Air Quality

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Cover: Is it really a choice between coal combustion and clean air? Resolving the dilemma means learning which emission compounds become truly harmful, how, and at what level of exposure—and then controlling them.

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Sharpen the Technology, Not the Ax

About 500 years ago the quality of the environment around London became unacceptable. This was caused by a rapid growth in population and, with it, a growth in resource consumption beyond the ability of that day's technology to compensate. A specific problem arose from the increased use of soft coal.

The solution appeared simple. The king ordered that anyone burning soft coal was to be beheaded. After a few executions, the impossibility of imposing this solution became apparent. Although the law remained on the books, it was not enforced.

Today, we are nearing a similar juncture. During the 1960s we began to perceive an inadequate concern for the environment in our drive for an improved lifestyle and increased personal income. Perception led to concern, which, in turn, led to action.

With characteristic American zeal, our first response to this perception of smog and subtler forms of air pollution was an objective of "zero discharge." The next step was to translate this ideal into a series of ever-tighter emission standards. More recently, the idea of "best available control technology," or BACT, became the guideline for environmental control.

However, in this issue of the JOURNAL, three articles discuss the need for striking an appropriate balance between environmental improvement and other societal goals, all of which are valued for their contributions to individual betterment and well-being. Another article describes a new R&D facility for air pollution control by the electric utility industry. These articles acknowledge our uncertain understanding of the significant environmental effects of coal combustion. This is not to say that we should wait until all the facts are in before taking action, but rather that we should be cautious and not overreact—following paths that may be counterproductive or from which there may be no return.

Achieving balance among conflicting societal objectives is not and will not be easy. We will never have all the facts. More important, individual perceptions of values will continue to differ. To some, economic growth, with its promise of eliminating poverty, is of prime importance. To others, improved human health is paramount; to still others, undisturbed wilderness. It is this balancing of different values and objectives that the political process must address. Unfortunately, because the fact base is always incomplete and the full accommodation of diverse sets of values impossible, the decisions rendered by the political process often appear inadequate for the importance of the issues.

Even so, we are more sophisticated, knowledgeable, and rational—in short, more civilized—than were the Londoners and their king of 500 years ago. The proof is that no one has yet called, "Off with their heads!"

René H. Malès, Director
Energy Analysis and Environment Division

Alongside the need for technology to increase the U.S. supply of energy—and, especially for EPRI, to improve its conversion to electricity—lies a commensurate need to control by-product effects on the environment.

The need for energy is familiar enough, consistently recognized and pursued for centuries. It was a matter of survival as early populations and civilizations proliferated. Yet those populations were not sufficiently dense, nor those civilizations sufficiently coherent, to need or be able to develop environmental controls. Besides, westward migration from the Fertile Crescent to the Pillars of Hercules, from Genoa to the New World, and eventually from St. Joe to Sacramento, was an ethic and, incidentally, a solution.

But migration is no longer an escape. And no longer can a new fuel divert our attention or obsolete whatever we had begun to learn about its predecessor. The size of our population, the state of our resources, the fact of our economy, and the diversity of our requirements demand that we use many fuel resources—and that we control the environmental effects of all of them.

Today we dominate our atmospheric environment as never before. Dominion carries with it responsibility for an active role in environmental solutions. Certainly this is the practical reality of EPRI's world. It is thus the motivation for the programs and professional spokesmen featured in the EPRI JOURNAL this month.

■ **"Air Quality and Health"** (page 6) reviews the beginnings of modern-day concerted efforts to correlate the composition of combustion products and their effects on human populations. It was a faltering start, as we now know, dealing with more variables and more disciplines than we might have supposed—and thus subject to more error in interpretation. But it laid the groundwork for investigative techniques and programs that will gradually improve our basis for air pollution standards and control mechanisms.

■ **"Setting Environmental Research Policies"** (page 12) is a timely commentary on the professional values and institutional considerations that must guide environmental research, if it is to be nationally effective. The views are those of EPRI's **Cyril L. Comar** and they are couched in his July testimony to a congressional committee. Director of EPRI's Environmental Assessment Department since early in 1975, Comar has dealt with problems of airborne emissions, their toxicity, and their hazards for over 30 years. He is an emeritus professor from Cornell University, where he headed the Department of Physical Biology and was director of the Laboratory of Radiation Biology.

■ **"Coordinating the Attack on Particulates"** (page 16) describes a new R&D facility and a relatively new focus on air pollution—the control of particulate matter, mainly from coal combustion. Fine particulates are seen increasingly to be a vehicle for compounds that can be harmful to the respiratory system. The $4.5 million Emissions Control Test Facility, now operating at Denver, is an EPRI-sponsored test bed for equipment to collect and measure the particulate residue from representative coal fuels.

■ **"Eisenbud: Energy Versus the Environment"** (page 19) acknowledges a rivalry that frustrates today's constructive efforts by both energy and environmental technologists. Merril Eisenbud is an EPRI Advisory Council member who documents—and has himself contributed to—many successful steps toward resolving the rivalry during his professional life. An early participant in the design of controlled laboratory and manufacturing air environments, Eisenbud is now a professor of environmental medicine at New York University. There he candidly discussed issues, problems, progress, and his own opinions with Marie Newman of the EPRI News Bureau.

■ This month's technical feature brings a change of pace. **"Validated Analytic Codes for the Nuclear Electric Industry"** (page 47) have been developed as a specialized tool for power plant design, construction, licensing, and operation. Because these processes are more complex—and more stringent—than their counterparts for fossil-fired plants, computer codes become a necessity. Developing them is beyond the ordinary capability of utilities, and EPRI has therefore come to play a central role on their behalf.

But new codes need to be validated—checked out so that they may be used dependably and their data cited authoritatively in regulatory proceedings. This job falls to **Walter B. Loewenstein,** director of the Safety and Analysis Department in EPRI's Nuclear Power Division. Loewenstein joined EPRI in November 1973 after 19 years with Argonne National Laboratory, where he was director of the Applied Physics Division. During that period he also was successively associate director and director of the EBR-II (experimental breeder reactor) project. Still earlier, Loewenstein served in teaching and research capacities at Ohio State University and Los Alamos Scientific Laboratory.

Coauthor **Jack B. Moore** is vice president of advanced engineering at Southern California Edison Co. and chairman of EPRI's Nuclear Safety and Analysis Task Force. At one time he chaired the nuclear safety task force of EPRI's predecessor, the Electric Research Council. A mechanical engineering graduate of Texas A & M University, Moore has been with Southern California Edison since 1949.

Loewenstein and Moore's article is based on a paper they presented in June at the annual meeting of the American Nuclear Society.

Comar

Loewenstein

Moore

AIR QUALITY and HEALTH

Is it really a question of coal combustion or clean air? The apparent dilemma stems from unknowns: Which compounds are truly harmful, and how are they created by complex chemical reactions in urban atmospheres? Accurate diagnosis and cure can only be an evolutionary product of methodical research.

☐ An EPRI state-of-the-art feature

With the likelihood that we will be depending more on coal as a fuel—in one form or another—in the decades ahead, it is important to understand what effects its combustion products may have on public health. Neither appropriate standards of air quality nor the most effective control technology can be developed without such understanding. Yet, despite generations of experience with coal as a fuel and decades of population exposure to its combustion products, less is known about the health hazards of coal and their control than is known, for instance, about the hazards and control of nuclear energy—which has been with us a much shorter time.

This lack of adequate understanding has been underscored recently by an EPRI general study on the sulfur oxides produced in fossil fuel combustion (EA-316) and by a specific reevaluation of some of the data gathered by the U.S. Environmental Protection Agency (EPA) in its Community Health and Environmental Surveillance System (CHESS) program (EA-450). The latter, in particular, raises serious questions about EPA's conclusion that there is a positive link between sulfur dioxide emissions and asthma attacks. Both studies were conducted for EPRI by the research firm of Greenfield, Attaway & Tyler, Inc.

One important implication of the reanalysis of CHESS data is that there is currently no solid basis for tightening sulfur dioxide emission standards at either the local or national level—at least, not until better evidence is developed. It may even turn out that sulfur dioxide produced in the burning of coal, and especially in the operation of smelters, is not the key ingredient in the exacerbation of respiratory diseases such as asthma. There is some suspicion, voiced, for example, by Cyril L. Comar, director of EPRI's Environmental Assessment Department, that very fine particulates, combined with other agents, may be the

The primate lung is the focus of EPRI-sponsored studies to establish the toxicity of atmospheric pollutants. One invaluable analytic instrument at the California Primate Research Center is a scanning electron microscope, which produced this 2000-times-magnified view of healthy lung tissue from a bonnet monkey. "Craters" are air sacs, known as alveoli. Between them at center is the cross section of a capillary, showing seven red blood cells. The conical organism in the lower right alveolus is a macrophage, one of the "scavenger" cells that, as the lung's primary defense, seek out and engulf foreign matter. *Photo courtesy University of California at Davis*

key to respiratory afflictions associated with air pollution. If that proves to be the case, the outlook for emission control by the utility industry could shift significantly and could perhaps be somewhat simpler than currently assumed.

Some unknown factors

The picture of emissions and their potential health effects is complex. Although it is known that various oxides of nitrogen and sulfur are being emitted, their exact combinations aren't known; and what happens to them after residence or aging in the atmosphere also is not known.

To begin with, the exposure of a particular community reflects to some extent the specific compounds coming out of a power plant stack. But when coal burns, many different compounds are formed, owing to the enormously varying composition of different coals and the varying conditions imposed by different combustion techniques. Conventional coal-fired plants, fluidized-bed combustion, and advanced technologies (like gasification and liquefaction) all yield different compounds.

Moreover, once in the atmosphere, these compounds are modified by meteorologic conditions; in the presence of ultraviolet light or moisture, emission components can react with one another to form still other compounds. Thus, the pollutant compounds on a dry day in Nevada are very different from those on a foggy day in San Francisco or on a muggy day in New York. But not enough is known about the mechanisms and processes of pollution conversion and transport to identify the real causative agents, or chains of agents, that may have impact on public health.

Still, it is well recognized that air pollution in general has deleterious effects. As Cyril Comar says, "Anyone with common sense accepts the fact that high levels of air pollution over industrial areas cause some detrimental health effects, as in respiratory disease. Your eyes water, and so on; you just know that *something* happens." But until specific compounds are demonstrated to be the cause of morbidity or mortality in human beings, there will be no sharply focused and cost-effective way of controlling them.

The major evidence supporting our ambient air quality standards has come from epidemiological studies, from observations of large populations exposed to particularly elevated levels of particulates, sulfur dioxide, and other compounds. It has been reported repeatedly, in London, in New York, in Tokyo, and in other cities, that when these compounds temporarily rose above certain levels, there was an increased morbidity rate, more admissions to hospitals, aggravation of chronic respiratory disease, and measurably higher death rates. Going in the other direction, in the years since London began a serious cleanup of its atmosphere—by cutting the use of soft coal—there have begun to be signs of beneficial health effects. James McCarroll, M.D., manager of EPRI's Health Effects Program, who has been in close touch with British investigators, reports that they are observing a marked decrease in chronic pulmonary disease. Although not yet published, the evidence will be appearing soon.

But general epidemiologic evidence at high pollution levels does not sufficently get to the basic mechanisms, either in the pollution processes or in their specific impacts on the human organism. It does not provide the basis of control technology: where to introduce it, what to control, and with what residual level of hazard to health. Only with such an informed basis can people make the best choices about controls, in terms of both health and cost. As it is now, the best that communities can do is try to obtain blanket protection by setting standards based on the experience of occasional events. The tendency, of course, in the face of undefined hazards, is to tighten general defenses or standards. But only when the specific agents of attack are identified can the most appropriate and truly cost-effective controls or defenses be organized to everyone's benefit.

The CHESS studies

The first massive attack on these questions was undertaken by the federal government. Between 1967 and 1975, EPA carried out its extensive CHESS program—about 80 studies on the possible relationship between air pollution and health—at a cost of \$20–\$30 million. The results of these ambitious studies have been much cited by the press, by legislators, in public hearings, and so forth, although not actually used to set air quality standards.

The CHESS air pollution data included daily measurements of sulfur dioxide, suspended particulates, total sulfates, carbon monoxide, ozone, hydrocarbons, nitrogen dioxide, and suspended nitrates. Monitoring was carried out in different communities around the country, so as to provide comparative data between high-, intermediate-, and low-exposure populations. Concurrent epidemiological studies included observations of acute and chronic cases of cardiac and respiratory illnesses, ventilatory function and acute lower respiratory disease in children, and aggravation of asthma symptoms. EPA's analysis of the asthma data gathered in New York in 1970 and 1971 concluded that there was a positive correlation between sulfates and asthma attacks.

Following publication of the first basic monograph on the CHESS studies in May 1974, the scientific community began to question EPA's conclusions and the methodologies EPA had used during the gathering and analysis of the statistical data. This led to an investigative evaluation of the adequacy of the studies by a subcommittee (chaired by George E. Brown, Jr.) of

Hermetic chamber at the California Primate Research Center will be this monkey's home for perhaps six months, during which the atmosphere of the chamber can be programmed for desired exposures to specific levels of gaseous and particulate pollutants. Goal of EPRI research is to determine the lowest level that produces toxic effects.

the Committee on Science and Technology of the U.S. House of Representatives. The Brown report, issued late in 1976, expressed strong reservations about the quality of the EPA data and expressly questioned their use in support of air pollution standards and regulatory decisions. Nonetheless, even after the Brown report was issued, the CHESS monograph continued to be used directly and indirectly in support of regulatory action, thus tending to confound efforts at arriving at rational control regulation.

In its own independent study of the sulfur oxide–asthma conclusions, EPRI obtained the original data from EPA and subjected it to a careful reanalysis. The new EPRI study shows that the data are not adequate to support any contention that there is (or is not) a correlation between the air pollution factors measured in 1970–1971 and the incidence of asthma at that time, and

Thorough toxicological research involves many disciplines. This is evidenced at the primate center by (1) the body plethysmograph, used by physiologists to monitor and measure an animal's lung capacity and function before and after pollutant exposure; (2) the electronic image analyzer, employed by morphologists to evaluate changes in lung tissue by quantifying the geometric patterns of highly magnified biopsies; and (3) lung tissue culture tagged with radioisotopes, used by biochemists to trace such metabolic processes as the synthesis of collagen—a major structural component—in the lungs of experimental rats.

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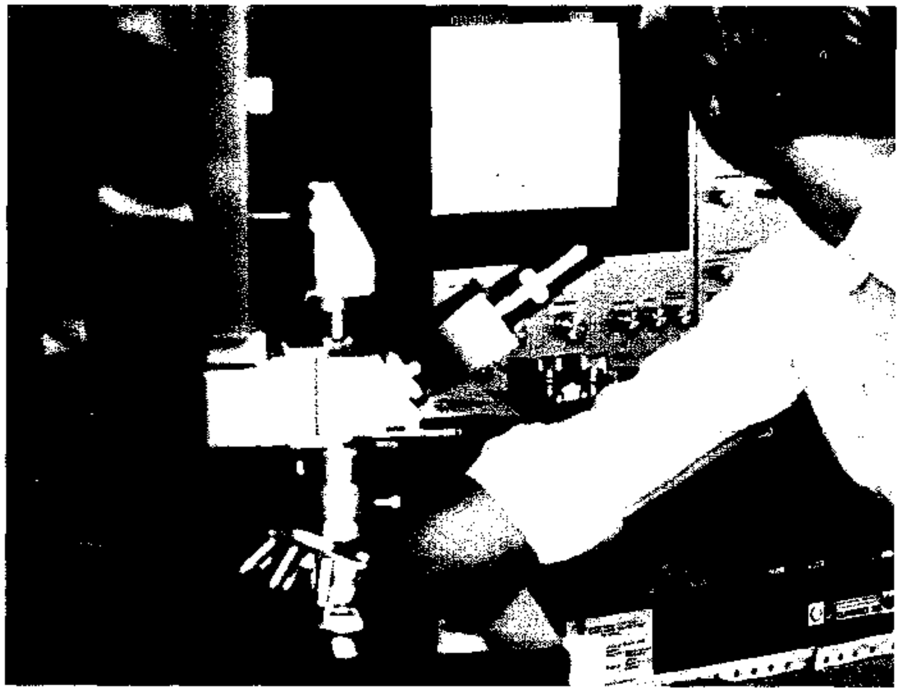

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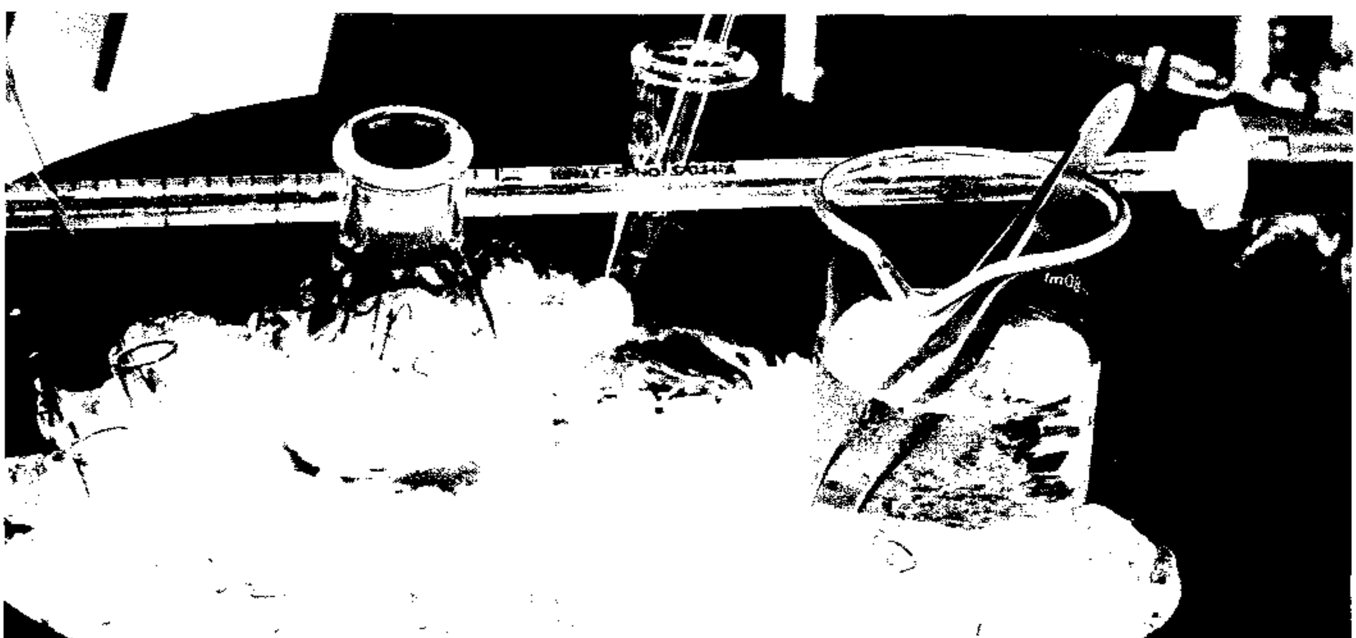


quite specifically that there is no evidence in the data for connecting sulfur dioxide or sulfates with asthma attacks.

What next?

In light of the EPRI findings, it becomes more important than ever to develop definitive, universally credible data on the interactions of air pollutants and health. Because the CHESS studies were massive and pioneering in their scale, it is generally recognized that there were bound to be some mistakes. Also, because the New York City sulfur oxide—asthma data of 1970–1971 constitute only one of many studies, it would be unfair to discount all the data gathered during CHESS, though there is some temptation to do that. "Any judgment," Comar says, "should await detailed reanalyses of other data sets."

Several additional reanalyses by EPRI are in progress, and EPA continues to modify and to pursue its analyses of CHESS and other data, both organizations cooperating in the attack on the unknowns.

EPRI's own state-of-the-art study (mentioned earlier) and its reanalyses of CHESS data are but the preliminary stages of a general research strategy on health effects. These preliminary studies were meant to determine what is known and what is not known, so as to establish unmet research needs. Working on the definition of goals is a committee of the National Academy of Sciences, cosponsored by EPRI, ERDA, and EPA.

Multi-tiered program

What EPRI is structuring is a kind of multi-tiered program, as McCarroll calls it, in which each layer of understanding builds on the information gathered in the stage preceding.

The first stage includes a screening of physical factors that may be relevant to health problems. It will develop a physical inventory of atmospheric pollutants: their names and forms, how to measure and monitor them effectively, and how they are converted during their movement from source to population exposed. This stage will determine the relative contributions of individual major sources to the final exposure.

The next phase, which is just starting, will include a series of animal toxicology studies, each looking at the problem from a different aspect. One study, at the Massachusetts Institute of Technology, will be headed by Dr. Mary Amdur, who has been a leading figure for nearly three decades in the study of sulfur oxides and pulmonary function. Dr. Amdur will work with combustion engineers and physical chemists to duplicate various combustion conditions in artificial furnaces, so as to expose guinea pigs to realistic products of fossil fuel combustion.

A second study, headed by Dr. T. Timothy Crocker of the University of California at Irvine, will be focused on the effects of mixed and "aged" atmospheres (those that have undergone changes typical of actual atmospheric conversions) on different species of animals (rats and beagles). These studies will also emphasize possible effects of pollutants on the developing lung; that is, they will duplicate the effects on lungs that are still in the process of growing and developing to maturity.

The third group, at the University of California at Davis, is setting up a multidisciplinary team at the National Primate Center, working with animals more closely related to humans. Using long-term exposure chambers, this team will even more closely simulate real-world conditions, in which there is continuous exposure of animals to pollutants for periods up to a year. Biochemists will observe enzyme changes in lungs of exposed animals; pathologists will study structural changes; infectious disease specialists will study host defense mechanisms against various respiratory infections; and so on. All three groups will interact closely so that the findings of any one group can help to throw light on the experiments of the others. Out of these experiments should come identification of the pollutants associated with fossil fuel combustion that are potentially of concern to human beings.

Building on these animal toxicology studies, the next stage will extend to humans, using both healthy volunteers and those who have various degrees of pulmonary impairment. The result should be a sharp definition of relevant physiological parameters and the possible types of functional impairment.

But even that information, obtained in closely structured situations, will not be enough to answer the question. At what point should control technology be introduced and to what degree? The final stage will be to embark on a large-scale epidemiological study, armed with the biomedical data that correlate specific exposures of specific compounds with specific effects. These latter studies, Comar foresees, will probably need to be conducted in collaboration with federal agencies, since the resources required to carry them out will be extensive.

How long will it take?

Health effects research differs from some of the "hard" sciences in that it may never be possible to unravel all the unknowns and arrive at ultimate, zero-risk solutions. Moreover, the research is a continuing process because possibly adverse health effects must be delineated for every new energy technology.

However, as our understanding grows in an incremental fashion, it is likely that in a few years we will establish a sound basis for effective and efficient pollution control technologies. In the meantime, we must depend on present air quality standards to provide a reasonable level of protection against irreversible or large-scale harm.

Setting Environmental Research Policies

Policy objectives . . . priorities . . . organization.
Congressional testimony by the director of EPRI's Environmental Assessment Department addresses their relationships to the pending U.S. coal commitment.

Timely counterpoint for this month's state-of-the-art feature was assured late in July when Dr. Cyril Comar of EPRI was invited to testify at a two-day congressional hearing on environmental implications of the increased use of coal. The forum was provided by George E. Brown, Jr., chairman of the House Subcommittee on the Environment and the Atmosphere, which has been involved in the policies and priorities of federally sponsored environmental research and is known for its 1976 report on EPA's CHESS studies.

Excerpts from the charter of the hearing establish its context and purposes: "We are trying to assess whether research on environmental problems related to the President's National Energy Plan is adequate and appropriate. . . . Clearly, there are many problems with burning coal for energy. The Subcommittee must deal with some of the policy implications of these problems, especially two. First, we must address the research necessary to get us the technical information we need. Second, we must address how this information can be made useful. . . . Until these questions are answered, we must not irretrievably commit ourselves—we must leave open the option of a nonfossil energy economy, perhaps nuclear, perhaps decentralized, low (or "soft") technology."

Testifying on July 26 were Bertram Carnow of the University of Illinois School of Public Health and Harry Perry of Resources for the Future, Inc., environmental and economic consultants. On July 27, Comar was joined by David Gates of the University of Michigan Biological Station and Thomas Fox, affiliated with Carnegie-Mellon University and science advisor to the governor of Pennsylvania.

I am Dr. Cyril Comar, professor emeritus of Cornell University and director of the Environmental Assessment Department of the Electric Power Research Institute (EPRI). The Institute, which has been in operation since 1973, was created by all segments of the utility industry to plan and manage an industrywide research and development program and is supported by investor-owned, government-owned, and publicly owned utilities representing 85% of the electric generating capacity of the United States.

Within EPRI it is my responsibility to direct a broad program to assess, develop, and manage environmental and health research to ensure that needed electricity is and will be generated in a way that is environmentally acceptable but at the same time not economically prohibitive. This is in both the consumer and the utility interest. The earlier we can determine what serious environmental hazards exist and make decisions on how to reduce them, the lower will be the long-term cost of the electrical systems.

The budget for this three-year-old program of health and ecological research is about $10 million in 1977 and is to be increased to total about $75 million over the next five years. The total budget for EPRI for 1977 is about $180 million, of which approximately 50% is being spent for technological research and development that can be regarded as environmentally motivated; about $60 million this year is devoted to coal-related research.

In order to be effective, EPRI environmental research must be coordinated with and supplement the research carried out by the various federal agencies. For that reason, over and above others, it is especially important for us that federal environmental research policies be wise, that the research be effective and efficient, and that the results of both federal and other research be rapidly incorporated into the mainstream of regulatory and industrial function for the benefit of society. I am especially pleased that this subcommittee recognizes the importance of the quality of research policy and I appreciate the opportunity to comment on issues as described in the hearing charter.

Need for research policy The level of attention to be devoted to research policy is governed by several factors, including (a) the importance of the problem to the well-being of large populations, (b) the scale of research needed, (c) the complexity of the problem, and (d) the urgency of needed research. In my opinion, because the above factors with regard to the burning of coal have not been carefully considered by the scientific and policy-making community in past years, we find ourselves today unable to cope adequately with the question of whether we should or should not encourage increased use of coal in the longer term.

In the near- and mid-term future it appears certain that even with the most spectacular success in conservation, public acceptance of nuclear power, development of solar and other energy sources, we are going to have to burn as much coal as physically possible. The health and economic well-being of almost all our people will be affected by how good a job we do in burning coal, while at the same time effectively and efficiently reducing exposure to those combustion products that are harmful.

Whether or not we have to change our lifestyle drastically may well depend on how accurately we can estimate the actual harmful effects associated with all energy production, especially coal and nuclear, and how well the public can understand the need to accept small risks as a trade-off for important societal benefits.

The scale of research needed can be gauged by comparison with the effort already expended on the biological effects of nuclear energy—over 30 years of research, under almost ideal conditions, at a cost of about $2 billion. Coal pollutants and their interactions are orders of magnitude more complex and diverse than are nuclear pollutants. Urgency arises because of pressures to convert from gas and oil now and to start building power plants now that will be in operation five to seven years hence.

The general research policy objectives are to ensure that an adequate strategy is developed and implemented, that all segments of the scientific and technical communities contribute according to their capabilities, and that the results are properly used by regulatory agencies and understood and accepted by industry. Following is a brief systematic discussion of the components of a research strategy, with emphasis and opinion on those aspects of the effects of coal use that have presented technical and institutional difficulties.

Problem recognition and identification In these days of great public sensitivity to environmental well-being, there is no dearth of recognized potential problems and therefore little possibility that important problems will be overlooked. The obvious concerns are related to the dissemination of sulfur oxides, nitrogen oxides, particulates, heavy metals, polycyclic organic materials, and radioactive materials. More recent and focused attention is being given to such matters as the specific forms of substances that may be most harmful (e.g., sulfates, sulfites, nitrates, organic materials, and very small particulates); long-range transport of pollutants; effects at low levels; effects associated with coal conversion; acid deposition effects on ecosystems; longer-term effects on climate, particularly from carbon dioxide; possibility of carcinogenic or mutagenic effects; possibility of effects on the young; and relationship to other sources (autos, smelters, paper mills, steel mills, pollutants within the home, and pollutants from natural sources). Related to electricity use, but not to coal, are the possible biological effects from high-voltage transmission.

Definition and priority ranking Once a potential problem is identified, it must be defined. Is it a real problem or is it a nonproblem? For example, there appears to be sufficient knowledge of nuclear matters to conclude that emission of radioactive materials from coal burning is a nonproblem. Is there also experience to ensure the absence of imminent harm of other kinds? Yes. The history of climatic changes over past years; the lack of observed health effects at pollutant levels near existing standards; the lack of observed effects from natural electrical fields, from existing high-voltage lines, and in workers exposed to high voltage—in all these our experience indicates that no immediate action is called for and there is time for long-term research to establish whether lower-level risks do indeed occur.

Of utmost importance is the need to rank identified problems. We must allocate our resources of research manpower and money carefully. There can be no justification for large expenditures of such resources to reduce small risks further when this means that larger risks are left unattended.

In my opinion, the highest priority should be given to research on direct health effects of coal combustion, followed closely by ecosystem effects (primarily the acid deposition problem). Of high priority is the possible severe consequence of carbon dioxide release on climatic change (the "greenhouse effect"). But this is a longer-term problem that can be studied by modeling projections—at least to give upper and lower bounds of changes in global temperatures that could be caused. If this turns out to be of major concern, then fossil fuel combustion will be essentially unacceptable, an important justification for expanding the nuclear and solar energy options. Other important priorities are visibility reduction and possible effects of high-voltage lines, primarily because of public perceptions.

Planning and implementation Research policy should stimulate and encourage the most capable organizations to undertake the needed research. Does the nature of the research indicate that it is best done at a national laboratory, by an industry, or at a university or research foundation?

Specific difficulties that need correcting can be mentioned. Research results from industrially supported organizations have often not been given full weight because of possible bias. EPA research has been regarded as subject to regulatory pressures. ERDA research programs have suffered because of the carry-over of momentum from a previous devotion to nuclear concerns. All these criticisms have some past justification, but corrective actions are being taken and future efforts should be evaluated on their merits.

As examples of the EPRI research strategy on health effects from coal burning, studies are under way in the following eight categories:

□ *Determination of which emitted pollutants are important and their physicochemical form.* The major substances of possible concern include particulates, sulfur compounds, nitrogen compounds, heavy metals, organic compounds, and radioactive materials. Special attention is given to the size characteristics of particulates and the oxidation states of the elements listed.

□ *Establishment of reliable methods for measurement and monitoring of air pollutants.* Unless the pollutants breathed by people are accurately measured, the usefulness of any observed health effects under controlled or epidemiologic conditions will be in serious doubt.

□ *Determination of transfer routes, movement rates, and conversion during transport from the source to the population exposed.* These studies are done on a regional as well as on a local scale in order to be able to predict ambient levels from emission levels. When combined with effects data, the results will permit better decisions on the degree of emission control and the effectiveness of intermittent or supplementary control systems.

□ *Estimation of relative contributions of major sources to population exposures.* It is necessary to know which activities (e.g., power plants, smelters, automobiles, steel mills, paper mills, home heating) contribute which pollutants to the ambient environment. Largely overlooked, a very important factor may be the pollutant levels existing within homes.

□ *Critical analysis of existing biomedical data.* Millions and millions of dollars have been spent gathering biomedical data that to some extent have been either misinterpreted or not adequately analyzed. Careful studies to get as much reliable information as possible from existing data are under way and are regarded as a worthwhile investment.

□ *Toxicological studies in animals.* These are necessary to screen potentially important pollutants to determine which ones should be studied further in human subjects. They are also needed to determine mechanisms of toxicity and establish dose-response relationships.

□ *Human clinical studies.* Selective clinical trials in humans are planned to permit as much extrapolation as possible from animal studies.

□ *Epidemiological studies.* Carefully designed, large-scale epidemiological studies are being done in combination with other biomedical data to provide human-risk assessment, that is, to quantitatively predict effects of air pollutants of concern on human health.

As with health effects, a systematic series of studies is being mounted to estimate the risk of damage to ecosystems from coal-produced pollutants. However, these are not yet as broad in scope as the health effects studies.

Interpretation and application of results

It has been said with some justification that environmental issues are emotional; environmental decisions are political; and environmental solutions are technological and sociological. Recognizing that decisions will remain largely political, it is hoped that research results can make the issues less emotional, the decisions somewhat less political, the solutions better balanced between engineering control and biological understanding and more clearly understood by the public.

It is EPRI policy not to become involved in decision-making or to take advocacy positions, but rather to provide a reliable data base in such a way that it can be used meaningfully by those who do have decision-making responsibilities. It must be emphasized that in the foreseeable future decisions will have to be based on social, political, and ethical considerations in addition to scientific and economic facts (which, in most cases, are so incomplete as to require intuitive judgments).

The basic question is: How can the scientific information that is available—and its limitations—be understood and displayed to the decision maker? Cost-benefit analysis techniques have been used and are available. However, in my opinion, because of inadequate data they are not useful in generating decisions. Rather, their role should be to provide a structured method of bringing discipline to a complex inquiry. As a practical approach to the question, three general principles are proposed:

□ In every environment and health assessment, the risk or the effect of taking a given action in connection with a pollutant should be weighed against the risk or effect of not taking that action.

□ All risks or effects should be expressed in terms of the changes they produce in our existing state of well-being.

□ For all estimates of risks or effects there should be a clear statement of the uncertainties with regard to the assessment that is to be used for decision making.

A basis for risk As an example of the application of these principles, we have compared the health effects from nuclear- and coal-produced electricity. For nuclear power, the highest and lowest values from all the scientific literature available to us range from 0.01 to 0.2 premature deaths among the general population per year per 1000-MW plant. Using the upper value, it is calculated that the added risk per year could be about 1 in 5,000,000. What does this mean in terms of the individual? The 10-year-old, for example, who has the lowest normal risk, could have his or her normal risk of death per year changed from 1 in 3800 to 1.0008 in 3800 as the price for additional electricity generation. This is an 0.08% increase in risk. The 65-year-old could have an increase in risk per year from 1 in 40 to 1.000008 in 40.

For coal, the highest and lowest values from all the scientific literature available to us range from 2 to 100 premature deaths among the general population per year per 1000-MW plant. A personal subjective opinion is that the most likely value would fall nearer the lower bound of the range, and for purposes of discussion, a value of 10 is used. Since the premature deaths from fossil fuel combustion products fall amost exclusively in the older age groups, it is postulated that there would be essentially no increased risk in the younger population and the risk of death per year, for example, in the 55 to 64-year-old group could be increased from 1 in 64 to 1.0013 in 64. For the ages over 65 the increase could be from 1 in 17 to 1.0013 in 17; this represents about a 0.1% increase.

The nuclear data have a much better factual base than do those for fossil fuels, but it is very unlikely that the actual effects could exceed the upper values given. In either case the effects on the normal risks of death are much smaller than those we have come to accept without anxiety from other technologies used in our way of life (transportation, for example) and are most likely much smaller than those that could occur from abrupt shortages of electricity. These comparisons, of course, are not cited as justification for acceptance of unnecessary additional risks. But they should help the public decide the levels of risk it is willing to accept in order to avoid socioeconomic problems that could result from inadequate electricity or from the prohibitive cost of trying to reduce all such risks to zero or to near-zero.

The major practical and technical uncertainty, in my opinion, lies in the lack of knowledge to make reasonable decisions about the nature and extent of control technology needed to protect public health from the larger amounts of coal to be burned over the balance of the century. We must do the research that identifies the real threats to public health and the environment. Simultaneously, we should be doing research and development to make available at lowest cost the technologies to control those risks.

Coordinating the Attack on Particulates

Controlling particulates will cost electric utilities billions of dollars over the next decade. A unique EPRI facility is now supporting and coordinating a broad program to develop better, less expensive equipment for particulate measurement and control.

□ An EPRI program article

According to Owen Tassicker, EPRI project manager for air quality control, "The electric utilities may face expenditures approaching $5 billion between now and 1985 for new equipment to meet particulate emission control standards."

In response to this situation, a facility to help reduce emissions from coal-fired power plants, at the lowest possible capital and operating costs, has been constructed under the sponsorship and direction of EPRI. The $4.5 million Emissions Control Test Facility at the Arapahoe Steam Electric Generating Station of Public Service Co. of Colorado was dedicated in Denver on June 23, 1977.

The coal commitment

Authoritative estimates of this country's recoverable coal range from 120 gigatons (billion tons) to as high as 2000 gigatons. As long as the actual amount of available indigenous coal lies within that range, we are blessed with enough to last even this energy-intensive nation for well over a century.

The problem the country faces is how to use this vast energy resource economically and without unacceptable injury to our environment.

Coal-fired power plants, now producing 45% of the country's electricity, consumed 400 megatons (million tons) of coal in 1975. They are expected to use 900 megatons per year by 1985 and 1500 megatons by 2000.

Technologies for converting coal into clean fuels (gasification, liquefaction, solvent refining, and so on) are now receiving substantial R&D attention. Overall, the progress is encouraging, but major commercial inroads are 15–20 years away.

In the meantime, conventional fossil fuels (oil and gas) are becoming more expensive and less available. With the national demand for electricity increasing at a rate of 5–6% per year, direct burning of large amounts of coal for electric power production during the balance of the century (and probably beyond) is a near certainty.

Range of operating conditions

The purpose of the new test center is to provide the nation's utilities and their suppliers with a major facility to support the development and demonstration of equipment for better particulate collection and measurement. Its objective is to respond to these new operating conditions with smaller and less expensive collection systems that offer improvements in efficiency and reliability.

At the test facility, new techniques for particulate collection will undergo further development and will be tested under actual operating conditions, using different grades of coal. The facility is capable of testing all particulate control devices (and some gaseous) at temperatures between 150°C (300°F) and 400°C (750°F) and at flow rates between 2.4 m^3/s (5000 ft^3/min) and 24 m^3/s (50,000 ft^3/min). Flue gas for the test facility will come directly from a boiler in the Arapahoe station.

"We expect that our work in particulate emission control development could save the utilities, and ultimately electric power consumers, over $1 billion in capital costs, as well as up to $50 million per year in industrywide reduction in precipitator maintenance and outage costs during the next decade," Tassicker explains.

One of a kind

Why Denver? After the entire country was surveyed for a suitable location for the Emissions Control Test Facility, Public Service Co.'s Arapahoe Steam Electric Generating Station was selected for a number of reasons. It offered a large piece of unused land with relatively easy access to a coal-fired boiler. There is a large supply of challenging coal. There are several key technological institutes nearby for engineering and analysis support. Not the least of the considerations, Public Service Co. is most interested and supportive of the project.

Is this facility modeled after similar installations elsewhere? No, according to Tassicker. It is the only facility of its kind in the world. It provides conditions, equipment, and staffing for emission control and test instrumentation demonstration and development that are well beyond the feasibility of individual manufacturers or utilities. It is not seen as a forerunner for similar facilities throughout the country because, as Tassicker says, "This is it for the whole country."

The estimated cost of facility operation and maintenance is $500,000 per year, with an equal amount budgeted for testing. This does not include the cost of the equipment to be tested.

The facility is now 75% completed and will be operational before the end of the year. In one sense, however, it will never be completed. It will be constantly upgraded and modified to accommodate innovations in emission control and

At the dedication (from left): Richard Walker, president of Public Service Co. of Colorado; Walter Piulle, EPRI manager of Emissions Control Test Facility; Richard Balzhiser, director of Fossil Fuel and Advanced Systems Division, EPRI.

testing instrumentation. The facility will ultimately be able to handle three independent tests simultaneously. Major equipment includes two ionizer-precipitator units, three filtration systems, laboratory and control facilities, a computerized hardware control and data logger, and real-time process and performance instrumentation.

Ionizer is first in line

One of the first control systems to be evaluated by the test facility will be the high-intensity ionizer, developed by Air Pollution Systems, Inc., (APS) of Seattle under an EPRI contract to improve precipitator performance. The ionizer, which is expected to be commercially available next year, could save utilities up to 70% in capital expenditures on retrofit installations and up to 30% on new units.

Initial field testing of the ionizer at 1.6 m^3/s (3500 ft^3/min) was conducted for five months at the John Sevier steam plant of TVA under the auspices of the TVA Power Research staff, EPRI, and APS. These tests verified the structural, mechanical, aerodynamic, and electrical reliability of the ionizer and justified the move to more comprehensive evaluation. Prototype testing at the Denver facility will be at flow rates of up to 16.5 m^3/s (35,000 ft^3/min) and under actual power station conditions. These latter tests will produce full-scale design data.

Management and operation

Walter Piulle has been named manager of the center for EPRI. He will be aided by an operating and maintenance staff of five under the direction of Kaiser Engineers. The testing staff, numbering from five to ten depending on the nature of the development and demonstration work in progress, will be provided by the Western Precipitation Division of Joy Manufacturing Co. and APS.

The physical plant and operating procedures for the test facility have been set up for all possible flexibility, according to Tassicker. EPRI will fund much of the testing, usually under cofunding or cost-sharing arrangements with the equipment developer. In other instances, however, where the manufacturers of the equipment have a proprietary interest, they will have access to the facility but will be required to meet the expenses associated with the testing.

Equipment to be tested will be evaluated by EPRI as to the probability of its successful application to utility systems. If it is approved, a test plan will be prepared. The execution of the test plan will be the responsibility of the test facility staff under Piulle. Public Service Co., the host utility, will provide the flue gas, generated by burning the desired grade of coal.

"Our philosophy is to make the facility available to all qualified candidates, to promote optimal utilization, and to encourage innovation and progress within the manufacturing industry," Tassicker concludes. "I should also point out that the facility will be equipped to test new instrumentation for measuring particulate and gaseous species in stack gases, as well as actual control equipment."

THE BASIS FOR NEW TECHNOLOGY

One of the major constraints in burning coal is the necessity of keeping sulfur emission at acceptable levels. How stringent these "acceptable levels" will be, according to federal, state, and local agencies, is not certain. But anticipated SO_2 emission control requirements are encouraging a shift toward greater use of low-sulfur coal (less than 0.5% sulfur content by weight), which requires minimum beneficiation. By the end of the century it is expected that utilities will burn somewhere between 350 megatons and 650 megatons of low-sulfur coal for electric power production.

Burning low-sulfur coal in power plants solves one problem (SO_2 emission control) but creates another. One of the most critical requirements associated with firing pulverized coal in utility boilers is the need to collect and dispose of large quantities of particulates, principally fly ash. A modern 2000-MW station, firing up to 20 kilotons (thousand tons) of coal per day, generates flue gas containing several kilotons of fly ash.

Recent studies and extensive testing point toward particulates as perhaps the major health hazard resulting from coal combustion. These small particles of fly ash can adsorb sulfates, heavy metals, and nitrogen compounds and carry them into respiratory systems. While the overall volume of particulate emissions from coal-fired plants is a major consideration, individual particle size has been established as a critical factor as well. The smaller particles tend to go deeper into the lungs, carrying potentially harmful matter with them.

Traditionally, electrostatic precipitators have been used by utilities to remove particulates. Collection efficiency of such devices reaches as high as 99%, leaving about 25 tons per day to be emitted from the stack of a 2000-MW station. However, regulatory action in recent years has increased collection efficiency requirements of precipitators from 95% to 99.5%. At the same time, the shift toward more low-sulfur coal is generating larger volumes of high-resistivity fly ash, which interferes seriously with precipitator performance. These two conditions have resulted in large and expensive precipitators, whose efficiency and reliability cannot be adequately predicted. New technology is needed to reduce their size and cost.

Eisenbud: Energy Versus the Environment

The key to understanding the energy-environment rivalry is to reconcile the differences between energy production on the one hand and environmental protection on the other.

▫ An EPRI interview

Energy versus the environment—there's no denying that a natural rivalry exists between them. They compete for scarce resources, national attention, and public support, and all too often that rivalry leads to absolute positions on either side of a question.

Too often one is either for nuclear power or against it; an advocate of growth or of no-growth; a soft technologist or a proponent of conventional technology. When the forces clash, the result is often confusion on the part of a public continually bombarded with facts and figures, theories and proposals, claims and counterclaims.

In an era of absolutes, a balanced philosophy is necessary to promote public understanding. Such a philosophy seeks to reconcile the differences between energy production on the one hand and environmental protection on the other. It includes the positive and negative aspects of both. This is the philosophy that is espoused and eloquently expressed by Merril Eisenbud, professor of environmental medicine and director of the Laboratory for Environmental Studies at the New York University (NYU) Medical Center. A former electrical engineer and present member of EPRI's Advisory Council, Eisenbud typifies the balanced approach and his public statements reflect his views.

On the atom: "The greatest challenge in our history confronts us as we decide whether to use this new source of energy to reach ever-higher levels of social accomplishment or to destroy what mankind has created."

On technology: "At a time when human inventive genius is bringing to the ordinary person the intellectual and material privileges and comforts that kings could not have enjoyed a few generations ago, there has developed a tendency to overlook the positive and to condemn technology for its negative effects."

On energy and the environment: "It has been the availability of artificial energy that has made it possible to raise the living standard of people above the mere subsistence level; however, the

"We have raised a whole generation of people who are misinformed about the facts of the environment."

availability of cheap energy has also resulted in an expanding industrial system that has frequently been indifferent to its degrading effects on the environment."

Merril Eisenbud discussed his views on energy and the environment during a recent interview in New York City, his birthplace 62 years ago and the site of many career accomplishments. Eisenbud loves New York City. He delights in showing it to visitors and, indeed, can take credit for many of its environmental improvements over the past decade.

In 1968 New York City established its formal Environmental Protection Administration and Eisenbud was asked to head it. The New York EPA was the first such agency, antedating the federal agency by three years. However, pioneering roles were nothing new to Eisenbud—he had been one of the first industrial hygienists in the country, working for an insurance company in Boston after he graduated from NYU's College of Engineering in 1936. He began by investigating electric hazards and accidents and recalls that he was given an opportunity to design an electrostatic air-sampling device to use in the field. "So I read what was then the world's literature on the subject (only one environmental journal was in existence at the time) and began to specialize in what has since become known as industrial hygiene."

When World War II broke out, Eisenbud found himself "one of just a handful of 'dustologists' in the country" and gained a lot of experience investigating conditions in aircraft plants, shipyards, and certain parts of the atomic energy program. This led to a request from the Atomic Energy Commission (AEC) in 1947 to build a health and safety laboratory. Eisenbud was the first director of the laboratory and retained that position until 1957; he also served as director of the New York Operations office of the AEC from 1954 to 1959. In 1959 he joined the faculty of the New York University Medical Center.

In recent years his studies at NYU have ranged from the health effects of microwaves (which took his laboratory group as far north as Greenland) to the health effects of abnormally high levels of natural radioactivity in Brazil. He is also coauthor of *The Biological Effects of Electrical and Magnetic Fields of Extremely Low Frequency,* a book that is of special interest to the utility industry.

Eisenbud describes himself as "probably one of the last fellows to beat the system," meaning that he was accepted by the academic world, received several honorary doctorates, and was elected to the National Academy of Engineering without actually earning a graduate degree. His reputation as an environmental health specialist has long been established, however, as evidenced by the invitation from New York City to set up its Environmental Protection Administration. The job involved operating three of the biggest departments in the city—the Sanitation Department, the Department of Water Resources, and the Department of Air Pollution Control—which Eisenbud did for two years, while on leave of absence from NYU Medical Center.

He is proud of NYC's environmental accomplishments in air and water quality control and believes that the country as a whole has seen significant improvements in these areas. The problem, he says, is educating the public to understand this.

"We have raised a whole generation of people who are misinformed about the facts of the environment," he contends. "In New York City, for example, the sulfur dioxide (SO_2) concentrations in the air have been reduced 85% since 1967. People don't know that. Newspapers never mention it. Concentrations of carbon monoxide (CO) were very much higher 50 years ago than they are today, basically because coal was being burned in private homes and it produced copious amounts of CO. The quality of our drinking water today is excellent, despite the fact that development of new instruments now makes it possible to detect minute concentrations of toxic

"We certainly need lawyers and politicians in the environmental movement, but there also needs to be technical input, and there isn't enough."

substances of which we were formerly unaware. We take clean water for granted, but this didn't come about easily. It required the expenditures of great sums of money."

Eisenbud believes that the benefits to the nation from electric energy have far outweighed the negative aspects of power generation. He once stated in a speech that "the ready availability of inexpensive electric energy is the most fundamental underlying factor that has made it possible to achieve the benefits of modern life." Some of these benefits are obvious: illumination, heat, appliances. Others, however, are more subtle. Eisenbud reminds people that electricity is necessary for the development and production of drugs that prevent and cure disease and for agricultural chemicals that increase farm productivity and facilitate food storage.

"Our whole life has been made much more comfortable," he says. However, he repeatedly emphasizes that the public often fails to consider the positive factors, and he believes that the electric utility industry should be making greater efforts toward public education. "There is much written about environmental deterioration by power generation, but not enough about the many ways in which energy provides a more hospitable environment," he states. "Air conditioning, for example, made it possible for people to live and work comfortably in parts of the world where it was not formerly possible."

Nuclear power is another example. The public just doesn't understand the issue, he claims.

"They have been presented with a whole series of problems that by and large have already been solved by government and industry, but it takes effort to convince them of this," he says.

According to Eisenbud, the problem is one of continual public education, particularly in the face of what he describes as "a powerful movement in this country and abroad dedicated to stopping nuclear power."

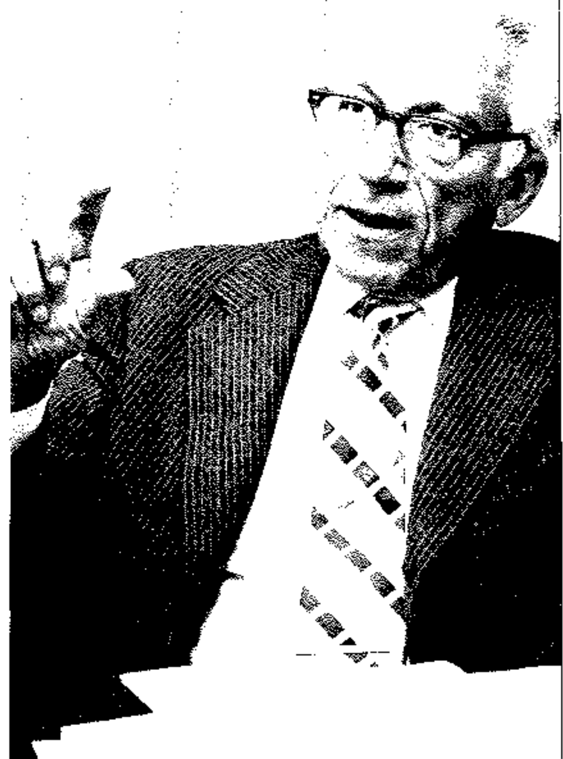
He explains that the public was first concerned about the effects of low-level radiation from nuclear power plants. Author of a textbook, *Environmental Radioactivity,* he recalls that in 1964 he and one of his associates published a paper showing that fossil fuel plants had put more radioactivity into the atmosphere than nuclear power plants had.

"Gradually people began to be satisfied that low-level radiation was not a problem, and then another question arose—could a nuclear reactor explode like a bomb? Well, gradually the public was convinced that this couldn't happen; then the question of economics came up, then sabotage, and now plutonium hazards and waste disposal."

Although he fails to understand concern about the waste disposal issue ("I think the difficulty here is that we have so many options that we don't know which one to pick"), he does believe that government and industry made a serious strategic mistake in their approach to the issue of fuel reprocessing.

"I don't think that the responsibility for fuel reprocessing should have been placed with private industry, and I said this 20 years ago," he says emphatically. "I think that to begin with, our country should have taken the position that fuel reprocessing should eventually be done under international auspices. I argued for this in 1956 when I was senior scientific advisor to the staff of the Preparatory Commission for the International Atomic Energy Agency, but I couldn't even get it on the agenda for discussion. It was too big a bite at the time." Eisenbud believes that the U.S. government should advocate this position today and contends that it should be a major objective in relationships with other countries. "Fuel reprocessing plants present a number of special problems that in my opinion preclude their construction and operation by the private sector," he contends.

He is in favor of continuing the breeder reactor demonstration program, even though he's not absolutely certain that the breeder will be needed in the future. "I don't think we can afford in 1990 or the year 2000 to be in the position of



"I don't see why these industries should expect the government to train people to come into their companies and tell them how to deal with environmental matters."

needing the breeder and not having had experience with it," he says. "Much better to have the demonstration unit and not need it, than to need it and not have it."

Eisenbud doesn't really like to compare the health and safety risks of nuclear power with those of fossil fuels. "We've been pretty sloppy in the way we've handled coal so far," he says. But he does admit that nuclear has been a much more amenable energy source as far as the environment is concerned. Asked whether he would prefer to live in a community powered by nuclear or by fossil fuel, he answered unequivocally, "Nuclear, by all means."

When Merril Eisenbud talks about the environmental effects of energy production, he emphasizes the time element of the problems. "We've got to be conscious that we are dealing with matters that are basically long range in nature," he explains. "Decisions we make today may have serious effects on the environment 100 or 200 years from now." He has criticized Americans in the past for being a nation of cliff-hangers—allowing crises to develop and taking corrective action only just before tumbling over the brink.

As cochairman and one of the driving forces behind the creation of the Committee on Environment and Ecology of EPRI's Advisory Council, Eisenbud helps to guide EPRI's research program on the environmental effects of electric energy production. His committee is focusing on some of the long-term problems that Eisenbud feels should be of concern to the industry. It's not an easy task to pinpoint them, he admits.

"Environmental research programs are really directed at moving targets in the sense that it takes a good 3 years to organize a research effort and probably another 10 years to get the right answers. By that time the problem you thought was important may turn out not to be and others may have come up."

Two long-range problems that concern Eisenbud relate directly to the expanded use of coal by electric utilities in the administration's energy program. Although public discussion has centered on the health effects of sulfur oxides and particulates, Eisenbud believes that these emissions from coal-burning plants can be controlled. Instead, he is concerned about rising levels of another emission, carbon dioxide (CO_2), which is released when coal, or any other fossil fuel, is burned.

"I'd say the greatest potential risk to the environment from greater coal use is that the CO_2 concentrations in the atmosphere may increase to the point of causing global climatic changes. The concentration has been rising for a century, but scientists are not sure what the consequences of the continued accumulation may be. However, the consequences of the 'greenhouse' effect are so serious you don't dare take a chance."

As Eisenbud explains it, "If we're going to go fossil fuel rather than nuclear, the increase of CO_2 is going to continue, and one can project that if it continues into the next century, it may increase the global temperature sufficiently to cause profound climatic changes. Polar ice could melt to such an extent that coastal cities could eventually be under more than 100 feet of water." The catastrophe could occur, he says, with just an extrapolation of the present growth rate of fossil fuel use into the mid–twenty-first century.

Another long-term problem that concerns Eisenbud is how to dispose of the solid waste that will be created by scrubbers installed for sulfur control. "This is going to create an enormous waste problem that may not justify the control," he says. "The sludges will come out of the scrubbers in enormous volumes, enough to fill vast valleys. With what we know now, I don't see how we can find use for even a fraction of it."

It is evident that when Merril Eisenbud refers to environmental problems, he is talking about a broad spectrum of societal issues that affect the quality of life. He does not limit his conversation to air pollution or water pollution—in fact, he places these problems lowest on his list of environmental priorities be-

"There has developed a tendency to overlook the positive and to condemn technology for its negative effects."

cause "they are the only ones for which we have the technical knowledge and the social institutions with which to develop programs of control." He believes that greater priority should be placed on other problems that are basically environmental in nature: poverty, population growth, waste of raw materials, inadequacy of urban design.

"I like clean air, of course, but from the point of view of health hazards, I can't get nearly as excited about cleaning the air as I can about preventing automobile accidents," he says. "We lose 50,000 or so people a year in automobile accidents, and that's an environmental problem. Cigarette smoking is probably costing us 200,000 lives a year, and that's an environmental problem. Heart disease is a major cause of death in this country and a big component of heart disease is diet. People eat the wrong foods. That's also an environmental problem in the broad sense."

The primary environmental problem, he claims, is poverty. "A person living in a half-burned-out tenement without a job or sufficient food doesn't care much about the quality of a trout stream or whether there's a little less haze in the air," he states.

Eisenbud believes that action should be taken to solve the real problems in our environment.

"We've got to design our highways better, put more money into enforcing traffic laws, bear down on drunken driving. We have to design our cities better. People live too far away from their jobs. We want to cut down on fuel use, but we can't because of the way our communities are laid out. We have to put more money into the improvement of substandard housing, and we have to control population growth. We need massive programs of public education on a scale that at least matches the advertising budgets of the cigarette, food, and over-the-counter drug industry. Now, you're not going to change all of this overnight, but these are real environmental problems and people ought to begin thinking about them."

As a pioneer environmentalist himself, Eisenbud admits that he is disappointed with the turn taken by the environmental movement today. He refers to it as an elitist movement in the economic sense—"The people who have the cabins in the woods and who don't want anyone else up there." He says the movement has suffered from a "deprofessionalization," which he deeply regrets.

"We certainly need lawyers and politicians in the environmental movement, but there also needs to be technical input, and there isn't enough. We have a gap between the technologist and the nontechnical politician. They're not communicating well. For instance, I see nothing wrong with the top person in a government agency being a political appointee with legal or government background, but we ought to have a deputy who's technically strong and who will interface with the technical community. Over the past 10 years the technical people have been pushed deeper and deeper into government organizations and they've been badly demoralized. The exodus of highly trained scientists, physicians, and engineers from the federal agencies is a tragedy."

One factor that Eisenbud identifies as contributing to this trend is the lack of technical training opportunities today for people who want to enter the environmental field. "The government, for economy reasons, got out of the training field," he explains. "You used to be able to get an MA or a PhD in these subjects, but you can't do that now, and fellowship programs are just about dead."

This is an area where Eisenbud believes the electric utility industry and other related energy industries have failed. He believes that industry should be pumping money into universities to reestablish fellowship programs and provide training for people to enter the environmental fields.

"The amount of money we're talking about is pretty miniscule," he notes. "We're talking about some tens of millions of dollars, which could easily be absorbed by the chemical industry, the mining industry, or the utility industry. I don't see why these industries should expect the government to train people to come into their companies and tell them how to deal with environmental matters." That's something that the industries should be doing for themselves, he contends.

Eisenbud has nothing but praise for the electric utility industry, however, when it comes to the establishment of EPRI. "It was a great step forward," he says, "and the pattern is being followed by other industries in setting up their own research institutes." He feels that at first EPRI's environmental research program was "too much concerned with short-term problems and not enough with long-term; too much concerned with air and not enough with water." But now he feels that a balance has been attained and that the program is making significant contributions to the environmental field.

Merril Eisenbud has reaped countless honors and served on numerous advisory bodies over the years as a result of his own efforts and contributions to the environmental health and safety of the country. Perhaps his greatest contribution, however, is his ability to stand apart from the struggle that pits energy against the environment and maintain a philosophy that balances the two. In an era of absolutes, Eisenbud's philosophy is wise and valuable.

At the Institute

Alternative Fusion Fuels Explored

The first comprehensive evaluation of alternative or advanced fusion fuels was undertaken recently during an EPRI-sponsored meeting hosted by Commonwealth Edison Co. in Chicago.

The June 27–28 meeting, which was attended by some 75 utility, industry, national laboratory, university, and federal government representatives, focused on the use of fusion fuels other than deuterium-tritium (D-T).

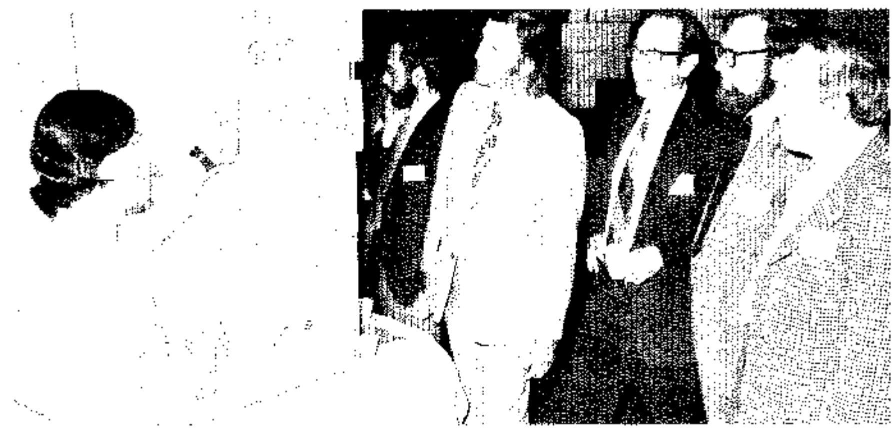
EPRI Fusion Program Manager Bill Gough told participants that EPRI, which has been active in alternative fusion fuels research for utilities since 1974, believes that the alternative fuel option should be explored, since it may simplify downstream technology. Alternative fuels, such as proton-boron-11, do not require breeding of tritium or a complex blanket structure for efficiently capturing high-energy neutrons. Also, unlike D-T, some alternative fuels, including proton-boron-11, produce essentially no high-energy neutrons and may not require remote handling of reactors.

A major problem with alternative fuels, however, is that they require much higher ignition temperatures than D-T, Gough said. While D-T requires an ignition temperature of 50 million degrees (50×10^6 °C), proton-boron-11 needs an ignition temperature of 3000 million degrees (3×10^9 °C).

The meeting was highlighted by several panel discussions on alternative fuels and how they would be applicable to the utility industry. Four working groups examined such aspects of alternative fuels as their role in the utility industry, their technical developments, and the new applications and energy conversion they permit.

The University of Illinois is preparing a report for EPRI on the conclusions of the meeting and the recommendations for R&D programs to better define the future role of alternative fuels.

Oak Ridge National Laboratory staff member Nermin A. Uckan explains the technical aspects of the bumpy torus fusion concept to (from left) EPRI Fusion Program manager Bill Gough; EPRI Fusion Program committee member Bill Worden; and host utility members from Commonwealth Edison Co., R. W. Goodrich and E. J. Steeve.



Swedish Delegation

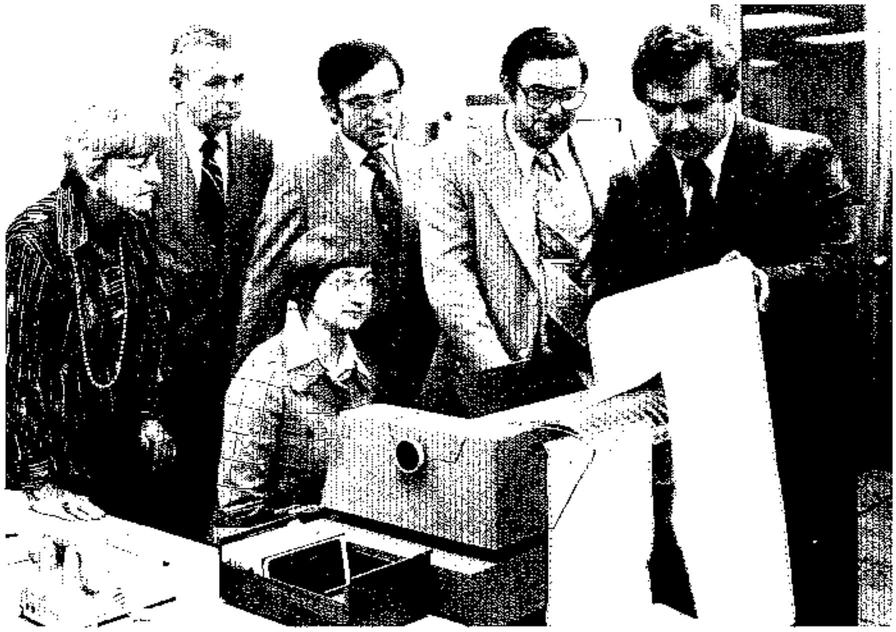
EPRI's Piet Bos (fourth from right) explains the Institute's research program on new energy sources to a group of Sweden's top energy specialists. The Swedish visitors were participating in a series of energy seminars held in three U.S. cities, which was sponsored by the Swedish Embassy, in cooperation with the Swedish Information Service.

Mathematical Models

Many of EPRI's mathematical models, which have been developed to help EPRI plan its internal research program, can be adapted for use by individual utilities. According to EPRI economist Jerry Karaganis, this is important if EPRI is to have industry feedback on the effectiveness of the models.

EPRI and industry representatives examine a model at the computer center of the New York Power Pool. From left are Helen Kackas, Charles Galloway, and Jim Oplinger, from General Electric Co.; Al Adamson, New York Power Pool; and Jerry Karaganis, EPRI. Seated is Nancy Desell of the New York Power Pool.

The model being transferred is the first multiarea model available to utilities. (Multiarea models allow engineers to study the effects of power transfer from different regions.) The model (RP208) is a general-purpose tool that can be used, for example, to assess expansion plans, environmental and economic situations, or the effect on utility systems of new technologies. Further information on the model can be obtained from Jerry Karaganis, EPRI.



Workshop on Nuclear Plant Fire Protection

To assure that all fire safety and fire protection aspects of nuclear power plants are as firmly in hand as the nuclear safety aspects, a workshop of 30 participants was convened June 27–28 at EPRI headquarters. The participants, who were active in fire protection and fire safety programs, were drawn from utilities, insurance groups, research laboratories, engineering firms, manufacturers, the Edison Electric Institute, the Institute of Electric and Electronic Engineers, and the American National Standards Institute.

The workshop explored areas in which EPRI might conduct research to meet utility needs. Much of the existing fire hazard work under way is channeled into specific interests of different groups. For example, the Nuclear Regulatory Commission revises standards for new construction and reviews plant safety and operating quality assurance programs. EPRI believes that the reliable, economic, high-availability operation of safe plants could also require original research.

The conclusions of the meeting are being evaluated to identify EPRI criteria for conducting research and development into utility fire protection.

A two-year EPRI project, which has already been initiated, was reviewed in the workshop. Its goal is to find and qualify for power plant use a noncombustible or fire-retardant motor lubricant, which will replace the petroleum oil used to lubricate the drive motors of main coolant pumps in PWRs. Leaking oil could catch fire and result in service interruptions, even though pumps are isolated in areas where almost all materials are stainless steel or concrete.

Identification or development of a fluid with good lubricating qualities but without the fire risk inherent in petroleum oil would enhance nuclear power plant reliability and safety.

EPRI asked 48 manufacturers and suppliers to nominate lubricants and has winnowed the list of 48 candidate materials to two: organic esters and phosphate esters. (Esters are compounds of acids and alcohols—ethyl acetate is a common example.) Rejected materials were those that were found to evaporate, to decompose or become very viscous at high temperatures, to cause stress corrosion cracking, or to have other disadvantages.

Project Highlights

Savings With Reduced Plant Outages

If outages in large fossil-fired steam power plants could be reduced by about 7%, the nation's electric utilities and their customers might realize an annual savings of $150 million to $200 million.

A recent EPRI report presented this conclusion of a study on the availability of fossil-fired steam power plants, 600 MW or larger. Information for the study came from annual plant availability reports published by the Edison Electric Institute (EEI) and from six regional meetings arranged by EPRI with representatives of utilities operating fossil-fired plants of that size. (*Availability Patterns in Fossil-Fired Steam Power Plants,* EPRI FP-422-SR)

A 600-MW power plant could serve a city of approximately 450,000 people. Although fossil-fired plants of this size or larger constitute a major portion of the nation's baseload capacity (the equipment that operates around the clock on relatively low-cost and plentiful fuels), they experience outages more frequently than plants of other sizes. EEI statistics show that the availability of the larger plants is about 73%, compared with 80% for smaller plants.

The EPRI report states that total outages in the larger plants cost the electric utility industry at least $750 million each year. If availability of these plants could be improved from 73% to 80%, the report concludes, the industry could save $150 million to $200 million annually. The report recommends that EPRI place priority on research to solve problems in the boiler, turbine generator, and auxiliary systems.

Contract Awarded for Geothermal Plant

A $4.6 million contract to San Diego Gas & Electric Co. (SDG&E) was recently awarded by EPRI to help support design and construction of the first commercial-size U.S. power plant to use geothermal hot water resources for electricity production.

EPRI's Geothermal Program Manager Vasel Roberts explained that $1 million of this funding is earmarked for design of the facility in 1977 and early 1978 and that $3.6 million will go to support construction in future years. SDG&E is seeking additional support from the federal Energy Research and Development Administration, which will be necessary to complete construction of the power plant. The total cost of the plant is expected to be around $41 million.

The 45-MW demonstration plant is scheduled to begin operation in mid-1980 near the town of Heber in California's southeastern Imperial Valley. It will be owned and operated by a consortium of utilities led by SDG&E. Other utility owners include Southern California Edison Co., the Los Angeles Department of Water and Power, and the Imperial Irrigation District. Additional support for the project will come from the California Energy Resources Conservation and Development Commission, Nevada Power Co., and Portland General Electric Co. Power generated by the plant from the natural hot water resources in the earth's interior will be sold to the Imperial Irrigation District, which provides electricity and water to the Imperial Valley.

Last year EPRI sponsored a study by The Ben Holt Co. and Procon Inc. that led to the selection of the Heber geothermal field as the best location for a commercial-size demonstration plant. Roberts stated that the project has several major benefits for the utility industry.

"It will help us to resolve major technical and environmental issues associated with the use of geothermal hot water resources," he explained. "It will provide economic experience essential to the assessment of the longer-range potential of geothermal energy, and it will provide valuable information on the reliability and longevity of geothermal reservoirs."

Geothermal energy exists in several forms within the earth's interior. The only form used in the U.S. is dry steam, which produces power in northern California at The Geysers, owned by Pacific Gas & Electric Co.

"Dry steam is the easiest form of geothermal energy to use, but unfortunately it is very rare in the U.S.", Roberts noted. "Hot water—hydrothermal—is the next most attractive form and is probably twenty times as plentiful as steam."

It is estimated that the Heber site has about 400 MW of hydrothermal development potential. That is enough power to serve the electricity needs of 400,000 people.

Research Continues on Compact Transmission Lines

Reducing the space occupied by overhead electric power transmission lines, while increasing the power capacity over rights-of-way, is the objective of a $700,000 project being supported by EPRI.

Power Technologies, Inc., a Schenectady, New York, consultant engineering firm, is conducting the experimental project, which is to provide data for the design and construction of 138-kV transmission lines, using the bundled circuit concept. This concept calls for transmission circuits to be designed with reduced spacing between conductors, employing new insulator technologies.

"Bundled circuits will offer utilities the option of using much smaller structures to transmit equal amounts of power," said Frank Young, manager of EPRI's Overhead Lines Program. "They would also allow the upgrading of many existing lines to higher power capacity levels with little change in appearance."

Young explained that the concept would permit more efficient use of right-of-way space. He also said that esthetic benefits would result from reducing the size of transmission structures, making these structures more acceptable to the public in crowded urban areas. Young added that bundled circuits may offer economic advantages to electric utilities and their customers.

An earlier research effort, also conducted by Power Technologies for EPRI, resulted in the preparation of *EPRI Transmission Line Reference Book 115-kV–138-kV Compact Line Design,* which will be published soon.

Benefits of Electric Heat Pumps

A recent EPRI study, conducted by Westinghouse Electric Corp., was successful in identifying methods for improving the reliability and efficiency of electric heat pumps in the colder climates of the northern U.S. These units have performed well in the milder environments of the South, the Southwest, and the West. (*An Investigation of Methods to Improve Heat Pump Performance and Reliability in a Northern Climate,* EPRI EM-319)

In summer, the heat pump works by removing heat from the air inside a home and exhausting it to the outside. In winter, the device pulls heat from air outside to heat the home.

Heat pumps are very efficient, although they lose some heating capacity as the air outside becomes colder. This decrease in heating capacity, combined with the increased heating requirement at colder temperatures, necessitates supplemental heating, usually in the form of electric resistance heating. Simple oversizing of the heat pump has been economically unattractive.

Since many homes, even with heat pumps, still require electric resistance heating, some utilities need just as much generating capacity—capacity that may be rarely used. If this happens, costs could rise, even though heat pumps can increase the efficiency with which electricity is used for space heating.

The report suggests several ways in which heat pumps could be designed and used to benefit both the consumer and the utility. For example, heat pumps would be more economical to homeowners if they were designed to use less electricity through improvements in the motor, compressor, and other components. At the same time, homeowners could install a solar heating and/or cooling system to augment and improve heat pump reliability and performance.

The report states that heat storage could be charged with off-peak, nighttime electricity. The heat pump would use this heat during the daytime to help mitigate the peak demand problem of the electric utility.

Lack of reliability, especially in colder climates, was the downfall of the heat pump in the late 1950s and early 1960s. For this reason, reliability will be a major concern of any technological improvements and will be a key factor in heat pump sales.

Computer Code for Geothermal Plants

A computer code has been developed that will provide important data for designing and maintaining geothermal power plants, according to Vasel Roberts, manager of EPRI's Geothermal Program.

The code, which was developed by Battelle, Pacific Northwest Laboratories under an EPRI contract, enables engineers to estimate which minerals in geothermal fluids will form deposits. This information is useful in designing geothermal power plants and in preventing operational problems.

The code is employed on a small laboratory computer and can help in predicting acid concentrations, gas pressures, potential mineral precipitants, and concentrations in aqueous solution at temperatures from 25°C to 300°C—the normal range for geothermal brines. The development of the code is part of an EPRI research effort to simulate scale deposition and corrosion over the lifetime operations of a geothermal plant.

EPRI Negotiates 22 Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP243-6	Combined-Cycle Power-Generating System Study	2 months	12.4	Westinghouse Electric Corp. *M. Gluckman*
RP901-1	Numeric Modeling Techniques for Three-Dimensional Recirculating Flows in the Near Field of Cooling-Tower Plumes	1 year	75.0	Envirodyne, Ltd. *J. Maulbetsch*
RP912-1	Corrosion Fatigue of Steam Turbine Blading Materials in Operational Environments	4 years	1329.7	Westinghouse Electric Corp. *R. Jaffee*
RP980-4	Evaluation of Magnetic Fluids for Coal Beneficiation	10 months	89.9	Colorado School of Mines Research Institute *S. Venkatesan*
RP983-1	Continuous Real-Time Assay of Coal	18 months	380.0	Science Applications, Inc. *O. J. Tassicker*
RP987-1	Compilation and Assessment of Solvent-Refined Coal Experience	14.5 months	292.8	Bechtel Corp. *H. H. Gilman*
RP1044-1	Fusion Reactor Remote Maintenance Study	1 year	99.1	Westinghouse Electric Corp. *N. Amherd*
Nuclear Power Division				
RP892-6	Ultrasonic System Optimization Project, UT Systems Development	3 months	21.6	Southwest Research Institute *E. Reinhart*
RP975-2	Nuclear Data File Development and Standardization Activities	2 years	132.0	ERDA *O. Ozer*
RP1027-1	Characterization of Irradiated Zircaloys	2 years	499.7	Argonne National Laboratory *H. Ocken*
Electrical Systems Division				
RP260-2	Compact Transmission Line Research	26 months	699.6	Power Technologies, Inc. *J. Piscioneri/ J. Ballard*
RP931-1	Ice Performance Evaluation of an Ice Release Coating to Be Used on Air Disconnect Switches	16 months	107.0	Allis-Chalmers Corp. *V. Tahiliani*
RP990-1	Application Survey and Evaluation of Advanced Cycle Systems	11 months	205.7	Ebasco Services, Inc. *R. Duncan*
Energy Analysis and Environment Division				
RP862-1	Sulfate Regional Experiment (SURE)	39 months	425.3	Environmental Research & Technology, Inc. *R. Perhac*
RP935-1	Air Quality Monitoring Network Design	7 months	64.9	Illinois Institute of Technology *A. Stankunas*
RP952-2	Supply of Fuels as Influenced by Transportation	10 months	89.8	Manalytics, Inc. *R. Riley*
RP954-5	Integration Initiation Project	1.5 months	6.3	Decision Focus, Inc. *J. Karaganis*
RP1006-1	Analysis of Load Management Experimental Data	3 months	90.0	University of Michigan *J. Boyd*
RP1007-1	Forecasting Model of Regional Electricity Consumption and Peak Demand	4 months	40.0	Charles River Associates, Inc. *R. Crow*
RP1058-1	Trace Organic Compounds in Urban Atmospheres	1 year	75.0	New York University Medical Center *R. Perhac*
RP1060-1	Development and Demonstration of a Lidar System to Measure SO_2, NO_3, and O_3	1 year	275.0	Stanford Research Institute *R. Perhac*
RP1063-1	Variation in Thermal Tolerances of Fish Species	2 years	100.0	University of Illinois at Urbana-Champaign *R. Kawaratani*

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

GAS TURBINES

Future gas turbine power plants will differ from present installations. Many changes are premised on the future availability of coal-derived fuels and the economic payoff resulting from higher reliability and efficiency. To identify the scope, priorities, and timing of these changes, EPRI has drafted an initial plan for gas turbine development, the gas turbine readiness plan, which is aimed at having acceptable units on the market by the time coal-derived fuels become available. Three major gas turbine developments are identified, each supported by projects in progress and to come.

- A reliable gas turbine plant, burning heavy oil (RHOP)
- An advanced gas turbine, burning coal-derived liquids (CDLP)
- A gas turbine for coal gasification–combined cycle plants (GCCP)

The gas turbine readiness plan (Table 1) shows how present open-cycle gas turbine work fits into the overall structure of technical developments expected during the next 12 years.

The plan evolved from an assessment of the future role of gas turbines. A computer analysis of many generation alternatives (EPRI JOURNAL, November 1976, p. 6) identified the probable future application of gas turbines on utility systems: initially, burning a variety of petroleum fuels, then using coal-derived liquids at a higher load factor, ultimately employing coal gasification around 1995 for baseload applications.

Sensitivity studies of many plant economic comparisons to capital cost, fuel cost, and so on, indicate a probable use of gas turbines as described. Defining those actions that must be undertaken to assure that acceptable plants are ready when an economic market exists is the purpose of the gas turbine plan. Or, to put it simply, the readiness plan is how we get from here to there.

Table 1
GAS TURBINE READINESS PLAN

Fuel Type	*Subprogram*	*Objectives*	*Current EPRI R&D Plans*	*When Ready*
Petroleum	RHOP	Reliability Long life in peaking service Dry NO_x Heavy fuel	Operation development group Application survey and evaluation of gas turbine system requirements Parameter monitoring for corrosion control in gas turbines Dual fuel capability optimization Thermal barrier coatings for heavy-oil gas turbines	1984–1986
Coal-Derived Liquid	CDLP	Waste heat utilization Higher temperatures 1427–1649°C (2600–3000°F) Higher pressures 16–21 kg/cm² (230–300 psia) Long life on coal-derived liquids	Water-cooled gas turbine development Ceramic rotor blade R&D Test and evaluation of methanol in a gas turbine system Combustors for coal-derived liquids with high-bound nitrogen	1985–1989
Coal Gasification	GCCP	Integration of gas turbine process with fuels plant Low-Btu combustion New controls Long life in baseload service	Design of alloys and coatings for use in gas turbines operated as part of coal gasification Low-emission combustor for 300-Btu gas from coal Powerton integrated coal gasification plant	1990–1992

Work continues on fine-tuning the plan. In the second quarter of 1977, meetings with ERDA were held and agreement in general terms was obtained on many of the plan's details. Additional meetings with manufacturers were then held to define their participation. This process of communication will continue until all parties, EPRI, ERDA, manufacturers, and utilities, are in agreement with the objectives of gas turbine R&D for the next decade.

Reliable heavy oil plant

According to the plan, the nearest-term gas turbine system is designated RHOP (Table 1). Five projects are under way that will lead toward the achievement of this objective. The basic project is an assessment of present gas turbine reliability and an application study to determine system requirements.

Gas turbine reliability was the subject of an EPRI workshop, held on October 12 and 13, 1976, in Arlington Heights, Illinois, and attended by representatives of 4 manufacturing firms and 25 utility members. Larger gas turbines were found to have availabilities under 90%, and all manufacturers were actively striving for better availability. The principal problems were hot corrosion and combustion difficulties.

As a result of the gap between desired and actual reliability, a users' group was formed, under the sponsorship of EPRI, to analyze data and compile a guide for gas turbine operation. The Operation Development Group met for the first time on May 11, 1977, in Atlanta, Georgia, to assess the operating practices of gas turbine users and to determine methods that would give higher operating reliability.

For the broad overview of current gas turbine use and technology, a contract was signed in May 1977 with Ebasco Services Inc. to perform an "Application Survey and Evaluation of Gas Turbine System Requirements." This project will determine anticipated use by the utilities, history of operation, shortcomings of the present plants, and desired future technology.

This work will provide details of the technical tasks necessary to support the RHOP system and satisfy the schedule in the gas turbine readiness plan. In support of this program, EPRI has initiated research on corrosion control and heavy fuel (No. 6) capability.

The EPRI project on corrosion control at United Technologies Corp. indicates that a significant number of gas turbines are subject to hot corrosion attack. Laboratory tests showed that hot corrosion is enhanced by the presence of chlorides and/or cyclic operation of the turbine. Each of these parameters has a quantitative effect on component life. Under the contract, data will be accumulated on these and other parameters, which will form the basis for a control system designed to operate the turbine under conditions to minimize the cost of electricity. Work on a control system has involved placing a sensor on Long Island Lighting Co. turbines to monitor sodium levels in the air and the fuel. In addition, washing tests on other turbines show some wash cycles are too short to remove all the sodium.

At Florida Power and Light Co.'s Putnam Station, the behavior and economics of heavy-oil and light-oil turbines will be assessed in an EPRI-sponsored study. Two identical Westinghouse gas turbines in a combined-cycle configuration will be run for a full year. One will burn No. 2 distillate oil and the other will burn No. 6 heavy oil. Close supervision and extensive instrumentation will provide data on costs, performance, emissions, availability, and maintenance.

Coating turbine hot-gas-path rotating parts with corrosion-resistant materials is a general practice. Another coating structure called Thermal Barrier shows promise, and a five-year program with ERDA and NASA, Lewis Research Center, has been started. The structure is a MCrAlY-bonded inner coat with an yttria-stabilized zirconia outer coat, which promises to keep base metal temperatures about 93°C (200°F) below the skin temperature. Work commencing in 1977 is aimed at bringing this technique into commercial use by 1981–82.

Coal-derived-liquid plant

The gas turbine readiness plan shows a CDLP system that may use higher-temperature turbines by the mid-1980s. The system necessitates greatly increased cooling capability. The EPRI water-cooled gas turbine development project at General Electric Co. is anticipated to achieve high gas temperatures, with turbine metal temperatures being held below 538°C (1000°F).

A cross section of the water-cooled bucket is shown in Figure 1. Water flows from the turbine wheel radially through the bucket and is collected after leaving the tip. Over 30% of the cooling water is collected, contributing noticeably to the high cycle efficiency of this turbine. Design of the cooling channels has been optimized to keep first-stage nozzle and bucket metal surface temperatures under 538°C (1000°F).

Testing has demonstrated that inner water passages have acceptable erosion, with a deposition rate of less than 1 mil per year. Tests of heat transfer from channel to metal surface have been used to check the design calculations.

A rotating shrouded rig has been run at gas temperatures up to 1650°C (3000°F). This unit is scaled from the full-size turbine and is constructed with some transparent path (for unfired operation) so that water collection phenomena may be observed.

Additional tests will commence soon on a ceramic-lined conbustor. The ERDA-sponsored high-temperature turbine technology program has progressed to a complete hot-gas-path design, based on EPRI data.

High-temperature turbines require better materials, and the potential of ceramics is being explored by two EPRI projects. Westinghouse Corp. has been evaluating ceramic buckets made of Si_3N_4. This has led to a complex design problem involving ways to attach the brittle ceramic airfoil to a metallic disk.

The Si_3N_4 ceramic strength is subject to degradation by grain boundary impurities. Strength clearly needs improvement to justify the current efforts to overcome the design difficulties of working with brittle materials. The strength problem has been documented by Columbia University, showing that tensile creep properties are significantly greater than bending creep. Westinghouse recently found that impurities in heavy oil attacked a ceramic-coated (ZrO_2) metal bucket, which had produced satisfactory test results with lighter oils.

With regard to the fuel tolerance of the CDLP gas turbine, a methanol-burning test has been authorized by EPRI on a Southern California Edison Co. turbine plant. Also under way is a project to develop combustors for coal-derived liquids with high-bound nitrogen and low hydrogen/carbon ratio. This is being performed by Westinghouse Corp. and will assess performance with H-Coal derivatives, solvent-refined coal products, and Exxon Donor Solvent fuels.

Gasification–combined cycle plant

The long-range gas turbine subprogram (GCCP) centers on the integration of coal gasification with the combined cycle. Only basic work is currently sponsored; however, studies on RHOP and CDLP subprograms will provide usable designs for the GCCP gas turbine.

The design of alloys and coatings for gas turbines in a coal gasification plant is an EPRI-sponsored project at United

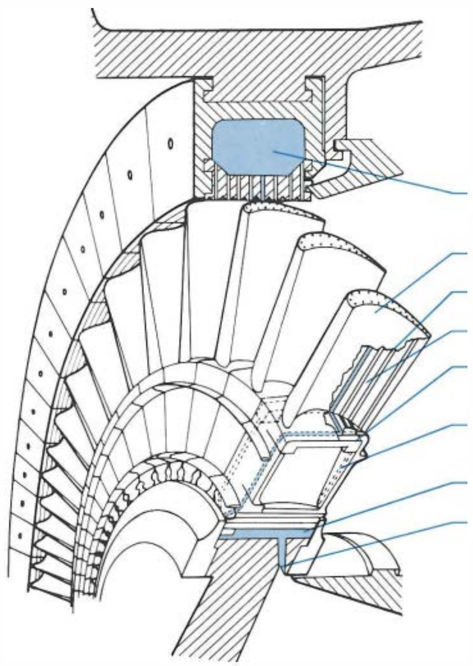


Figure 1 Cross section of the water-cooled gas turbine, revealing the coolant passages and water collection system. The machine permits high gas temperatures, with turbine metal temperatures below 538°C (1000°F).

Figure 2 Ceramic heat exchanger, designed for closed and semiclosed gas turbine cycles. Ceramics allow higher temperatures than state-of-the-art heat exchangers.

Technologies Corp. Progress in evaluating particulate erosion was described in the EPRI JOURNAL, August 1977, p. 48. Tentative conclusions indicate that turbine parts are eroded by particulates larger than 2μm diam and that frequent washing or cleaning is necessary to remove adhering smaller particles.

The heart of a GCCP is the gas turbine combustor. EPRI-sponsored work with United Technologies (at a Texaco facility in Montebello, California, that can produce 300 Btu/scf gas from coal) is expected to show that the full-engine NO_x emissions goal of 75 ppm or less is practical.

EPRI is participating in the integrated coal gasification test facility at the Commonwealth Edison Co.'s Powerton Station. Fixed-bed gasifiers, fuel gas cleanup, a gas turbine, and a heat recovery steam generator will be operated as an integrated plant. The purpose will be to gather the information on integrated control and environment that is necessary for the design of a full-scale plant.

The open-cycle gas turbine program under way supports all three efforts defined in the readiness plan. It consists of 12 separate projects, 5 of which apply to today's plants.

Indirect-fired gas turbine cycles

In order to be competitive with the thermal efficiency of open-cycle systems, closed (or semiclosed) gas turbine cycles require exchange of heat at temperatures above 816°C (1500°F), where current metal technology is not considered adequate. A project with Airesearch Manufacturing Co. of California is aimed at designing a ceramic (siliconized silicon carbide) heat exchanger. The configuration shown in Figure 2 operates with the hottest air passing across the tubes (from left to right) and with the turbine air flowing through the manifolds and U-tubes. A module of 25-MW capacity would measure about 7 m × 2.4 m (23 ft × 8 ft) and contain 746 tubes. Fins on the tubes would offer a 40% weight reduction and a 60% tube/joint reduction.

Slag buildup that bridges the tubes is a problem. The material adheres readily to the tube surface but does not react with it. Tests employing thermal shock, 15 different materials, and larger spacings failed to dislodge the slag. Even an air lance removed only part of the slag. Cleaning by melting the slag at temperatures of 1260–1370°C (2300–2500°F) will work. Testing continues on structural and bending properties. *Program Manager: V. Cooper*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

SOCIOECONOMIC EFFECTS

Federal and state agencies are requiring more and more information about the social and economic effects of new energy projects before approving them. This has prompted the utility industry to give special attention to these effects.

EPRI is pursuing a research program responsive to the technological needs of the industry while considering possible socioeconomic effects from the application of new technologies. Through EPRI the industry is seeking information and guidance that will enable it to satisfy regulatory requirements as well as fulfill its obligations to society.

An EPRI planning study of the socioeconomic impact of power generation has been undertaken as a step in this direction (RP936). The contractor, Environmental Systems Dept., Power Systems Co. (Westinghouse Electric Corp.), reviewed past and present regulations and attempted to predict future regulatory trends. A state-of-the-art review was completed of socioeconomic research on this subject. Based on research results and projected needs, goals were identified that might be included in an EPRI research program.

A workshop was held in June to review and redefine research goals. It was attended by the contractor, consultants, and utility and EPRI representatives. Among the recommended goals was the development of handbooks to aid in assessment, mitigation, and monitoring of socioeconomic effects.

One such handbook would serve as a reference and procedural guide for the utility industry in assessing socioeconomic impacts. Its use could lead to cost-effectiveness in the industry by providing acceptable, standardized procedures for carrying out impact evaluations capable of withstanding the scrutiny of regulatory review.

Such a handbook would be prepared from existing knowledge and methodology as well as from new information developed from other EPRI research. This might include development and validation of techniques for accurately predicting movement and distribution of the work force in connection with a utility project and for deriving valid economic multipliers for new energy development projects. Current techniques for estimating these factors tend to yield highly uncertain estimates. The validity and reliability of socioeconomic impact assessments will increase only when the procedures for determining important variables are improved.

The handbook would also include a description of established and emerging techniques for conducting a sociocultural impact assessment. Current social impact assessment focuses on demographic and socioeconomic effects. The accompanying sociocultural effects—influences on community structure and lifestyle—have not been studied as thoroughly. Recent interpretations of environmental laws and regulations, influenced by public participation in the regulatory process, reflect a move toward consideration of sociocultural effects. Individuals, groups, and institutions are increasingly demanding that government and industry identify and alleviate sociocultural impacts. Given this trend, a set of guidelines for carrying out sociocultural (as well as socioeconomic) impact assessments of utility projects would be useful to the utility industry. EPRI is planning to prepare such guidelines. *Project Manager: Ronald Wyzga*

ENERGY TRANSPORTATION

Transportation, transmission, distribution, and storage constitute essential links in supplying energy to the consumer. To understand the economics of energy supply, the role of these functions must be clear. Although historically they have received less attention than energy production and conversion, the characteristics and cost of these services and their future evolution will condition, if not limit, the applicability of various conversion technologies. Transmission and transportation technologies also play an important role in determining interregional differences in the energy-economics picture.

In the president's recent energy proposal, it was suggested that coal production and consumption might be more than 1×10^9 t/yr by 1985, a substantial increase over current rates of coal shipment. Because transportation is a crucial component of the delivered price, it is important to understand the nature of future costs of alternative modes of transportation.

Due to possible large increases and shifts in demand for transportation by the energy sector, historical data alone may not be adequate for forecasting. For this reason EPRI's research in energy supply and storage emphasizes engineering process-level detail in the transportation of energy. This process-level detail can be aggregated to regional and national levels and combined with historical information to provide more accurate forecasts of prices and quantity.

An initial study of the capability of the existing transportation network to handle increased amounts of coal determined areas of research (RP437). The study used an aggressive coal production and consumption case and routed the required shipping over the existing transportation network. Measures of capacity were applied to certain key bottleneck regions, defined by such physical barriers as mountain ranges in the case of rail and locks in the case of waterways. The results of the study show that waterways are being used to near capacity and a significant increase in shipments would require additional capacity. The total rail network can handle the large increase in coal shipments, but in some areas the traffic might be so heavy that circuitous routes would be required.

In a follow-on study of cost models for fuel transportation (RP866), these localized problems are being investigated in more detail, aided by process models that characterize engineering details of the transportation component. Given the desired level of shipments, input prices, and the current state of technology, the models develop costs of coal shipments between any two points. The models consist of three basic components: cost models for unit and through-train shipments of coal over existing rights-of-way; river, intercoastal, and lake shipments of coal by barge; and loading and unloading facilities at coal source and sink location, and intermodal transfers of coal. These process models will be used to examine some of the possible bottleneck regions defined in the previous study, with emphasis on the determination of the capacity of various railroad links and examination of the incremental cost of more circuitous routes.

A third study on supply of fuels as influenced by transportation will develop costs of other modes of transportation for coal and other fuels (RP952). In the case of coal, independent parameters of transportation costs of coal by slurry pipeline will be developed. In addition, an examination of electrified railroads for short hauls will be made. For oil and gas, the technology of the pipeline network will be studied in detail. This will provide the Energy Analysis and Environment Division with information to assess such future possibilities as the technical difficulty and the investment required to reverse pipelines to transport large volumes of Alaskan oil to the Midwest. The nature of the oil tanker fleet will also be examined—its loading and unloading technologies will be looked at from the standpoint of costs, likely developments, and environmental problems. A similar examination will be made of the liquid natural gas tanker fleet, with some consideration given to the transport of methanol.

Components of these studies will be used in other research efforts of the Supply Program for forecasting future utility fuel supply and future market possibilities for electricity.

The results of this subprogram will be examined in the context of the entire energy supply picture. For example, such results will be combined with existing knowledge concerning transmission and distribution of electricity to determine what research might be needed for the analysis of alternative modes of conversion of coal in the ground to electricity for the consumer. The investment requirements will be determined and possible investment strategies examined. In-house research consists of improving methodologies used in the specifications of the transportation network and gauging uncertainties in these methodologies. *Project Manager: Rex Riley*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

SYSTEM PROTECTION

Progress continues to be made on fault current limiters (FCLs), last reported in the July-August 1976 issue of the EPRI JOURNAL (pp. 27–28). Five projects were under way at that time: four were of the switched-impedance type and one of the tuned-circuit type. One of these projects, with Phoenix Electric Corp., has been completed (RP324). Another, with Westinghouse Electric Corp., will be completed early next year (RP654).

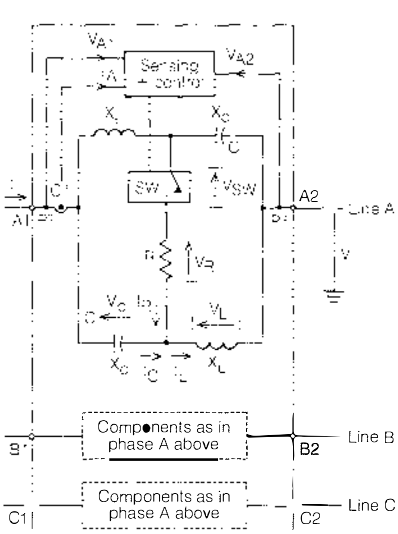
The Westinghouse project developed, through analytic methods and model tests, the necessary design information for the FCL shown in Figure 1.

In the load-carrying state, the switch, SW, is open and the two parallel L–C branches represent essentially zero net impedance to the 60-Hz load current. In the event of a fault, SW can be closed and a resistor, R, inserted between the two branches, which then act more nearly as damped parallel resonant circuits. The net impedance of the circuit with SW closed is X^2R, where X is the 60-Hz impedance of the reactive components. The impedance is resistive so that after the off-set is damped, the fault current is in phase with the voltage. There are an infinite number of values for X and R for any given net impedance. The project has developed means to optimize these parameters as well as predict performance of the circuit.

An FCL of this design could be made mostly with available devices, so very little component development is needed. However, size and cost evaluations may preclude the use of this system in many applications.

The protective device developed by Phoenix, a current-limiting conductor (CLC), was completed last year and a final report is now available (EL-286). In principle, the CLC is a linearly extended solenoid. Its inductance increases as the air gap between the armature and the core is reduced by magnetic forces resulting from the fault current.

Figure 1 Basic circuit connection for controlled impedance fault current limiter.



In addition to the design formulas that were developed for the CLC concept, an analysis was made of the nonlinear interaction of the electric circuit, magnetic circuit, and mechanical system. Both steady-state and transient solutions were obtained.

A fractional CLC device was first built and tested, with the results confirming earlier analysis. Then typical designs for distribution circuits were developed and the costs were calculated. The conclusion reached was that considerable further development would be required to reduce size, weight, and cost to acceptable levels.

Of the remaining projects, the one at Gould, Inc., appears to be the most practical for near-term development into a usable device (RP281–1). The objective is to build a 69-kV switched-impedance prototype FCL, test it at full power, and then conduct an extended field trial. Southern California Edison Co. will provide the full power test facility and the trial installation site. The device is expected to be installed in 1979 at Antelope Substation, Lancaster, California, in the low-voltage leads of a 220/69-kV transformer bank. Eventually the utility will require one FCL for each of three banks at this location.

It has been determined by Gould engineers that a relatively simple di/dt sensor with time delay will adequately sense faults as well as discriminate between faults and other surges. Analysis indicates that if the di/dt remains above a threshold level for 0.4 ms or longer, then the fault cannot be the result of switching surges or lightning.

A model di/dt sensor has been built and laboratory tested. It will be installed at Gould's Heberlein High Power Laboratory, and its behavior under different fault conditions will be observed. Then the sensor will be installed at the Antelope Substation for a trial period before installation of the FCL.

The bypass switch poses the most challenging engineering problem. To open a 2000-A switch and successfully commutate current into a parallel circuit in 1 ms is a formidable task. Ordinary circuit-breaker mechanisms, with their long linkages, are immediately defeated by the speed of sound in the linkage material. Accelerations of several thousand times that of gravity are required. Several novel approaches to this switching problem have been analyzed thus far, and the decision has been made to develop a bypass switch using a chemical propellant actuator. This design promises to be the most simple, reliable, and cost-effective.

Resistor materials have been evaluated thoroughly. Present thinking is that either solid Nichrome wire or hollow wire filled with compacted magnesium oxide arranged in a low-inductance configuration offers the most cost-effective choice.

The commutating silver-sand fuses have been designed, but the overall packaging must await completion of the bypass switch.

There are two approaches to the development of FCLs that use vacuum technology. One, at State University of New York at Buffalo (SUNYAB), is a spin-off from the space effort (RP476).

This project is developing a unidirectional, coaxial vacuum device with a small axial cathode and a large annular anode. When a plasma is established in the evacuated space between the electrodes, negative ions and electrons flow from the cathode to the anode with a very low voltage drop. A magnetic field can then be applied around the anode, which will cause a sharply increased voltage drop in the plasma. Under some conditions the current can be maintained with high voltage drop and thus absorb energy in the anode. In this mode, the vacuum device is the current-limiting impedance. In another mode, the magnetic field can be applied in such a way as to force a current to zero and commutate the current into a parallel impedance. Tests up to 10,000 A and 10 kV are being conducted. Plasma diagnostic experiments are also being conducted to determine the physical mechanism and controlling parameters of the phenomenon.

The project is scheduled to continue through 1978 at SUNYAB (RP993). At least two industrial laboratories are interested in investigating this device, and EPRI is anxious to start a complementary industrial project when funds are available.

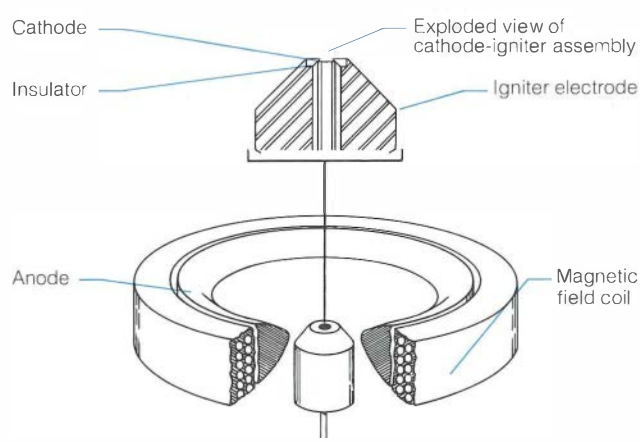
The second vacuum project is at Westinghouse (RP564). The commutating vacuum switch being developed has been tested in both a demountable chamber with viewports and in sealed vacuum envelopes. High-speed movies of the plasma behavior have been made with currents up to 15,000 A. Currents up to 10,500 A have been successfully commutated into a parallel capacitance-resistance network by sealed devices.

We expect to test 12 device configurations in 1977 and early 1978 to determine limits of performance for the concept. The published report covering the first year's work is now available (EPRI EL-393).

The device uses forced instability of vacuum arcs to insert an impedance into the line during the fault current rise. The current-limiting technique is summarized in Figure 2.

After a fault is sensed, the contacts are separated rapidly and the transverse magnetic field applied when the contacts are sufficiently far apart (~2 cm). Application of the magnetic field causes an increase in arc voltage, which forces current into the parallel capacitance-resistance network. This development has the conceptual advantage of combining means in a single bidirectional device.

Figure 2 Vacuum arc device capable of limiting or interrupting the flow of current.



Industry interest in FCLs was demonstrated on September 28, 1976, when 120 engineers and scientists representing 26 electric utilities, 14 manufacturers, 7 universities, consulting engineers, ERDA, two national laboratories, and EPRI gathered at SUNYAB for a symposium sponsored by EPRI's Substations Program. The symposium included three days of intensive discussion of arc physics, power circuit breakers, and FCLs. Participants came from all parts of the United States, as well as from Canada, Brazil, Austria, and Switzerland. Almost all were active investigators in these fields or were responsible for application of such equipment to power systems. Equal amounts of time were allotted to presentations of prepared papers and to open discussion. A few participants prepared written (but not verbatim) accounts of the discussions, and these are published in the proceedings, together with the prepared papers (EPRI EL-276-SR). *Project Manager: Richard Kennon*

Switching devices

The continued increase in the use of shunt reactors and series and shunt capacitor banks at EHV transmission levels has produced a need for switching devices specifically designed for this application. While this switching operation is beyond the capability of conventional disconnect switches, the use of costly circuit breakers is equally unacceptable. Therefore, a project was initiated with Westinghouse to develop a family of switches to cover applications through the voltage range of 242–800 kV (RP655). These switches should be capable of interrupting 600 A of inductive or capacitive current. The switches will be restrike-free, or will include resistors to reduce overvoltages.

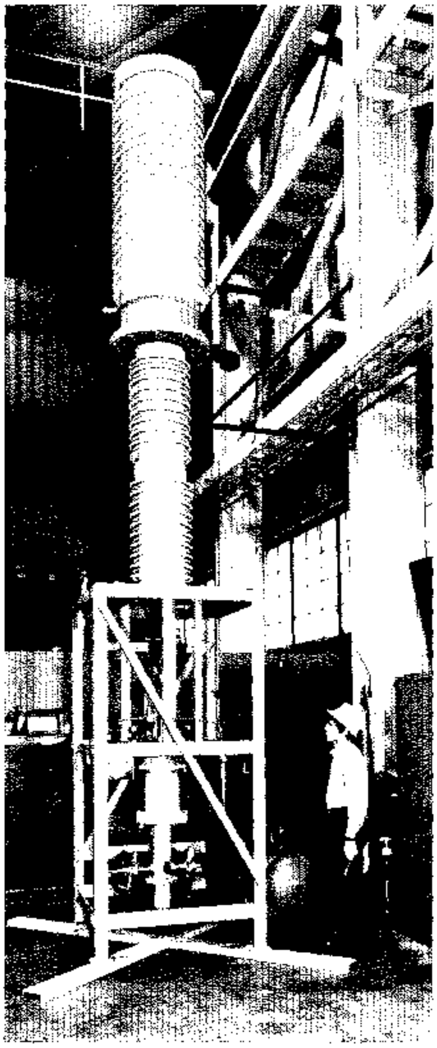
Through a recently completed test program, the performance of a 230-kV interrupter switch was verified (Figure 3). As anticipated at the start of this project, a satisfactory 230-kV design has been established with a single-break interrupter.

The last phase of this project is scheduled to be completed in early 1978. It will result in a three-phase capacitor switch that will be installed on the 500-kV system of the Bonneville Power Administration, which is both cosponsor and host utility for this project. In addition to meeting the original interrupting and closing requirements, this switch will incorporate 75-ohm, preinsertion resistors to curb the switching surges. *Project Manager: Vasu Tahiliani*

OVERHEAD TRANSMISSION

Recent cascade failures of transmission lines have focused attention on the need for a better understanding of unbalanced longitudinal loading. Very little work has been done on the dynamic aspects of broken conductors, ice release, and other impact loads applied to transmission structures. An EPRI project with the University of Wisconsin and GAI Consultants will involve

Figure 3 Prototype 230-kV reactor/capacitor switch.



actual field tests on an existing transmission line (RP1096).

The unique opportunity for field testing of a transmission line was made possible when Wisconsin Power and Light Co. decided to dismantle an existing 130-kV line to make room for a new 345-kV line on the same right-of-way. Approximately seven miles of double-circuit lattice towers will become available to EPRI for testing before the new line is built. In this project, longitudinal loads will be created by breaking line components. Then, a series of mechanical measurements will be made, leading to a determination of dynamic impact factors. At the conclusion of the project, the towers may be tested to destruction. This project should increase the understanding of dynamic loading on both structures and foundations. One possible development would be a recommended procedure for multiplying static loads by a series of dynamic impact factors to predict the dynamic loads caused by unbalanced longitudinal loading. *Project Manager: Mike Silva*

Insulating materials

Improved outdoor insulating materials can affect the cost and reliability of substation and transmission equipment. The cost of porcelain often accounts for 25–35% of the cost of substation equipment and transmission lines. EPRI felt that a two-pronged attack on porcelain cost was desirable.

One procedure was an attempt to improve the mechanical characteristics of porcelain without increasing the energy input requirements or the cost of the material (RP424 and RP427). It appears that reasonable success is being achieved in both projects.

The other approach was to develop a possible replacement for outdoor porcelain that employed lower energy inputs. This resulted in an acceptable substitute material at reduced costs (RP480).

An attempt was made to employ high-alumina electrical porcelain, which is used in utility applications where high strengths are required and a price premium can be justified (RP424). This contract is with I-T-E Imperial Corp., which is a manufacturer of this type of porcelain, and with Alfred University, which is well recognized for its expertise in electrical porcelain development. The high alumina electrical bodies have a mean flexure strength of 124,106 kPa (18,000 psi), compared with approximately 75,845 kPa (11,000 psi) flexure strength for the more common quartz electrical porcelains.

The alumina electrical porcelain is in the final stages of development and shows very promising characteristics. The development work indicates that there is an almost inverse relation of strength to flux particle size, which is attributed to the improved opportunity for uniform dispersion particle phases in the glass. Quartz is more detrimental to strength characteristics than is porosity because of the nature of cracks surrounding quartz particles. Agglomerates of Al_2O_3 effectively reduce the amount of particle phase dispersed in the glass and also act as a large pore in the system. The results of this data indicate that by using the proper raw materials and preparation techniques, a mean flexure mechanical strength of 303,369 kPa (44,000 psi) on 50% Al_2O_3 samples fired at 1138°C (2080°F) can be achieved in production kilns. Individual specimens within this development group broke at 379,212 kPa (55,000 psi). These strengths are equivalent to spark plug insulator bodies, which contain over 95% Al_2O_3 and are fired at 1760°C (3200°F).

Using the same materials and preparation techniques, a body containing 20% Al_2O_3 yielded a mean strength of 185,120 kPa (22,500 psi) at a firing temperature of 1138°C (2080°F). This strength compares favorably with a conventional commercial porcelain, which requires twice the Al_2O_3 at a firing temperature 933°C (200°F) higher. Prototype electric insulators have been successfully produced with these new materials and production techniques. Work is now progressing on the attachment of metal fittings to the porcelain. A final report will be available on this project soon.

McGraw-Edison Co. has a contract to develop a higher-strength electrical porcelain, using the standard quartz electrical porcelains as a starting point (RP427). The standard quartz-based electrical porcelains have a mean flexure mechanical strength of 75,845 kPa (11,000 psi) and are those most commonly used in the electric industry. The McGraw-Edison investigators felt that these standard formulations could be improved without increasing the cost of the material or firing temperatures by properly using fluxes to control the mullite crystals in the porcelain body. The purpose here was to actually grow mullite crystals in a rod-like form during the firing process, which would act as reinforcing rods in the porcelain. This would prevent crack propagation and thereby substantially increase the strength of the porcelain.

The investigators developed very sophisticated instrumentation that allowed them to rapidly evaluate a large number of formulations with respect to the mullite crystal sizes and configurations and their relationship to the final porcelain strength. This activity has resulted in at least a doubling of electrical porcelain mechanical strength, using standard production equipment and firing temperatures. Prototyping is now under way to adapt production techniques to the new formulations and to design final equipment to take advantage of the higher mechanical strengths now being achieved. It is expected that these higher strengths will reduce the cost of these materials. The final report on this project will be available shortly.

An attempt was made to develop a possible substitute material for porcelain in outdoor applications at reduced cost (RP480). The basic material originally investigated was a polymer-impregnated concrete that had been used extensively as a construction material in outdoor applications in the U.S. and many foreign countries. The material showed exceptionally good weathering capabilities, high mechanical strength, and low cost when compared with electrical porcelains. The polymer-impregnated concrete proved to have exceptionally good dielectric properties, far superior to those of porcelain. However, problems were encountered in production techniques and surface preparation, relegating this material (at the present stage of development) to specialized applications.

The project was therefore redirected to the development of a closely related substance. This new material, commonly called polymer "concrete," is actually a combination of 90% silica and 10% polymer, which acts as a binder. It was determined that the new material requires very simple processing techniques and provides an exceptionally good insulating material that appears suitable for outdoor applications. The material exhibits mechanical strengths in excess of standard electrical porcelains and a dielectric strength twice that of standard electrical porcelain. It can be produced at half the cost of porcelain and requires no firing during its processing. Laboratory testing indicates that it exhibits mechanical and electrical characteristics superior to either of its individual components in bulk form, is easily molded into a wide variety of shapes, and provides excellent surface characteristics. Field testing is expected to begin during the latter part of 1977. The final report, *Development of Polymer-Bonded Silica* (Polysil) *for Electrical Application* (EPRI EL-488) is now available and a prototype bushing is shown in Figure 4. *Project Manager: Robert Perry*

Figure 4 Polysil bushing prototype exhibits high strength, good dielectrics, and low cost. It appears suitable for capacitive grading designs at high voltages.

Compact transmission lines

Four papers based on EPRI-funded research on compact transmission lines were presented at the IEEE Power Engineering Society 1977 Summer Meeting in Mexico City, July 17–22.

A comprehensive series of experiments and analytic studies demonstrated the feasibility of constructing 138-kV lines with phase spacings as low as 1 m (3 ft). Furthermore, this offers the potential of improved esthetics, reduction of required right-of-way space, and line cost economics.

A fifth paper presented at the IEEE Summer Meeting discussed the power-frequency contamination performance of long, vertical insulator strings. This paper was based on research performed at Project UHV. *Project Manager: Joe Piscioneri*

UNDERGROUND TRANSMISSION

An attractive alternative to full-scale testing of cable systems can be effected through accurate modeling. Even the accelerated tests at Waltz Mill are costly and require years to complete. For this reason, the University of Illinois (UOI) has been carrying out model studies for cable systems (RP7853). UOI has also addressed modeling of diffusion chambers (entrance regions for cable oil) and electrohydrodynamic (EHD) pumping.

Models of numerous cable systems, including one designed after the forced-cooling facility at Waltz Mill, now accurately reflect thermal and hydraulic performance. In this area, UOI is presently working on the effects of cable snaking and twisting on pumping-power requirements and pressure drop–friction factors. Methods of optimizing systems for heat transfer and pump efficiency (pressure drop) are also under consideration.

The model studies for the EHD pump are progressing favorably. A model of a segmented electrode conductor has been fabricated and is currently being tested (Figure 5). Although not optimized from the standpoint of efficiency, the remainder of the model testing will concentrate its efforts on optimization of pump parameters. The segmented electrode produces the traveling electric field inside the fluid (dielectric) that pulls the molecules of oil down the pipe. Using a 20-kV potential, a

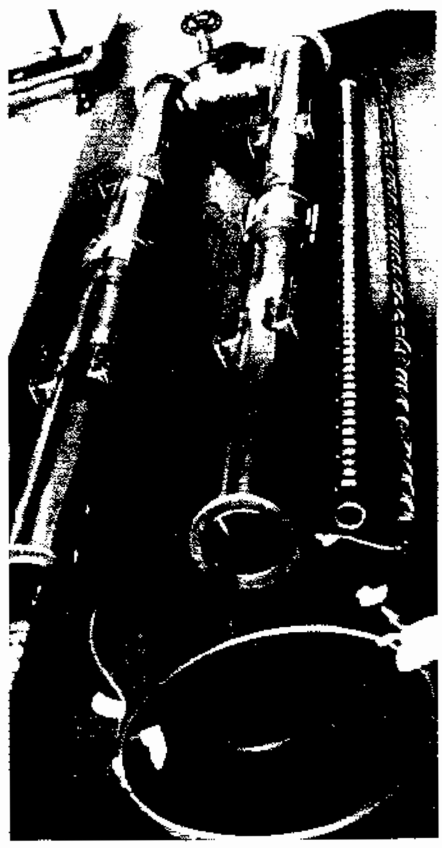


Figure 5 Closed-loop test components for model-testing of the traveling wave conductor in an electrohydrodynamic pump.

flow rate of 6 mm/s with a modest temperature gradient has been achieved. These experiments are designed merely to prove that the concept works with dielectric cable oils.

A new type of conductor, which uses a periodically varying impedance in the insulation to produce a traveling field, is expected to do a more effective job of pumping fluids. This new conductor will be smaller in diameter and could easily be pulled into the return pipe of the existing Waltz Mill forced-cooling facility for testing. *Project Manager: Tom Rodenbaugh*

Water jet cutter

The water jet cutter mentioned in the June issue of the EPRI JOURNAL has passed some significant milestones (RP7860). To optimize jet performance, numerous tests have been conducted on concrete with aggregate material to determine optimal striking angle, pressure, standoff distance, width of cut, and number of passes needed to cut 20.32 cm (8 in) of concrete. These tests have been performed at 5.07 MPa (35,000 psi) and 6.09 MPa (42,000 psi). At these pressures, cutting passes may be made at the rate of 19 cm/s (7.5 in/s) and 20.3 cm/s (8.0 in/s). Advancement rates can be increased and the number of required passes (~20) to cut a kerf in 8 in of concrete can be decreased by keeping the nozzle standoff distance 0.64 cm (0.25 in) throughout the entire cut. This means an advanced nozzle control system to guide the nozzle into the cut as it is being kerfed. The design rate for cutting three slots is 0.61 m/min (2 ft/min), which should be achieved. This means in an eight-hour day, approximately 292 m (960 ft) of concrete could be cut. *Project Manager: Tom Rodenbaugh*

Cable materials

The basic materials employed for transmission cables today are fundamentally identical to those in use more than 40 years ago: paper tape insulation based on cellulose, combined with oils. Although cable reliability has improved over the years due to improved manufacturing methods, materials have not really advanced significantly. In fact, dielectric losses have precluded their use in self-cooled modes beyond the 550–765-kV level. The need to decrease dielectric losses has resulted in the development of several synthetic polymer composites in the past. The results to date, however, have been discouraging, primarily because of mechanical deficiencies in these new materials.

With this in mind, EPRI has initiated a program with the National Bureau of Standards to investigate the possibility of employing synthetic polymeric tapes as cable insulation (RP7864). The objective of the program is to develop a screening program for porous polymers that have potential in high-voltage cable applications. The approach to be employed by NBS will be to

- Review the state of the art of cable making technology
- Develop a list of pertinent property requirements for insulating tapes
- Identify suitable test methods and procedures for evaluating such tapes, including the development of innovative test methods that may be required
- Perform laboratory work on suitable systems to demonstrate feasibility of the approach
- Develop a guide and manual

In view of the number of synthetic polymeric materials being developed and suggested to EPRI for cable applications, this program will produce a master screening program. It is anticipated that new cable-development projects may result from this initial screening program. *Project Manager: Bruce Bernstein*

SYSTEM RELIABILITY

When major electric power systems are interconnected through ties of relatively small capacity, low-frequency intersystem oscillations are likely to be troublesome for some operating conditions. Spontaneous intersystem oscillations, which have occurred in the western and some midwestern states, attest to this aspect of system behavior. The long distances that separate concentrations of generating capacity in those systems also separate many individual generating plants from other machines, so that localized, poorly damped, higher-frequency modes of oscillation also exist. The potential for unstable oscillations must be considered in planning the bulk generation and transmission system, in designing control systems for turbine generators and dc line terminals, and in system operations.

Present practice depends almost entirely on time-domain simulation for large system analysis, with computing costs that are relatively high. Information is received in a form that is often not suitable for study purposes.

A recently completed project by Westinghouse resulted in an alternative to time-domain simulation for damping studies (RP744). This alternative involves the use of a linearized system model and the calculation of only those complex conjugate eigenvalues that are most intimately related to generator rotor motions. The final report, *Frequency Domain Analysis of Low-Frequency Oscillations, Phase I* (EPRI EL-485) is now available.

The models required for power system dynamic simulations and transient analyses are growing larger and more complex as power system interconnections are becoming more significant. Dynamic simulation studies already require a significant portion of the computer capacity of electric power utilities. Thus the industry is faced with conflicting requirements:

- Reduce the cost of dynamic simulation without sacrificing reliability
- Allow for more realistic simulation through the use of more complex models

A project recently completed by Boeing Computer Services improves both the efficiency and the reliability of today's simulation and gives the capability to perform the more complex simulations of tomorrow (RP670).

The approach taken in this project was to identify the fundamental characteristics of dynamic power system models and to relate these to candidate numerical methods. The performance characteristics of the methods were analyzed for efficiency, reliability, and stability. Finally, extensive testing was performed on selected test cases to identify the best computation procedures for solving power system dynamic problems. Smaller cases were tested first, and testing on the larger cases is now under way.

A diagnostic transient stability program has been developed for the testing. This program not only performs transient stability computation but also analyzes the performance of the numerical methods. The diagnostic program, developed entirely on this research project, is presently being documented for use by other researchers.

Conclusions of this first phase include specific recommendations of integration methods, step-size requirements, and algebraic solution methods that will provide the basis for a new industry standard transient stability program. Recommendations are also included that will be useful for improving the efficiency and reliability of existing stability codes with minimal changes required. The final report, *Power System Dynamic Analysis, Phase I* (EPRI EL-484) has been published. *Project Manager: Paul Anderson*

Dynamic equivalents

The increased size and complexity of the power system models, in conjunction with the need to perform simulations over longer time periods, require large blocks of computer core and long computation times to perform transient stability studies. As a result, the cost of running transient stability studies represents a sizable expenditure by utilities.

The major accomplishment of two research projects has been the development of a computer program that can reduce a large-scale system model into a smaller equivalent model for use in transient stability studies (RP904, RP763). The program has been demonstrated and validated, using large-scale representations of both the eastern U.S. and the western U.S. interconnected systems.

The computer program accepts a normal transient stability data base as input and develops an equivalent that is a fraction of the size of the full power system representation, while adequately retaining the dynamic characteristics of the full system. The reduction process requires only a fraction of the time needed for a transient stability simulation. Test results have shown that the reduced dynamic equivalent is two to six times more efficient than the original system in terms of computer running time and memory storage, thereby offering significant savings in computation costs.

The dynamic equivalents program has the capacity for handling 2000 buses, 3000 lines, and 350 generators. The program also incorporates 2 synchronous machine models, 6 excitation system models, 10 prime-mover governor models, 3 power system stabilizer models, and a nonlinear load representation. As such, the dynamic equivalents program will be large enough for use by most utilities in the western U.S. A six-month extension of the project will attempt to enlarge the program to handle 5,500 lines and 10,000 buses for use by any system in the U.S. The final report, *Development of Dynamic Equivalents for Transient Stability Studies* (EPRI EL-456) is available. *Project Manager: Tim Yau*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

PERFORMANCE OF VARIOUS THORIUM FUEL CYCLES IN LMFBRs

Use of thorium-based fuels in LMFBRs has recently been receiving uncommon attention due to the shift in emphasis away from the plutonium fuel cycle intended by the new administration. Application of these fuels in LMFBRs has been studied off and on over the years. Recent EPRI studies of the performance of a variety of thorium-based fuels in LMFBRs and their results for the important fuel cycle and safety parameters are the basis of this report.

Thorium can be employed in the form of a mixed oxide, mixed carbide, or metal alloy fuel. A review of the physical property data for mixed ThO_2 fuels indicates that these fuels have similar and somewhat better material properties than those for the mixed uranium oxides. The thermal and irradiation performance of the mixed-ThO_2 fuels should therefore be very similar to that of the UO_2–PuO_2 fuel, for which an extensive data base exists. Similar statements can perhaps be made about the comparability of the thermal and irradiation performance of mixed-thorium carbide to that of mixed-uranium carbide fuels.

Thorium in the form of metal alloys (Th–U, Th–Pu, Th–U–Pu) was studied on a laboratory scale some years ago (*1*). Some key material and thermal property data (e.g., phase diagrams, conductivity, density, fabrication potential) were established. Some limited sample irradiation testing was performed (*1-3*) to establish the swelling rates, and one transient-heating-to-failure experiment (*4*) was carried out. Results of these limited investigations indicate that thorium metal alloys have reasonably high melting temperatures, limited swelling rates, and mild failure modes. These results also indicate that the thorium metal alloys have significantly better material, thermal, and irradiation performance than the uranium metal fuel currently employed for EBR-II, which has achieved consistently high burnups recently (*5*). The candidacy of the thorium metal alloys as fuel for fast reactors is therefore considered attractive.

The fertile material in the radial blanket contributes significantly to the total breeding gain but does not materially affect the core Na-void Δk. Therefore most of the cases that were considered employed depleted UO_2 or uranium metal blankets; however, some ThO_2 and thorium metal blankets were considered. Reactor control in the metal alloy cores is like that in EBR-II (i.e., fuel out and absorber in, while no control is included in the calculations for the oxide fuel cores).

The results of fuel cycle analyses using the REBUS code for the equilibrium and first core cycles are presented in Table 1. The reference PuO_2–UO_2 core is Case 9, and the comparison shows that there is a definite penalty in breeding ratio with the ThO_2-based fuels. This disappears when the metal alloy fuels are employed as fuel. The ^{235}U-fueled cores (both oxide and metal alloy) lead to a converter instead of a breeder reactor. In these calculations the core fuel was discharged at 9 at% average burnup after three cycles, and the radial blanket, after eight cycles. It is seen that the breeding ratios for the equilibrium cycle are somewhat lower than those for the first core cycle due to fission product buildup, except for the ^{235}U-fueled systems where ^{233}U produced helps in increasing the breeding ratio.

Na-void Δk and Doppler coefficients for the starting composition of the first core cycle were determined through the CITATION code and are also shown in Table 1. It is clear that the outstanding feature of the thorium-fueled core is the very marked reduction in the positive Na-void coefficient (in fact, it is negative for whole core voiding) and the sufficiently high Doppler coefficient, both of which play key roles in strengthening the arguments against the occurrence of energetic core dispersal during the initial phase of the hypothetical accidents considered in licensing appraisals.

Preliminary calculations were performed to assess the thermal performance of both the oxide and the metal alloy fuels. The heat ratings (kW/ft or W/cm) for both of these fuels could easily be as high as those for the UO_2–PuO_2 fuel.

Many options possible

It appears that there are many possible options for use of thorium-based fuels in LMFBRs. The more attractive options are with metal alloy fuels: the Th–U–Pu ternary alloy core with uranium or thorium metal blanket exceeds or matches the breeding performance of the UO_2–PuO_2 system, while providing a negative Δk for whole-core voiding and a sufficient Doppler coefficient. Such a system could have an integrated fuel reprocessing plant, as was the case when the EBR-II was first operational, and the entire facility could be readily safeguarded. The PuO_2–ThO_2 core with ThO_2 blanket having a breeding gain of $\sim$ 0.11 could serve as a ^{233}U-producer from a plutonium charge. If the aim is not to use plutonium at all, then only a converter reactor is possible; however, the bred ^{233}U is more valuable than the charged ^{235}U in both LWRs and LMFBRs, which enhances the apparent conversion ratio.

There is at present no irradiation experience with full-length thorium metal alloy or oxide fuel elements in a fast reactor environment. There is also very little experience with the back end of the thorium fuel cycle. It is clear that a great amount of development and demonstration work is necessary before the utilization of thorium-based fuels in LMFBRs can become a reality. *Program Manager: B. R. Sehgal; Project Scientists: Ching-Lu Lin and J. Naser*

Table 1
RESULTS OF FUEL CYCLE CALCULATIONS
(total power = 2500 MW [thermal])

Case No.	Core Fuel Material	Radial Blanket Material	Core Volume (l)	Cycle Length (d)	Total[a] Core Fissile Mass (kg)	Ratio of Fissile[b] Production to Fissile Absorption	Extra Fissile Material Production (kg/cycle) ^{233}U	^{235}U	^{239}Pu	^{241}Pu	%ΔK for Na[c] Voiding (whole core)	Doppler[c] Coefficient (whole core)
1	ThO_2–$^{235}UO_2$	ThO_2	6795	223	3920.5	0.84	477.1	−588.5	—	—	—	—
2	ThO_2–$^{233}UO_2$	ThO_2	6795	225	2569.2	1.05	38.7	—	—	—	—	—
3	ThO_2–$^{239}PuO_2$	UO_2	6795	228	2958.7	1.15	434.3	—	−341.6	3.8	—	—
4	Th–^{235}U	Th	5630	262	4010.0	0.96	584.0	−619.4	—	—	—	—
5	Th–^{233}U	Th	5630	261	2645.3	1.14	108.0	—	—	—	—	—
6	Th–^{233}U	U	5630	265	2584.7	1.21	−44.1	—	210.1	—	—	—
7	Th–^{233}U–^{239}Pu	U	5630	280	2695.7	1.31	335.8	—	−104.9	1.7	—	—
8	Th–^{233}U–Pu[d]	U	5630	271	2502.6	1.34	266.8	—	31.3	−48.9	—	—
9	UO_2–$^{239}PuO_2$	UO_2	6795	256	2950.8	1.23	—	−31.3	165.1	7.6	—	—
1	ThO_2–$^{235}UO_2$	ThO_2	6795	223	4202.0	0.83	563.5	−685.8	—	—	−1.89	−0.0078[e]
2	ThO_2–$^{233}UO_2$	ThO_2	6795	226	2611.7	1.08	59.8	—	—	—	−1.98	−0.0107
3	ThO_2–$^{239}PuO_2$	UO_2	6795	228	3084.7	1.21	587.1	—	−460.7	2.1	0.62	−0.0093
4	Th–^{235}U	Th	5630	262	4384.4	0.94	707.5	−755.3	—	—	−2.52	−0.0068[e]
5	Th–^{233}U	Th	5630	261	2738.5	1.17	134.4	—	—	—	−2.58	−0.0086
6	Th–^{233}U	U	5630	265	2674.3	1.22	−37.7	—	216.3	—	−2.25	−0.0087
7	Th–^{233}U–^{239}Pu	U	5630	280	2817.4	1.36	458.6	—	−191.6	1.0	−0.52	−0.0084
8	Th–^{233}U–Pu[d]	U	5630	271	2610.6	1.39	358.8	—	−11.54	−66.4	−0.73	−0.0089
9	UO_2–$^{239}PuO_2$	UO_2	6795	256	2988.2	1.30	—	−40.7	211.5	3.3	3.25	—

[a] Beginning of cycle values.
[b] Middle of cycle values.
[c] These values apply to the start of the first core cycle.
[d] Contains LWR-generated plutonium.
[e] Values are those of thorium only.

PREDICTING LIFETIME OF TURBINE ROTORS

A two-year project to increase the reliability of steam turbine rotors by advancing in-service nondestructive evaluation techniques and interpreting the significance of their results in an analytic lifetime-prediction system is underway at EPRI (RP502). The contractors are Southwest Research Institute; Battelle, Columbus Laboratories; and Westinghouse Electric Corp.

Primary project emphasis is placed on ensuring the integrity of the forged turbine rotor spindle. The project will also evaluate the lifetime-prediction system for 1950-vintage rotors manufactured from air-melted chrome-molybdenum-vanadium steel.

The continuing search for a quantitative explanation of the rate of subcritical crack growth in the Gallatin No. 2 IP rotor (which during a cold start on June 19, 1974, suffered a rotor burst of the combined IP–LP section while at ~ 3400 rpm) has led to the tentative conclusion that the mechanism was primarily cyclic stress rupture, augmented by plane strain conditions and the microstructure of segregate bands. Linkup between clustered defects by fatigue crack growth appears to be less significant than ligament rupture by yielding or creep cavitation. Another possibility under investigation is that the intergranular fracture is a reflection of ferrite grain boundary embrittlement rather than stress rupture.

Test results from a project sponsored by the Metals Properties Council (MPC) indicate that under certain combinations of creep interspersed with reversed strain cycling, the rupture lifetime is reduced by about one-third the static value and the low cycle fatigue lifetime to between one-tenth and one-hundredth of the steady cyclic life. These results are considered significant as the specimens are of normal bainitic microstructure and contain a very low density of inclusions.

Specimens from this project have been made available by MPC and are undergoing further metallographic evaluation. Further evaluation of Westinghouse test specimens from the Gallatin rotor indicate that the segregated material fractured exclusively transgranularly in a short-time creep test but that the imposition of one reversed strain cycle per day resulted in intergranular fracture similar to the subcritical crack zone in the rotor in a comparable length of time.

Research by England's Central Electricity Generating Board (CEGB) has been focused on the mechanics of linkup between inclusions by localization of inelastic deformation. This process is known to be accelerated by hydrostatic tensile stress, but quantitative measurements are not available. Therefore, a few creep-fatigue interaction tests with blunt-notched wedge-opening-loading specimens of segregated Gallatin rotor material are planned to investigate the effect of triaxiality.

The CEGB also makes use of postyield, inelastic fracture mechanics in assessing the significance of cloud- and cluster-defect indications. While linear elastic fracture mechanics applies to the growth of cracks from single defects, it appears that rapid linkup in arrays of high (~ 20%) volume fraction of small flaws can occur rapidly by inelastic shear, whereas negligible crack extension is predicted by linear elastic fracture mechanics. For this reason, tentative criteria have been developed whereby the onset of localized shear can be predicted as a function of inclusion (or pore) size and spacing, local stress, and temperature and stress state. When one of these criteria is met, the flaw is assumed to spread to the boundaries of the cloud or cluster.

The generation of fracture mechanics data has been completed for the Joppa No. 3 IP rotor, except for the long-term cyclic creep tests. A linear elastic crack growth algorithm has been selected for the statistical representation of growth rate for any range of stress intensity, temperature, and frequency. Auxiliary tests have shown no effect of air versus inert environment or of in-phase cycling of stress intensity and temperature. The possibility of effects of temper embrittlement on crack growth rate in segregated material exists, especially when the bore strain peaks below 149°C (300°F). Both isothermal and out-of-phase stress intensity–temperature tests of Gallatin material are being evaluated.

A user's manual and a programmer's guide have been completed for transient thermal-elastic stress analysis. The computer program determines the heat transfer coefficients from the history of inlet and outlet steam conditions and rpm, models the geometry, and either determines the stress-temperature history at selected locations or scans for critical regions.

The program has been checked against Westinghouse calculations for the Gallatin No. 2 IP rotor and found to be in close agreement. Detailed transient calculations have been conducted for the program rotors (Joppa No. 3 and Buck No. 6) and for the Seward No. 5 LP rotor. Interest is currently centered on combining the lifetime prediction system from this project with automated duty cycle "damage accumulation" systems.

The Joppa and Buck rotors have been completely examined by two commercial bore sonic systems; portions of Joppa were reinspected by one system. In general, there is poor agreement between amplitude data and about 50% correlation between indications of any amplitude by both systems when a scan volume element of 0.2 in³ is adopted at corresponding locations, that is, agreement is defined as the presence of any indication reported by one system within a volume (Δz = 1.0 in [2.54 cm], Δr = 0.5 in [1.27 cm], $r\Delta\theta$ = 0.4 in [1.016 cm]) centered at the coordinates of an indication reported by the other system. The correlation was also 50% among the 10 largest reported indications. However, the correlation between initial scan and rescan indications was only 20%. Most of the largest indications in the Joppa rotor are on the order of an equivalent flat-bottom hole (EFBH) diameter of 0.1–0.2 in (0.254–0.508 cm). A single large flaw, 0.4 in (1.016 cm) tangential by 0.25 in (0.635 cm) axial dimension, was found by both systems and verified by hand-held transducers.

Attention is currently focused on the statistical correlation of defect density in cluster indications. Indicated defect density is arbitrarily defined to be the volume fraction of inclusions and porosity within a specified volume element when the EFBH diameters of each signal from the volume element are assumed to represent diameters of spherical reflectors. Actual defect density is determined by metallographic sectioning. Because fracture takes place on the plane of maximum tensile stress, the sectioning is performed on radial-axial planes. Maximum cross-sectional areas of individual defects are calculated by assuming ellipsoidal shapes; areas comprised of many small defects are analyzed by conventional statistical metallurgical techniques.

The initial results of these measurements show good agreement between the number of individual defects per unit volume. Surprisingly, the density of flaws determined metallographically is lower than that calculated from the bore sonic data.

Sectioning of the Buck No. 6 rotor has been held in abeyance pending certain modifications of the bore sonic procedure. These modifications are anticipated to include a method of examining the near-bore region (0 to 1/8 in [0 to 0.3175 cm] depth), a reduced axial advance of the mechanical drive to improve the repeatability of flaw amplitude, and a software program to calculate flaw volume fractions in clusters.

Work on flawed test blocks has been discontinued because of the limitations on time. Also, efforts to obtain samples of naturally flawed material with suitable densities of inclusions or porosity were unsuccessful. Instead, artificial clusters of drilled holes have been machined into calibration blocks and are being employed to determine the effects of transducer size and frequency and axial advance per rotation of the inspection head on the resolution of individual reflectors. Following the optimization of the bore sonic procedure with the aid of these calibration blocks, it is planned to examine portions of the Buck No. 6 rotor and to verify flaw indications by sectioning. *Program Manager: F. E. Gelhaus*

EVALUATION OF COMPUTER CODES FOR FUEL ROD MODELING

An evaluation of six fuel rod modeling codes has been sponsored and completed by EPRI as a step toward a more effective utilization of these codes by the electric utility industry.

A final ranking of the codes by predictability, ease of use, and computer running time has been made. Five industrial companies—vendors and consultants—were involved in the evaluation (RP397).

- S.M. Stoller Corp., with BelgoNucléaire as subcontractor, investigated versions III-G, -H, and -J of the COMETHE code.
- O'Donnell and Associates, Inc., investigated CYGRO-3 and LIFE–THERMAL-1—the latter being the firm's conversion of the fast breeder code LIFE-3 to LWR application.
- Science Applications, Inc., investigated BEHAVE-4 and GAPCON–THERMAL, versions 1 and 2.
- Combustion Engineering, Inc., investigated the FMODEL code and provided technical coordination of the overall evaluation effort. C–E's technical coordination involved a selection of standardized materials properties for uranium- and mixed-oxide fuels, the characterization of experimental data, and comparisons of code results with experimental data.

During Phase I of the project (*6*), each contractor procured, mounted, and made operational the respective codes. An overview of code capabilities and modeling assumptions was performed. The results of the overview showed some important common characteristics of all codes: assumptions of longitudinal axisymmetry and one-dimensional time-invariant radial heat transfer; treatment of $r-\theta$ and some z variations as discontinuous functions at segment boundaries, treatment of fuel flux depression, and the lack of direct treatment of clad ridging within each axial segment. Phase I included parametric studies on linear heat rating and ramp rates; fuel-cladding gap; fill-gas composition and pressure; fuel density, enrichment, and in-pile densification; and solid versus annular pellets.

Cladding parametric studies on differential pressure, temperature, fast-neutron flux, and wall-thickness effects were performed by modeling an empty Zircaloy tube. While most codes showed the same relative sensitivities to typical LWR design variations, modeling deficiencies in some codes provided rather significant differences in absolute predictions of fuel rod performance data, such as fuel peak central temperatures. These variations were reduced significantly by standardizing on properties, by adding needed models, and by correcting errors within some of the codes.

Two code benchmarking stages followed Phase I, the results of which are included in the report on Phase II (*7*) and summarized below for Phase III (*8*). Twelve well-characterized, experimental and commercial fuel rods were modeled in nine separate case studies. Rod power histories and axial flux gradients were explicitly modeled in each case. Design and operating regimes of PWRs and BWRs were represented. Rod design variables included fuel densities, 92–98% of theoretical; fuel pellet diameters, 0.742–1.854 cm (0.292–0.730 in); fuel-cladding diametral gaps of 60.96–304.8μ (2.4–12 mils); cladding wall thicknesses of 457.2–1016μ (18–40 mils), and fuel rod prepressurization to 2.20 MPa (320 psia). Peak linear heat ratings varied from 262–820 W/cm (8–25 kW/ft) among the rods.

The prediction capabilities of each code were evaluated in phases II and III by comparisons of code predictions with experimentally measured data. Experimental parameters used in the evaluation were fuel peak central temperatures, either measured by tungsten-rhenium thermocouples or inferred from fuel grain-growth metallography; cladding strains, measured either by posttest profilometry or in situ strain gages; fission gas release; rod internal pressure; and end-of-life diametral gaps and fuel central void radii. The cases studied in phases II and III are the basis for ranking the codes according to their relative abilities to predict available experimental data.

Code ranking conclusions

The major conclusions of the modeling code evaluation program, as shown in Table 2, are:

▫ COMETHE-IIIJ was judged to be the most versatile code for application by the utility industry to both thermal and structural analyses.

▫ COMETHE-IIIJ can save considerable computer running time, compared with the next two codes in the ranking.

▫ BEHAVE-4 and LIFE–THERMAL-1 are ranked together behind COMETHE-III-J. Both have significant potential for future application with additional benchmarking. LIFE–THERMAL-1 is better than BEHAVE-4 and equivalent to COMETHE-III-J for fuel thermal analysis. LIFE–THERMAL-1 also provided the best prediction of gas release among the codes in Phase III. BEHAVE-4 is better than LIFE–THERMAL-1, and potentially could be better than COMETHE-III-J for fuel rod structural analysis.

▫ GAPCON–THERMAL-2 is ranked fourth, largely due to its lack of inelastic cladding models and its relative overprediction of fuel temperature and fission gas release in Phase III.

▫ FMODEL and CYGRO-3 are not suitable for utility use in their present state, considering the alternatives available in the four top-ranked codes. These two codes were evaluated through Phase II, and work was subsequently discontinued in favor of focusing on the four program codes of higher potential. *Program Manager: F. E. Gelhaus*

Table 2
CODE RANKING SUMMARY

Objective Ranking[a]

Code	*Overall Ranking*	*Fuel Temperature*	*Equiaxed Grain Growth*	*Fission Gas Release*	*Cladding Strain*	*Running Time*
COMETHE-III-J	1	1	1	2	1	2
BEHAVE-4	2	1	4	3	2	3
LIFE–THERMAL-1	2	1	1	1	3	3
GAPCON–THERMAL-2	4	4	3	4	NA[b]	1
CYGRO-3[c]	5	—	—	—	—	—
FMODEL[c]	5	—	—	—	—	—

Subjective Ranking

Code	*Thermal Model Completeness*	*Structural Model Completeness*	*Other Bench-marks*	*Documen-tation*	*Ease of Use*	*Improv-ability*
COMETHE-III-J	Excellent	Good	Excellent	Excellent	Good	Good
BEHAVE-4	Good	Excellent	Fair	Good	Fair	Good
LIFE–THERMAL-1	Good	Good	Poor	Good	Good	Good
GAPCON–THERMAL-2	Good	Poor	Good	Good	Good	Good
CYGRO-3[c]	Poor	Good	Fair	Fair	Fair	Fair
FMODEL[c]	Fair	Good	Poor	Fair	Fair	Fair

[a]Based on the results of code benchmarks in phases II and III.
[b]Not applicable. Does not treat anelastic effects.
[c]Deleted from further evaluation following Phase II.

PWR FUEL PERFORMANCE SURVEILLANCE STUDIES

A broad program of LWR fuel performance studies is under way at EPRI. The status of projects on BWR fuel surveillance was reported in an earlier JOURNAL issue (*9*). In this second of three articles, the corresponding work on standard product line irradiations in PWRs is described.

Combustion Engineering, Inc.

The C–E project (RP586) consists of three tasks, A, B, and C, which have been designed as follows:

- Task A—to obtain fuel performance data on test rods that have systematic variations in the initial as-fabricated parameters such as fuel stability, internal pressure, fuel density, and initial cladding properties

- Task B—to establish a broad and statistically significant data base on the performance of standard product line C–E fuel rods

- Task C—to obtain timely data on power reactor fuel rod performance phenomena that might affect the EPRI fuel rod modeling and separate-effects studies

Tasks A and C emphasize material variables and pellet-cladding interaction (PCI), respectively, but will also provide data on standard 14 × 14 assembly performance. Task C was reported earlier (*10*). Task A on pilot bundle irradiations will be described in the third and concluding article in this series.

Task B specifically addresses performance statistics from C–E standard 16 × 16 assemblies and is discussed in detail below. Task B (characterized fuel rod irradiation test program in 16 × 16 assemblies) includes the irradiation of six standard 16 × 16 assemblies, two each for cycles 1, 2 and 3, respectively, in the Arkansas-1 reactor. Each assembly will contain a minimum of 50 precharacterized, removable rods distributed in positions within the assembly so that a spectrum of operating power levels will be available to broaden the variables that can be evaluated at interim and terminal examinations. Interim examination of all six assemblies is planned during refueling shutdowns after each cycle. Whether selected fuel rods will be examined destructively in hot cells is an option not yet decided at this time.

The fuel rods are currently undergoing detailed precharacterization. The Zircaloy cladding has been manufactured by Sandvik Special Metals Corp. in a normal production run. The cladding characterization phase included measurement of mechanical properties, texture, hydride orientation, and out-of-reactor, low strain rate deformation behavior. In addition to the inner-diameter and outer-diameter dimensional data normally obtained on the clad tubing material, a minimum of 300 fuel rods will be measured to obtain as-loaded dimensions. A sufficient number of fuel rods will be profiled to obtain diameter and ovality measurements so that changes in diameter and ovality can be tracked by similar instruments during refueling outages. A random selection of approximately 100 UO_2 pellets from each lot (three lots will be used, one for each batch of different enrichment) were dimensionally characterized and the density distribution determined. About one-half of these pellets will be placed in known axial locations in selected fuel rods. The remainder will be set aside as archive material. The normal lot certification data and archive materials will be available for all fuel rod components.

Insertion of the assemblies is planned for early 1978. During irradiation, power and burnup history for each bundle will be collected in sufficient detail to permit the computation of rod-by-rod nodal power and burnup, if necessary. At each refueling shutdown, the six 16 × 16 assemblies with characterized rods will be removed from the reactor and moved to the spent fuel pool for leak testing (if there is failed fuel in the core) and visual inspection. The length of the assembly and peripheral rods will be measured. During the shutdown, a target of 20 precharacterized rods per batch will be scheduled for examination and measurement. The actual scope of work to be done during an outage, however, is totally dependent on the utility's refueling outage schedule. At some time after the refueling outage, precharacterized rods retained in discharged assemblies will be measured. A target of 100 rods will be eddy current tested after each shutdown.

As with other projects, hot cell examination remains an option to be exercised if nondestructive examination (NDE) data disclose any effects relevant to continued safe, economic performance.

Westinghouse Electric Corp.

This project (RP611) has two tasks:

- Task A—to develop a performance data base on the 17 × 17 fuel assembly design

- Task B—to develop a performance data base on the 15 × 15 fuel assembly design

The objective of Task A (fuel performance, 17 × 17 fuel assembly design) is to accumulate a large data base for the 17 × 17 array fuel assembly design, which will be acquired through operation of standard and special removable rod fuel assemblies in a representative large PWR system.

The Vepco Surry-1 and Surry-2 reactors, which contain 15 × 15 fuel assemblies, each contain two special 17 × 17 fuel assemblies with extensively characterized fuel. For compatibility reasons, these assemblies have seven spacer grids as contrasted with the normal eight-grid design. Preirradiation characterization data includes fuel pellet densities, cladding dimensions, neutron radiographs, and profilometry of 15 finished rods (*11*). Archive pellets, tubes, and rods are available for additional characterization if the irradiation data indicate a need.

On-site NDE of Surry-1 and Surry-2 fuel assemblies after each cycle follow the same general pattern and involve TV visual examination, profilometry, eddy current, gamma scan, and grid force measurements of the removable rods (*9*, Table 1).

Reactor and fuel assembly operation is monitored closely in order to determine accurately fuel assembly power history, temperatures, and burnup levels as a function of time. In addition, any unusual or anomalous operating conditions or trends are monitored. The data are sufficiently detailed to permit calculations of individual rod axial nodal power and burnup history.

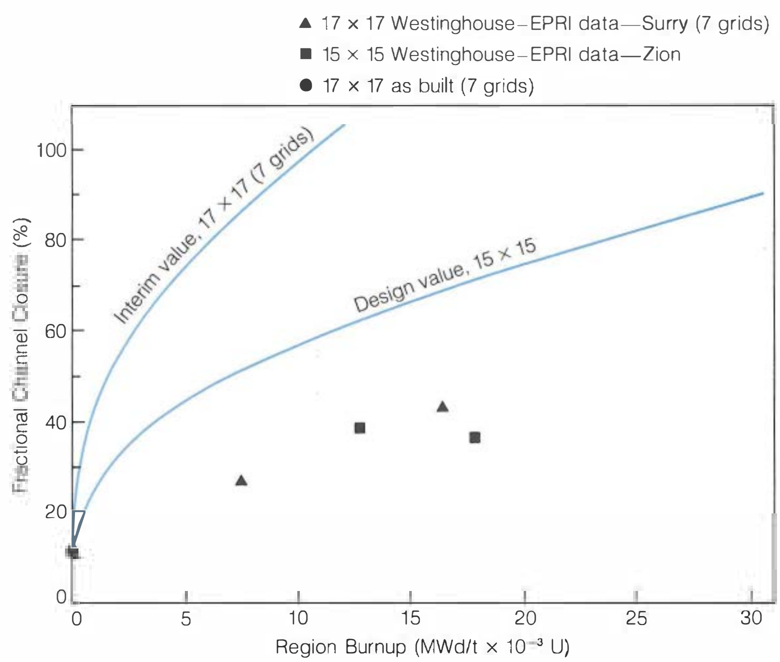
All four assemblies were examined after one cycle of irradiation and found to be in excellent condition (*12*). The assembly pair in Surry-1 has completed two cycles of irradiation, was examined and has been discharged as planned. The assembly pair in Surry-2 is currently in its second cycle of irradiation and after inspection in the fall of 1977 will be irradiated through a third cycle.

The objective of Task B (fuel performance, 15 × 15 fuel assembly design) is the accumulation of a 15 × 15 assembly irradiation performance data base through testing well-characterized fuel during and following irradiation in a representative, large PWR system. Task B is presently limited to on-site NDE (*9*, Table 1), which will allow screening of unusual fuel performance conditions for optional extended evaluation.

The Commonwealth Edison Zion-1 reactor initial core consists of 193 fuel assemblies with excellent traceability records on fabrication. Region 3 fuel contains two special removable rod assemblies, which have 104 well-characterized removable rods (*13*).

On-site NDE of the Region-2 and Region-3 fuel assemblies, including the removable rod assemblies, was conducted after the first cycle and another is planned after the second cycle. The on-site program (*9*, Table 1) consisted of (a) visual examinations and TV taping of 20 fuel assemblies, (b) dimensional measurements of three assemblies, (c) removal of two test rods from each of two removable rod test assemblies for optional extended evaluation, (d) measurement of rod breakaway and withdrawal forces, (e) TV inspection taping of the four test rods, and (f) measurement of grid cell spring forces for the vacated grid cells after fuel rod removal (*12*).

Figure 1 Data points on chart show 95 percentile of observed channel closures, well below the limiting curves established by NRC for channel spacing reduction. The limiting curves, at operating temperature, are the design values in the case of the 15 × 15 PWR fuel bundles and the interim values for the new 17 × 17 bundle design. The 17 × 17 values are interim because the only 17 × 17 cores loaded in utility units thus far (at the Trojan and Beaver Valley-1 plants) are still in their first cycle of operation, and no data are yet available. The 17 × 17 bundle has eight spacer grids, compared with seven for the 15 × 15 bundle. For the lead data reported here, special 17 × 17 bundles having only seven grids were fabricated for testing at Surry in order to be compatible with the 15 × 15 core.



Surry and Zion on-site examination results

Visual examination of the Surry and the Zion assemblies showed them to be in excellent condition (*12, 14*). There was no evidence of defects in the fuel rods or structural anomalies in the fuel assembly skeletons. Significant observations included local crud deposits and rod bow.

High frequency of small, circular, local crud deposits was observed on the peripheral fuel rods from both regions in the Zion assemblies. However, there was no apparent adverse effect on the fuel rod performance. In contrast, the fuel rods in the Surry assemblies were covered with only a very thin film of crud.

Of particular interest were the measurements of fuel rod bow in these assemblies.

Fuel rod bowing affects power density by changing neutron moderation locally and affects thermal-hydraulic performance (notably, departure from nucleate boiling) by reducing hot channel pitch, and thus, flow area. The maximum power density that can occur in the core during normal operation affects the peak clad temperature following a LOCA. For this reason, conditions that affect power density must be understood and accounted for in establishing operating guidelines. The NRC has approved fuel rod bow or channel spacing reduction limits for PWR assemblies (Figure 1).

Rod bow behavior was determined by measuring channel spacing from videotapes of the peripheral rods (*12, 14*). The 17 × 17 Surry and 15 × 15 Zion data have been plotted in Figure 1, together with the design limits. The data points represent fractional channel closure at the 95th percentile for the worst axial grid span versus region average burnup. As such, these points are maxima for closure values from all spans. The two 17 × 17 data points consist of cold results from all four assemblies after one cycle, or about 7500 MWd/t uranium, and from the Surry-1 demonstration pair after two cycles, or about 16,000 MWd/t uranium. The Zion data points consist of cold results from 20 fuel assemblies (10 Region 2 and 10 Region 3) after a region average burnup of about 18,000 and 12,800 MWd/t uranium, respectively. The solid lines are the NRC design limit curve for 15 × 15 fuel and an interim limit for 17 × 17 fuel considered in a recent NRC report (*15*). These curves apply to the worst grid span and contain a 1:2 cold-to-hot factor. The accuracy and precision of the TV procedure for measuring rod bow has been evaluated on the basis of duplicate measurements on a rod bow standard. For the range of channel closure data shown in Figure 1, the system has a negative bias of 5% (underestimates closure, overestimates opening). The standard deviation of the system precision is ± 7.4%. Also shown is the as-built fractional closure at the 95th percentile for the 17 × 17 assemblies.

As the figure shows, the 17 × 17 data fall in the mid-range of the 15 × 15 data, well below the 15 × 15 design limit. Therefore, the 15 × 15 design limit provides adequate conservatism for the 17 × 17 assembly. The additional grid in the normal 17 × 17 assembly would reduce the rod bow even further. The EPRI data are now part of the official Westinghouse fuel-licensing data base. The Zion rod bow data contributed to the granting of the full power license for Cycle 2 operation. High power density plants such as Zion had been restricted to 85% power in their first cycle, pending accumulation of operating experience. *Program Managers: J. T. A. Roberts and F. E. Gelhaus*

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Validated Analytic Codes for the Nuclear Electric Industry

by Walter B. Loewenstein
and Jack B. Moore

Utility requirements for computer codes to support design, licensing, and operation of nuclear plants are increasing; EPRI has developed five major such codes and is working on a number of others for utility use.

□ An EPRI technical article

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In recent years utilities having nuclear power plants have seen marked changes of emphasis in their requirements for validated computer codes—that is, codes that can be used confidently for design, licensing, and operation.

Prior to these changes in requirements, development and validation of software was carried out principally by government agencies, reactor vendors, and architect-engineers. However, as the nuclear power plants and their operating practices have matured within the industry, the need for reliable and accurate prediction of engineering and safety performance have become paramount. Such requirements are motivated by continuing regulatory dialogue, as well as by the need to provide flexibility for procurement, operations, and design modification.

To provide such flexibility, a number of electric utilities have independently developed significant capability for sophisticated analysis of both normal and off-normal NSSS behavior for their particular systems. The capability for such analysis requires that each developer assemble large complexes of supporting software, input data, and integral validation correlations.

Much of the work for assembling such a computational complex has features common to many of the utilities. The effort to validate computer codes runs along two streams—a generic effort, and work peculiar to development of individual special-purpose codes. EPRI's R&D program focuses on both streams of effort. Therefore, the generic work concentrates on adaptation of existing major software into validated computation packages oriented for the utility user.

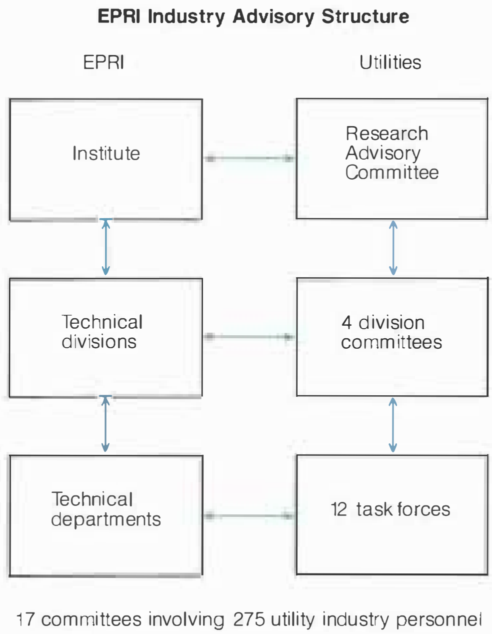
The prime motivation for initiating utility-sponsored computation development is to obtain a confident resolution of real and legislated problem areas. Computation developments in the U.S. and elsewhere have been both profuse and prolific, but they have frequently been done in a specialized or single-discipline format. The resulting difficulties arising from the use of such software routinely for production was an early stimulus for the Electric Research Council—and subsequently for EPRI—to sponsor common computation tools for the utility industry. Where possible, these have emphasized adaptation of existing codes. Where necessary, new codes were developed. The validation of computation methods has always represented a significant portion of this work.

Requirements from many sources

The requirements for utility computing capabilities come to EPRI from many sources. A primary input is from EPRI's industry advisory structure (Figure 1). Each technical department at EPRI has a corresponding task force, consisting of about 15 utility representatives who have management and engineering responsibility in the technical aspects of their utility's operations corresponding to the scope of the technical department that they advise. In addition to identifying the general areas of endeavor they believe EPRI should address, they review each proposed research project, evaluate it for its suitability in meeting their needs, and either concur that it should be pursued, or recommend revisions, or recommend that it not be pursued. This interaction between the EPRI technical department and its task force results in a detailed comparison of utility requirements and the steps being taken to meet those requirements. Broader issues and needs are identified at the Division Committee and Research Advisory Committee levels.

In addition to this formal review process, there are numerous contacts between EPRI and individual utilities, reactor vendors, other contractors active in many facets of the nuclear industry, and government agencies—especially the Nuclear Regulatory Commission, which cosponsors some research work with EPRI.

Figure 1 Flowchart shows the interaction at different levels between the EPRI staff and the electric utility industry that EPRI exists to serve.



Based on all these inputs, EPRI has developed nuclear computer code capability for electric utilities in the following areas:

- Reactor and core analysis
- Fuel cycle management and optimization
- Safety analysis
- Fuel modeling and performance analysis
- Reactor systems and operations analysis
- Structure analysis
- Fuel cycle cost evaluation
- Probabilistic methodology
- Interactive analysis

In general, once the need and scope have been identified, each of the code development activities has attempted to meet the following objectives: a high degree of user orientation; documentation including theory, programming, applications, and examples; extensive benchmarking to ensure that the ability of the code to yield physical results is well known; implementation in the major computer systems.

The process used for meeting these objectives is shown in Figure 2. The planning step includes input of requirements from the utilities, identification of the modeling effort required, development of experimental programs to obtain the required test data, and development of the code itself, along with the required benchmarking and other validation steps. In addition to the major computer programs that are developed directly for use by the utilities, EPRI is developing many other codes for its own use or for use by contractors to support EPRI R&D work.

Major codes developed by EPRI

EPRI has developed five major computer codes, as well as a number of other programs for special purposes.

STEALTH In the evolution of computation methods in mechanics, tradition has separated the effort into distinct combinations, such as solid or fluid, steady state or transient, linear or nonlinear. The formulation for solids has been biased to the finite element method, while the treatment of fluid mechanics has leaned toward the finite difference technique. Recently there has been a trend to unify the solid and fluid formulations into a common general form known as continuum mechanics. Here a problem is delineated by its material specification, while sharing common conservation laws.

There has been a void in the public domain for a general modular, user-oriented, explicit, finite-difference computer program to address transient, nonlinear events. Although this technology exists in the defense community, it is limited by narrow applications, unfamiliar terminology, and the high degree of sophistication required of the user. EPRI has transferred this technology by distribution of STEALTH.

One- and two-dimensional versions of STEALTH are already available to interested parties. A three-dimensional version will be available by the end of this year. Current extension includes coupling with finite elements to address fluid-structure interaction. The general code architecture allows a high degree of flexibility so that users can either treat it as a component code or build it into a systems code.

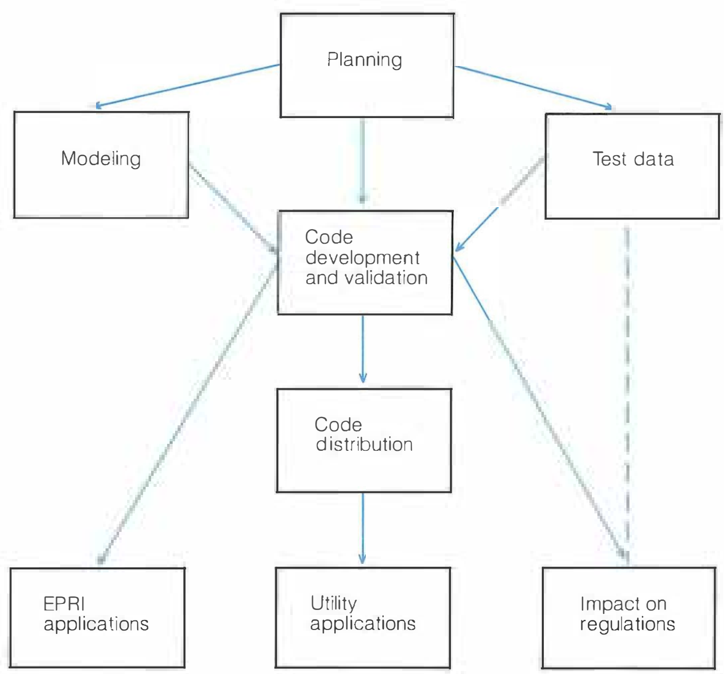
Applications of the STEALTH code include seismic wave propagation, residual stress from welding, clad-pellet interaction in fuel rods, waterhammer analysis, BWR pressure-suppression system, missile impact, and thermal-mechanical response of a heat source in salt. In many of these problems, STEALTH has been used to evaluate the significance of transient, nonlinear effects.

A part of the validation process for STEALTH has been the analysis of the impact of a rigid cylinder on water—an idealization of the fluid-structure interaction considerations investigated for the BWR Mark-I pressure-suppression pool. Calculations for a flexible cylinder 20 msec after impact, and apparent distortion of the cylinder, are shown in Figure 3. Measurements for this situation have not yet been made.

ARMP is intended to benefit the numerous utilities that are finding an increasing need for an analytic capability for reactor fuel management and operations analysis. Unfortunately, up to this time such a capability (one that can be used with reasonable confidence) has not been openly available to the utility industry.

ARMP has undergone extensive development over the past two years. It has also

Figure 2 EPRI computer code development has general as well as specific objectives, and the strategy to meet them is shown in the flowchart.



been subjected to initial testing and benchmarking to establish a level of confidence in its use. The computer code package is now available with its documentation and has been distributed to the utilities that have requested it. It has the capability of treating both PWRs and BWRs, and it includes few-group cross-section generation (EPRI–CELL), PDQ, and 3-D nodal capability as major components of the package.

As a result, the utility industry now has a full reactor analysis capability. For advanced heterogeneous fuel assemblies, this ARMP code package can provide design verification, safety and licensing support, in-core fuel management, evaluation of neutronics accuracy for economic studies, and core operations support. It thus provides utilities with a fuel management and an operations support analytic tool, as well as a mechanism for the effective exchange of information and experience. Such a unified system lays a foundation for greater utility engineering capability and increases confidence in its use.

ARMP is also available in both IBM and CDC versions. Two workshops to acquaint utilities with its use have been sponsored by EPRI.

MEKIN is sponsored by EPRI to provide the nuclear industry with a publicly available computational capability validated against benchmarks for analyzing reactor core transients in PWRs or BWRs. MEKIN's capabilities include analysis of space-dependent transients in BWRs and PWRs, a neutronic model for transient neutron diffusion theory, and a thermal hydraulics model (the modified COBRA IIIC for smeared assemblies).

This computer program provides a solution in three dimensions for the time-dependent, two-group, neutron diffusion equations and corresponding thermal-hydraulic equations that model the transient behavior of an LWR. It provides options to treat the following effects: one or two neutron energy groups; zero to six delayed neutron families; equilibrium xenon; motion of control rods entering the core from top or bottom to simulate drive-in and scram; feedback to neutron cross sections due to coolant temperature and density and to metal temperature; heat produced by fission and by radioactive decay processes; heat deposition in metal and in coolant; neutron cross-section perturbations as largely arbitrary functions of position and time; thermal-hydraulic core boundary conditions as functions of time.

MEKIN is available in both IBM and CDC versions and is being distributed (without charge) to those who request it for experimental use—it is still only a developmental tool, however. NRC and a number of utilities, reactor vendors, and consultants now hold MEKIN.

RETRAN is a new system of codes based on the extensive analytic and experimental work that has already been done on RELAP-4 and its predecessors.

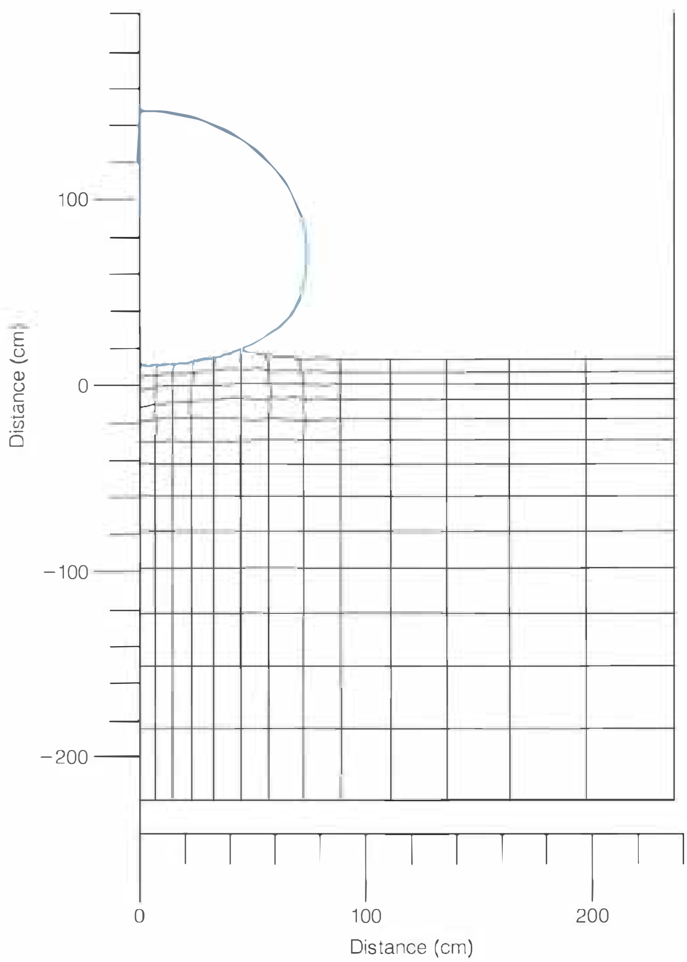
The majority of nuclear power plant safety analyses are concerned with postulated accidents, occurrences, or operating conditions that require calculational modeling and simulation of the performance of the nuclear system, including the reactor core. Many such analyses are directed toward the optimal approach to fuel design limits or design-basis hypothetical accidents, such as LOCAs. These analyses have usually been performed by reactor suppliers or fuel fabricators, but utilities find it necessary to move into this area more and more.

Utilities that operate nuclear plants have found that backfits are becoming less an exception than a way of life. These backfits, which are very visible and expensive when hardware is concerned, are frequent in safety-related areas and require time-consuming analysis. Their sources are not limited to new NRC criteria but stem also from hardware problems, design changes, and development of improvements in the original safety analyses made by reactor vendors.

For utilities that have opted for reload fuel suppliers who are not also reactor suppliers, these problems are compounded by interface problems, proprietary information concerns, and diffusion of vendor responsibility. Clearly the concept of total reliance on the original safety analysis as an umbrella for further resupply has faded. Consequently, there is an increasing need for utility engineers to perform safety analyses at various levels of complexity. The need for flexible computer programs is thus apparent.

RETRAN contains the capability to treat small- and large-break LOCAs and opera-

Figure 3 Computer-derived calculations using the STEALTH code yielded this graphic representation of the effect on a flexible circular cylinder of being struck by a rapidly rising pool of water (20 μs after impact).



tional transients. The emphasis of the LOCA capability is on a best-estimate capability in order to help quantify the conservatisms in existing evaluation models. The systems analysis capability is expected to be used by the utilities for operational support, design changes, and licensing. Preliminary release of RETRAN was made in June this year, and general release is planned for next year.

Other code development work

Another area of endeavor has been development of probabilistic methodology. This effort has resulted in codes to help automate probability analyses. For instance, the WHAM family of codes is tailored for probability tree analysis, GO-C for safety and reliability analysis, and CAT for automatic fault and success tree construction. Another application of probabilistics is an attempt to put the ATWS (anticipated transient without scram) problem in perspective (JOURNAL, March 1977, p. 37). EPRI has concluded that the true probabilistics of ATWS are considerably lower than those published by NRC.

Other engineering code development includes steam generator modeling applications and COBRA adaptation. Of particular interest is the analysis of bubble formation in water when air or steam enters, as occurs in a BWR pressure-suppression pool during a LOCA. EPRI experiments have re-created a small-scale version of that behavior, which was simulated with the SURGE code developed for this purpose.

In the nuclear analysis area, improvements in data and methods have been incorporated in the CINDER fission product code, HAMMER spectrum code, and SAM Monte Carlo code.

This summarizes major computer code development that has been chartered by the electric utilities and the framework in which the utilities' needs are identified—the codes that have progressed to the point where they are available for use by the utility industry.

Development of other codes is under way. These projects include an LMFBR system transient code, modifications to the COBRA code to treat open-core lattices, remote multiplexing availability, and present valve cost calculations, fuel modeling, and a crack propagation code.

The number of contractors involved in this effort is large and includes universities; vendors; national laboratories; smaller consulting firms, such as Energy Incorporated, Nuclear Associates International, and Science Applications Incorporated; and the electric utilities themselves.

Validated analysis capability has been and is being developed with the recognition that user- and problem-oriented validated computation packages have a significant potential payoff to the consumer. The lifting of an operating restriction that permits increasing a plant's power output level from a derated condition by 1% results in a saving of several hundred thousand dollars per plant year. Similarly, the confident prediction of the course of a low-probability event can result in savings of tens of millions of dollars for a confirmatory test program for each event, and there could be more than a few of those. Finally, if such open-ended issues cause plant shutdown for only a few days, additional costs of hundreds of thousands of dollars per plant day would be incurred.

The payoff is high—but only for software that focuses on the issues.

New Technical Reports

Each issue of the JOURNAL includes summaries of EPRI's recently published reports.

Inquiries on technical content may be directed to the EPRI project manager named at the end of each summary: P.O. Box 10412, Palo Alto, California 94303; (415) 493-4800.

Requests for copies of specific reports should be directed to Research Reports Center, P.O. Box 10090, Palo Alto, California 94303; (415) 366-5432. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others pay a small charge. Research Reports Center will send a catalog and price list on request.

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Microfiche copies are available from National Technical Information Service, P.O. Box 1553, Springfield, Virginia 22151.

ELECTRICAL SYSTEMS

Current-limiting fuse study

EL-453 Final Report (RP428)

Current-limiting fuses, used to protect distribution lines and substations from damaging fault currents, have long been the subject of technical improvement and cost reduction efforts. Higher continuous ratings have also been desirable.

This study was designed to improve performance, with corresponding higher current ratings in a single barrel. The overall program was directed towards new element design, gas impregnation, and composite polymer sand fillers. The new element design is based on a freestanding cylinder approach with a large surface-area–to–volume ratio and provides better heat transfer and higher arcing gradients. New filler mixtures also increase arcing gradients and improve interruption capability. Better heat transfer, higher arcing gradients, and improved interruption capability improve overall performance of the fuse and increase the current rating. Full-size experiments (15 kV, 200 A) conducted by Allis-Chalmers Corp. demonstrated significant improvements in average arc voltage and rating capability when compared with state-of-the-art technology. *EPRI Project Manager: R. Kennon*

Development of dynamic equivalents for transient stability studies

EL-456 Final Report (RP763)

Continued growth in interconnection size and increased emphasis on system reliability has resulted in large power systems models for transient stability studies. Increased model size and complexity, in conjunction with the need to perform simulations over longer time periods, require large blocks of computer core and long computation times, resulting in sizable expenditures by utilities.

This report presents the R&D results of system dynamic equivalents for transient stability studies performed by Systems Control, Inc. (SCI). A computer program has been developed that can reduce a large-scale system model into a smaller equivalent. The program has been demonstrated and validated using large-scale representations of both the eastern and western U.S. interconnected systems.

The program accepts a normal transient stability data base as input and develops an equivalent a fraction of the size of the full power system representation, while adequately retaining the dynamic characteristics of the full system. The reduction process requires only a fraction of the time needed for a transient stability simulation. Test results have shown that the reduced dynamic equivalent is two to six times more efficient than the original system in terms of computer running time and memory storage, thereby offering significant savings in computation costs. *EPRI Project Manager: T. S. Yau*

ENERGY ANALYSIS AND ENVIRONMENT

Survey of laboratory modeling of plume dynamics

EA-323 Final Report (RP677-2)

This report describes the second of two EPRI surveys on modeling the physical and chemical behavior of power plant stack plumes. The first report was *Air Quality Models: Required Data Characterizations* (EC-137).

The second report focuses on the use of laboratory models for physically simulating power plant plumes and for evaluating mathematical plume dispersion models. Present laboratory facilities for plume modeling include wind tunnels water flumes, and towing tanks. The principles of operation of each type are discussed and the advantages and disadvantages for both uses assessed.

The report, prepared by Flow Research Co., concludes that laboratory models are best suited to simulating physical plume behavior in the near field, that is, at distances of 5 km or less. For evaluating mathematical models, laboratory models are especially useful in simulating flows over complex terrain, near buildings, or with density stratification. *EPRI Project Manager: C. Hakkarinen*

Uranium data

EA-400 Final Report (RP489)

The main purpose of this report, carried out by S.M. Stoller Corp., is to describe and assess the data systems of four of the five generally accepted indicators of present and future domestic uranium supply capability. These are estimates of reserves, resource estimates, projections of production capability, and marketing. The assessment is from the user's standpoint and reflects the contractor's perception of that user's interests and needs for information. The fifth item, information on exploration activity and results, is treated in a companion report, *Uranium Exploration Activities in the U.S.* (EA-401) ERDA is the principal, and in some areas the only, source of the estimates and the information. *EPRI Project Managers: M. F. Searl and J. Platt*

Uranium exploration activities in the U.S.

EA-401 Final Report (RP490)

An important energy supply issue concerns the size of the uranium resource and the rate at which uranium resources can be found, developed, and produced. (The uranium resource issue is explored in a companion report, EA-400).

This report covers the history and results of uranium exploration. It draws heavily on ERDA data, on the experience of the S.M. Stoller Corp., and on information provided by private firms. The report consolidates a large volume of material, providing a tool for analysis and informed projection of uranium exploration activity. *EPRI Project Managers: J. Platt and M. F. Searl*

Coal mining cost models (Vol. I: Underground mines)

EA-437 Final Report (RP435-1)

The Underground Coal Mining Cost Model represents a systematic approach to computing the costs and requirements associated with opening and operating a new coal mine. The final product generated by the procedure is production cost per annual ton. This figure would cover all operating and capital recovery expenses and provide the desired return on investment. The model incorporates essential features of mining engineering, mining experience, cost engineering principles, and common sense required to analyze all cost aspects of producing coal from a new underground mine.

Both the underground cost model and its counterpart, the Surface Coal Mining Cost Model (Vol. II), have been developed by NUS Corp. to serve as resource planning tools to support EPRI's Supply Program. These models are intended to provide an engineering approach for determination of production costs to be used in developing coal price-availability relationships. It must be emphasized that it is not the intent of this model to provide the precise cost estimates required for mine investment decisions or coal purchase contracts. *EPRI Project Manager: T. E. Browne*

Coal mining cost models (Vol. II: Surface mines)

EA-437 Final Report (RP435-1)

EPRI's Supply Program had this Surface Coal Mining Cost Model and its companion, Underground Mining Cost Model (Vol. I), prepared by the NUS Corp. as one approach to developing the production (process) cost component of coal supply schedules (price-quantity relationships). This process engineering model addresses the production cost component.

Electric utilities and others will find the model a useful tool for making approximate cost estimates for coal from specific properties. It must be emphasized that it is not the intent of this model to provide the precise cost estimates required for mine investment decisions or coal purchase contracts. As a resource planning tool, the model can find useful applications in estimating production costs from a variety of mining situations. The uniformity of approach can also facilitate sensitivity analysis of production costs as influenced by changes in the various cost components. The model can also be used for rapidly determining operating or capital requirements.

Both models represent a substantial improvement in the tools available for coal production cost analysis. They have been reviewed by several coal production experts, who have made valuable comments. Additional refinements can be made, and EPRI plans further tests by utilities and coal companies. EPRI would like to receive criticism and comment from readers and users of both models; they should be sent to the manager of the Supply Program. *EPRI Project Manager: T. E. Browne*

Evaluation of CHESS: New York asthma data 1970–71, Vol. II. Original and supporting analytic data

EA-450 Final Report (RP681-1)

Vol. II of this report presents the original data and analytic results that are summarized and described in Vol. I of the evaluation by Greenfield, Attaway & Tyler, Inc. of CHESS (Community Health and Environmental Surveillance System).

Appendixes II-A and II-B document the findings in sections 2 and 3 of Vol. I. Appendix II-C includes all data pertaining to the relative risk discussion in Section 4. The tables in Appendix II-D display details of the multiple and stepwise regression analyses presented in Section 3.4. Exhibit 1 in Appendix II-F is the reprint of the paper describing the hockey stick function used by CHESS and discussed in Section 5. The data base upon which all calculations were made has been reproduced in two sections of Appendix II. Daily asthma attack histories for each panelist are displayed in Appendix II-A, tables A-1b and 1c through A-6b and 6c. Appendix II-E presents the complete tabulation of air quality parameters, demographics, study design variables, and asthma attack rates by day of study for each of the three New York communities. *EPRI Project Managers: C. L. Comar, J. McCarroll, and R. E. Wyzga*

Effects of electric fields on large animals

EA-458 Second Interim Report (RP799-1)

The purpose of this project is to determine whether exposure to electric fields has a detectable effect on a large experimental animal—the Hanford miniature swine, selectively bred for use as a stand-in for man because of its similar internal physiology. Effects on USSR linemen and switchyard workers reportedly occurred after prolonged and repeated exposure to HV fields. Similar effects (nausea, loss of appetite, and so on) have not been seen in the U.S. But if such effects can be caused by strong electric fields, related responses should be demonstrable in the experimental animal used in this study (see EPRI EA-331 for detailed review).

This second interim report details planning and construction of housing and experimental facilities by Battelle, Pacific Northwest Laboratories for chronic exposure of the animals to 30-kV/m electric fields. The goal was to ensure constant, well-defined exposure of test subjects to electric fields, while holding all other parameters constant for both test and control animals.

Breeding of the F_0 generation is nearing completion; preliminary growth data and blood chemistry are being collected. The goal is to obtain 40 female piglets of similar size and shape so dosimetry will be comparable. Surface fields and dosimetry are being characterized, using full-scale models of pigs. These data, plus data collected for the related study on small animals being funded by ERDA, will provide a basis for defining the internal dose received by the swine and for extrapolating results to humans. *EPRI Project Manager: H. A. Kornberg*

Regional reference energy systems

EA-462 Topical Report (RP442-1)

A regional energy systems formulation is presented, incorporating an integrative view of the energy system, with all resources, technologies, and uses of energy set forth in a uniform manner. Based on the reference energy system (RES), this approach is broadly applicable to the assessment of energy technologies and policies at a regional level.

Reference energy systems have been developed by Brookhaven National Laboratory for each of the nine census regions; summaries of the regional data for the entire U.S. are given. RESs were formulated for the base year 1972, and projections were developed for 1980, 1985, and 2000. RES and associated data provide a baseline against which the substitution of alternate technologies and policies can be evaluated. The system incorporates a detailed disaggregation of regional energy demands in the residential, commercial, industrial, and transportation sectors. The regional supply of fossil fuels, including the supply of electricity by type of generating plant, is projected through the year 2000. *EPRI Project Manager: R. W. Michelson*

FOSSIL FUEL AND ADVANCED SYSTEMS

Development program for an ionizer-precipitator fine-particle dust collection system as applied to coal-fired utility steam generators

FP-291 Final Report (2 vol.) (RP386-1)

This report summarizes the development of a high-intensity ionizer for the collection of fly ash by electrostatic precipitators. An executive summary is presented in Vol. I.

This technology provides effective electrostatic precipitation of fine-particulate, very high resistivity fly ash, by imposing a higher degree of charge on the particles. The electrode assembly results in intensely ionized flue gas leading to a particle charge as high as four times that currently being achieved. Such an ionizer would be the first or charging stage of an improved two-stage power station electrostatic precipitator immunized against high resistivity dust.

Generally, laboratory analyses and testing have provided necessary data to proceed with design of a larger-scale field pilot. Economic evaluations of the concept, based on laboratory data, indicate potential cost savings on new systems and retrofit upgrades. Possible mechanical arrangements for incorporating the high-intensity ionizer into conventional design precipitators are indicated for both new and retrofit installations. Small-scale field pilot work was undertaken at an operating utility to supplement laboratory work. *EPRI Project Manager: O. J. Tassicker*

Summary evaluation of atmospheric pressure fluidized-bed combustion applied to electric utility large steam generators

FP-308 Final Report (2 vol.) (RP412-1)

A fluidized-bed combustor (FBC), using limestone to absorb SO_2, appears to have sound potential for burning high-sulfur eastern coals while staying within antipollution regulations. This literature search conducted by the Alliance Research Center, Babcock & Wilcox Co., amasses available FBC data, analyzes the state of the art (to make initial efforts to establish design criteria), and identifies further R&D needs. Almost 650 books, papers, and reports were studied and eight fluidized-bed facilities visited.

The fluidized bed is used successfully in several industries and appears reasonable as a coal combustor for steam power generation. However, insufficient information presently exists to design and construct a prototype system for utility applications that will have a high probability of success. FBC experiments have been conducted with bench-scale models, except for two or three. Several areas of concern require experimentation on a large-scale prototype FBC to gain sufficient reliability in design criteria and the necessary correlations.

The final report of this work consists of an executive summary, a formal report of approximately 130 pages, and detailed appendixes in a separate volume. *EPRI Project Managers: T. E. Lund and H. H. Gilman*

Physical coal preparation

FP-314 Final Report (TPS76-645)

This report presents results of a survey to determine need, scope, and extent of coal preparation research projects to be considered by the utility industry. The report includes the recommendations of participants from the EPRI Coal Preparation Workshop.

Twenty R&D projects have been identified by Kaiser Engineers, with expenditures outlined for each project. If all are selected, the suggested budget would be an estimated $16,290,000 over the next five years. However, detailed schedules of investigations or outlines of tests required are not within the scope of this study. *EPRI Project Manager: S. Venkatesan*

An investigation of methods to improve heat pump performance and reliability in a northern climate

EM-319 Final Report (3 vol.) (RP544-1)

In the past, the heat pump gained a reputation with consumers and electric utilities for poor reliability, particularly when used in northern climates. However, as interest in wider use of heat pumps increases with rising energy costs, data on performance and reliability of improved heat pumps are needed. This study was the first step in providing such data on a consistent basis.

Component and subsystem improvements with the potential for implementation by 1980 were identified. Improved systems were then configured and analyzed for their benefits to, and impacts on, consumers, electric utilities, and the manufacturing industry. Air-to-air heat pumps were emphasized and the impacts of storage and/or solar augmentation were investigated. Three utility service territories were selected to illustrate annual life-cycle cost optimization for the case of a flat electricity rate structure.

Five improved heat pump systems were identified and analyzed for performance, reliability, cost, utility impacts, and development requirements. Compared with a 1975 state-of the-art heat pump, the improved units offer heating COP improvements of 30–40% and annual life-cycle cost reductions of 9–14%. Additional reductions in annual life-cycle cost are possible if (1) the reliability of the average heat pump can be improved to the higher levels achieved by a few manufacturers and (2) the home is insulated to the higher standards now being proposed by NEMA, electric utilities, and insulation manufacturers. The results of the project conducted for EPRI by Westinghouse Electric Corp. will be valuable to utilities in planning and implementing consumer information programs as well as in evaluating proposed time-of-day rates. *EPRI Project Managers: J. W. Pepper and Q. Looney*

A comparison of hydrothermal reservoirs of the western United States

ER-364 Topical Report 3 (RP580-1)

This report documents a portion of the results from a one-year study to assess feasibility of constructing a 25- to 50-MW (electric) geothermal power plant using low-salinity hydrothermal fluids as the energy source. Results are presented of a comparative study of 16 U.S. hydrothermal reservoirs, selected for comparison on the basis of available data, development potential, and representativeness of known hydrothermal reservoirs. Six reservoir and fluid criteria were evaluated for each reservoir: depth and lithology, reservoir temperature, tested flow rate per well, fluid chemistry, magnitude of the reserve, and reinjection potential.

Two conceptual models for hydrothermal reservoirs are discussed: sedimentary and volcanic. A hypothetical reservoir representing the mean of the majority of commonly occurring U.S. hydrothermal reservoirs was defined as an aid in assessing representativeness of the actual reservoirs. Its properties were derived by comparative study of reservoirs, statistical data. and reservoir engineering calculations from which performance was estimated. The hypothetical reservoir appears to have a reasonable prospect for economic development using current technology.

Ranking of the reservoirs according to development potential was not possible because of incomplete information; the Valles Caldera, Heber, and hypothetical reservoirs were ranked according to temperature only. Nine minimum criteria to determine whether a hydrothermal reservoir has development potential are proposed by the contractor, Geonomics, Inc. *EPRI Project Manager: V. W. Roberts*

Molecular profile analysis of coal products

AF-390 Final Report (RP316-2)

This report describes a new approach to the characterization of coal liquefaction products by a detailed molecular weight profile analysis. A methodology and an instrumentation have been developed, using field ionization mass spectrometry to produce molecular weight profiles of coal liquefaction products in the mass range 100–1000 atomic mass units, including coal oils and asphaltenes.

The computerized technique allows the distinction between primary constituents and secondary pyrolytic or catalytic products. Preliminary experiments with field desorption to analyze asphaltenes and preasphaltenes yielded encouraging results. This report, prepared by Stanford Research Institute, also discusses the possibility of determining chemical structure of individual constituents in a complex multicomponent mixture by collision-induced dissociation. *EPRI Project Manager: W. C. Rovesti*

Physical property improvement of coal liquefaction products

AF-392 Final Report (RP626)

The objective of this work was to identify the causes of high viscosity and to improve viscosity reduction in coal conversion products. The strategy was divided into two major approaches: location and isolation of functionalities responsible for high viscosity, and utilization of chemically reactive and unreactive additives to overcome internal forces responsible for the association of large molecular species.

The major cause of high viscosity is the presence of preasphaltenes, which were shown to be saltlike species derived from the interactions of basic nitrogen with acidic protons. At least 20% of the nitrogen atoms in solvent-refined coal are basic, and over 80% of them are located in the preasphaltenes as determined by methyl iodide (MeI) precipitation.

A benzene-soluble fraction was liberated from the preasphaltenes by precipitating the basic nitrogen with MeI. In this new asphaltene, 62% of the oxygen was analyzed as hydroxyl groups. Melt viscosity and softening temperature of H-Coal were reduced with 1–5 wt% acids, anhydrides, epoxides, amines, and amides. N-methyl-2-pyrrolidone (NMP), propylene oxide, and acetic anhydride were especially promising. At 330°F and 1% acetic anhydride, a reduction from 24.13 to 14.35 poise was observed, and at 2 wt% of propylene oxide, a reduction from 16.08 to 6.97 poise. Treating costs for these three cases were estimated at $2.22, $0.60, and $1.26 per barrel. Limited work indicated that these additives are less effective in viscosity reduction of SRC. This investigation was carried out by Atlantic Richfield Co. *EPRI Project Manager: W. C. Rovesti*

Improvements of electrolyte and seal technology for sodium-sulfur and sodium antimony trichloride load-leveling batteries

EM-413 Final Report (RP726-1)

This study was divided into four separate tasks: In Task A, possible procedures were technically defined and costed for manufacture of beta-alumina tubes by using extrapolations of current practice. Powder from either molten-state or solid-state reaction, with tube-forming by either isostatic pressing or electrophoresis plus isostatic pressing were considered. Three sintering techniques using available furnaces were examined. In Task B, aluminum-alpha-alumina seals made by the proprietary thermocompression technique were fabricated and tested. Leak-tightness, resistance to thermal cycling, and corrosion resistance to polysulfides under static and electrochemical conditions were determined.

In Task C, performance of the sulfur electrode was computer-simulated by an iterative method based on experimental data for thin electrodes, allowing optimized tube and electrode dimensions to be determined. The optimized tube was close to that determined as the cost optimum in Task A. Cells, modules, and units for an 100-MWh load-leveling battery were designed and costed. Particular attention was paid to reliability and safety, including automatic disconnection of failed cells and heat transfer and recovery. In Task D, 23 electrolyte tubes were fabricated and delivered to EPRI by the contractor, Laboratoires de Marcoussis, France. *EPRI Project Manager: J. R. Birk*

The effects of gaseous environments in gas-cooled reactors and solar-thermal heat exchangers on the creep and creep-rupture properties of heat-resistant metals and alloys

ER-415 Final Report (TPS 76-622)

Energy conversion systems employing heat exchangers use closed-cycle gas turbines with helium as the working fluid. An important design criterion for heat exchanger and turbine systems is the creep strength of the tubing, blading, and vane materials. The design data for these materials have generally been obtained in air. However, there have been reports of adverse environmental effects of helium on the creep strength and ductility of these materials. Many of the environmental data have been obtained by using relatively impure helium from high-temperature helium-cooled reactor systems (HTGRs). However, power conversion systems using coal or solar energy as the heat source would use commercially pure helium, not subject to the carbonaceous gases that are picked up when helium is used as the coolant for the HTGRs.

In this report Stanford University has summarized the environmental effects of helium on the creep properties of heat exchanger alloys, as well as critical experiments under worst conditions, based on the literature, to determine the maximum extent of the effects. It was found that the environmental effects reported in the literature are relatively small—not more than a factor of two in rupture time or creep rate. Variations in rupture time of this order of magnitude are commonly observed in experimental scatter and in heat to-heat variations. Experimental work on a cobalt-based superalloy, HA188, confirmed this conclusion. *EPRI Project Manager: R. I. Jaffee*

Availability of fossil-fired steam power plants

FP-422-SR Special Report

This report summarizes recent experience regarding availability and reliability of fossil-fired steam generating units of 600-MW or more capacity. To define problem areas and develop a strategy for improving availability, the statistics compiled by EEI have been analyzed. Conclusions were supplemented by meetings with utilities that operate power plants in that category.

The first stage in the process was a grouping of the EEI data. Eleven problem areas, each with total annual direct costs to the industry of at least $15 million, and a further thirteen with costs between $5 million and $15 million, were identified.

To supplement the EEI data, six regional meetings were held with utility representatives directly concerned with operating fossil plants of over 600 MW. The discussions generally confirmed the relative importance of the problem areas and provided information on causes and relationships between problems. The report summarizes the results of these meetings and the nature of the major problems in the boiler, turbine generator, and auxiliary components, with recommendations for a systematic approach to effect improvements. *Prepared by D. Anson, EPRI; EPRI Project Manager: D. Poole*

Preliminary system analysis of a fixed-mirror solar-power central station

ER-434 Final Report (RP739-1)

As part of EPRI's Solar Program objectives to evaluate alternative distributed receiver systems, General Atomic Co. has been contracted to perform a preliminary systems design and evaluation of their fixed-mirror solar concentrator (FMSC). To assist in this evaluation, a computer program was written to model a preliminary system definition of a power plant design for an FMSC.

Analytic models were developed to simulate performance and to project the cost of subsystems using both heat transfer salt (Hitec) and carbon dioxide gas (CO_2) as the primary heat transfer fluids. It was found that the Hitec system cost was about half that of the CO_2 system.

The computer code was implemented for preliminary plant cost estimates and data on the sensitivity of plant cost to changes in design parameters. Limited, preliminary results have been used to indicate trends in cost sensitivity. *EPRI Project Manager: J. F. Cummings*

Investigation of mechanism of reactions involving oxygen-containing compounds in coal hydrogenation

AF-442 Annual Report (RP713-1)

Initial stages of a study of oxygen-functionality changes during coal liquefaction are described in this report. The first stage consisted of developing complex analytic techniques to separate, characterize, and analyze coal and coal derivatives and to quantify oxygen-containing functional groups.

In the second stage, preliminary liquefaction experiments were carried out to establish operating conditions, provide samples for analysis, and so on. A kinetic model was developed to describe the liquefaction of Belle Ayr subbituminous coal in hydrogenated anthracene oil.

The third stage, now under way at Gulf Research & Development Co., consists of performing detailed liquefaction experiments to establish the kinetics and mechanism of reactions of oxygen-containing compounds. Emphasis is being placed on noncatalytic solvation of subbituminous coal. *EPRI Project Manager: W. C. Rovesti*

Status of titanium blading for low-pressure steam turbines

AF-445 Final Report (TPS76-641)

Titanium is of interest for blading the last stages of low-pressure steam turbines. It is stronger, lighter, and more corrosion and erosion resistant than the standard 12Cr steel that has been used for blading for many years. The lower density of titanium permits longer blades to be used for last-stage rows, which is useful in large units. Its lower density also results in lower stresses on the attachment to discs or shafts, reducing their susceptibility to stress corrosion cracking. A possible disadvantage of titanium is its low damping capacity, which requires careful design to tune out resonant vibrations, and the use of mechanical damping with shrouds and lashing wires.

This report documents a survey conducted by Battelle, Columbus Laboratories to summarize the worldwide status of titanium blading in the low-pressure steam turbine. The use of titanium blades is being considered worldwide for steam turbines, particularly for larger ones, because of better corrosion resistance. *EPRI Project Manager: R. I. Jaffee*

Stibine formation and detection in lead-acid batteries

EM-448-SR Special Report (RP370)

The literature review and analytic studies reported in this document were undertaken because there was no clear evidence of the state of the art of formation and detection of stibine and arsine from lead-acid batteries. Previous analytic techniques did not provide accurate results and thus were useless in providing guidelines for the EPRI/ERDA Battery Energy Storage Test Facility specification for a 1.2 MWh lead-acid battery.

An existing National Institute for Occupational Safety and Health program—with the Industrial Hygiene Research group at SRI—to improve standards and methods of detection for stibine and arsine facilitated development of an improved analytic method specific to the lead-acid battery. The results reported here show that this method applies exactly to detecting gases in a practical battery situation; is faster and more accurate than colorimetric tests; measures small amounts in short time intervals and permits tracking of peak quantities that may be generated for only a few minutes; utilizes standard laboratory equipment and procedures; and is remarkably simple. *EPRI Project Manager: W. C. Spindler*

Fusion-driven actinide burner design study

ER-451 Final Report (Vol. 1) (RP473-1)

The tokamak fusion test reactor (TFTR) is planned as the first controlled thermonuclear device to burn deuterium and tritium. The goal of this study was to demonstrate early practical use of TFTR technology to dispose of long-lived actinide wastes from fission reactors. Disposal is effected by arranging the wastes in a blanket configuration close to the tokamak plasma so that high-energy neutrons from the reactor can be used to transform long-lived fission waste products into more acceptable short-lived nuclides.

This design study has developed the principal characteristics of a beam-driven tokamak fusion-fission hybrid reactor for actinide depletion. The reactor provides a fusion neutron wall loading of $\sim$1 MW/m^2. The blanket is fueled with residual actinides contained in the high-level waste from the LWR-U cycle. These actinides are the only fissionable material contained in the fast helium-cooled blanket lattice and provide sufficient neutron multiplication to give neutron fluxes in the range of 10^{15} n/cm^2 per second.

A principal result of this study by Westinghouse Electric Corp. has been development of a revised criterion for assessing long-term radiotoxic hazard potential from the actinides. This criterion relates hazard potential from the waste to that of the naturally occurring parent uranium ore. Results indicate that a significant increase in hazard potential occurs over the first few years of irradiation because significant transmutation occurs, as well as fission of the actinides. Therefore, the total fluence required from effective depletion is quite high.

Candidate design concepts are potentially applicable to all tokamaks and to many other fusion concepts as well. Other aspects of the actinide burner are discussed, including environmental and safety considerations, scoping estimates of system cost, and requirements for supporting development. *EPRI Project Manager: N. A. Amherd*

Utility requirements for fusion power

EP-452-SR Special Report (TSA76-56)

A study funded jointly by EPRI and McDonnell Douglas Astronautics Co. was undertaken to identify utility fusion power requirements and to define a role for utilities in the fusion development process during the 1980s. This preliminary report serves mainly as a planning document for future requirements analyses.

A requirements organization was defined to consist of three major chronological phases: research and development, plant installation, and plant operation. Thirty-seven requirements were identified, covering all categories. In addition, training, environment, safety, licensing, and utility models were identified as five matrix-type requirements, applying to more than one of the three phases.

Comments received from utility representatives revealed a consistency of key issues in the fusion development process, which will form the basis for eventual establishment of definitive roles during the 1980s. Preliminary candidate roles were identified as public education, commercialization studies, industry investment analyses, training plan implementation, alternative reactor concept development, ERDA concept design review, and requirements refinement. *EPRI Program Manager: W. C. Gough*

Phase equilibrium in coal liquefaction processes

AF-466 Final Report (RP367-1)

Vapor-liquid equilibrium data in H_2/solvent systems are needed for reliable and accurate design of coal liquefaction processes. It is necessary to know when and where, in the liquefaction plant, multiphases, and the quantities and compositions of the phases, can be expected to coexist. This information is vital for the accurate sizing of plant equipment, including the vessels, piping, and compressors. The information should also be useful for the analysis of reaction kinetic data of coal liquefaction.

This work by Purdue University extends experimental investigation of phase equilibrium of H_2/heavy solvent systems to 250 atm in pressure and 430°C in temperature. Gas-liquid equilibria in mixtures of hydrogen and heavy hydrocarbons were determined experimentally in simulation of coal liquefaction process conditions. A flow apparatus was built to produce the saturated equilibrium liquid and gas samples. Equilibrium data were obtained on four binary mixture systems of hydrogen with tetralin, diphenylmethane, 1-methylnaphthalene, and bicyclohexyl, respectively. Comparison of the new data on the vapor-liquid ratio K of hydrogen was made with correlations of Chao and Seader, and Grayson and Streed. Substantial deviations of the data from the correlations were indicated up to 37% from the Chao-Seader and 30% from the Grayson-Streed. However, the new data show a regular orderly behavior with respect to the solubility parameter of the solvent, indicating that improved correlation can be developed, based on the Chao-Seader scheme. Additional data are needed on hydrogen solubility in other solvents and in mixtures, including coal liquids, to revise the existing correlations for improved results or for developing new correlations. *EPRI Project Manager: L. F. Atherton*

Cool storage assessment study

EM-468 Final Report (TPS76-650)

This report describes a study to assess the state of technology for air conditioning electrical load reduction in residential and small commercial installations at utility peak load times by using cool storage. The study was carried out as three tasks by General Electric Co.

In the first task, a literature survey and an assessment of cool storage materials and devices were cataloged. An ideal cool storage material should possess the following three characteristics: handling properties and cost similar to that of water, a small volume change at phase change, and a freezing temperature near 45°F. No such material was found, but several potential materials were identified for long-range R&D.

In the second task, an assessment of system performance factors was carried out, based on a series of system computer simulations. The systems study compared four air conditioning systems with a baseline conventional central air conditioner in a 1500-sq-ft house in Washington, D.C. The four systems included sensible and latent heat storage media in cycles using one and two heat pumps. In the final task, technological barriers limiting practical applications of cool storage systems were identified and R&D recommendations made. *EPRI Project Managers: J. W. Pepper and Q. Looney*

The application of Lummus antisolvent de-ashing technology to a well-converted, solvent-refined coal solution

AF-473 Final Report (RP524-2)

This report supplements a previous report (AF-234) from the Lummus Co. that presented experimental data on the application of Lummus antisolvent de-ashing technology and an economic comparison between its process and de-ashing via state-of-the-art rotary precoat filtration.

This report presents similar experimental data on an economic comparison for a well-converted (95% moisture- and ash-free [MAF] coal), SRC-derived de-ashing feedstock prepared at the Wilsonville SRC pilot plant from an Illinois No. 6 (Monterey Mine) source coal. A 99+% ash removal was observed when an antisolvent/feedstock wt ratio of 0.55 and underflow withdrawal of 25 wt% (based on total settler feed) were employed.

An economic comparison indicated that Lummus antisolvent de-ashing was economically superior to filtration for the higher conversion case. *EPRI Project Manager: R. H. Wolk*

NUCLEAR POWER

Documentation of utility experience with process computers in power plants

NP-290 Final Report (RP618)

The utility industry is rapidly increasing its reliance on process computers for power plant operation and control. This report presents extensive information on technical details of 334 power plant computer installations and qualitative aspects of planning, procuring, and operating such systems. The qualitative information was obtained from utility executives, computer project managers, superintendents, results engineers, and chief operators associated with a subset of 156 plants belonging to 69 utilities. From these detailed responses it was possible to evaluate planning, specification, selection, implementation, testing, installation, and training activities and to correlate each of these with the performance of the final computer system.

The summary section of this report presents a number of significant findings, including a strong endorsement by plant personnel of the value of existing computer systems; support for expanding the function of such systems in new power plants; a need for better definition of system goals in terms of improved plant productivity; and identification of various activities that appear to have a significant impact on final computer system performance. Subsequent sections deal with these subjects in greater detail by presenting conclusions based on the analysis of responses from over 600 utility, architect-engineer, and computer system vendor personnel. The actual responses are tabulated by question and category of respondent in the appendixes.

The reader who has experience with power plant computer systems should find the detailed analyses of planning, procurement, and installation practices useful for evaluating practices within his own utility. For the reader who is considering the procurement of his first system, this report by Macro Corp. should serve as an invaluable guide. *EPRI Project Manager: A. B. Long*

Subcritical crack growth in ferritic materials for LWR vessels

NP-304 Final Report (RP232-4)

The goals of this investigation were to develop a single specimen method for determining the onset of subcritical crack growth and to characterize the influence of subcritical crack growth on the fracture toughness of ferritic materials used in LWR vessels. The method for identifying the onset of subcritical crack growth was based on the ability to detect very small load changes at any load level. The basic theory assumed crack growth would be accompanied by small load changes, which could be sensed by equipment designed to record and analyze signals for a piezoelectric load cell. Early results were very promising, but subsequent testing failed to reproduce the expected load perturbations that could be associated with crack growth.

The material characterization studies used the multiple-specimen, resistance-curve procedures to generate relationships between the J-integral and subcritical crack length. These efforts produced upper-shelf fracture toughness values at two temperatures (RT_{NDT} + 120°F and RT_{NDT} + 180°F) for the materials investigated, three heats of SA-533 Grade B, Class 1, three submerged arc welds, and three manual arc welds.

From the results of this research conducted by Combustion Engineering, Inc., it can be concluded that detection of subcritical crack growth with a load change monitor does not appear feasible and that upper-shelf fracture toughness values are significantly reduced when the onset of subcritical crack growth is used as the limiting criterion, that is, J-integral values based on crack growth are half those based on maximum load and K_I values are reduced by 30%. *EPRI Project Manager: R. E. Smith*

Radioactivity in mixed-oxide fabrication using LWR recycle plutonium

NP-404 Final Report (RP306-3)

At EPRI-sponsored workshops held in 1974, several technical areas were identified that appeared to require further assessment. One of these, the question of appropriate methods of fabrication of mixed-oxide (MOX) fuel, is explored in this report.

The purpose of this study by Babcock & Wilcox Co. was to evaluate the range of expected isotopics and radiation emissions for LWR-generated plutonium for various uses and to relate these data to fabrication plant design requirements. The fuel fabrication methods examined and evaluated range from manual to fully remote operations. An extensive survey of MOX fabrication experience is also included. This study has confirmed a conventional plant concept as an appropriate design for MOX fabrication but identifies changes in regulations and fuel-cycle implementation methods that may result in varying degrees of remote fabrication operations at added expense.

Key results of this report are a definitive compilation of MOX radiation sources and an indication of the nature (that is, mechanized, hybrid, remote) of a MOX fabrication facility for various plutonium uses. *EPRI Project Manager: M. E. Lapides*

Nuclear fuel performance evaluation

NP-409 Final Report (RP509-1)

An evaluation was made of the ability of Scandpower Inc.'s empirical fuel performance model POSHO (Power Shock) to predict the probability of fuel pin failures resulting from pellet-clad interaction in commercial nuclear power plants. POSHO provides an analytic method to calculate failure probabilities associated with power level maneuvers for different fuel assembly designs. Application of the method provides a basis for risk-benefit decisions concerning operational procedures, fuel designs, and fuel management.

One BWR and one PWR were selected to compare model predictions with actual failures, as determined from postirradiation examination of the fuel and activity release data. The fuel duty cycles were reconstructed from operating records and nodal power histories were created by using Scandpower's Fuel Management System (FMS) computer programs. Nodal power histories, coupled with the relative pin power distribution in each node, were processed by the fuel failure prediction model, which tracks the interaction power level for each pin group in each node and calculates power shocks and probability for pellet-clad interaction cracks. Results were processed statistically for expected number of cracks, number of failed fuel pins in each assembly, and total number of failed assemblies in the core.

Fuel performance in the BWR, Quad Cities-2, was in approximate agreement with the observed performance. Fuel performance in the PWR, Maine Yankee, was in approximate agreement with two of the three fuel designs. The high failure rate in the third design, Type B fuel, was not calculated by the POSHO pellet-clad interaction model. *EPRI Project Manager: F. E. Gelhaus*

Characteristics of instrumentation and control system failures in LWRs

NP-443 Topical Report (RP705-1)

This report is one of a series being produced by Science Applications, Inc. (SAI) that is related to nuclear power plant availability and reliability. In order to reach the conclusions presented, SAI has drawn from the large body of data submitted to the NRC by nuclear power plants.

Characteristics of instrumentation and control (I&C) system failures, including set-point drift problems, are discussed in this report. Specific topics included in the discussion are general trends in the occurrence of I&C failures, principal reactor systems affected, variation in I&C failure rate over time, and the impact of I&C problems on plant availability. A total of 977 I&C failure events and 640 set-point drift events, reported by LWR licensees, provided the basis for the observations and conclusions presented. *EPRI Project Manager: W. L. Lavallee*

Assessment of thick-section radiography

NP-461 Final Report (RP607-1)

The use of X-radiography as a nondestructive testing technique is widespread in the nuclear industry. It is used extensively in quality control of materials and components during fabrication and to a lesser extent during in-service inspection. The ASME Pressure Vessel Code requires that final acceptance of a component be based on established standards of a radiographic examination. The high degree of component reliability required, combined with the thick sections encountered, strains the capabilities of the X-radiographic inspection technique.

The objective of this project was to assess thick-section radiography methods, using an integrated model of the source, geometry, and imaging system. Science Applications, Inc., modeled the system with detailed transport codes previously developed for shielding calculations. To check the validity of the calculations, results were compared with results from representative experimental data in the literature, from user organizations, and from benchmark experiments.

The basic results are that (1) the imaging system shows the most potential for optimization of present techniques; (2) further work with collimators shows little promise; (3) optimum energy range is 8–15 MeV; (4) backscatter may be significant in some applications; and (5) xero radiography does not appear to be promising for high-energy radiography. Unresolved areas that warrant future efforts are also identified. *EPRI Project Managers: G. J. Dau and K. Stahlkopf*

Steam plant surface condenser leakage study

NP-481 Final Report (RP624-1)

This report presents the results of a study by Bechtel Corp. to determine factors that affect the deterioration and subsequent leakage of main surface condenser tubes in electric power plants. Several areas related to condenser tube leakage were studied, including design, materials, chemistry, operation, and maintenance.

The data were obtained through field trips to operating power stations, mail questionnaires, and a literature search. The field study concentrated on large fossil-fueled plants, nuclear plants, and plants having condensers tubed with titanium. Tubing failure information was presented as a function of tubing material, cooling-water conditions, failure mechanisms, condenser design, and several other parameters. Information was also presented on the criteria for retubing condensers, and recommendations for future work pertaining to condensers were discussed. *EPRI Project Manager: W. L. Lavallee*

PLANNING

Coal and nuclear generating costs

PS-455-SR Special Report

Using results of studies made by several organizations, EPRI performed an analysis of the costs of producing electricity from coal and nuclear power with available technology. The analysis was made on a regional basis to consider differences in coal characteristics, transportation differences, and labor and local material costs in various parts of the country. The major factors affecting coal and nuclear generating costs were investigated on a consistent basis.

The overall results of the study indicate that (1) both coal and nuclear generation can be economically attractive in all regions, depending on specific circumstances; (2) nuclear generation shows an average economic advantage in all regions, particularly in the East, where higher delivered coal prices prevail; and (3) any new baseload generating technology must achieve levelized busbar costs of 35–45 mills/kWh to compete with existing technology on an economic basis. The work has established a benchmark for evaluating other studies and has provided a base for sensitivity analyses. *Prepared by: C. L. Rudasill*

Perspectives on the electric utility industry: a handbook

In order to carry out R&D programs effectively, EPRI staff need a clear and accurate perspective of the characteristics and structure of the ultimate user of the Institute's research output—the electric utility industry. A series of seminar presentations was organized to develop such a perspective. It offered an in-depth, authoritative description of the evolutionary trends, institutional framework, long-term goals, and future R&D needs of the electric utility industry.

The biweekly seminars were held at EPRI over the six-month period March 15–October 5, 1976. Topics included: (1) the past history, current status, and future trends of the industry; (2) a long-term projection of the need for electricity supply in the U.S. and the relationship of electricity demand to the national economy; (3) planning and operation of electric generation and transmission systems for individual utilities and power pool interconnections; (4) procurement policies for fuels, plant equipment, siting and environmental issues associated with power plant and transmission line construction; (5) unique characteristics of small, publicly owned utilities; (6) problems and practices in utility financing and retail rate design, as well as recent changes in the role of the regulatory agencies; and (7) needs and criteria for R&D in the electric utility industry.

The handbook on this series will serve not only as a reference for EPRI staff but also as an important source of information for other professionals in the energy R&D field and for energy policymakers. *EPRI Editor: O. S. Yu*

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