deal with safeguarding of reprocessing plants.



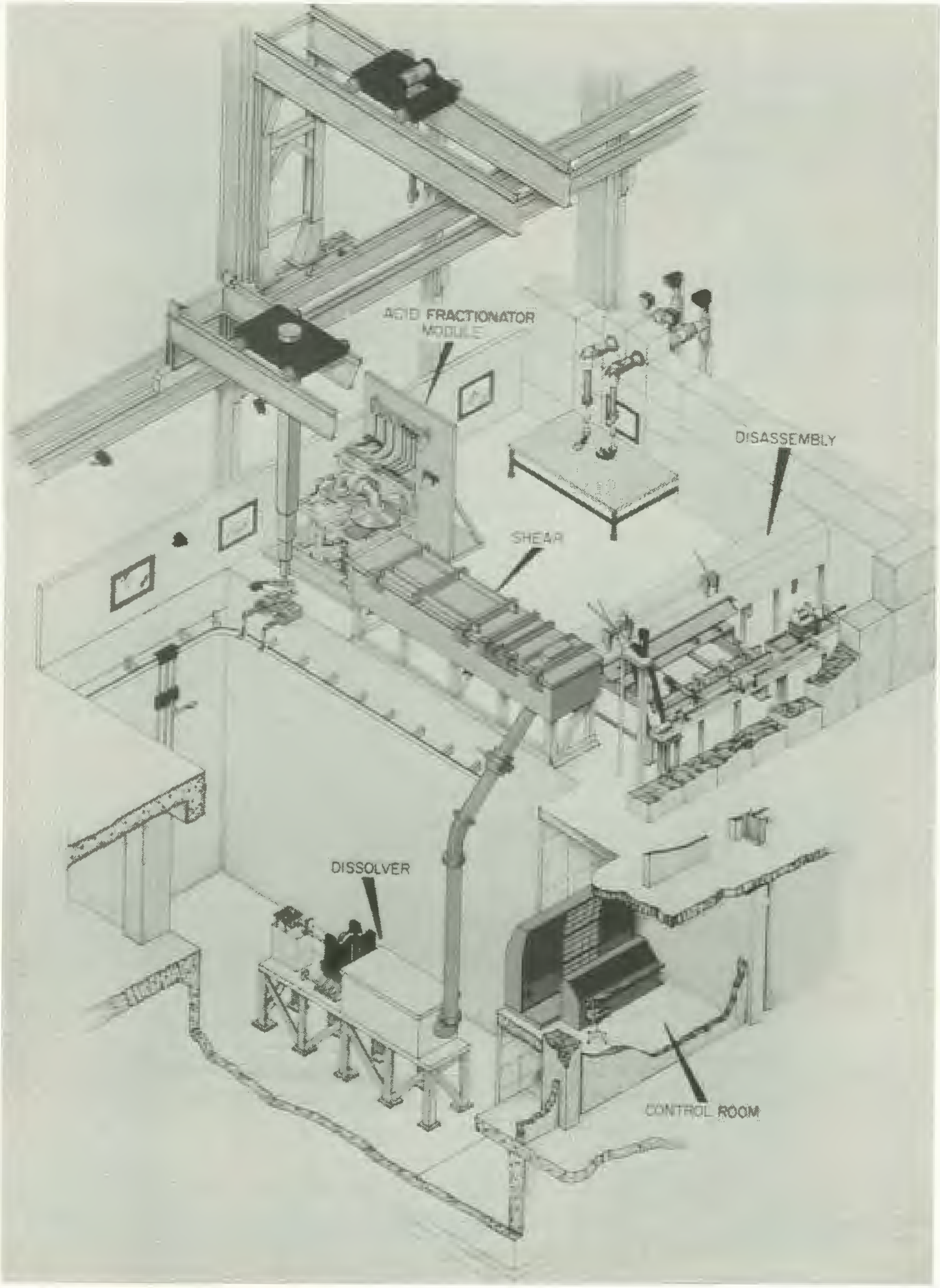
Jim McNair of General Atomic Company points out a feature of the automated liquid sampler during the June 22, 1982, dedication of the Integrated Equipment Test Facility. The computer-controlled sampler moves along a track and removes samples at specific points for delivery to a central analytical laboratory. The sampler protects employees from needless exposure to radioactive materials.

This technology being developed and tested at ORNL's Fuel Recycle Division (with support from the Chemical Technology, Analytical Chemistry, Instrumentation and Controls, and Engineering Technology divisions) is expected to be safer, more efficient, and more reliable than the conventional technology developed in the 1960s. Similar technology is already being used at the Department of Energy's Savannah River Plant for plutonium production, although without the added complexity of shearing and dissolving power reactor fuel. The technology will be applied to spent fuel from nuclear power plants when the go-ahead is given for commercial reprocessing at facilities in Barnwell, South Carolina. Says William Burch, director of the Fuel Recycle Division, "The reprocessing technology of the 1980s being developed at ORNL and elsewhere promises even greater plant reliability, operator safety, environmental protection, and safeguards against the intentional diversion of nuclear fuel for bomb-making by terrorists or outlaw nations."

The IET Facility

A stepping-stone in the path to an advanced reprocessing technology for all nuclear fuels is ORNL's test facility to demonstrate advanced remote operation and maintenance technology for future fuel reprocessing plants. The $16-million Integrated Equipment Test (IET) facility, a simulated reprocessing plant, will be fully operational in 1985. "The IET bridges the gap between individual components and the design and operation of a demonstration plant for reprocessing breeder fuel by the mid-1990s," says Orlan Yarbro of the Fuel Recycle Division.

Engineers operating the IET project will conduct nonradioactive tests of advanced fuel reprocessing



This schematic shows the layout of equipment in the Integrated Equipment Test facility.

equipment, instrumentation, and chemical processing and maintenance techniques.

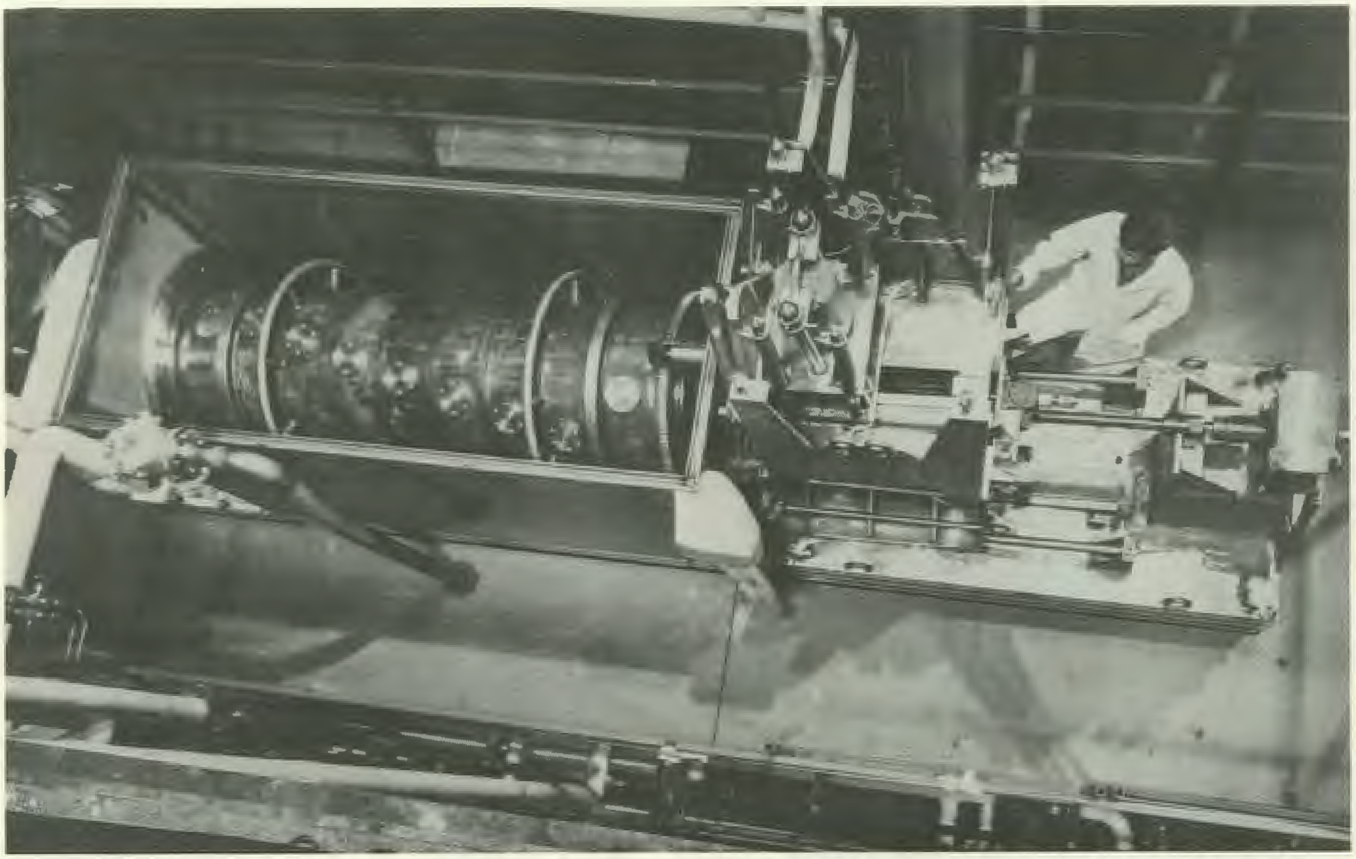
The IET will be a focal point for integrating old technologies with new ones. Old technologies include motors, pumps, valves, and tanks. New technologies include a laser disassembly system; a modular shear; a rotary dissolver; a battery-driven, computer-controlled liquid sampler; improved seals for pipe connectors to minimize leakages; and the combined use of power manipulators, cranes, television equipment, and computers for remote operation and plant maintenance.

The bright orange, yellow, and blue cranes, mechanical arms, and rotatable hook suspended from the facility's ceiling are now being used to demonstrate remote operation and maintenance in a large canyon below. The machines, monitored via television cameras, are operated by technicians in a distant control room that has TV monitors and manipulators.

This TV-based remote manipulation system is safer and has a much wider range of operation than do conventional systems, which depend on window-mounted equipment (master-slave manipulators, cranes, and wrenches). The new system will become even more advanced as ORNL researchers under the leadership of Mel Feldman and Bill Hamel develop and test advanced robotlike manipulators.

These "servomanipulators" will have "elbows down" and "wrist movements" resembling those of a person whose arms reach out to unlock and open a desktop file drawer, for example. Other improvements may permit an operator to merely touch a TV screen in various places so as to signal the remote servomanipulator to take a specified action.

Industrial psychologist Margaret Clarke of Oak Ridge Associated Universities is studying ways to improve the operator-machine interface. The goals of her study are to help operators better control the machines and to ensure that the right machines and controls are selected and properly positioned to reduce human mistakes. Says Clarke, "We have found that a black and white television, with cameras at an offset position,



The pilot-plant version of the ORNL-developed rotary dissolver is in the canyon of the Integrated Equipment Test facility where it can be remotely operated and maintained.

Fuel Recycle Research Results

The Fuel Recycle Division was created in March 1981 and held its first information meeting June 22–23, 1982. These results were reported.

- A 9-kW carbon dioxide laser has selectively cut and cropped simulated fuel bundles like those designed for breeder reactors and pressurized-water reactors.
- A continuous rotary dissolver has been developed which shows improvements over batch dissolution processes. It was reported that the rotary dissolver yields a uniform product, significantly decreases the size of the off-gas treatment system, and more effectively rinses the particulates so as to reduce losses of plutonium with the scrap.
- The possibility that fissile material in a reprocessing plant might achieve criticality (sustained chain reactions, as in a nuclear power plant) is worthy of concern. Research findings indicate that nuclear criticality can be avoided if gadolinium (a neutron absorber) is used as a soluble poison and if the mass of fissile material present in any one point is limited to 116 g.
- Several processes have been developed to remove radioactive gases from the off-gases emitted during nuclear fuel reprocessing. These include a fluorocarbon absorption process for krypton and a solid sorbent for iodine. Plans are being drawn up for an Integrated Hot Off-Gas Facility, which will demonstrate the combined technology for the collection, immobilization, and conversion to a permanent storage form of airborne radioactive components from a nuclear fuel reprocessing plant.
- A computer program called MATEX, which mathematically models the solvent extraction process, has been developed. Because running computer models is less costly than are chemical engineering experiments, MATEX promises to save money in evaluating proposed reprocessing flowsheets.

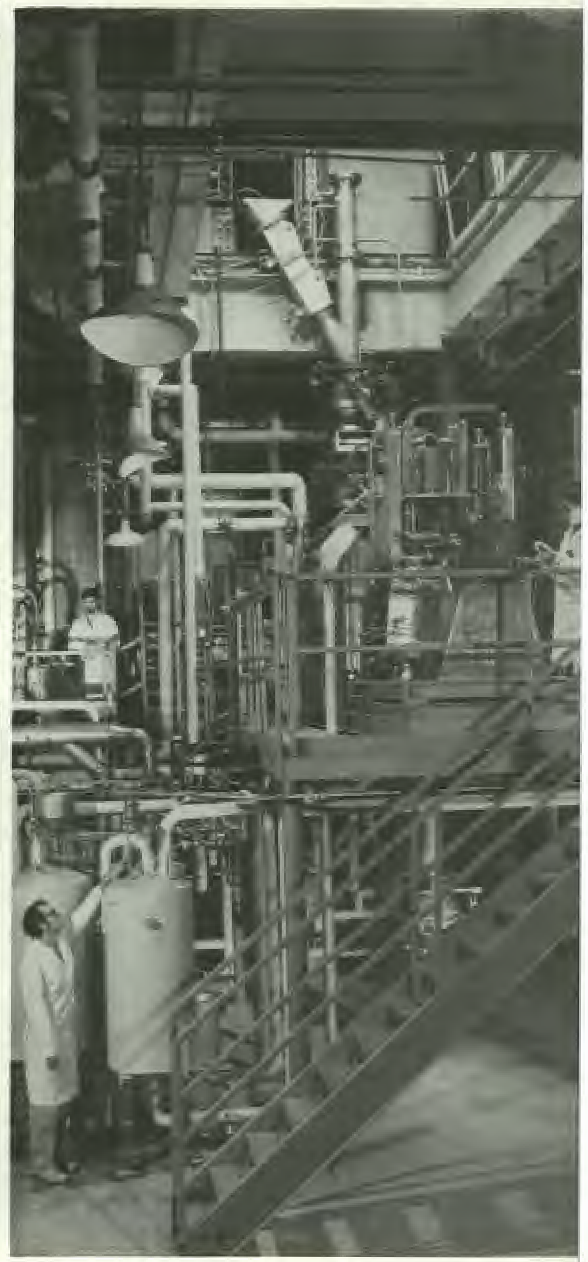
provides adequate visual information for performances of simple, small-volume tasks. We are now designing and evaluating viewing systems for more complex, large-volume tasks. We hope to develop computer-aided visual depth information to aid the operator's interpretation of the two-dimensional scene on a TV monitor."

Herman Postma, ORNL director, is especially approving of IET and the Fuel Recycle Division's activities because they are at the cutting edge of technology. "This facility is highly appropriate for a national laboratory," said Postma at IET's dedication ceremony. "It's important, large, and complex and has the latest state-of-the-art equipment."

And because of its futuristic appeal, Postma finds the facility fun. After all, he was the lucky one who maneuvered the mechanical arm that pressed the special button that activated the laser that cut the ceremonial ribbon and caused a specially placed firecracker to pop. It was a sound heard 'round the reprocessing world.

In the Integrated Equipment Test facility control room, Steve Richardson, left, and Lee Thompson remotely operate manipulators (inset) that can run or repair simulated reprocessing equipment.

Working at the rotary dissolver and associated tanks, pipes, and valves typical of a fuel reprocessing plant are Tom Morelock (bottom left), Mark Baldwin (top left), and Lee Thompson.



Rear Admiral H. G. Rickover in an official 1955 Navy photograph.

lab anecdote

Captain Rickover and Oak Ridge

By HERB POMERANCE

In January 1982, Admiral Hyman G. Rickover, father of the nuclear submarine, retired at age 82. He had spent more than 50 years in the U.S. Navy, 35 of them in the "Nuclear Navy." He was proud of the innovations he had brought about as head of the naval division of the U.S. Atomic Energy Commission (AEC) and later the Department of Energy.

Throughout his career, Rickover was a colorful and controversial figure. People who worked with him years ago still swap "Rickover stories," anecdotes in which the line between fact and legend is often blurred or even erased entirely.

Rickover began his nuclear career in Oak Ridge in June 1946; his mission was to design and construct an advanced submarine engine. A captain at that time, he worked with the Power Pile Division of Clinton Laboratories (now Oak Ridge National Laboratory), which was operated by the Monsanto Chemical Company. This division was occupied with the pebble-pile nuclear reactor, which was proposed by Farrington Daniels for the generation of electrical power. Rickover also spent a third of his time learning radiochemical analysis in the laboratory of Larry Corbin, now retired from ORNL's Analytical Chemistry Division.

The captain is remembered for his performance in the classroom as well as in the labs of Oak Ridge. In the fall of 1946, Clinton Laboratories Training School, humorously dubbed the "Klinch Kollege of Knuclear Knowledge," began its only year of lecture courses. Among its student body of 50 industrial and government engineers were Captain Rickover, three other Navy officers, and three civilian naval scientists. The naval officers had been assured that they were being sent to Oak Ridge without a leader; however, Rickover went to the head of the Army's Manhattan Engineer District (which ruled Oak Ridge) and asked to be assigned the task of making out their fitness reports, which are like performance appraisals. Armed with that power, he then assigned the officers to take notes in the courses and participate in various projects.

How was the captain as a student? Jack Cunningham of ORNL's Metals and Ceramics Division remembers Rickover as an avid learner, "a real sponge" at the lectures. Don Ferguson, long-time director of ORNL's Chemical Technology Division, recalls that the questions asked by the captain were always pertinent. And it was well known that Rickover demanded exactitude; once, when Harry Soodak made a mistake in a mathematical derivation on the blackboard, the captain was quick to take him to task, whereupon Harry honored the correction by saying he would eat crow for lunch.

Outside the classroom and labs, the captain made a different kind of impression. Some Oak Ridgers were struck by his frugality. He did not own a car, but he got around, thanks to the public bus system then in Oak Ridge. During his stint in Oak Ridge, his wife and son remained in Washington, D.C.; he lived in a dormitory room in Cambridge Hall, part of which still stands on Tyrone Road.

At social gatherings, Captain Rickover was a skilled, though frustrating, conversationalist. He would often start and vehemently dominate a discussion and then suddenly say, "We can still be friends," even as he turned to talk to someone else, leaving the first fellow choking on unsaid replies.

Nuclear Submarines

It is fair to say that Rickover and Oak Ridge owe much to each other. Rickover appreciated and built upon the technical achievements in Oak Ridge. Thus, Oak Ridge's contribution to the Nuclear Navy went far beyond the training of Navy officers and civilian scientists at the reactor school.

The pressurized water reactor that Rickover favored for powering Navy submarines is an outgrowth of the unpressurized Materials Test Reactor (MTR), which was designed in Oak Ridge and built in Arco, Idaho. This type of reactor helped Rickover solve the difficult problem of producing enough mechanical power by fission within the size and weight limitations of the submarine.

The MTR, which turned out to be more workable than Daniels's pebble-pile reactor, consisted of a parallel arrangement of fuel element plates. Each plate was made of enriched uranium sandwiched in aluminum cladding; between the plates, water would flow and carry away the heat. The problem with this design was that aluminum, while a satisfactory structural material for a low-temperature experimental reactor, was not suitable at high temperatures.

A. R. Kaufman, a professor of metallurgy at Massachusetts Institute of Technology, suggested that zirconium can withstand high temperatures. At his instigation I discovered in 1947 that zirconium is an ideal cladding material because it absorbs few neutrons. However, the zirconium used must be pure. As extracted from the earth, zirconium usually is contaminated with hafnium, a nuclear reactor "poison" that absorbs a high number of neutrons and thus kills chain reactions.

In 1948, researchers in Oak Ridge, including Warren Grimes, Charles Barton, Glenn Clewett, and William Leaders, developed a method for separating zirconium from hafnium, thus yielding a material resistant to high temperatures and having a low neutron-absorption cross section. Captain Rickover adopted it as the material for fuel cladding in Navy reactors. (Incidentally, the Oak Ridge process is still used throughout the world; zirconium rods containing uranium pellets make up the fuel cores of virtually all light-water reactors.)

Rickover incorporated zirconium cladding in his advanced MTR design; the MTR design, in turn, became the basis for the prototype land-based submarine reactor, which operated successfully in 1953 (also at the AEC's desert test site in Arco). A year later the first nuclear submarine was launched—the *Nautilus*, powered by a pressurized water reactor based on the MTR-derived prototype. The *Nautilus* is famous for reaching the North Pole, following a 1600-km (1000-mile) mission under the polar icecap.

At this same time, a sodium-cooled reactor developed by the General Electric Company was installed in the submarine *Sea Wolf*. Rickover, however, then chose to put all his eggs in the water-cooled basket and to rely solely on pressurized water reactors for the Navy's submarines. The two companies that built submarine engines for Rickover, Westinghouse Electric Corporation and GE, used their experience to build water-cooled reactors for most of the country's nuclear power plants.

Wanted: Reactor Training

Oak Ridge also contributed men to Rickover's effort. Frank Kerze joined him to work on zirconium-hafnium separation tasks. Ted Rockwell served him as a shielding expert, and Jack Kyger was a section chief.

ORNL researchers performed some reactor and metallurgical studies for the Navy, but reactor training courses are what Rickover wanted most from ORNL. Therefore, the Training School, which was closed in late 1947, reopened in early 1950, after Rickover asked Alvin Weinberg to revive the training program. Under the new name Oak Ridge School of Reactor Technology (ORSORT), the school trained engineers for private industry as well as government posts until it closed in 1965.

In the early days of ORSORT, Rickover had much to say about the acceptance of students, the curriculum, and the teaching methods. Dick Engel remembers the time Rickover walked into a lecture and, after three steps, interrupted the lecturer with a tirade on how "no one studies diligently anymore." When I was a teacher at the reactor school, the ORSORT director once gave me some comments on how to improve my teaching. Apparently, Rickover had met with the Navy students, asked for their criticisms of ORSORT teachers, and then recorded these criticisms in a letter to the school's director.

Several years ago, Larry Corbin received a phone call from Rickover. "I want you to analyze something for me," the Admiral said. Larry replied that Rickover had no contract with ORNL. "Must I get President Carter to send you an order?" Rickover demanded. Larry did the job.

My favorite tale about Rickover was told me by an ORSORT student, one of 20 or so who had AEC scholarships and were eligible in the spring for nuclear employment. Along with three others, he drove to Washington at his own expense for an interview with the captain about joining the AEC's Naval Reactors Branch. On the way, the applicants compared notes on Rickover's style of interviewing. During the interview, Rickover asked the ORSORT student if he had a question. "Yes," replied the student. "Why are you a bastard?"

The question apparently intrigued Rickover. He kept returning to it during the interview while presenting the student information on available jobs, pay scales, and the challenges of working in the Nuclear Navy. Yes, the student got the job! ornl

The Minnesota State Capitol in St. Paul will be heated by the hot water district heating system now under construction.

Hot Water District Heating for St. Paul

By CAROLYN KRAUSE

To cut back on imported oil for heating buildings, a Minnesota city has imported an idea from Sweden, home of many Minnesotan ancestors. The Swedish connection, however, was not a direct one. Acting as a catalyst, Oak Ridge National Laboratory played a key role in stimulating the city of St. Paul to adopt the Swedish technology of district heating—the energy-conserving method of supplying buildings with heat from a central source.

Last fall, the green light was given for installation of the nation's first large, hot water district heating system in St. Paul. Construction will begin this spring, thanks to the political leadership in St. Paul and the technical and financial support supplied largely by the city of St. Paul, the state of Minnesota, the U.S. Department of Housing and Urban Development, and the U.S. Department of Energy.

On October 1, 1982, St. Paul Mayor George Latimer and Hans Nyman, president of the District Heating Development Company, announced that enough needed customers had made the commitment to use the hot water district heating system. Thus, the company will be able to raise funds in the long-term bond market to finance construction of a piping network and heating plant modifications.

The October announcement was welcomed as a milestone at ORNL, where hot water district heating has been studied since 1976. Under the leadership of Irv Spiewak in the Engineering Technology Division and Mike Karnitz and Jim Kolb in the Energy Division, ORNL has had a guiding hand in the St. Paul project, which has been under way for three years.

As a key member of a team of federal, state, city, and private organizations, the Laboratory helped a utility warm to the idea of replacing St. Paul's old steam district heating system with a modern, hot water system similar to the technology used in Sweden and other European countries. ORNL has served as technical coordinator for DOE funds and provided leadership in technology transfer.

"The St. Paul project," says Karnitz, "represents a landmark in cooperative energy planning by federal, state, and city levels of government and by private enterprise."

Karnitz states that Mayor Latimer, chairman of the board of the St. Paul District Heating Development Company, also played a pivotal role in helping the project to overcome institutional barriers. The mayor is credited with selling the concept of hot water district heating to St. Paul citizens and persuading building owners to convert to the new heating system. Among the customers are the State Capitol complex; four hospitals; downtown businesses; hotels; municipal and county government buildings; and the well-known razor blade manufacturer, the Gillette Company.

Jim Kolb, left, and Mike Karnitz discuss the economics of the hot water district heating system to be built starting this year in St. Paul.

The first phase of the St. Paul project, expected to be completed in 1986, is estimated to cost $43.8 million, including $24.5 million for the piping system and $6.6 million for retrofitting power plants to serve the hot water district heating system.

When negotiations are completed, Northern States Power Company could convert a turbine of its High Bridge coal-fired power plant into a cogeneration facility that produces both electricity and hot water for its customers. The district heating company plans to buy hot water from the utility. Because the hot water district heating system will use part of the heat that the High Bridge plant normally rejects to the Mississippi River, the coal-fired plant turbine will double its efficiency—that is, about 80% rather than 40% of the energy that it produces by burning coal will be put to work.

ORNL's Role

ORNL first became involved in transferring technology from across the sea in 1977, when Spiewak and other members of the Engineering Technology Division suggested to DOE that hot water district heating be investigated for possible use in northern U.S. states. DOE's response was that ORNL should identify a city interested in pursuing such a project and then conduct studies on the feasibility and desirability of installing hot water district heating.

At that time, the Northern States Power Company announced its intention to abandon its steam district heating system in St. Paul because it was unprofitable and in disrepair. The Minnesota Energy Agency, a state government body now called the Department of Energy, Planning, and Development, reacted to this decision by encouraging the company to consider adapting a power plant for cogeneration to provide hot water district heating.

When Karnitz searched for a suitable metropolitan area for study, he found that St. Paul, the state of Minnesota, and Northern States Power Company had some interest in embarking on a district heating venture. As a result, after examining a number of possible sites for a district heating project, ORNL and DOE selected the twin cities of Minneapolis–St. Paul as the site at which such a project would most likely succeed.

"We helped the Twin Cities gather and analyze data and performed studies to determine whether the concept of hot water district heating was viable there," says Karnitz. "We found it was particularly viable for St. Paul because it had an old steam district heating system that was falling apart. Minneapolis, on the other hand, has a newer steam system that is operating fine."

Karnitz then assisted in coordinating a number of studies, some of which were conducted in-house and others under subcontract using DOE funds."These studies," he says, "showed that a modern hot water district heating system coupled with cogeneration can more than double the fuel efficiency of electric power plants. In addition, our studies found that such a technology can cut consumption of imported oil and natural gas, reduce air pollution, and provide a reliable, economically competitive supply of heat to businesses and homes."

In Uppsala, Sweden, installation of district heating piping is an ongoing process.

Steam to Hot Water: A New Twist

In 1877, Birdsill Holly constructed a boiler in the basement of his Lockport, New York, home and used its steam to provide space heating in his neighborhood. Thus began steam district heating, an American idea. About 25 years ago, the Swedes and other Europeans turned to the American concept but gave it a new twist: they used hot water instead of steam because water retains its heat content for a longer distance. Now, Americans are finding the European concept attractive for conserving energy.

District heating is a way of providing space heat and hot water to buildings from a central source. Any fuel can be used as a heat source for boiling water—coal, oil, natural gas, enriched uranium, solar energy, wood, biomass, and garbage. The heat in the form of steam or hot water is transported via a network of pipes from the central source to heat exchangers in buildings. In a cogeneration plant, some of the fuel energy can be used for heating buildings while the rest makes steam for spinning a turbine to generate electricity.

Steam district heating is still in use today on a small scale in northern cities and at some universities and military bases in the United States. Such heating systems had greater appeal 100 years ago and were commonplace in American cities at the turn of the century. By the middle of the century, however, many of these systems fell into disuse because of two simultaneous trends. Large power plants were subsequently sited so far from cities that it was no longer economically feasible to pipe steam because of the high cost of piping and the severe heat losses over long distances. Meanwhile, oil and natural gas became so abundant and cheap that they were readily adopted as heating fuels in individual furnaces.

In the mid-1950s in Europe, however, it was recognized that district heating could reduce the amount of money spent on imported oil for heating buildings. The Swedes and other Europeans developed hot water district heating because hot water can be piped from a power plant to downtown buildings and homes 65 km (40 miles) away with little loss of thermal energy.

Because of the Arab oil embargo in 1973 and environmental concerns, the U.S. government and national laboratories such as ORNL began to explore various environmentally benign options that conserved energy to help reduce oil imports. One attractive option was hot water district heating because of Europe's favorable experience with it for about 25 years. Thus, with the St. Paul project under way, the technology of district heating is once again being transferred—this time to the United States from nations across the sea.

The Swedish Connection

Using DOE funds, ORNL sponsored a number of technical studies on the feasibility of district heating and cogeneration for the Twin Cities. Many of these studies were conducted by outside organizations, such as the Minnesota Energy Agency; United Engineers and Constructors, Inc.; KVB, Inc.; and Touche-Ross and Company.

Perhaps the most important of the early studies was performed by Studsvik Energiteknik AB, a laboratory in Sweden. In 1976, ORNL's Irv Spiewak, who had some contacts at Studsvik, explored the possibility of some cooperative projects involving ORNL and Studsvik. When Spiewak learned that Studsvik had done some district heating planning studies, ORNL staff members made arrangements for the Swedish laboratory to study the Twin Cities for DOE.

The Studsvik study on the Twin Cities concluded that hot water district heating from either coal-fired or nuclear cogeneration power stations is technically feasible, capable of conserving large quantities of fluid fuels, and economically viable with appropriate financing.

"This study by the Swedes," says Karnitz, "had a lot of credibility because many Minnesotans are of Swedish descent. In fact, I witnessed several meetings in which the Studsvik researchers and Minnesotans spoke to each other in Swedish. I believe that the mutual respect that developed between the Swedish researchers and the Minnesotans stirred up enthusiasm for hot water district heating and cogeneration."

Another important contact with Swedish district heating experience was made when Hans Nyman, chief engineer at the Uppsala district heating utility company, came to St. Paul in 1978 to participate in an ORNL-sponsored study on conversions of buildings to district heating. He helped persuade Mayor Latimer that St. Paul could become a demonstration city for a new hot water system based on Swedish technology.

As a result, upon the recommendation of the Minnesota Energy Agency, the nonprofit St. Paul District Heating Development Company was incorporated in June 1979, with Mayor Latimer as chairman of the board and Hans Nyman as chief operations officer. DOE agreed to cosponsor the demonstration project proposed by the new company.

In a granite tunnel beneath Stockholm runs a large transmission pipeline that is part of the city's hot water district heating system.

Money for St. Paul

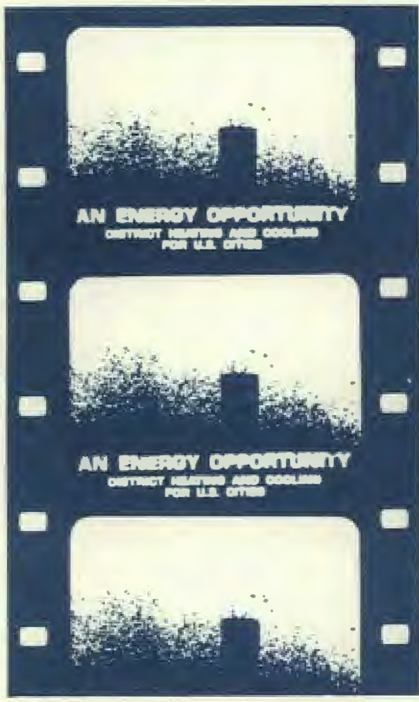
DOE funds, managed by Kolb at ORNL, helped support the company's formation and the project design. In addition to DOE money, support for the company came from the city of St. Paul, the state of Minnesota, and Northern States Power Company. The design work cost about $700,000, almost half of which was paid out by DOE.

More financing for design activities and construction work also came in March 1981, when St. Paul received a $7.5-million U.S. Urban Development Action Grant (UDAG) for the first phase of the project. According to a 1982 market assessment report coauthored by Kolb, this UDAG grant marked the "first step toward actual implementation of a cogeneration, hot water district heating system" in St. Paul.

Now that a sufficient number of St. Paul customers have been signed up, the St. Paul District Heating Development Company can buy $35 million worth of revenue bonds from the bond market to support construction of the district heating system. Over a 30-year period, the company will pay back the principal and interest on these bonds with the revenue received from district heating customers.

Air Pollution Study

According to a study conducted at ORNL in 1981, air pollution in St. Paul will not be reduced as much as it was in Stockholm as a result of district heating because the shift from individual furnaces that burn relatively clean natural gas to a large, coal-fired heat source will slightly increase sulfur dioxide emissions in the St. Paul area. This is the bad news. But the good news is that street-level pollution in St. Paul will actually be less than it is now because the coal pollutants will be discharged through high stacks and thus will be dispersed over a wide region. This Twin Cities study was performed by Karnitz, Frank Kornegay, and Howard McLain of the Energy Division and Brian Murphy, Richard Raridon, and Eileen



John Ridley, ORNL cinematographer, films the installation of a district heating pipeline at a home in Uppsala, Sweden. Directly in front of him is ORNL's Marvin Payne, who served as sound man for the film.

ORNL's Prize-winning Film

ORNL has helped to get the word out across the nation about the Swedish success with hot water district heating and the plans for St. Paul. In 1979, DOE asked ORNL to make a movie for city and community leaders to provide background on district heating technology. Titled "An Energy Opportunity," the film was produced by cinematographer John Ridley of the Information Division with Marvin Payne as the audio engineer and Jim Kolb as technical director. The movie received a Certificate of Creative Excellence in the 1982 U.S. Industrial Film Festival.

The movie tells about the changes brought about in Stockholm and Uppsala, Sweden, since 1953, when hot water district heating systems were installed. At that time, most buildings had individual furnaces that discharged smoke through chimneys. Today, 350,000 people in Stockholm live comfortably in homes served by district heating. And now that the furnaces are gone, the Swedes have more living space and no worries about the hazards of combustible fuel.

In addition, the air that Stockholm and Uppsala residents breathe is cleaner because their heat comes from a central source equipped with air pollution controls instead of individual furnaces whose exhaust gases cannot be easily filtered. Because of district heating, sulfur dioxide pollution in Stockholm has been cut to half of what it was about 25 years ago.

According to the ORNL film, the Swedish economy has benefitted from district heating. This heating technology has reduced Sweden's oil imports by 30%, and because district heating costs the consumer less than burning oil, district heating has strengthened the economy by saving Swedish consumers a considerable amount of money.

In the film, St. Paul officials state that heating buildings by burning coal at a central power source (the High Bridge plant) instead of burning oil in individual furnaces will save the equivalent of 4×10^4 m^3 (2.5×10^5 bbl) of oil per year. Because natural gas will become more expensive than district heating in the late 1980s as gas prices escalate in response to deregulation, it is expected that many gas consumers will be hooked into the St. Paul system. Thus, more gas will be available for residents in outlying areas.

District heating has other advantages, too: it's safer and more reliable than other competitive heating systems. Also, the ORNL film points out that district heating construction money is spent within the city and can help reduce unemployment there.

The ORNL film has been well received. It has been shown to leaders of more than 50 cities and utilities throughout the United States.

Schlatter of the Computer Sciences Division.

According to Karnitz, "By replacing many individual natural gas and oil heating units with a few coal-fired cogeneration units, St. Paul would have only a slight increase—about 3%—in total emissions of SO_2. However, the pollution increase could be even higher without district heating should natural gas supplies be curtailed. Our mathematical models show that substitution of oil for gas would result in even greater SO_2 emissions than would occur with district heating.

"Although the total emissions will be slightly higher with district heating and cogeneration because coal would replace clean-burning gas, use of tall stacks at the cogeneration plants will permit greater dispersion of the SO_2 emissions. Because of the tall stacks and because the central plant will burn the fuel more efficiently and have flue-gas cleaning equipment, we can expect street-level air to be cleaner than before.

"Of course," Karnitz notes, "air pollution from district heating would be eliminated if coal cogeneration were replaced with nuclear cogeneration."

Because of the high stack, sulfur dioxide pollution from the High Bridge coal-fired power plant is well dispersed. An ORNL study indicates that street-level pollution in St. Paul will decline when hot water district heating replaces individual building furnaces.

Howard McLain and Brian Murphy (from left, sitting) discuss the results of their ongoing study for the U.S. Environmental Protection Agency on the air pollution aspects of the district heating system planned for St. Paul. Looking on are two other participants in the study, Ron Sharp, left, and Frank Kornegay.

Transferring the Technology

The district heating study project in the Twin Cities has already exerted an influence beyond the boundaries of St. Paul. "As an indirect result of the St. Paul studies," says Kolb, "Wilmar, Minnesota, a city of 20,000, decided to replace its steam district heating system with a hot water one. Wilmar is employing the same design and type of piping that St. Paul will use. Its piping installation was completed during the summer of 1982 and is already in use."

As the St. Paul project moved ahead in 1982, ORNL played a continuing role in fostering the development of district heating systems. Karnitz and Kolb have offered technical advice to 13 of the 28 cities receiving funds from HUD to pursue the possibility of district heating. Cities the group has advised include New York City, Albany, Baltimore, and three cities in Massachusetts—Lawrence, Springfield, and Cambridge. Karnitz has done some consulting work with a utility in St. Louis which is proposing to replace its steam district heating system with a hot water one that would use a new refuse combustion facility as its heat source.

For the most part, however, district heating studies at ORNL are drying up. Nevertheless, Karnitz and Kolb can point with pride to the St. Paul project. This $43.8-million undertaking, which has the potential of expanding into an $80-million heating system as residential customers tie into the system, has blossomed from a small seed that was planted at ORNL and was nourished by $2 million from DOE.

"A hot water district heating system in St. Paul," says Karnitz, "could serve as an energy conservation model for the nation." ornl

BOOKS

The Atomic Complex,

Bertrand Goldschmidt, American Nuclear Society, LaGrange Park, Ill. (1982). 474 pp. Reviewed by Herbert Inhaber, Health and Safety Research Division.

In many a horse race, the order of horses emerging from the far turn is often different from their order going in. This image conjured up by Goldschmidt is suggestive of what has happened in the international "horse race" among nations developing and using nuclear energy.

Up until 1970, the United States seemed to have an insurmountable lead in all phases of nuclear energy and weapons development, but a variety of factors—environmental, legislative, and emotional—has tripped up horse and rider. Coming out of the far turn, the American rider sees the tricolor of France in the lead. Unlike the United States, France has an advanced breeder reactor program, standardized components and construction practices for water-cooled reactors, and plans for generating more than half its electricity from nuclear power by the next century. The location of the finish line is not clear, but few would now bet that the United States will place first.

How the French assumed a leading position in the nuclear energy horse race is the subject of *The Atomic Complex*. The author has had considerable experience in the French atomic energy program as well as some personal involvement in the American and British nuclear programs. Like Dean Acheson, Goldschmidt was "present at the creation." Starting as a personal assistant to Marie Curie in 1933, he has spent almost half a century in the nuclear enterprise, rising to chairman of the Board of Governors of the International Atomic Energy Agency.

The book is divided into two broad parts: one dealing with military uses of nuclear energy and the other with civilian and peaceful uses. In all of it, Goldschmidt stresses how the French have reacted to world developments. This is useful not only because France has almost assumed the lead in some nuclear work but also because it provides a much-needed perspective on how other countries view the world scene.

The book, a revision of a French edition, has been kept remarkably up to date, as evidenced by references to recent events such as the Israeli attack on the Iraqi reactor and the nuclear freeze movement. In his allusions to the latter, the author is more than skeptical. Writes Goldschmidt, "There will be no way of checking the accuracy of weapons-stock declarations by a country possessing vast numbers of such weapons. A country would, therefore, always keep back a clandestine and undetectable reserve. The last chance of returning to a world free from atomic bombs. . .has vanished for a long time."

The freeze movement has been stimulated in part by Jonathan Schell's series of articles in the *New Yorker* and by his book *The Fate of the Earth* published in 1982. Schell agrees with Albert Einstein's statement in a 1950 letter to President Harry Truman that nuclear war would wipe out all humans, if not all species, on earth. Goldschmidt, however, estimates that explosion of the world's stocks of nuclear weapons (some 50,000 warheads) might only double the present level of natural radioactivity, thus suggesting that the gloomy predictions of Schell and Einstein may be wrong.

A fascinating aspect of the book is the detailed discussion of diplomatic maneuvering on nuclear matters, ranging from nonproliferation treaties to weapons strategies to purchases of uranium. One gets the impression that, if Goldschmidt himself was not present at these high-level meetings, he must have had his personal fly on the wall. While most of these interminable conferences dealt with weighty subjects, such as the possibility of nuclear war, Goldschmidt, nevertheless, provides us some humor. For example, in London meetings leading up to the 1968 Nonproliferation Treaty, the French refused to cooperate and, before going home, bought Scottish wool pullovers while jokingly referring to the nonproliferation sessions as the 'Cashmere meetings'.

In addition to a broad discussion of nuclear policy issues, the author sprinkles his pages with anecdotes illustrating his points. For instance, he pokes fun at the United States by noting that Admiral H.G. Rickover, believing that the French would simply be unable to build reactors for an underwater vessel, approved the transfer of uranium-235 to the French nuclear submarine program. French nuclear subs now cruise the seas. The Admiral may have had foresight in many matters, but he struck out on this one.

Goldschmidt's dramatic story of the development of the hydrogen bomb gives little space to the role of J. Robert Oppenheimer, who has been characterized by his detractors as obstructionist or even treasonous. The author leaves the impression that the momentum toward developing the H-bomb, including the revelation of the spying of Klaus Fuchs, was so great as to stifle all opposition. He notes the irony that lithium, used to build the H-bombs that have brought such anxiety to the world, can itself be employed to treat certain cases of nervous depression.

A good half of the book is devoted to civilian nuclear power and how it has developed from the first "piles," as reactors once were called. He goes into perhaps too much detail on the ins and outs of the French reactor program and all the false starts and blind alleys it took before it got under way. One has the sense that Goldschmidt is not very happy with the French choice of pressurized water reactors, but he doesn't propose an alternative.

As a Canadian, I was intrigued by the kind words he showers on the CANDU heavy-water reactor, especially the comment that of all nonbreeder reactor designs, it uses uranium most efficiently. He says that a world without enrichment or reprocessing could have been realized if the CANDU were the standard design and that the task of the nonproliferation treaty drafters would have been easier as a result. But he concedes that the decisions of the big powers concerning enrichment and use of light-water reactors determined the choices to follow. The small lesser powers, such as France, had to acquiesce or be crushed.

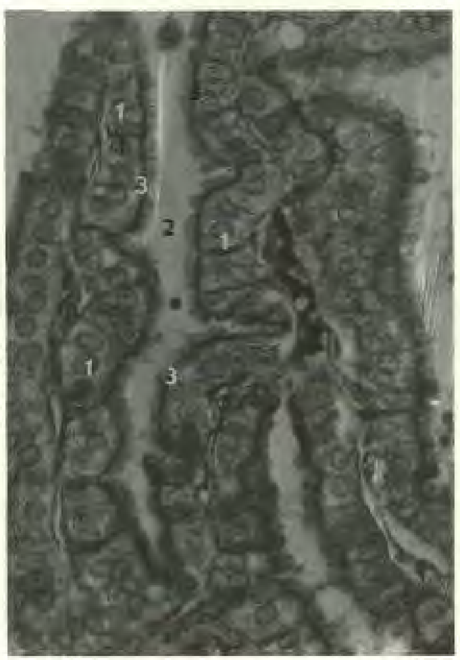
Goldschmidt is generally optimistic about the future of civilian nuclear power; he regards the period from 1974 to 1981 as a temporary setback rather than the shape of things to come. As one might expect, his opinion of former President Carter is not flattering. He regards the Carter policy on reprocessing and proliferation as "the heaviest blow [the development of nuclear energy] had received throughout its history." He also disapproves of Carter's declaration that the Clinch River Breeder Reactor is obsolete. "As a result of this new misfortune," writes Goldschmidt, "the American breeder program itself became even more obsolescent."

The author holds out more hope for the Reagan Administration, but he reserves complete judgment. He notes that the new French Socialist government, after some hesitation, is proceeding fairly vigorously with the country's vast nuclear program, although its impetus has been slowed somewhat.

I found *The Atomic Complex* to be an invaluable addition to the history of the nuclear age largely because the author has been in the midst of many of the battles. Some readers will find the diplomatic history ponderous, with its endless maneuverings and schemes. While Goldschmidt presents the French viewpoint—I suspect he was instrumental in formulating much of it—he tries to be reasonably objective about the attitude of others. Those who favor the nuclear enterprise will take heart from his final optimism. He clearly is distressed over the opposition to what was once regarded as a *wunderkind*, but he believes that reason will prevail. Will it?

Histological Atlas of the Laboratory Mouse, *by William D. Gude, Gerald E. Cosgrove, and Gerald P. Hirsh. Plenum Press, New York and London (1982). 151 pp. Reviewed by Diana M. Popp, Biology Division.*

Although isolated examples of mouse histology appear in scientific journals, the examples generally are limited to the specific tissue addressed by the report and rarely are in color. Textbooks of histology—the branch of anatomy that deals with the microscopic structure of animal tissues—emphasize the relationship of tissue structure and function and illustrate primarily human or mammalian tissues. The illustrative tissue sections or drawings in textbooks are usually idealized representations of cellular architecture and are usually in black and white. Thus, the tissue preparations encountered in practice frequently do not resemble the illustrations. For the mouse histologist in particular, a good handbook of mouse histology has not been available until this publication.



Among the illustrations of stained mouse tissue found in the Histological Atlas *is this one labeled "Fimbria of Oviduct."*

In this book, Gude and his colleagues Gerald E. Cosgrove and Gerald P. Hirsch, all former employees of the Biology Division, have compiled representative tissue sections, accurately reproduced in color, that show detailed structural characteristics of the mouse. This convenient handbook can be easily used at the microscope by the student becoming acquainted with normal mouse histology as well as by the experienced investigator interested in elucidating specialized structures through the use of special stains to better understand effects of radiation or chemicals on mouse physiology.

The atlas is divided into 12 sections based primarily on organ systems. A short text at the beginning of the handbook describes the special features of each organ system, especially structural details of each tissue as they appear in atlas illustrations and under the microscope. Succinct descriptions of each illustrated section provide the user easy access to the information necessary to interpret slides under the microscope.

Following the text, the book has 168 full-color figures that reproduce tissue sections in structural detail. In many cases, these figures show similar tissues sectioned in a different position, reproduced at a different magnification, or prepared with different stains. This variety of perspectives is helpful in interpreting differences that occur in actual practice.

Except for a few figures, the color reproduction is vivid and faithfully represents subtle differences in color and tone that are characteristic of cellular structures. Moreover, the color reproduction shows the respective ability of different stains to emphasize or identify special structures such as nerves, collagen, enzymes, pancreatic cells, and reticular fibers.

The book pictures several rare examples of murine (mouse) histology. For example, sections of the pineal gland in the brain, the organ of Corti in the inner ear, the three lobes of the pituitary gland, maturing follicles in the ovary, taste buds in the tongue, the heart valve, and all phases of the murine estrus cycle are presented. In addition, the comments on structural differences between similar organs in the mouse and other mammalian species, as well as on the effect of differences in sex and age on mouse tissue, are helpful in interpretations of histological preparations.

Following the text and color figures are descriptions of fixation and staining methods and formulas for the fixatives and stains that they recommend. They also give helpful hints and precautions in the preparation and use of these fixatives and stains. The methods are easy to follow, and the formulas are presented clearly.

One note of caution: this book does not teach structure and function and cannot supplant a textbook on histology. Users should have a three-dimensional concept of the major organs and familiarity with many of the anatomical terms. However, for the histology student or experienced scientist puzzling over a thin slice of tissue under a microscope, the atlas is indispensable in helping the observer relate tissue detail to the whole organ.

BOOKS IN PRINT

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

Soil Microbiology: A Model of Decomposition and Nutrient Cycling, by O. L. Smith, CRC Press, Inc., Boca Raton, Fla. (1982).

Advances in Nuclear Science and Technology, ed. Jeffery Lewins (Cambridge, England) and Martin Becker (Troy, N.Y.), Plenum Press, New York and London (1982). Four of the seven contributors are members of ORNL's Engineering Physics Division: G. de Saussure, J. H. Marable, R. W. Peelle, and C. R. Weisbin.

Gaseous Dielectrics III, Proceedings of the Third International Symposium on Gaseous Dielectrics held at Knoxville, Tennessee, March 7-11, 1982, ed. L. G. Christophorou, Pergamon Press, New York (1982).

Liquid Piston Stirling Engines, by Colin D. West, Van Nostrand Reinhold, New York (1982).

A Desirable Energy Future, by Colin D. West, with Robert Livingston, Truman Anderson, Ted Besmann, Mitchell Olszewski, and A. M. "Bud" Perry, Franklin Institute Press, Philadelphia (1982).

Advances in Design and Analysis Methodology for Pressure Vessels and Piping, ed. C. E. Pugh and B. C. Wei (U.S. Department of Energy), American Society of Mechanical Engineers, New York (1982).

Measuring the Effects of Utility Conservation Programs, Workshop Proceedings, EPRI EA-2496, ed. Eric Hirst, Electric Power Research Institute, Palo Alto, Calif. (1982).

Health Risks of Energy Technologies (American Association for the Advancement of Science's Selected Symposium Volume), ed. Curtis Travis and Elizabeth Etnier, West View Press, Boulder, Colo. (1983).

Sam Carnes, a native of Albuquerque, New Mexico, joined the Social Impacts Analysis Group of ORNL's Energy Division in 1978 after receiving a Ph.D. in political science from Northwestern University. On one of his first projects, an analysis of the impacts of the Resource Conservation and Recovery Act on energy supply, he participated with Emily Copenhaver and four others in developing a multidisciplinary integrated assessment of the impacts of emerging hazardous waste management policy on various non-nuclear energy supply options. The substance and approach of this early effort were quite useful in his subsequent participation in research reported here. In addition, he has also recently worked with Copenhaver and two other Energy Division researchers—John Sorensen and Jon Soderstrom—on analyzing the impacts on psychological and community well-being of restarting Unit 1 of the Three Mile Island nuclear power plant. The objectives of this analysis include identifying potential mitigating measures to offset any adverse effects of a decision to restart the plant. Carnes's research interests include community politics, public participation in intergovernmental decision making, and the design of mechanisms for resolving intergovernmental conflicts. Emily Copenhaver is an environmental policy analyst who works in the Health Studies Section of ORNL's Health and Safety Research Division. She has also collaborated with Carnes and Sorensen on organizational interactions in emergency planning for nuclear power plants. A graduate of the University of Tennessee at Knoxville, Copenhaver is currently coediting with Phil Walsh and C. S. Dudney a book for CRC Press on *Indoor Air Quality*. She is also editing and contributing to the DOE *Health and Environmental Effects Document on Coal Liquefaction*. And she cochaired with Dennis Parzyck the Health Physics Society Symposium on "Energy for the Future: Facing the Radiation Issues" at the recent annual WATTec Energy Conference.

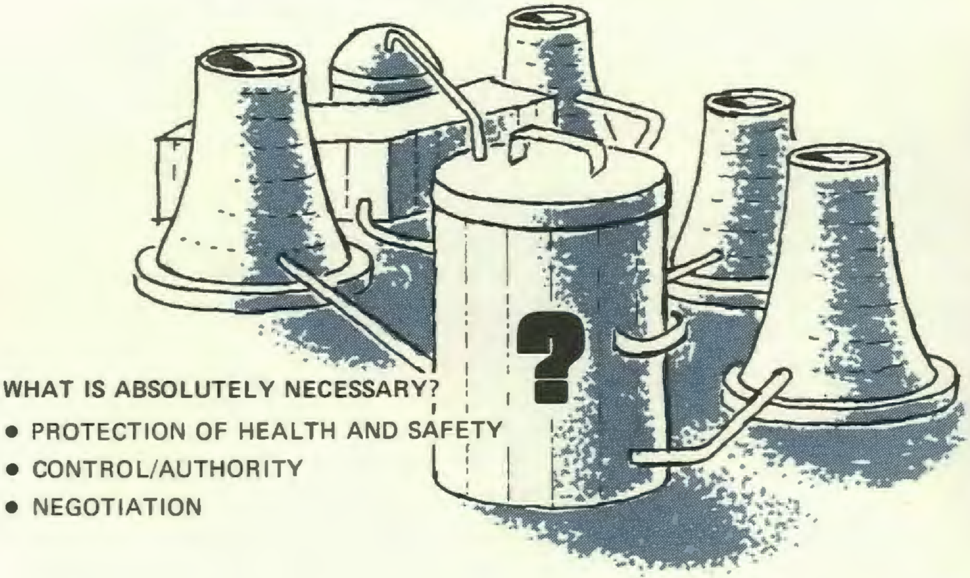
John Reed, Emily Copenhaver, Jon Soderstrom, Elizabeth Peelle, Sam Carnes

Community Incentives for Housing Nuclear Waste Repositories

By SAM CARNES and EMILY COPENHAVER

Communities and waste disposal facilities appear to be a volatile combination, whether the wastes being disposed are nuclear wastes, chemical residues, or plain household garbage. The *"not-in-my-backyard"* syndrome is the social scientists' label for persistent local opposition to siting any kind of unwanted facility, including airports, prisons, and waste disposal facilities. This term is commonly used by news reporters, magazine writers, politicians, public interest groups, and others interested in the recurrent conflicts over this issue.

Our research team members have long been interested in community behavior, chemical and radioactive wastes, and siting concerns. Recently, we blended these interests in our study of what, how, and when incentives might encourage more community interest in hosting nuclear waste repositories. Our research may be applica-



ble to the broader issues of siting any kind of facility that provokes both positive and negative effects and reactions in the potential host community.

Even if all existing nuclear power plants were shut down and plans for future ones were scuttled, current wastes already on hand indicate a need for siting at least one repository to provide adequate health and environmental protection. An extensive range of social and institutional issues, however, currently hinders governmental attempts to resolve the problem of radioactive waste disposal. These problems include changes and inconsistencies in the nation's waste management program, governmental conflicts and credibility gaps, uncertainty regarding the regulation of wastes, questions of fairness, and general public distrust. Only now is a national policy on waste siting beginning to emerge with the recent passage of a federal bill that calls for the selection of a permanent burial site for high-level nuclear wastes by 1987. The Nuclear Waste Policy Act of 1982 specifies that the Department of Energy cannot go ahead with a planned burial site if a proposed host state objects, unless both houses of Congress overturn that state's objections. Thus, it is clear that states and their communities will have a strong voice in site selection. Whether they agree to accept a DOE-proposed site for sequestering high-level nuclear wastes may depend on what guarantees and incentives are offered them.

How To Build Trust

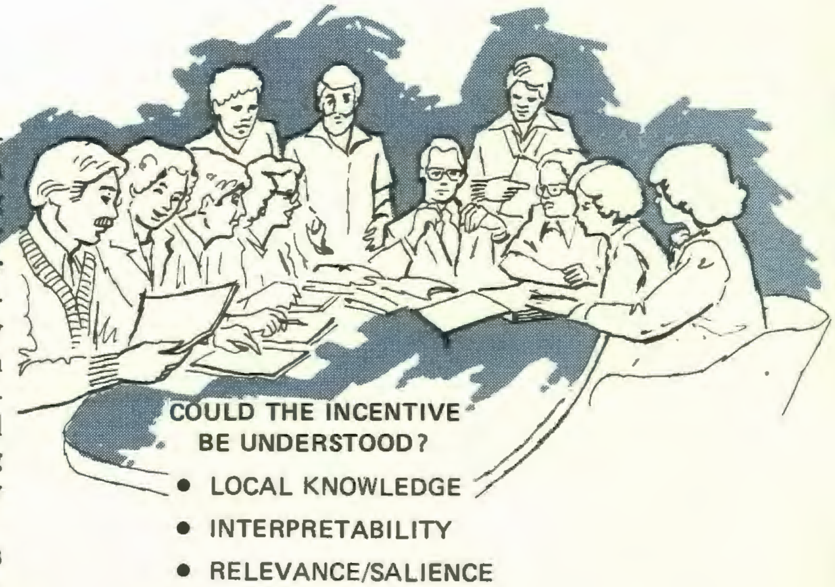
Public confidence in all types of government and business has declined steadily and substantially in recent years. It is commonly accepted that the development of a more trusting environment is a prerequisite for inducing communities to agree to host a nuclear waste repository. We believe this trust would emerge if the host community were guaranteed (1) protection of public health and safety and the environment, (2) a significant measure of local control in the siting and licensing process, and (3) negotiations for reconciling differences and building consensus.

The presence of adequate, reliable, and enforced regulations that protect the health, safety, and environment of residents near a proposed radioactive waste facility is a vital element in the siting process. Much of the opposition to such facilities arises from the perception that waste management facilities may endanger health and safety. Both the degree and probability of risk from normal and abnormal operations of the proposed facility may be in dispute.

Existing regulations may not be known or understood, or their functioning may be discounted and viewed as unreliable. The agencies responsible for enforcement of existing regulations may not be trusted or respected. Additional guarantees, over and above those mandated by federal or state law, may be a reasonable subject for discussions by interested parties.

Nonradioactive waste management and land use have traditionally been local prerogatives. However, with the passage of the Resource Conservation and Recovery Act (P.L. 94-580) in 1976, the federal government began to exercise significant control in these areas. Between the two extremes of federal preemption and state or local veto is a range of compromise approaches in which the different levels of government share power. Compromise begins with the concession that the potential host community has a legitimate role in the design and implementation of a siting strategy.

David Bjornstad, economist, surveys a report with John Sorensen (right), a behavioral geographer.



Negotiation builds trust by permitting public participation. Negotiation also builds community consensus in support of a less-than-desirable facility by reconciling differences. The central issue to be negotiated is under what conditions, if any, a repository might be sited in or adjacent to a community. Most radioactive waste management negotiations have been conducted between only federal and state/tribal jurisdictions, but a new trend in managing another form of waste—toxic chemicals—suggests an alternative approach. Increasingly, local communities are participating in negotiations on siting chemical waste disposal facilities. This approach may well prove useful for nuclear waste repositories.

In their research on the prospects and constraints of using incentives in the siting of nuclear waste repositories, researchers in ORNL's Energy Division employed the negotiation techniques advocated by their work. Thus, team members of varying academic backgrounds were able to agree on the conceptual model as it developed. Besides the authors, the research team includes John Sorensen, behavioral geographer; Jon Soderstrom, environmental psychologist; Elizabeth Peelle, sociologist; Dave Bjornstad, economist; and John Reed, sociologist.

A conceptual model and definition of its characteristics were developed on an extensive review of the literature, interviews with selected siting experts and interest group representatives, results of a survey in the state of Wisconsin, and prior work of group members in hazardous waste policy, siting research, and social impact analysis.

Incentive Types

Survey data (see box) has shown that incentives can change the minds of people originally opposed to local siting of a nuclear waste repository that meets a national need. In developing our conceptual model, we classified incentive types so that one can determine why a particular incentive might be offered, to whom it might be offered, and what institutional and administrative arrangements might be necessary to implement the incentive. Most recent discussions of incentives have emphasized a fairly narrow approach, focusing on the use of direct payments. Other types of incentives may play just as important a role as monetary ones in the siting process. Packages or mixes of incentives may be more attractive than any single benefit.

An incentive might be developed to *mitigate*—prevent or minimize—the risks or other negative impacts that may be anticipated to occur during normal construction and operation of a high-level waste facility. For example, the private firm that constructs the repository might purchase easements to serve as a buffer between the repository and residential areas. Citizens could be kept continually informed about actual radiation levels monitored at the site through brochures, newspaper articles, radio and television programs, and a telephone hotline. Health risks from radiation levels could be put into perspective by establishing acceptable risk levels, and radiation levels could be monitored by an independent agent. A job-training program could be set up to train the unemployed for work in building or operating the waste repository.

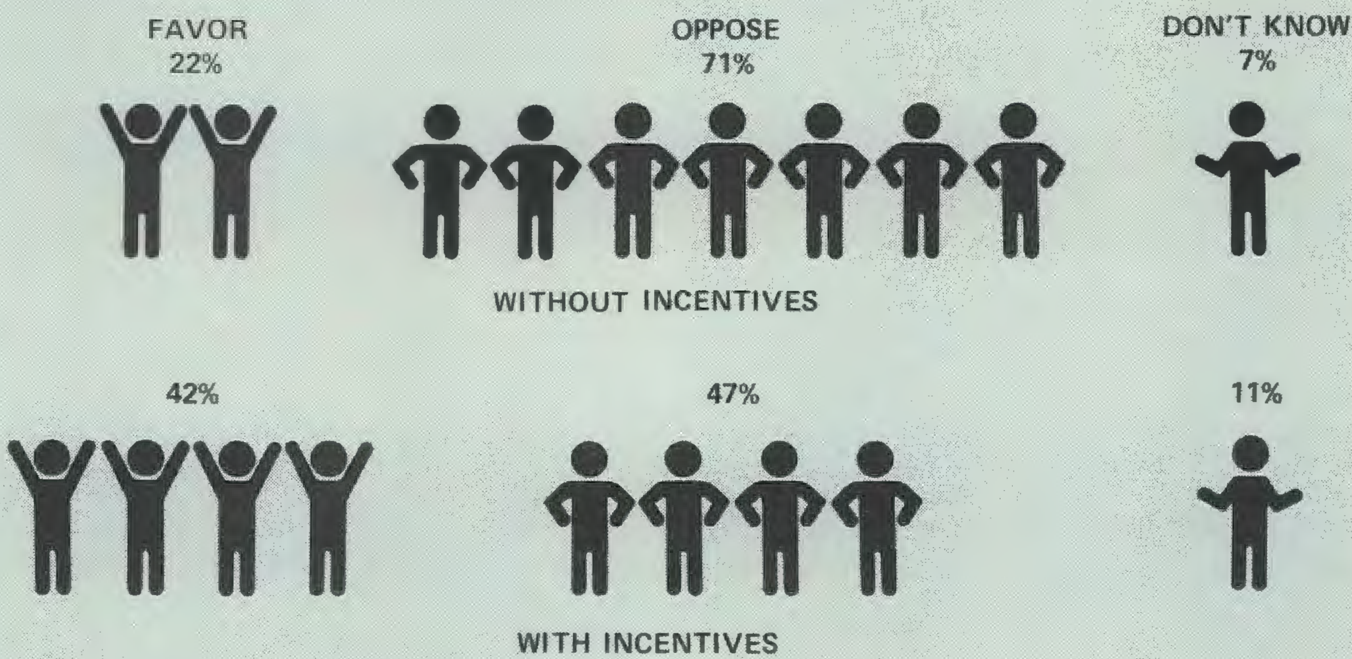
Mitigation alone, however, is not likely to neutralize local opposition to waste facility siting, because it is not possible to accurately predict all risks and costs or to eliminate all problems. Even if it were, mitigation is largely based on perceptions of the local population, and successful mitigation requires public involvement in determining the buffering, monitoring, and other options needed and in administering these options.

An incentive might also *compensate* actual damage in the event of an emergency, accident, or other unforeseen anomaly. The traditional view of compensation involves a "make whole" concept or a provision of replacement costs. There seems to be ample local precedent for this sort of compensation. Examples of compensation might be government-backed insurance policies to pay for damages incurred because of the repository and the imposition of excise taxes on utilities that ship their nuclear wastes there.

Finally, one incentive, which goes beyond either previous type, might be to *reward* a community for

WILL INCENTIVES WORK ?

ONE SMALL SURVEY IN WISCONSIN SHOWED THAT INCENTIVES AND PUBLIC PARTICIPATION CAN AFFECT THE ACCEPTANCE OR OPPOSITION TO RADIOACTIVE WASTE SITING



Survey Results and Interpretation

Quantitative evidence supporting the potential usefulness of incentives in siting nuclear waste repositories is extremely limited. However, a telephone survey of 426 randomly selected residents of three rural Wisconsin communities was conducted in 1980 on the acceptability of hosting a nuclear waste repository.

Professor John Kelly of the University of New Hampshire, who made the survey, found that 24% of the respondents (77 people) dropped their initial opposition to hosting a repository when they could stipulate various incentives and public participation activities for their communities. Put another way, Kelly's survey showed that only 22% favored a repository if no incentives were offered. But 42% favored it when offered a package of incentives, including (1) substantial payments to their community and access to information about the repository, (2) authority to independently monitor the facility, (3) representation on a board to govern the repository, and (4) power to shut it down.

These findings suggest that nonmonetary incentives, such as independent monitoring and access to information, may significantly increase public acceptance of radioactive waste repositories. Moreover, results help confirm that packages of incentives may be more attractive than single incentives, especially if the former include measures that greatly increase community control of the facility.

Although a 20-percentage-point shift in the acceptability of a repository appears significant, it does not produce a majority (much less a consensus) favoring a repository. In a *real-world* application of a potentially much broader range of incentives, this shift might be much less or much greater. The size of the change in public opinion may be more nearly accurately predicted by a thorough evaluation of the incentive system in the context of a potential host community. These are some of the conclusions of our study on "Incentives and Nuclear Waste Siting: Prospects and Constraints," to be published in the interdisciplinary journal *Energy Systems and Policy*.

"Rewards must be perceived as positive inducements and not as a form of conscription or being 'bought off'..."

assuming risks and costs in order to meet non-local (i.e., national, state, regional, or international) needs. The idea of helping solve national problems by assuming additional burdens is in itself not very compelling to local populations. Therefore, although there is less precedent for it, there are reasons for the use of rewards.

Some of these local costs and risks are less tangible than those potentially offset by mitigation or compensation, for example, changes in community character, the stigma presently associated with garbage disposal or "dumping" activities, and resistance to the added risks to local health for the sake of providing benefits on a much broader scale.

Rewards must be perceived as positive inducements and not as a form of conscription or being "bought off" on health and safety considerations. If perceived as either of these types of situations, the reward will likely be viewed as a bribe. In addition to direct payment, tax incentives, and other specific monetary rewards, reward systems include (1) linking of repository siting to the provision of other, more desirable federal projects or projects, such as urban renewal and job training; (2) avoiding other hazardous facilities; or (3) preventing undesirable land uses in a given area. Interstate and regional compacts that distribute a multitude of hazardous facilities exemplify how the latter concept can be effectively implemented.

Among these three types of incentives—mitigation, compensation, and rewards—the first two have been officially endorsed by federal and state government agencies as useful mechanisms in alleviating many of the direct, quantifiable impacts of facility siting. For example, the U.S. departments of Defense, Interior, and Energy and the U.S. Army Corps of Engineers, among others, have had experience with mitigating adverse impacts associated with decisions in their respective areas, and the state of New York compensated some 200 families by buying their homes in the Love Canal area of Niagara Falls, after toxic wastes leaked from a closed hazardous waste disposal facility over which a school and residences were built. The use of rewards has had more limited application by governmental entities in past siting practices. Rewards, however, are commonly a part of siting agreements involving the private sector, where community facilities such as schools and parks are upgraded or developed from scratch.

Which Work Best?

Having classified and examined different types of incentives, we tried to determine when, or if ever, any of these incentives will really make the siting of repositories more welcomed, fairer to all those concerned, or easier to administer. The dominant siting issues are public acceptance, the necessity for fairness, and institutional uncertainties. Unless a particular incentive or mix of incentives can address these concerns, we believe that successful siting strategies will not increase appreciably. To determine what incentives to use, we came up with three questions: Will the incentive work? Can it be understood? What are the consequences of implementing it?

Will the incentive work? Incentives will have to be designed to fulfill many functions, and the community must believe both that the incentive will adequately address its concerns and that it will be provided as agreed upon and continued over the long time periods involved in the operation and maintenance of a repository (even after its closure). Setting up a viable way to administer or implement an incentive program will also be critical to making the incentive work.

Can the incentive be understood by the community? Are most people in the community fully aware of the facility and the incentives? Do most people understand the purpose of the incentives and how they would be implemented? Do people in the community perceive the incentives to be relevant to their needs? Whether the incentives will actually succeed in their purposes of overcoming local opposition and developing support for siting the repository depends on whether the answer to each of these questions is *yes*. The more the community

One Town May Host Repository

During the current recession, there is evidence that the jobs created by development of nuclear waste repositories constitute an incentive for at least one town to accept low-level radioactive wastes. The uranium-mining town of Naturita, Colorado, which has a high unemployment rate due to low demand for uranium, is now receptive to the idea of returning to the ground what was once extracted from it. The town of 800 people is permitting Chem-Nuclear Systems, Inc., to test 400 sagebrush-covered hectares (1000 acres) 24 km (15 miles) from downtown as a possible site for burying contaminated refuse from nuclear research and uranium refinement. It is estimated that 100 new jobs would be created for truckers, welders, mechanics, and technicians. Because former uranium miners can hold most of these jobs, the town of Naturita sees a nuclear waste repository as a way out of its economic recession.

However, the state of Colorado and towns along the transportation routes may not be as receptive to the establishment of a nuclear waste repository on purely economic grounds without a consideration of environmental or perhaps even ethical issues in siting less desirable facilities among the economically disadvantaged. These issues are indicative of the complex, interactive situations that must be presented when considering all siting and, to an even greater degree, when considering the use of incentives.

understands the functions of incentives (that is, mitigation, compensation, or reward) and the more positively community residents view the incentives as addressing their own concerns and perceived impacts on their community, the more likely the incentives will reduce community opposition.

What are the consequences? The potential consequences of using each incentive depend on how it affects various segments of the community's population and whether they do indeed reduce public opposition to siting a facility. How the benefits, costs, and risks of a repository are received or borne by different individuals or groups in and beyond the community will certainly affect the acceptability. In simple terms, who benefits, who pays, and how do these effects accrue over time? Mitigation, compensation, and reward are likely to affect individuals and groups in different ways. Unless incentives are designed and implemented with great care, the people who benefit from them may not be the same people who are expected to bear added risks or costs. Therefore, some incentives might need to be distributed to residents adjacent to the repository, while others might be distributed more evenly to all members of the community. For example, immediate neighbors might receive their own dosimeters, while a series of monitoring stations might be established to measure radiation levels for other parts of the community.

The siting of any hazardous facility will likely generate conflict and opposition. Some siting incentives, however, may themselves generate additional conflict in the potential host community, over and above that generated by siting the facility itself. For example, the creation of jobs might cause wage inflation that could upset town merchants who are unable to raise wages to attract employees. What's more, different groups in the community will have varying, and sometimes competing, goals to be met in the siting process. Some groups may prefer immediate gratification with direct monetary payments, while others may wish to enrich their children and grandchildren with deferred payments.

The possibility of conflicting goals should not obscure the significant role incentives can play in developing community support for the siting of a repository. Consequently, of critical importance is the creation of the opportunity for all interested groups to be represented in negotiations. In this way, divergent attitudes and reasons for those attitudes can be discovered, and the community can determine what package of benefits, if any, would be necessary to develop a consensus favorable to a repository.

Our approach, which focuses upon including the potential host community as a full partner in the siting process, has much intuitive appeal for us and offers a means of possibly resolving an important national problem. The approach may also be useful in addressing the siting of other hazardous facilities (e.g., chemical waste disposal facilities) or opposition to unpopular proposed land uses. We recognize, of course, that an incentive-based program should not supplant technological or other social considerations in the siting process. Instead, incentives should help achieve the best possible technical solution, one that otherwise might not be implemented because of social and political constraints. ornl

technical capsules

Airborne Metals

For more than half of the land area in the eastern United States, the forest canopy is the initial point of contact for metals in the atmosphere. These airborne metals are deposited on tree leaves by two means known as wet and dry deposition. In the first case, the metals are dissolved in rainwater; in dry deposition, the metals are attached to particles that settle on leaves.

In the past two years, Steve Lindberg and his colleagues have studied the role of the atmosphere in contributing metals to forest ecosystems and the interactions of acid rain with metals and vegetation. To make their measurements, they developed an automatic dry deposition sampler which protects the dry particles from rain. Ten devices of this type are now being used to collect dry deposition samples in the Walker Branch Watershed, a forest in the Oak Ridge Environmental Research Park consisting primarily of mixed oak and hickory trees.

Here are some of their recent findings, some of which were published in the March 26, 1982, issue of *Science* magazine:

- The atmosphere contributes one-third or more of the total amount of lead, zinc, and cadmium reaching soils beneath the forest at Walker Branch Watershed during a typical growing season.
- Almost all of the lead reaching soils in this forest was deposited from the atmosphere. (Auto emissions are the chief source of atmospheric lead; such emissions will be reduced because of the Environmental Protection Agency's new rule which permits one-third less lead in gasoline by 1990.)
- Dry deposition is less intense than deposition of metals by rain, yet up to 90% of the total annual input of metals to the forest is by dry deposition.
- Because acidic solutions dissolve heavy metals on particles, concentrations of these metals deposited on leaves by acid rain plus dry deposition are 50 to 500 times as high as concentrations in rain alone. Lindberg has stated that metals in solution are more likely to get into leaves than are metals firmly attached to particles.
- Acid rain percolating down through the forest canopy is progressively neutralized. Says Lindberg: "The fully developed oak canopy has a substantial effect on rain acidity, decreasing the strong acid concentration in rain reaching the forest floor by 20 to 40% on an annual basis and by nearly 100% in isolated storms. The canopy also alters the acid composition of rain from 70% strong acids (such as sulfuric and nitric acids) above the canopy to 60% weak, mostly organic acids below."

Environmental scientists inspect automatic dry deposition samplers which collect metal-bearing particles typical of what falls from the atmosphere onto the forest canopy. These samplers are being used at ORNL's Walker Branch Watershed to study the ways by which metals are transported to forests and their soil.

Environmental Risk Assessment

Because many industries are interested in the probability that use of a specific technology will have a specific effect on the environment, such as a reduction in fish life, ecologists at ORNL and elsewhere are pioneering new methods for environmental risk assessment. An environmental risk assessment differs from assessments performed in compliance with the National Environmental Policy Act of 1969 in that it is not constrained by legal requirements and it estimates the probability of certain prescribed consequences of an action (endpoints) rather than disclosing the expected consequence.

Glenn Suter, Larry Barnthouse, D. L. DeAngelis, R. H. Gardner, R. V. O'Neill, C. D. Powers, and Douglas Vaughan of the Environmental Sciences Division have developed new probabilistic methods for environmental risk assessment using existing mathematical and computer simulation.

One method that they developed for estimating the probability of reaching an endpoint is to generate the probability density of the endpoint by summarizing the errors associated with extrapolating laboratory data to the endpoint. "For example," Suter says, "estimating the probability of a reduction in largemouth bass populations on the basis of LC_{50} data on fathead minnows requires extrapolation between the two species and between acute toxicity to adult fish and chronic toxicity to all life stages. These extrapolations can be performed using regression analysis of existing data." (LC_{50} refers to the lowest concentration of a toxic substance at which half of an exposed group dies.)

A second probabilistic method for environmental risk assessment developed at ORNL involves error analysis of toxicological effects propagated through an ecosystem model. Monte Carlo simulation of a lake model called SWACOM is used to estimate the probability that a toxicant will have a specific environmental effect as a result of direct effects on the species of interest or indirect effects on the food chain.

The SWACOM model has been applied by the ORNL researchers to predictions of the effects of phenol (a coal liquefaction pollutant) on the production of game fish such as carp, catfish, white bass, green sunfish, and bluegill. The model estimated the probability that the game fish population would be reduced by a specific amount (25%, for example) by a specific concentration of phenol.

Radionuclides as Tracers

The fate of some chemical pollutants in river, estuarine, and coastal systems of the eastern United States may be easier to determine because of an ORNL discovery that certain radionuclides tend to move at the same rate and accumulate in the same places. By measuring the distribution of these radionuclides, Curtis R. Olsen, I. L. Larsen, and Norm Cutshall of the Environmental Sciences Division are determining the rates and types of environmental processes which affect pollutant transport and accumulation.

Because cesium-137 is the easiest of the radionuclides to measure, they began studying its relative distribution in water, suspended matter, and sediment samples from the Susquehanna, Hudson, and James rivers as a possible means of tracking other contaminants, radioactive as well as chemical. Their Susquehanna River studies began as a cooperative effort with scientists from the Maryland Geological Survey, Smithsonian Institution, and Columbia University to measure offsite contamination of the river following the March 28, 1979, accident at Three Mile Island (TMI).

Interestingly, they found that radioactive cesium contamination in the Susquehanna River was much less than that of the naturally occurring radioactive potassium-40. They also determined that almost all of the reactor nuclides (cesium-137, cesium-134, and cobalt-60) detected in the river were attributable to releases from the Peach Bottom nuclear power plant, not TMI. Many of the released radionuclides were trapped in the sediments behind Conowingo Dam on the Susquehanna River and in the upper portions of Chesapeake Bay.

Olsen and his colleagues have also used measurements of radiocesium distribution to determine offsite contamination of the Hudson River by the Indian Point nuclear power plant in New York. They found that 80% of the total sediment burden of reactor nuclides was deposited in the inner-harbor zone 40 km downstream from the reactor. They also found that this same site was a major accumulation zone for polychlorinated biphenyls (PCBs) and trace metals.

In the James River study, the ORNL researchers, in cooperation with scientists from the Virginia Institute of Marine Science, used the distribution of radiocesium to determine the whereabouts of kepone, a toxic chemical released by an industry at Hopewell, Virginia, up until 1975. They used the same technique to map the distribution in the Hudson River of PCBs, toxic chemicals whose release into the environment is no longer permitted. Their measurements of radionuclide distributions indicate that these contaminants are rapidly buried in sediments at sites of high deposition, reducing the exposure of organisms to further contamination.

The ORNL researchers also found that naturally occurring beryllium-7, which has a 53-d half-life, is a good radioactive tracer for chemically reactive substances. They studied the movement of beryllium in waters to estimate the rate at which contaminants are removed from the water column by settling particles. They found that beryllium half-removal times range from 4 to 8 d in the estuarine environment to 20 to 60 d in adjacent coastal water during May–July 1981. "By analogy," says Olsen, "these half-removal times should be characteristic of other particle-reactive substances or contaminants."

Integrated Compartment Modeling

A new computer code developed at ORNL can construct a set of algebraic equations from a differential equation to produce numerical results of interest to ecologists. The code, called the Integrated Compartment Modeling (ICM) technique, was developed by George T. Yeh of the Environmental Sciences Division initially to simulate flow dynamics. ICM is flexible and efficient, according to Yeh. It can handle one-, two-, and three-dimensional problems at the same time, and it offers a large savings in computer coding efforts.

The method has been successfully applied to determining moisture and heat transport in soil and other unsaturated porous media. It has also been used to simulate the hydrodynamics of chemicals, including oil spills, in stream and river networks.

Potential ecological applications include modeling of fish migration in coastal waters, calculating population distribution in heterogeneous landscapes, and computing the critical size of a heterogeneous region for supporting a species.

ICM has also been applied to several physical problems, including one being worked on in the Engineering Technology Divison and another in the Chemical Technology Division. It has been used in computations of heat transfer and diffusion in high-temperature, gas-cooled reactors and to calculate radionuclide movement from a nuclear waste repository that has been flooded.

Advanced Reactor Shielding

Oak Ridge National Laboratory is the U.S. Department of Energy's center for reactor shielding analysis. Perhaps even more importantly, it is also a source of computer codes and information used internationally for designing reactor shields to protect equipment, workers, and the public from radiation. Codes and data used for shielding analysis worldwide have been developed by ORNL's Engineering Physics Division.

One prime example is the Discrete Ordinates Transport (DOT) code, the computer code developed under the leadership of ORNL's Fred Mynatt, who received DOE's E. O. Lawrence Award in 1981 for his innovative work in shielding analysis. The two-dimensional DOT code, whose development has continued under W. A. Rhoades, has been used by the French to design the shield for Phénix, a 250-MW liquid metal fast breeder reactor. DOT is also being used by the French for shield design on Superphénix, a huge 1200-MW breeder under construction.

Like the French, the Japanese use a version of DOT on a five-year, information exchange agreement as well as the ANISN one-dimensional discrete ordinates code developed by ORNL's Ward Engle. ANISN, which has become a standard in the shielding industry, is used worldwide as is the Evaluated Nuclear Data File, to which ORNL has contributed much cross-section data on the neutron-absorption properties of shielding materials, such as sodium, concrete, iron, and steel.

ORNL shielding studies have also made important contributions to the U.S. breeder reactor program. For example, ORNL calculations showed that a change was needed in the original shield design for the Fast Flux Test Facility (FFTF), the sodium-cooled reactor in Richland, Washington, which has been operating for two years to test breeder reactor components.

"Our calculations," says Dan Ingersoll, "showed that the original shield design for the reactor vessel support shield would allow too high a neutron dose in the head compartment over the reactor cavity. Westinghouse Electric Corporation then redesigned the shield according to our calculations. In 1981, we made measurements which confirmed the correctness of our calculations and showed that the shield redesign worked. As a result, the neutron dose in the head compartment was reduced by a factor of at least 10,000."

ORNL researchers also contributed to the shielding design of the Clinch River Breeder

Inside the Fast Flux Test Facility in Richland, Washington, is a sodium-cooled reactor for testing fuels and materials under normal operating conditions. ORNL provided guidance in the design of the FFTF shield.

Reactor (CRBR), a demonstration plant to be built in Oak Ridge to show that electricity and new nuclear fuel can be simultaneously produced. "Because we couldn't monitor core neutrons accurately due to interferences from neutrons released from stored fuel, we recommended that stored fuel be moved away from the reactor site," states Ingersoll, who adds, "This recommendation was followed." In other studies done for the CRBR, the ORNL researchers performed an analysis to show how neutron fluxes from nuclear fuel moving in and out of the reactor core would prevent accuracy in monitoring of the reactor core and interpreting these interferences. The scientists also conducted several shielding experiments to determine the effectiveness of the breeder shielding design and to verify analytic methods.

ORNL experimenters use the Tower Shielding Facility (TSF) to obtain shielding data. In their experiments, they use neutron and gamma detectors to determine the effect of shielding on TSF reactor neutrons by measuring doses of neutrons coming through various shielding configurations. (Among the ORNL researchers who have been involved with these experiments are Dave Bartine; Cliff Clifford, now at Princeton University; Ingersoll; R. E. Maerker; F. J. Muckenthaler; and C. O. Slater.)

The experimental data are compared to the results of calculations to determine how accurate the calculations are in modeling neutron transport through shielding. When discrepancies occur between the calculated results and data, the analytic methods or nuclear data are improved to reflect the experimental findings.

Over the years, ORNL has relied on experimental data and shielding analyses to improve its two-dimensional DOT code and a three-dimensional Monte Carlo code, called the MORSE code. The most recent versions of these ORNL codes are now being sought by the British, French, and Japanese.

Who Pays Coal Severance Taxes?

Since 1973, use of coal to produce electricity has climbed by 5.5%/year. Because of the adverse environmental effects of extracting increasing amounts of low-sulfur coal for combustion in power plants, several western states felt justified in imposing a severance tax on coal sold to utilities.

In the past few years, politicians and economists have been debating this question: Who pays severance taxes—coal producers or utility customers? Sen. Dale Bumpers of Arkansas, for example, has argued that the people in his state pay the tax—$3/t of coal—on their electric bills. Some economists, however, insist that market forces prevent coal taxes from being passed on to consumers. Who is really right?

To answer this question, economists David Vogt and Bob Shelton of ORNL's Energy Division studied both spot market sales and long-term contracts in which the coal price is allowed to change to accommodate taxes. Then they performed an ecometric analysis of severance taxes and the price of delivered coal.

Vogt and Shelton found that, while coal producers try to add on taxes as part of the final cost, they often cannot do so because market forces will not allow the price to rise. These producers must hold their prices down to compete with other coal producers, including those in states that do not impose severance taxes. Under these circumstances, severance taxes are largely paid by coal producers and not consumers.

"In the short run," says Vogt, "coal producers try to pass the tax through to the utilities, which in turn may pass it onto consumers on their electric bills. But, in the long run, market forces lower coal prices and impel producers to absorb much of the tax. Thus, only some of the tax is actually passed onto consumers, and the rest is paid out by the producer."

Are Utility Conservation Programs Worth It?

Several private and public utilities, including the Tennessee Valley Authority, have launched conservation programs to encourage consumers to use less energy in their homes. In some programs, utilities offer participants money or interest-free loans to be used for weatherstripping, installing insulation, or buying energy-efficient appliances.

The motivation for residential conservation programs has been that saving energy would cost less than the construction and operation of generating plants that would be needed if energy demands were not kept down. Some economists, however, have argued that the recent rise in energy prices alone reduces energy demand enough to head off the need for additional power plants.

Several utilities in Connecticut, Massachusetts, and the Pacific Northwest are now asking ORNL to help answer these questions: Are programs to induce consumers to install insulation or buy more efficient appliances worthwhile compared to merely letting energy prices rise? Is the money saved by consumers and utilities greater than the amount invested in the residential conservation program?

Under the leadership of Eric Hirst of ORNL's Energy Division, engineers, social scientists, and computer programmers have developed a plan to help estimate energy savings from utility residential energy conservation programs. The plan, developed for the Bonneville Power Administration in the Northwest, looked at the energy savings from weatherization, water heater wraps, and shower flow restrictors.

Says economist John Trimble: "We found that the participants in the Bonneville utility conservation program differ from nonparticipants as a group. Participants have more education and higher incomes, own their own homes, live in single-family homes, have more energy-efficient homes, and are more interested in conserving energy. But most important, participants, as a group, consume more energy than nonparticipants. Thus, the kind of people in the group indicate that our sample has a selection bias, which dictates that we use modeling to better estimate energy savings."

The ORNL evaluation seeks to measure two types of energy savings: by participants and nonparticipants, assuming a program for all utility customers, and by participants and nonparticipants, assuming no program.

"We designed our energy models," says Trimble,"to correct for selection biases. One source of selection bias is the fact that participants select themselves to be in the program. Other biases arise because participants are higher energy users as a group, and this influences the types of energy-

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consuming appliances they buy as well as what home weatherization measures they choose."

Tests of the model for the Bonneville Power Administration indicate that the model can estimate energy savings from conservation programs and thus indicate whether the utility programs are cost effective. The model can also help reduce the following uncertainties that have inhibited other utilities from starting conservation programs: an unstable regulatory environment; lack of information on the cost, reliability, and performance of conservation measures; and questionableness of customer response and acceptance.

Besides Hirst and Trimble, other ORNL participants in the study include Energy Division researchers Linda Berry, Richard Goeltz, and Phyllis Zuschneid.

Small Pipe Breaks in Reactors

For years, nuclear safety researchers focused on experiments simulating loss-of-coolant accidents (LOCAs) due to large pipe breaks. Then, after the March 28, 1979, accident at the Three Mile Island nuclear power plant in which a stuck relief valve led to the partial uncovering of the reactor core, many researchers redirected their attention to small-pipe-break LOCAs. The Nuclear Regulatory Commission began to sponsor a number of small-break LOCA studies, including two major series of experiments at ORNL in 1980.

In a small-break LOCA, reactor coolant is gradually lost. If makeup flow from emergency cooling systems is insufficient, the reactor core may become partially uncovered, thus subjecting the core to potentially damaging temperatures. This raises at least two unanswered questions: How is the heat transferred from the partially uncovered core? To what extent do vapor bubbles, formed by boiling water, cause swelling of the liquid-vapor mixture, thereby reducing the amount of core uncovering?

To answer these questions, Tom Anklam and his colleagues in the Engineering Technology Division obtained thermal-hydraulic data on a simulated portion of a reactor core. Using ORNL's Thermal Hydraulic Test Facility, a high-pressure loop containing a bundle of 64 electrically heated rods, they conducted a series of experiments on heat transfer and fluid flow under conditions similar to those in a small-break LOCA.

ORNL researchers found that heat is transferred from the uncovered core primarily by convection and radiation to dry superheated steam. It was also determined that the heat transfer could be predicted using a simple model developed by Anklam.

The researchers also examined fluid flow in the covered portion of the core. They studied the effect of void fraction—the fraction of volume in a liquid-vapor mixture that is occupied by vapor—on the extent of core uncovering in an accident. According to their results, the higher the void fraction of the two-phase mixture, the less the core is uncovered for a given liquid inventory. In other words, the steam causes the water level to be pushed up, thereby cooling the core and reducing the severity of the accident.

Says Anklam, "The experiments showed that void fraction increases with decay power level and decreasing system pressure. We also found that the experimental data were predicted reasonably well by an empirical void fraction correlation developed by H.C. Yeh of Westinghouse."

It was also found that under some conditions, spacer grids—the mechanical structure that holds the rods in a bundle configuration—substantially reduced rod temperatures at and downstream from the grids. In tests where the uncovered core was refilled, the spacer grids substantially enhanced the rewetting of the dry fuel rods.

readers' comments

December 3, 1982

Dear Editor:

There is a small error in the Fall issue of the ORNL *Review*. On page 17, the book *Introduction to Nuclear Reactions* (John Wiley) by me, said to be in print in 1982, was published in 1980. My new book is titled *Direct Nuclear Reactions*, now in press at Oxford University Press.

Sincerely,

Ray Satchler

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Forty years ago, the Graphite Reactor was built as a pilot plant for production of plutonium. Ground was broken February 1, 1943, and the 1-MW air-cooled pile was put into operation nine months later.