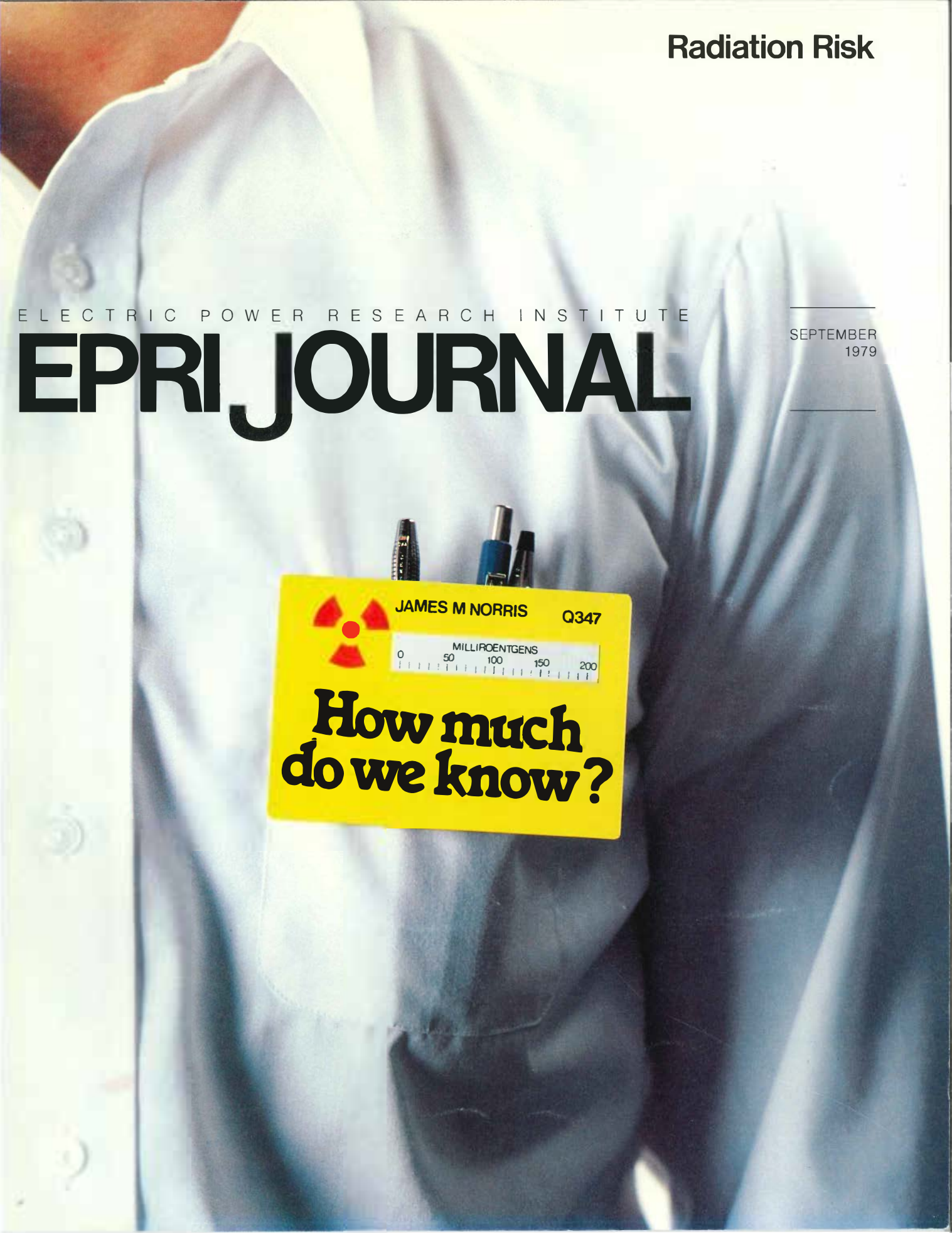
Radiation Risk

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

SEPTEMBER
1979



EPRI JOURNAL is published by the
Electric Power Research Institute.

EPRI was founded in 1972 by the nation's
electric utilities to develop and manage a
technology program for improving electric
power production, distribution, and utilization.

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Cover: Measuring the exposure to ionizing radiation and the risk to human health has been the focal point of radiobiologic research for the past three decades. A vast body of knowledge has been accumulated.

EPRI JOURNAL

Volume 4, Number 7 September 1979

Public Acceptance of Radiation Risk

This month's lead article recounts the history of radiation risk assessment and the extent of our current knowledge about the effects of radiation on health. Experience with agents that are known to be harmful at very high exposure has been used to assess the risk of low-level exposure. However, accurate risk assessment of low-level exposure is difficult: The precise relationship between low-level exposure and risk is not yet fully understood and is unlikely to be refined by further experiment because the effects of low-level exposure, if any, are so very small.

There are several ways to estimate low-level risk, such as extrapolation of the effects from high-dose exposure to test animals, interpretation of the limited data available from occasional group exposure to moderate- or high-dose levels, epidemiological analysis of large populations exposed to low levels, and the testing of theories about cellular damage and repair in the body. Each of these methods has limitations that result in risk estimates that can only be charted within bands of uncertainty rather than as precise values. In the case of radiation exposure at the levels usually associated with public exposure from the nuclear power industry (levels well below those received from our natural background), the uncertainty band ranges from the much-debated upper estimates (based on a linear dose-response relationship) to the possibility of a threshold below which the risk from a small dose practically vanishes. There is a common belief that "no amount of radiation is good for you," but this disputes the concept of threshold and has no basis in experimental science: All life has developed in a radiation-filled universe and some level may even be essential for natural evolution. Although we do what we can with the available information, it is precisely this small degree of risk from radiation at low levels that creates the measurement difficulty and the continuing controversy over the size and shape of the band of uncertainty.

Another equally important issue related to radiation risk is the public acceptance or rejection of risk. One approach common to many evaluations of the impact of energy systems is cost-benefit analysis. Under this method, risks are

considered social costs to be compared with the benefit of energy supplies and are balanced with the costs of the available methods to reduce such risks. Advocates of this approach argue that this process allocates resources as efficiently as information permits. An extreme counterpoint to this analytic approach is the zero-risk philosophy best exemplified by the Delaney Amendments' ban on carcinogenic food additives (such as saccharin), regardless of the level of risk or the benefits that their use provides.

A conservative approach to risk is easy to accept when the lost benefits are marginal—such as with fluorocarbon aerosol propellants. But the issue with low-level radiation, whether from medical applications or nuclear power, is substantially different. In these cases, the alternatives to the activities that create radiation risk also carry risks. For example, the health risks associated with available nonnuclear energy sources (such as coal) are generally considered to be higher than those for nuclear power, and the survival risk of increasing our energy imports may be higher still. Thus, the paradox: Hesitation to increase nuclear power because of a fear of radiation risk magnifies the social and political risks inherent in an insecure foreign energy source. In this vein, as a noted political scientist has observed, ''No-risk is the highest risk of all.''

The issue is not that our attitude toward new, uncertain, or hard-to-detect risks is unreasonable (this attitude probably reflects today's social consensus); rather, the issue is that we seem unable to apply this critical attitude impartially to each technology in the full range of future energy options. What is needed is a broader perspective that recognizes that political and social risks often outweigh perceived technological risk and its uncertainty. Thus in the case of energy, supply malnutrition may be a more serious risk than the small uncertainties in our existing diet.

Chauncey Starr
Vice Chairman, EPRI

Authors and Articles

Despite 85 years of accumulating scientific knowledge, misconceptions about the source, nature, and consequences of radiation still abound. In particular are the popular beliefs that radiation is strictly a product (or by-product) of modern technology and that science still knows very little about the health effects of radiation.

The truth is we live in a sea of radiation and always have. Each of us receives each year about 100 millirem of exposure from the natural background—radiation that emanates from the cosmos, from ordinary soils, rock, building materials, and even from our own bodies. We also receive roughly the same amount from medical and dental diagnostics each year.

As for the health effects of radiation, billions of dollars of research effort have, in fact, been poured into this area over the last 30 years. And emerging from these studies is the consensus that radiation is a relatively weak carcinogen and represents but minimal risk to the general public at low levels (i.e., levels below 5000 millirem). Nevertheless, this prevailing opinion rests on assumptions, such as linearity and dose rate, that have been brought into contention by a number of recent and highly controversial studies. "Radiation and Human Health" (page 6) examines these assumptions and explores the likelihood that these controversial studies will unravel today's consensus in radiation biology.

Leonard Sagan, author of this month's lead article, has been involved in radiation studies and risk analyses during most of his career. Beginning in 1961, just six years after he graduated from the University of Chicago Medical School, Sagan spent three years in Nagasaki as medical department chief for the Atomic Bomb Casualty Commission. Later, with a graduate degree from the Harvard School of Public Health, he worked for three years with AEC as a research physician in nuclear medicine, thereafter joining the Palo Alto [California] Medical Clinic, where he became associate director of environmental medicine. Since February 1978 Sagan has been with EPRI's Environmental Assessment Department as comanager of the program for health effects and biomedical studies. Sagan has also served as a consultant to AEC Nevada Operations Office (1968–1970) and to TVA (1971), and he has been on medical advisory committees of the Oak Ridge Associated Universities and Amnesty International.

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When the April 1979 Edison Centennial Symposium drew together speakers and panelists to explore the theme of science, technology, and the human prospect, there was an implicit question: Is that prospect altogether positive? The question is often charged and divisive, but Philip Handler, president of The National Academy of Sciences, responded in a paper that acknowledged a legitimate distinction. The benefits from science and technology, he explained, have often been more pronounced for individuals than for society as a whole.

"Energy, Technology, and Social Achievement" (page 14), abstracted from Handler's symposium paper by Nadine Lihach, *Journal* feature writer, elaborates the distinctions he drew and goes on to consider their relevance for the scientist or the technologist who must look ahead and weigh the alternative results that may flow from his work for individuals and for society.

Philip Handler has headed The National Academy of Sciences for 10 years, following 30 years on the faculty of Duke University, finally as chairman of the biochemistry department. Both before and during his term with NAS, he has served on national science advisory committees appointed by the president.

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Acid rain is a strong verbal image, and perhaps for that reason it has attracted such wide public scrutiny and nearly categorical condemnation of power plants as the cause of it all. Acid rain has also attracted wide scientific scrutiny, but here the image of the phenomenon itself, its causes, and its effects is far less distinct. Treatment of the subject is hardly an exposé; it is more like the first several chapters of a detective story.

"Tracking the Clues to Acid Rain" (page 20) was written by Jenny Hopkinson of the *Journal* staff in cooperation with two EPRI Environmental Assessment Department researchers who are helping to shape the investigation, seeking a theory of acidification that will include and reconcile both the causes and the effects of acid rain.

Robert Goldstein has worked in environmental science since 1969, first as a theoretical ecologist heavily involved in modeling studies at the Oak Ridge National Laboratory, then (since April 1975)

as a project manager in the Ecological Effects Program of EPRI's Environmental Assessment Department. Earlier, he earned BS, MS, and PhD degrees in nuclear science and engineering at Columbia University and taught physics at Queens College in New York.

Charles Hakkarinen began his work in EPRI's Environmental Assessment Department in April 1974, while completing requirements for his PhD degree in environmental science and engineering at the University of California at Los Angeles. He had previously earned BS and MS degrees at the University of Maryland in mathematics and in meteorology, respectively. Hakkarinen has been closely involved in EPRI programs to instrument and monitor air pollution transport; currently he is technical assistant to the director of the Energy Analysis and Environment Division.

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National productivity and economic growth, and the energy fuels that drive them, have special value for anyone who hasn't shared in the well-being they promise to deliver. This point is clearly evident to the chairman of the National Association for the Advancement of Colored People—"Margaret Bush Wilson: Articulating the Black Perspective" (page 25). Interviewed for the *Journal* by Marie Newman of EPRI's Washington, D.C., office, Wilson reviews the many institutional, educational, and technologic perceptions (including those from her own early life) that she must integrate in representing a constituency that still lacks what she terms economic parity.

Sagan

Handler

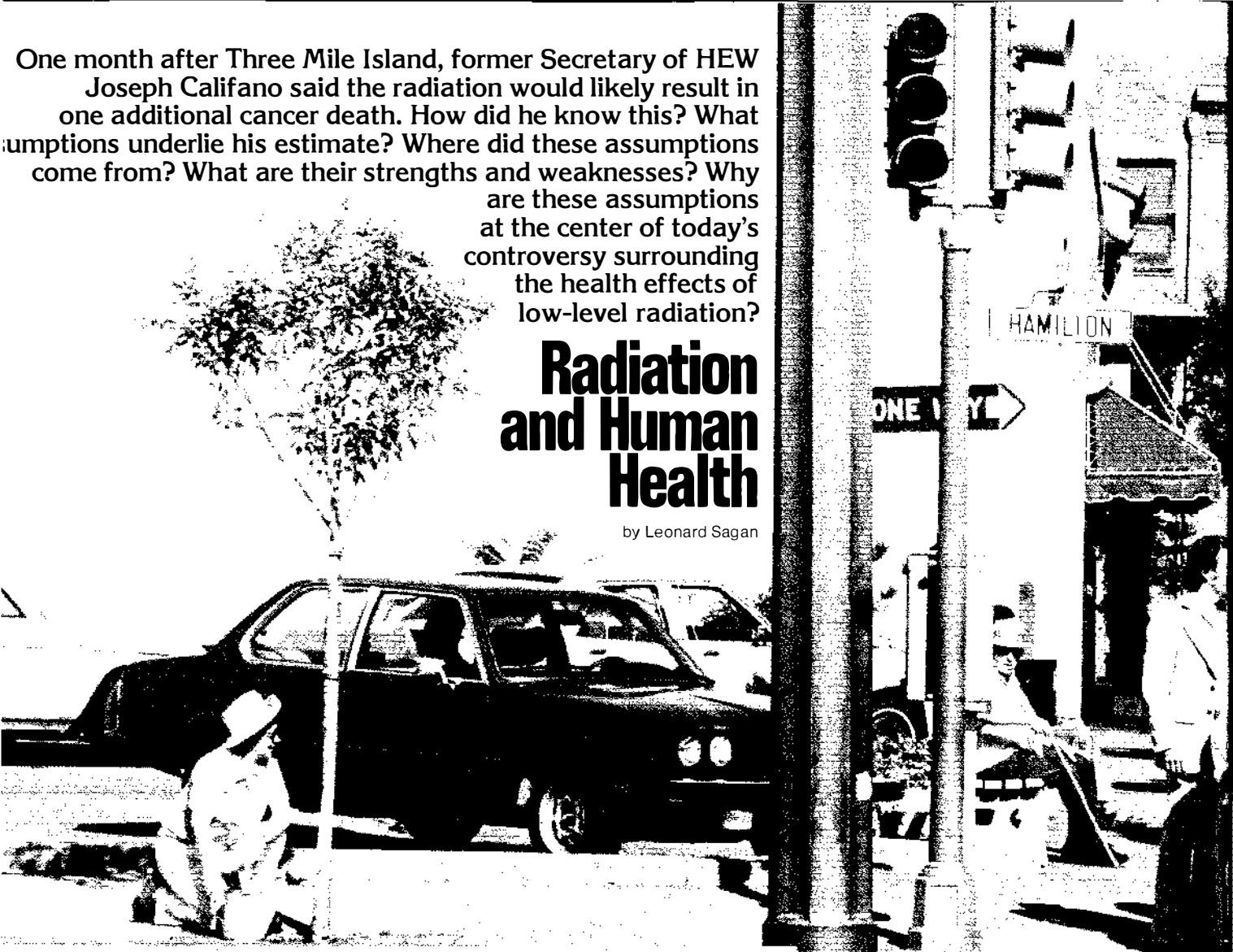
Hakkarinen

Goldstein

One month after Three Mile Island, former Secretary of HEW Joseph Califano said the radiation would likely result in one additional cancer death. How did he know this? What umptions underlie his estimate? Where did these assumptions come from? What are their strengths and weaknesses? Why are these assumptions at the center of today's controversy surrounding the health effects of low-level radiation?

Radiation and Human Health

by Leonard Sagan



ANNUAL RADIATION EXPOSURE TO U.S. POPULATION

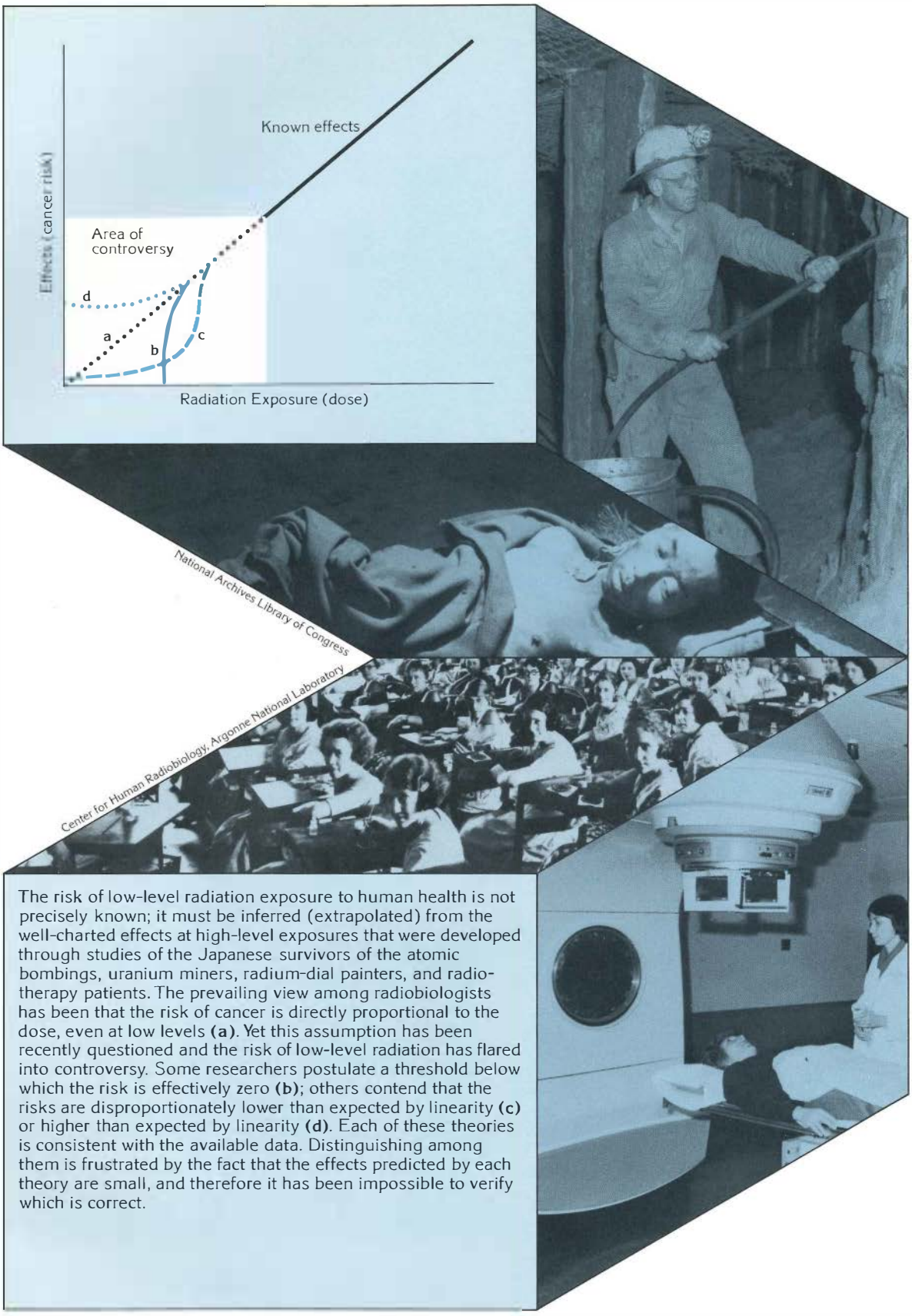
	Dose		Statistical Projection	
	Average (mrem)	Total (person-rem)	Cancer	Genetic Defect
Source				
Natural background	100	21,700,000	3,050	193
Technologically enhanced*	5	1,000,000	150	10
Medical diagnostics	85	18,500,000	2,600	164
Nuclear power (general public)**	0.03	6,000	1	0.05
Nuclear power (workers)	600	33,000	5	0.3
Nuclear weapons (development and fallout)	6	1,400,000	200	13
Consumer products	0.03	6,500	1	0.06
Effects				
Total from all radiation sources			6,007	381
Total from all causes, known and unknown			400,000	356,000
Percent from all radiation sources			1.5%	0.1%

Note: Calculations by Ralph Lapp, based on estimates of the BEIR committee.

*Mainly from naturally occurring radionuclides redistributed by human activities, such as mining and milling of phosphate and burning coal.

**Assuming normal operation, normal exposure. The radiation from the TMI accident (50-mile radius) was 1.5 mrem, 3,300 person-rem, expected to produce 1 cancer, 0.05 genetic defect.


UNION



The risk of low-level radiation exposure to human health is not precisely known; it must be inferred (extrapolated) from the well-charted effects at high-level exposures that were developed through studies of the Japanese survivors of the atomic bombings, uranium miners, radium-dial painters, and radiotherapy patients. The prevailing view among radiobiologists has been that the risk of cancer is directly proportional to the dose, even at low levels **(a)**. Yet this assumption has been recently questioned and the risk of low-level radiation has flared into controversy. Some researchers postulate a threshold below which the risk is effectively zero **(b)**; others contend that the risks are disproportionately lower than expected by linearity **(c)** or higher than expected by linearity **(d)**. Each of these theories is consistent with the available data. Distinguishing among them is frustrated by the fact that the effects predicted by each theory are small, and therefore it has been impossible to verify which is correct.

When Wilhelm Roentgen observed in 1895 that X rays would expose photographic film, he opened the door for the widespread use of X rays in medical diagnosis. Soon after it was also found that as with most physical and chemical agents, too much can be harmful. A report published in 1903 in the *New England Journal of Medicine* revealed that mice exposed to large doses of X rays died soon afterward.

It was also observed that human skin chronically exposed to X rays, as on the hands of dentists, would ulcerate and eventually develop cancerous growths. And when Madame Curie and a number of other early radiation workers developed leukemia, it became clear that bone marrow as well as skin was sensitive to malignant changes following excessive radiation exposure.

By the 1920s it was known that radiation exposure would produce genetic change in insects, and there was suspicion that infants whose mothers had been heavily exposed during pregnancy might be born with developmental defects. Concern at the time focused on medical uses.

Two radiation protection agencies were organized in the 1920s to provide guidance for occupational exposures (e.g., occupations involving the use of radium for the treatment of cancer), the International Commission on Radiological Protection (ICRP) and its American counterpart, the National Council on Radiation Protection and Measurements (NCRP).

Yet knowledge accumulated slowly. By the close of World War II, many fundamental aspects of radiation effects were still unknown. How much radiation is required to produce adverse effects? Are there differences among various kinds of radiation (gamma rays, X rays, alpha and beta particles, or neutrons) in their ability to produce health effects? Is the outcome affected if the radiation exposure is delivered over a short or a long period of time? Are diseases other than cancer increased by radiation exposure? Are children more sensitive or less sensitive than adults?

Leonard Sagan is manager of the Biomedical Studies Program in the Environmental Assessment Department of EPRI's Energy Analysis and Environment Division.

Following World War II, with the likelihood of the introduction of nuclear energy into the peacetime economy, an enormous scientific effort was undertaken to answer many of these questions. Literally billions of dollars were poured into the effort. Extensive studies were carried out on laboratory animals and exposed human populations—Japanese atom bomb survivors, persons receiving radiotherapy for a variety of disease conditions, and persons exposed occupationally, such as radium watch-dial painters and uranium miners. As a result, it is often said today that we know more about radiation exposure and its effects than we know about the effects of any other physical or chemical agent.

Bodily risk assessment

There was a recognized need after World War II to assess risk and to provide guidelines for permissible exposures to the public. Other organizations joined ICRP and NCRP in monitoring the literature and in assessing risk: The National Academy of Sciences formed the Committee on the Biological Effects of Ionizing Radiation (BEIR) and the United Nations formed the Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

In recent decades these agencies have achieved a remarkable degree of unanimity in their estimates of radiation risk. This is not surprising because these organizations have been reviewing the same data and making the same assumptions. Yet today this consensus is less clear. The validity of these assumptions has been challenged by several recent studies and this dispute is central to the controversy over low-level radiation risk. Before moving to the commonly accepted estimates of risk and some of the specifics of the present controversy, it is important to review three of the fundamental assumptions: dose

HOW DO WE MEASURE RADIATION?

Ionizing radiation produces a stream of fast-flying particles or waves that come from the nucleus of unstable atoms or man-made machines. The conventional unit of measurement of the amount of energy deposited in living tissue is the radiation absorbed dose, or *rad* (1 rad equals 100 ergs per gram of tissue).

Radiation comes in several basic types: alpha, beta, and neutron particles and gamma and X rays. Since these vary widely in their ability to penetrate tissue and alter molecular structure through ionization, the rad is weighted for the increased biologic effect of particles (i.e., a rad of exposure from alpha particles produces a greater biologic effect than a rad from X rays). This weighted measure of exposure is a *rem*, and it is independent of the type of radiation (i.e., a rem of exposure would be expected to produce a constant biologic effect, regardless of the type of radiation).

In discussions of low-level radiation, dosage is often expressed in millirem (mrem), which equals $\frac{1}{1000}$ of a rem. For example, the average person in the United States receives 85–100 mrem per year from medical sources and an additional 100 mrem per year from natural sources, such as from the radioactivity in soil and building materials, cosmic radiation, and the natural radioactivity in the human body itself.

The *person-rem* is a measure of population exposure rather than a measure of exposure to an individual. It is defined as the added doses to each of the exposed individuals. The underlying assumption is that of a linear relationship between dose and effect. For example, 100 persons exposed to 2 rem each would be 200 person-rem, and the ultimate effect is assumed to be identical to one person receiving 200 rem, which would also represent 200 person-rem.

rate, the so-called linear theory, and total-body exposure.

Just as radiation effects are modified by dose, they are also sensitive to the time over which the dose is delivered—the dose rate. This is no different from essentially all other human responses; for example, a given dose of alcohol, drugs, food, or sunshine will be much less damaging if the exposure is experienced slowly over a long period of time. Animal experimentation has shown that protracting the exposure of some animals (low dose rates) produces a dramatic increase in longevity compared with those animals receiving the same exposure but at high dose rates. In fact, at a dose less than 3 rem per week, no effects on longevity can be detected. This moderating effect can also be shown in the development of cancer. Animal studies carried out in several laboratories have shown that the development of tumors is reduced if the dose of radiation is protracted.

The linear theory refers to a straight-line extrapolation from high doses with demonstrable effects to low doses where there are no demonstrable effects or, at least, questionable effects. Studies of the radiation effects in humans have mostly been carried out following exposures that were very intense (i.e., high dose and high dose rate). Notable examples include the Japanese survivors of the atomic bombings and those persons treated with radiation for rheumatoid spondylitis, the two populations on whom greatest reliance is placed in developing risk estimates. But essentially no detectable effects exist in persons who have been exposed to low dose-rate radiation similar to that experienced in the operation of nuclear power plants. The nagging question then becomes how we should extrapolate from the high dose, high dose-rate exposure to the low dose, low dose-rate exposure. The assumption that has nearly universal acceptance is that effects at low doses will be proportional to, or linear with, those that occur at high doses and high dose rates. Because among the Japanese A bomb survivors approximately 200 cases of cancer occurred after the entire group had been exposed to almost 2,000,000 person-rem, it has been assumed that each 10,000 person-rem of exposure will produce one future case of cancer, even if the average dose to each individual is small.

Many knowledgeable people believe this assumption of linearity probably leads to an exaggerated estimate of risk. They base their opinion on a variety of lines of evidence. For example, Edward Webster of Harvard Medical School has recently shown that when the Nagasaki experience (primarily gamma-ray exposure) is examined separately from that of Hiroshima (strong neutron component to the exposure), the risk of cancer falls to at least half of that expected from linearity. Because gamma radiation is the type of exposure predominately associated with nuclear power, the Nagasaki experience is the more appropriate for estimating risk from nuclear power. Webster also points out that a number of other exposed populations studied (such as groups of radiologists, X-ray technicians, and women treated with radiation for cervical cancer) show no excess of cancer.

The third assumption underlying the radiation risk estimates is that the entire body is exposed. If part of the body is shielded, particularly if the exposure is limited to an extremity, the effect of the exposure will be minimized or even absent. It is this phenomenon that permits radiotherapists to use doses to small target tissues that would be lethal if the whole body was exposed. Typically, several thousand rems are used for cancer therapy.

Risk estimates: cancer and genetic effects

Having described the sources of data and the limiting assumptions, it may be useful to examine the magnitude of the risks and apply them to some occupational groups. Based on the reviews of The National Academy of Sciences and the United Nations, the risk estimate for cancer is about 100 cases per million person-rem. In other words, if a million persons are exposed to 1 rem above natural background during their lifetime, then the expected number of cancers in this group would be increased above the normally expected 200,000 cancer deaths by about 100 (i.e., from 200,000 to 200,100). Such a small increase, should it occur, could not be detected by statistical means, given the normal variability in cancer frequency.

Applying this risk estimate to the 60,000 people in the United States who are involved with radiation in their work (excluding medical personnel) and assuming 40 years of continuous work at the average exposures experienced today (0.6 rad per year), one can calculate that the risk of cancer from occupational exposure would be increased by less than 3%. Since the frequency of cancer varies as much as 100% among areas of the United States, the risk of occupational radiation exposure, even over a lifetime, is small compared with other environmental causes of cancer.

In the early years following World War II, when little was known about the carcinogenic risks of radiation, genetic effects were considered the more hazardous. The situation is now reversed. We now know that the cancer risks are greater and the genetic risks less than was previously thought.

Geneticists had at first thought that recessive mutations (those that require a damaged gene from both parents before becoming manifest in the offspring) might accumulate in each successive generation following several generations of exposure. The modern evidence is that such a phenomenon does not occur. Animal studies carried out over many generations, with exposures of 200 rem per generation, show no apparent change in fertility or evidence of poor health.

Furthermore, studies of the descendants of Japanese survivors of the

atomic bombings show no evidence of genetic effects from the radiation exposure. Nor are genetic effects shown by any other studies. These statements, while reassuring, should not be taken to mean that radiation exposure is not mutagenic. Circumstantial evidence makes it almost a certainty that radiation can produce such an effect in humans. Our problem lies in the fact that we do not know exactly how genetic mutations will manifest themselves, which makes it very difficult to adequately design experiments for their detection.

Recent research on cancer provides some new perspectives on the mutagenicity of radiation. It is becoming clear that all, or at least most, carcinogenic agents also have a mutagenic effect. This has now been widely demonstrated with the Ames bacterial mutation test and with other in vitro and in vivo tests. Although these relationships are only now beginning to become clear, it seems convincing that radiation is by no means unique in its ability to produce genetic change and could be contributing less to the burden of genetic mutation than many other agents.

Fetal effects

The human organism appears to be most fragile at the extremes of life. Whether it is air pollution, starvation, or infectious disease, the elderly and the very young (particularly the in utero fetus) are at greatest risk. The effects of radiation are no exception to this pattern. Early observations during the 1930s indicated that women who had been inadvertently treated with radiation during early pregnancy had an increased risk of bearing malformed children. Again, studies of the Japanese population who survived the atomic bombings have provided us with our best information on these effects. Of the women who were pregnant and heavily irradiated at the time of the bombings, many bore children who were mentally defective and/or had microcephaly (an underdeveloped head). Generally, the central nervous system seems to be the developing system most sensitive to radiation.

Data are too few and their variability too high to allow any firm conclusion about the relative radiation susceptibility of different embryologic structures within each species, but in a few cases malformations have been ascribed to exposures as low as 10 rem. In the vast majority of cases, the dose-response relationship is not linear, implying less effect per unit dose at lower doses. Except for microcephaly, there are no accepted estimates of risk because there have been no consistent findings of defects at doses between 1 and 20 rem. For microcephaly, the risk per rem of exposure is thought to be 1 per 1000 if the individual exposure is greater than 10 rem.

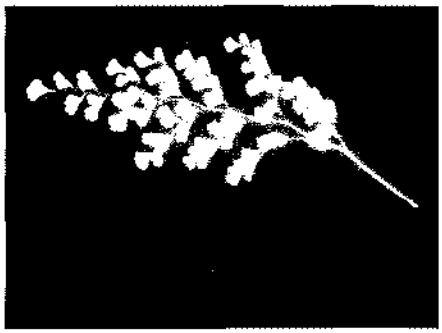
To place radiation risk in context, it is important to point out that the normal risk to the fetus during its nine-month sojourn in the uterus is high. Approximately 50 out of every 1000 children born alive have some developmental defect apparent at birth. Therefore, if 100 pregnant women were exposed to 10 rem each, the risk of a congenital malformation would be increased by only 2% (i.e., from 50 to 51 per 1000). Airline stewardesses, whose annual occupational exposures are about 0.5 rem, would experience an increased risk to the fetus of much less than 1%, even if they continued to fly throughout their pregnancy.

In addition to congenital malformations, there is also evidence that the developing fetus is more sensitive than other age groups to the carcinogenic effect of radiation. Studies in both England and the United States have produced evidence of an increase in cancer among children exposed in utero.

Recent controversial studies

The preceding describes what has generally been accepted as the consensus in radiation biology. It is still the prevailing view, although several studies have recently been published from which conflicting conclusions have been drawn.

Many animal and plant tissues are sufficiently radioactive in their natural state to expose photographic film. This autoradiograph is of a species of fern growing in a region of Brazil where the soil has a high content of thorium.



Dr. Eduardo Penna-Franca

These have received wide attention in the press and have thrown doubt in some quarters on the validity of the commonly accepted risk estimates. Each deserves some comment.

The most notable of these controversial studies was performed by Thomas Mancuso, Alice Stewart, and George Kneale (MSK). In 1964 Mancuso was commissioned to undertake a study of mortality among employees within Atomic Energy Commission laboratories. The first journal publication of data from the study appeared 13 years later in *Health Physics,* which reported an increase in cancer frequency among employees of the Hanford, Washington, nuclear facility who had been exposed to radiation.

For a number of reasons, this report created an enormous amount of interest and contention. First of all, the methodology was unusual and depended on a technique called proportional mortality, which ignores the population at risk; that is, it compares relative frequency of causes of death rather than generating rates of disease based on the exposed population. This technique is not often used because of the difficulty of interpreting such data. The MSK study has also been criticized for the practice of assigning average radiation dose values to persons with various causes of death. The problem with this technique is that a single high exposure to an individual can give a high average value for the

entire group, most of whom were not exposed.

There were other reasons for skepticism of a radiation effect in the MSK observations, namely that leukemia, the disease most sensitive to radiation exposure, was not found to be increased in this population. Other cancers not usually found to be increased by radiation were among those that created the excess mortality rate: multiple myeloma (a rare bone marrow tumor) and carcinoma of the pancreas.

A number of scientists have now published critiques that have raised serious questions about the validity of the MSK conclusions. These include analyses from the Nuclear Regulatory Commission and The National Academy of Sciences, as well as from reputable groups in Canada and the United Kingdom.

Despite the scientific controversy over interpretation of the data and the authors' conclusion, the MSK paper might not have created so much interest had there not been the widely publicized charge by Mancuso that his project was purposely terminated because the sponsor, DOE, was displeased with published conclusions. This charge led to congressional hearings and official investigations by DOE and then by the Office of Management and Budget, both of which concluded there had been no wrongdoing.

The MSK report did, however, create some concern about the accuracy of the generally accepted estimates of risk and the occupational exposure standards that are based on them. If the contested MSK findings are correct, then those risk estimates are low by a factor of 10. It was in this climate that three other studies appeared that seemingly lent weight to such a contention, those of Irwin Bross, T. Najarian, and Joseph Lyon.

Bross drew on the work of Saxon Graham, who published a study in 1963 known as the Tri-State Leukemia Study. This study concluded that radiation exposures to adults at diagnostic levels (less than 1 rem) could induce leukemia in their children even when the parents' exposure preceded conception by as much as 10 years. In a number of subsequent papers, Bross reanalyzed those data, using an unusual statistical technique, and developed a dose-response relationship that indicates (as does the MSK study) a much higher radiation risk estimate than generally accepted. Several critiques of Bross's technique have now appeared, including commentary by The National Academy of Sciences' BEIR committee. A critique by John Boice and Charles Land of the National Cancer Institute, published in the February 1979 issue of the *American Journal of Public Health,* commented, "Although the data base for the Tri-State survey was large, the 'new statistical methodology' introduced by Bross et al. depends on a model that is far too complex to be useful. Without the incorrect statistical manipulations employed by the authors, the analysis would produce estimates so imprecise as to be meaningless." Boice and Land concluded that "it is doubtful that the model is a reasonable representation of the relationship between radiation dose and leukemia risk."

The Najarian study bearing on low-level radiation exposure was published in the British medical journal, *Lancet,* in May 1979. This work used mortality data on former employees of the Portsmouth Naval Shipyard in New Hampshire. The authors, T. Najarian and T. Colton, surveyed the next of kin of the deceased workers. The relative was asked whether the employee had worn a film badge or had worked with radiation. The deceased group was then compared with U.S. males of similar age who had died of leukemia or other cancers. Najarian concluded that leukemia was increased 7.6-fold among the shipyard workers, based on the observation of 6 cases within the employee exposure group. It has subsequently been learned that two of these six employees had not been radiation workers, one had less than 1.0 rem of occupational exposure, and the other three had an aggregate exposure of less than 25 person-rems. Because one would expect 1.1 cases of cancer in a nonexposed population of similar size, the significance of the increase (3 cases) is in some doubt. Moreover, Najarian's observation seemingly contradicts the MSK study, which found no increase in leukemia among an occupationally exposed group.

The recent study by Lyon et al. analyzed childhood leukemia and cancer among children living in southern Utah during the period of weapons-testing fallout (1951–1958). In comparing these children with those living in northern Utah and those in southern Utah before and after the weapons-testing period, a significant increase in leukemia was found. Although the authors are cautious in their interpretation of these data, there is a strong implication that radiation is responsible.

There are also certain reasons for having reservations about a verified radiation effect in this study.

- It is not clear why mortality from leukemia was so low both before and after the exposure period in the high-fallout counties.

- When all other childhood cancers were examined, it was found that there was an inverse relationship between exposure and other types of cancer; that is, exposure produced a decrease in other cancers almost identical in magnitude to the increase in leukemia.

- We have very poor estimates of the dose from fallout and so cannot attempt a dose-response analysis for this population.

So, although this study is consistent with a low-level radiation effect, inconsistencies in the data suggest the need for caution in interpretation.

The BEIR committee of The National Academy of Sciences, which was intended to objectively survey and review the literature on radiation effects and

thereby provide some overview and perspective by the scientific community, has itself become an issue of controversy. Two opposing views of low-level radiation risks have developed within that committee: There are those who feel that linearity still represents the most appropriate model for low-level exposure and those who feel that such a model overestimates the effects from low-level exposure.

Although this committee was expected to render its final report last year and to have held a press conference this year, no report is yet in sight. Unfortunately, news of the disagreements within the committee have reached the public and have only served to reinforce the mistaken notion of great uncertainty in the scientific community. In fact, however, the range of disagreement and uncertainty is small compared with the scientific uncertainties of the risk from other environmental exposures.

Where are we now?

In this writer's view, the preponderance of evidence from the mass of human and animal studies strongly supports the risk estimates described earlier in this article and recommended by ICRP and the published reports of the BEIR committee. The recent controversial studies reviewed above are all so sufficiently flawed or incomplete that we need not yet abandon the opinions of the majority of the experts.

Is it likely, or even possible, that we are in error? Again, the preponderance of evidence is that if we are in error, we have probably erred in the direction of conservatism—that is, we have overestimated the risks. Yet, no one is complacent. A number of new studies have been spawned by these recent reports, some by EPRI, some by others. The National Institutes of Occupational Safety and Health has begun a survey of mortality at all naval shipyards. A study of persons exposed to military weapons testing is also being initiated. Lyon intends to pursue his Utah studies, and in spite of the very low exposures, health studies of populations around Three Mile Island are planned.

What conclusions, then, should the reader draw from this brief overview of radiation biology and discussion of recent controversial studies? First, carcinogenic agents, whether radiation or chemical, are relatively weak in the promotion of cancer; therefore, attempts to study the relationship between exposure and response will necessarily be plagued by all the limitations of the epidemiologic technique. This technique is a powerful tool when an agent, such as the measles virus, produces disease in a high proportion of exposed persons, but it is a clumsy tool when an agent such as radiation affects only a very small number of exposed persons. For example, in the Japanese survivor population, who have been under surveillance now for almost 30 years, there have been a total of only 77 excess leukemia cases and about 130 additional cases of other cancers among the more than 100,000 persons studied. Even in this heavily irradiated population, it is the rare individual who suffers effects. To detect such small effects, particularly in the presence of other carcinogenic agents, such as cigarette smoking, becomes a herculean task.

There can be no doubt that high doses of radiation are harmful and that we can predict with a high degree of probability the risk of subsequent effects in such populations. What remains in some doubt is the question of whether small doses, such as occupational exposures of a rem or two per year, have the effect predicted by linearity, or have no effect, or (most likely) have an effect somewhere between those two.

In the near future, we are not likely to know more about this, just as we are unlikely to know whether small doses of any carcinogenic material are harmful or not. Until we do, we must carefully balance the risks and the costs of reducing those risks, guided by the scientific evidence at hand. ■

WHAT EPRI IS DOING

EPRI is engaged in two different research efforts related to low-level radiation effects. One is a cooperative effort with the Pennsylvania State Health Department to evaluate the health effects, if any, of the Three Mile Island accident. This will include an evaluation of the radiation effects, the effects of stress and anxiety, and finally, the economic costs both explicit and implicit in these health incidents.

A second study, also just getting under way, is directed toward the effects of occupational exposure within nuclear plants. This is intended to be a long-term study of all operating personnel and should provide information on the relative risk of working with radiation compared with other utility exposures.

EPRI is also attempting to provide accurate information and perspectives on low-level radiation effects by providing succinct reviews of new studies as they appear in the literature. EPRI is sponsoring a workshop for radiation experts who will review the studies alluded to in this article and provide some overview for the utility industry.

Technology has been the principal engine of social change and economic development in the industrialized world. Many of us once shared the belief that science-based technology would continue to derive change, that economic growth would continue and bring with it betterment of the human condition. But faith in that axiom is declining in the scientific and technical community: Some of us cling to the belief that human ingenuity will produce new technologies that will alleviate the problems associated with the old and provide new and unanticipated benefits; others consider that the anticipated consequences of technology have already injected the seed of inevitable disaster into human affairs. I find myself in a middle position, clinging guardedly to optimism.

There is no need to rehearse the technologies that have molded the societies of industrialized nations. This process can be categorized in human dimensions and in institutional or social dimensions, which are different from but clearly intersect with the first. Human progress refers to improvements in the circumstances of individual members of society —their health, their living conditions, and their capacity to realize their individual physical and intellectual capabilities. Institutional social progress means improvements in the functioning of the social institutions that enable members of a society to interact effectively with one another, as well as with other societies.

Quick inspection reveals that within industrialized nations, the impact of science and technology on individuals has been beneficial. The quality of individual life has been transformed by the availability of electric power, the internal combustion engine, and a thousand other technologies. But in the institutional social dimension, the contributions of science and technology seem much smaller—in some ways, perhaps, negative.

Change in the human condition

A considerable fraction of humanity has shared, to some degree, the joy of scientific knowledge. Worldwide, people's lives have been immeasurably enriched by some knowledge of science, of what we are and where we are—a sense of understanding. The faith that what is not understood today will be learned tomorrow is a vastly different life experience than is the ignorance that engendered superstition and black terror through most of history.

The dramatic improvement in public health in the last century was mainly achieved by relatively unsophisticated science and technology. Improved sanitation followed upon knowledge of bacterial and viral pathogens and the chemical and engineering science required to deal with them.

Improvement of nutritional status reflected scientific knowledge of the consequences of malnutrition; sufficient income to purchase an adequate, balanced diet; and an agribusiness that provides an abundance of diverse foodstuffs at relatively low cost and ensures their nationwide distribution.

Illness, too, is not unknown, but a combination of drugs and surgical skill has made the ages from 10 to 45 relatively uneventful and free of pain for most of us.

Increased productivity on the farm, made possible by the right technologies, made the industrial labor force possible. Industrial productivity, increasing over many decades, enabled the abolition of sweatshops and a decline in the number of working days per year and hours per day, while increasing family income sufficiently to allow the young an opportunity for increased schooling.

With increased productivity came in-

Philip Handler has been president of the National Academy of Sciences since 1969. This article is an *EPRI Journal* abridgment of the speech given by Handler at the Edison Centennial Symposium, April 1–4, San Francisco, California.

creased family income. Decreased working hours and increased income also engendered leisure activities, which have become, in turn, a significant component of the economy.

In short, the sense of positive movement toward longer and richer lives for a great many people seems very compelling and finds its origin in science and technology.

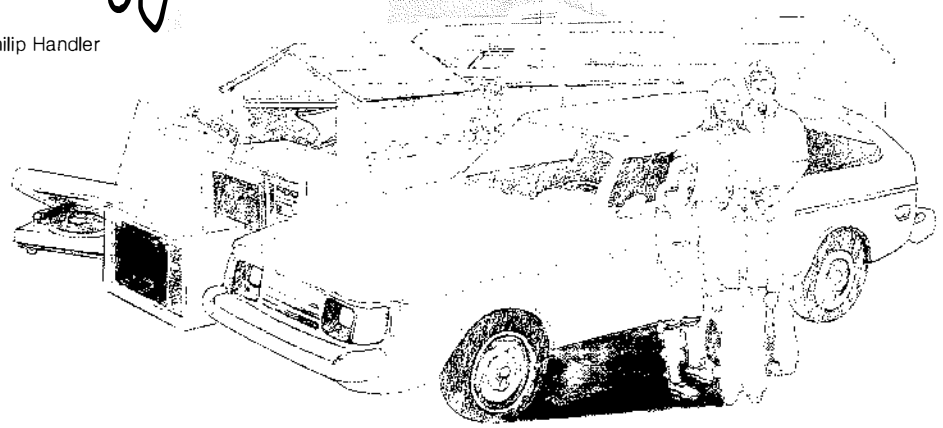
Put as cruelly as possible, society was not kind to horses until it lost the need for horsepower. Slaves were freed as a result of a national upheaval, but it happened when slavery was changing from an economic asset to a liability. Legislation protecting children and women at work was passed when the economy could tolerate it. The release of women from the kitchen finds its origin in the invention of the tin can. The operation of affirmative action in our time was made possible by the multitude of employment opportunities in an expanded economy. Enhanced educational opportunities then appeared, a necessity for participation in a labor force where the median level of skill required to hold a job has been rising steadily for a century.

But science and technology have not solved all social problems, and may have created some. Unemployment, for example, exists. In principle, it is remediable by education, which gives the unemployed a place in a more skilled sector. But since 1967 the proportion of unemployed persons who say that they simply cannot find a job has steadily increased, while the fraction citing lack of

The case for science and technology as mitigators of the individual human condition is beyond argument..

Science, Technology, and Social Achievement

by Philip Handler



Change in social dimension

When we turn to indicators of institutional social progress, however, matters look less rosy. To a certain point, all goes well. The profound change in the status of women and minorities in our society during the last few decades needs no recounting. The success of these movements was made possible primarily by technology and an expanding economy.

training, education, or other personal handicap as the primary reason has steadily declined to less than 10%.

The rising personal aspirations of our society, coupled with our history of upward social mobility, are now inversely mirrored in frustration and discontent. Crime statistics show this best: The homicide rate has more than doubled since 1960, as has the rate of aggravated assault; reported robberies have nearly quadrupled; property crime rates have tripled.

As society becomes increasingly interdependent and complex (in some part, the consequence of advancing technology), government, industry, educational institutions, the church, and the courts have come to be viewed as decreasingly competent in managing their responsibilities. The conditions under which science and technology have flourished are the very conditions that pose major challenges to social relationships and social institutions. The growth in the size of organizations and the resultant increase in specialization necessary to support rapid scientific and technological development have created difficult management problems at all levels of society.

But in the institutional social dimension, the contributions of science and technology are mixed—in some ways, perhaps, negative.

Mass communication and the rising level of the population that result from and contribute to science and technology have generated greatly increased expectations, too, some of which cannot be fulfilled. At any given time, we compare ourselves with others, and this universal access to the communications media has fed unrest. Unfilled expectations in lower income groups and the sense of social malaise in the upper income groups place great pressure on our social institutions.

Meanwhile, society's classic stabilizing features have lost their strength. Geographic mobility, increasing separation of the workplace and the home, and increased participation of women in the labor force have placed great strains on the family. Religion has been seriously threatened by the rise of science, which offers no acceptable substitute.

Looking outside our national boundaries, the advance of technology has begun the process of welding humanity into a single community. Transportation and communications have given hundreds of millions of persons increasing acquaintance with peoples elsewhere. But this has not homogenized us, as evidenced in the "Yankee Go Home" signs in so many corners of the world. While economic interdependence for resources and markets could serve as a unifying force, it also places the greatest possible strain on international relations, and those strains will dominate international relations for the indefinite future.

There have been some changes that may be considered as social progress in the institutional sense. The past century witnessed widespread acceptance of the principle that the state has an obligation to protect the welfare of its citizens. It is now taken for granted that there should be regulations in support of the health, safety, and well-being of individuals. Although the economic system is currently suffering from overregulation, we must remind ourselves that for the majority of our population, life has improved not only because the standard of living is higher but also because risks generally have been radically reduced relative to the past, largely because of the intervention of the state.

Political power has been redistributed in the direction of greater equity—women vote, blacks vote. There has been a dramatic increase in public awareness of how our society operates. It's taken for granted that social arrangements can be altered for the better and that it is appropriate to strive for such alterations. So although we've certainly not found the solutions to many social ills, in at least some areas the illness has been identified in ways that make solutions imaginable, if not yet achievable. The new social sciences have begun to contribute significantly to social progress. For example, we now collect statistics on society, population, and the economy. Through such statistics, presumably one can learn whether we have been making things better or worse.

To sum up, the case for science and technology as mitigators of individual human circumstances is beyond argument. However, the effects of science and technology on institutional social circumstances have been less impressive. Although there have been improvements, science and technology may indeed have had negative effects overall.

The dilemma

Let us now turn to the social context in which science and technology develop and function. There is, indeed, concern for the societal impact of new technologies, but it is important that these social issues are not permitted to distort objective evaluations of safety, economics, or technical performance.

Difficulty arises in the scientific community from confusing the role of scientist as scientist with the role of scientist as citizen—a confusion of the ethical code of the scientist with the obligation of the citizen. This blurs the distinction between scientific and political questions.

Yet in the mind of a scientist there need be no conflict between science and human progress. The scientific ethos itself should compel the behavior of the scientist when contributing to evaluation of the social value of a specific technology. Unfortunately, when presentation of his analysis and recommendations is also suffused with a social or political etiology, the scientist can unconsciously become a partisan and leave scientific ethos behind.

The necessity for scientific rigor is even greater when scientific evidence is being offered as the basis for the formulation of public policy than when it is simply expected to find its way in the marketplace of accepted scientific understanding. Political decision makers have no choice but to rely on the validity of the findings of science. This places a heavy burden on scientists who bring such matters to public attention. Announcement of each experiment may generate public alarm that can neither be justified nor assuaged. Once a compound or a power plant has been publicly called into question, however meager the evidence, decision concerning its use becomes unavoidable. The sensible guide would be to accept substantial hazard only for great benefit; minor hazard for modest benefit; and no hazard at all if it can be avoided without penalty. But in most cases, quantitative assessment of risk has been lacking. Accordingly, the current guide to our behavior appears to be to place a value of minus infinity on any possibility whatever of, say, carcinogenesis. The result has been a stream of regulations, each well intentioned and most commendable. But in the absence of persuasive data concerning the magnitude of risks to humans, the sum of such regulation can engender public cynicism (the "carcinogen of the week"), snarl life in the workplace, and slowly paralyze the economic life of the nation.

I applaud the evolution of the Clean Air Act and its amendments from 1970, when it mandated reduction of risks to zero irrespective of cost, to 1977, when it asked that decision be based on comparison of marginal cost with the marginal benefits of pollution abatement. That amendment, however, returns to the technical community the burden of identifying and quantifying the risks and of relating health effects to exposure levels. It also leaves us with the responsibility of developing the risk-benefit calculus that is now so lacking. But the problems of our day involve risks and benefits that usually accrue to different groups and costs, risks, and benefits that are incommensurable. Costs are reckoned in dollars; benefits, in esthetic or material values; risks, in human lives. And it is for this reason that while risk-benefit analysis can certainly inform the decision maker, the decision necessarily must still turn on a value judgment. The acceptability of a given level of risk remains a political, not a scientific, question. And when scientists enter these areas but fail to recognize the boundaries, unspoken etiological and political beliefs easily becloud seemingly scientific debate.

It is time, I think, to return to the ethics and the norms of science so that the political process may proceed with greater confidence. The public may wonder why we don't already know that which appears vital to decision. But science and technology will retain their place in public esteem only if we admit our uncertainties and assert the need for further research. We shall lose that place if we dissemble or if we argue as if all necessary information and understanding were in hand. Scientists best serve public policy while living within the ethics of science—not those of politics.

These considerations reveal a painful dilemma. All of us cherish the democratic ideal, which is that matters might be so arranged that persons affected by public policy could have a voice in framing that policy. Implementation of that ideal with respect to the public management of technology and applied science has a less-than-noble history. Unless opposed by major economic factors easily understood by the polity, scare tactics prevail all too readily. The issues that must be factored into decisions concerning nuclear power, auto emissions, and food additives are complex even for the scientist, engineer, or economist. So we require institutions and procedures that of themselves are democratically accountable, while decision making is left to those who have been given that authority on our behalf.

The dangers of ignorance

For two centuries concern has occasionally welled up for the societal consequences of one or another technology. But until recently, science itself was viewed by society as an autonomous venture of high integrity whose conduct was best left to scientists. That view is changing. For instance, in medical research, there has been public concern for the use of human subjects, so such institutional procedures as informed consent have been initiated. The controls are cumbersome, but worth it. In other instances, however, the problem has first been flagged by attention within the scientific community, then elevated to the status of a public issue. There has been pressure not to undertake certain studies because of fear that society might not be able to live with the answers gained in investigations of recombinant DNA, for example. Macfarlane Burnet, an Australian immunologist, noted, "It is a hard thing for an experimental scientist to accept, but it is becoming all too evident that there are dangers in knowing what should not be known."

I reply that it must be far more dangerous to live in ignorance than to live with knowledge. The uses of knowledge, of science, are unpredictable. There is intrinsic value in knowledge of our own genetic mechanisms. Conversely, the ugly possibilities that concern Burnet could occur only at the end of a long and difficult experimental road, in full view of many observers.

Historically, freedom of inquiry came to be cherished as the scientific search for truth freed mankind from dogmatic

religious and political thought. To use the government for the suppression of ideas that might otherwise flow from research would take us back to an era of dogmatism from which man has only recently escaped.

We have little understanding of the factors that prompted the acceleration of science in Europe two centuries ago or the circumstances that caused the technological torch to move from Europe to America a century later. But we do know that we now live in an overpopulated, competitive, interdependent world the United States no longer dominates; that many another once-powerful, prosperous, dominant civilization has disappeared, and even now we are sharing the torch of technology with several other nations. Understand that I am concerned for a serious possibility: Few can readily believe that the United States could lose its prominent place in the world. Yet many nations at the apex of their power were inwardly doomed when their willpower began to falter, and therefore we should be most careful about retreating from the challenges of our age. As Shakespeare put it, "We must take the current when it serves, or lose our ventures."

We can be unabashedly optimistic concerning the prospects for continuing great discoveries in every discipline of science; our current malaise stems from the time delay in meeting the high hopes and expectations raised by science and technology. I see no alternative but to address vigorously the principal questions of science itself and to use our ever-widening understanding, our increasingly sophisticated technology with grace, charity, and wisdom. We are not omnipotent, but neither are we the foils of powerful forces over which we lack control. Our joy must be found in the exercise of our unique human capabilities to eradicate that which we abhor and to promote that which we value and cherish. Science is the principal tool that our civilization has developed to mitigate the condition of man. ■

SYMPOSIUM DOCUMENTARY AVAILABLE

Philip Handler, president of The National Academy of Sciences, is one of the speakers appearing in *Science, Technology, and the Human Prospect*, a 45-minute video cassette, which explores the impact of scientific discovery and technological innovation on our society and considers the future direction of technical development. The film documents the Edison Centennial Symposium held in San Francisco, April 1–4, 1979, as an official event of the International Centennial of Light.

Narration is by Chauncey Starr, symposium chairman and vice chairman of EPRI. Other speakers who appear in the film include Philip Morrison, professor of physics at the Massachusetts Institute of Technology and book review editor for *Scientific American;* F. Kenneth Hare, director of the Institute for Environmental Studies and professor of geography and physics at the University of Toronto; Gunnar Hambreaus, president of the Royal Swedish Academy of Engineering Sciences; Wolf Häfele, deputy director of the International Institute for Applied Systems Analysis, Austria; René Dumont, retired member of the National Institute of Agriculture, Paris; Sumitro Djojohadikusumo, professor of economics at the University of Indonesia, Jakarta; and many others, including business leaders, writers, educators, and students.

Through interviews and speech excerpts, viewers are given a review of the effect science and technology have had on modern society and lifestyles and a look ahead toward some new goals for the human race. The documentary will provide high school and college students, as well as adult general public audiences, with an informative and stimulating survey of these vital issues.

For further information about the availability and price, contact Research Reports Center.

Tracking the Clues to Acid Rain

What causes acidity in atmospheric and surface waters? How does this acidity affect living matter? EPRI is seeking the answers.

Rain falls over the Adirondack Mountains in New York State, runs through the trees and soils, and merges with the streams that flow into a group of three lakes. Water samples along this complex pathway are routinely gathered by researchers and analyzed for acidity. And a puzzle that defies simple assertions of cause and effect begins to emerge.

Water-sample measurements show considerable differences in the acidity of the three lakes. This finding contrasts sharply with rainwater samples, which show very little difference in acidity.

What causes the differences in the acidity of the lake samples? If precipitation is not the only factor of influence, what are the others? For instance, do vegetation, soils, and bedrock help acidify surface waters? And how does precipitation become acidic in the first place? What are the relative contribu-

tions of utility combustion, industrial combustion, automobile exhaust, other anthropogenic sources, and natural sources?

These questions have mobilized studies on the formation and effects of acid precipitation. Since the 1950s observers have documented the acidity of rainfall and surface waters in the northeastern United States and northwestern Europe, particularly Scandinavia. Concern has been voiced about effects on fish, forests, and vegetation, and assumptions have been made about the cause. The idea has been publicized that fossil fuel combustion is the main source of the sulfates and nitrates that can produce acid rain. Acid rain has been given as the primary reason for acidification of surface waters, for decline in fish populations,

and for decreasing forest productivity.

The data on acid rain effects that were collected over the past two decades have validity, but the conclusions drawn from them are highly inferential. Too few avenues of the acidity network were traveled; too few scientific disciplines were included in tracking the facts.

EPRI has approached the gap in the knowledge about acid rain from two directions: earth and atmosphere. Advisory workshops have been held and a number of projects have begun. In an integrated study on the effects of lake acidification in the Adirondacks, researchers are amassing data and building a mathematical model. The formation and transport of acid rain are being investigated in two other projects: one is a joint EPRI–CERL study (CERL is the U.K. Central Electricity Research Laboratories, the research unit of the British electric utility), and the other is being performed by Rockwell International Corp. for EPRI. A number of other organizations, such as EPA, DOE, the Department of Agriculture, and the National Oceanic and Atmospheric Administration (NOAA), are also working on the acid rain problem and sharing in EPRI's research results.

Focusing the search

To ensure that the search for clues to the formation and effects of acid rain was pointed in precisely the right direction, the advice of a number of respected scientists was sought. In September 1978 Robert Goldstein, manager of EPRI's Adirondack study, and Gwyneth Howells, head of CERL's biology department, set up a jointly sponsored workshop in Scotland on the ecological effects of acid rain.

The participants—a small, international group—discussed interactions and effects of dry and wet deposition on vegetation, soils, surface waters, and aquatic ecology, including fish. They also considered methods of data collection, sampling, and analysis.

But most important, the group corroborated the precise objective of the Adirondack study in this statement: "It was agreed by all that there was a need for an acceptable theory of acidification of waters, distinguishing and quantifying acid sources and their relationships."

Quantifying the effects of acidity helps in estimating the cost of ecological damage, but to estimate the cost of preventing the damage, it is vital to find out how acid rain is formed. So in August 1978, Charles Hakkarinen, EPRI project manager, conducted an advisory workshop in Utah to pinpoint precise directions for research into the formation of acid rain. Workshop participants—scientists from the United States, Canada, and Europe—recommended that EPRI focus on instrumentation, field studies, modeling, laboratory studies, and data analysis and interpretation. Most important, they emphasized the need to investigate cloud chemistry, not only in various geographic regions of this country but also over the four seasons. They estimated that at least $20 million of research funding would be needed to answer the critical questions about acid rain formation.

Monitoring the effects

Although the ecological effects workshop supported the need for EPRI's Adirondack study, it did not mitigate "the difficulty of doing a total ecosystem study," according to Goldstein. He continues, "A unique aspect of this project is that it is an interdisciplinary study that requires a group of people with expertise and experience in a diversity of disciplines to work together in a cooperative, integrative fashion." Scientific specialties employed in the study are micrometeorology, plant-nutrient relations, plant-water relations, soil physics, soil chemistry, geology, hydrology, lake chemistry, and mathematical modeling.

Researchers are concentrating on three Adirondack lakes: Woods Lake, which shows considerable acidity; Sagamore Lake, which has a variable pH; and Panther Lake, which has a pH of 7. (pH is a measure of acidity; on a scale of 0 to 14, 7 is neutral, numbers under 7 indicate increasing acidity, and over 7, increasing alkalinity.)

One research team (with participants from the University of Virginia, Cornell University, U.S. Geological Survey, and Brookhaven National Laboratory) measures the quantity and quality of runoff that flows into the three lakes. They regularly monitor the chemical and biological parameters for the lakes and have drawn up preliminary maps of soil and vegetation types.

Other researchers measure the amount and chemical nature of substances deposited by rain, snow, and dry fallout. Still others study the effects of acid precipitation on microorganisms, on the biochemical activity in soils, and on weathering of soils and rocks. Core samples of lake sediments have been taken for chemical analysis and for dating strata containing plankton remains.

Dating strata helps to indicate historical trends of acid precipitation in the United States, or more precisely, levels of lake acidity in the past. Analyzing strata of lake sediment may help answer such questions as how lakes become acid or whether they, in fact, *become* acid or are as acid as they always were. As has been demonstrated by the differences in pH of the three lakes being studied by EPRI, rainfall acidity does not necessarily correspond with lake water acidity.

Fish populations are said to be decreasing in some Adirondack lakes, which may be the result of increasing acidity. But the pH history of the lakes is not known, nor is the size of fish populations in the past. It is possible that the lakes have always been acid. It is also possible that reproduction is not taking place at previous levels. Low pH in precipitation can cause aluminum to be released from soil, and if this aluminum enters the lake water, it could prevent fish from reproducing. Other reasons for the disappearance of fish could be the destruction of spawning grounds, the increase in sport fishing, or the replacement of native populations by exotic species, which in turn disappeared because they could not adapt to extreme

seasonal fluctuations in the weather.

Just two facts are clear: The rain is acid, and the surface waters are acid. The step-by-step explanation is still locked in the natural world, but clues are being discovered and documented. These clues, or data, will be used by Tetra Tech, Inc., of Lafayette, California, management contractor for EPRI's Adirondack study, to build a model of the routes taken by precipitation after it falls.

A major question is what happens in the soil system around a body of fresh water. If in the same geographic area the acidity of rain is at one level and the acidity of lakes is at another, the chemical reactions in the soil must be investigated. In addition to the atmosphere, sources of acid can be the respiration of plant roots and microorganisms, element uptake by plant roots and other living matter, reactions of chemical compounds in soils, and decomposition of organic residues.

A University of Virginia researcher, who coordinates the Adirondack field research activities on acid rain effects, postulates certain hypotheses about the hydrology of the three watersheds. For example, the hydrological characteristics of Woods, Sagamore, and Panther lakes are different. Using the model, analysis of hydrological data validates this hypothesis. The volume of the flow in the streams of Woods Lake watershed increases more quickly in response to rainfall than do the stream volumes of the other two watersheds. Factors that contribute to this response are greater amounts of bedrock outcropping, steeper slopes, and thinner soils around Woods Lake. Acid rain apparently has less time to react with the soils in the Woods Lake watershed and hence has less chance to be neutralized by the soils.

Each of the other researchers also produces a set of specialized hypotheses, which is integrated into the unified model.

Cloud chemistry

Up to now, most measurements have been made on rain after it falls. But in an EPRI project managed by Ralph Perhac, acting director of the Environmental Assessment Department, rain samples are taken directly from the atmosphere in an attempt to learn how acid rain forms.

Last year EPRI and CERL began a 2½-year project, funded at nearly $1 million, to define the chemical reactions in the atmosphere that yield acid rain. To find out, researchers collect samples of atmospheric water directly from the clouds. They fly a specially equipped airplane over the North Sea from the U.K. to the coast of Norway and calculate the U.K.'s contribution to the acid rain that falls over Norway.

Based on the results of this project, similar cloud chemistry experiments will be run in the United States, possibly in 1980.

Cloud physics

The formation of acid rain goes hand in glove with its transport. In the project conducted by Rockwell, EPRI is trying to define the source of acid-containing air, not only in the Northeast but also as far away as Tennessee and Indiana.

Rockwell operates a network of nine precipitation chemistry monitoring stations located adjacent to some of EPRI's Sulfate Regional Experiment (SURE) air quality stations, which are in an area extending from eastern Kansas to the Atlantic coast and from southeastern Canada to mid-Alabama. Each station has two collectors that are sampled daily. Rockwell combines the data from the analyses of the samples with meteorological data from the National Weather Service of NOAA, such as storm movements and wind direction, in an effort to calculate the source of acid deposition. Because this is not an easy task, the Rockwell project is viewed as a preliminary effort to develop the methodology by defining the major pitfalls and drafting guidelines on how the experiment should be carried out in the future.

One example demonstrates how difficult it is to track the facts of acid transport. Not only must the source of acid-containing air be traced but also its elevation in the atmosphere must be ascertained. Chemical matter that is being carried aloft at 10,000 feet may be going in a different direction from that being blown along at 5000 feet. As Hakkarinen points out, "You have to know where the cloud is and where the air is coming into the cloud. Compass directions can be off by almost 90° with incomplete data; when you project calculations to 1000 miles from the suspected source, you could be mistaken about the state that receives the acid rain; you could even be mistaken about the country, if you're in Europe."

The Rockwell project's major connections with the Adirondack project are twofold. First, it may help answer the question on where the acid rain in the Adirondacks is coming from. Second, it could help identify acid-sensitive areas in North America that might suffer from acid rain effects in the future.

EPA directions

Another parameter in predicting effects of acid rain is the season of the year. If it is spring, or budding time, crops may be more prone to damage by acid rain than at other times in the growing cycle. EPA's Corvallis Environmental Research Laboratory in Oregon has an experimental farm at which tests are run on the effects of acid rain on some major U.S. field crops.

Knowledge gained in these studies should increase understanding of the environmental effects of acid rain on forests and managed agricultural land, as well as on aquatic ecosystems, such as lakes, streams, and bogs.

Aquatic ecosystems may be affected by nutrient cycling, or lack of it, in the same way as the soils are affected. Because natural organic litter that decomposes in lakes and streams provides nutrients for aquatic vegetation and fish, the onset of acidity in the water may prevent that decomposition, thus depriving aquatic communities of nutrition.

EPA plans to conduct studies of acid rain effects on soil and water in the northeastern and possibly in the southeastern United States during the next few years.

Using input from EPRI's SURE network, DOE's Multistate Atmospheric Power Production Pollution Study (MAP3S), and research results from the Department of Agriculture's National Atmospheric Deposition Program, EPA will attempt to determine the overall atmospheric contribution to acidity in those regions.

Comparing measurements

The effectiveness of integrating research results depends on the establishment of standards in collection and analysis methods. To illustrate how widely collection methods differ, Donald Pack, consulting meteorologist to EPRI, enumerated a few. At the present time, DOE's MAP3S researchers collect precipitation on what they call an event basis. When it begins to rain, the collectors open automatically. These devices remain open until it stops raining, or the event ends, and the sample is then analyzed.

In the National Atmospheric Deposition Program samples are collected weekly. In a parallel program, some Canadian researchers leave collectors out for a month and only then send samples to the laboratory for analysis.

In EPRI's Adirondack project, samples are collected every 24 hours if rain has fallen during the previous day. The rationale for the more frequent collection is that winds and weather are less likely to change over 24 hours than they are over a week. It is thus helpful to eliminate as many fluctuations of chemical transport as possible in trying to relate the source of the chemical that causes acidity to the received precipitation. There is also concern that samples left standing outdoors for several days may become contaminated.

A mass of nonstandardized meteorological data is accumulating worldwide. Much of it is received by the World Meteorological Organization (which has 121 members—mainly the meteorological services of the member countries) because WMO offers to publish research results on behalf of members. The resultant literature reveals the differences between methodologies used by laboratories and the difficulty in comparing research results because different laboratories use different units of measurement. To reconcile the discrepancies, the Tennessee Valley Authority has instituted new quality control procedures, and the U.S. Geological Survey, EPA, and DOE's Environmental Measurement Laboratory are also planning to set up comparative investigations of laboratory sampling and analysis.

Approaching the clues

A spur to continuing research is the puzzling nature of data variability. Both chemical and meteorological fluctuations elude understanding of the amount and rate of conversion of material emitted into clouds and later deposited on the ground and into surface waters. Each raindrop may have a specific sulfur- or nitrogen-saturation point. This may mean that to whatever degree humans either load or relieve the atmospheric burden of chemicals, the acidity of rain will change little. We need to discover the sources of atmospheric acid, the relative contribution of each source, and the ecological effects of the atmospheric acids. If the effects are detrimental, then the cost of these effects must be compared with the cost of controls required to reduce the acidity.

Scientists have studied the physics of clouds for more than 20 years; it is hoped that unraveling the chemistry will not take as long. Regulators cannot wait for decades for the information. Maybe a compromise will emerge that will forestall the institution of misdirected regulatory standards, set up in haste to satisfy legitimate concerns. It is in the interest of utilities, EPRI, government, and the general public that the most effective strategy be put into action to solve the problem of acid rain.

More answers should be known when the results of EPRI's work are presented at the 1980 International Conference on the Ecological Impact of Acid Precipitation, planned to take place in Norway. ■

NEW FEDERAL ASSESSMENT

In his annual message on the environment on August 2, 1979, President Carter announced that the federal government is about to launch a comprehensive, 10-year assessment of the acid rain problem. The present annual funding for acid rain research is to be doubled to $10 million. This amount will be made available for the first full year of operation.

The president said that by January 1, 1980, a plan for conducting the assessment will be completed. This plan will identify ways to ensure that the assessment is undertaken jointly with private industry wherever appropriate and that the results of the assessment will be incorporated into agency decision making.

A standing acid rain coordination committee will plan and manage the assessment program. The committee will be cochaired by the Department of Agriculture and the Environmental Protection Agency (EPA), with an executive secretary from the Council on Environmental Quality. Members of the committee will be policy-level representatives from the Interior, Energy, Commerce, State, and Agriculture departments, EPA, the National Science Foundation, the Council on Environmental Quality, and the Office of Science and Technology Policy.

Through the Department of State, the assessment program will be coordinated as far as possible with acid rain research programs in Canada, Mexico, and other countries.

Margaret Bush Wilson: Articulating the Black Perspective

"Economic parity is the dominant thrust of the black movement today," says civil rights leader Margaret Bush Wilson. Energy is the driving force to achieve that goal.

Four years ago when Margaret Bush Wilson was elected to chair the 70-year-old National Association for the Advancement of Colored People (NAACP), her fellow board members, mostly male, were puzzled about what to call her. Chairwoman? Chairperson?

Today her eyes twinkle when she recalls herself declaring, matter-of-factly, before the national board of 64 civil rights leaders:

"Listen, it doesn't really matter what you call me, as long as you understand I'm in charge."

That quality of self-confidence and determination tempered by a sense of practicality and humor is a hallmark of this woman who not only serves in a volunteer capacity as chairman of the nation's oldest and largest civil rights organization but is also senior partner in the St. Louis law firm Wilson, Smith, & Smith, specializing in real estate and housing matters.

"I'm not really hung up on titles and names," she says today. "In fact, I kind of forget I'm black and female. I mean, I didn't have a thing to do with either of those, and so I can't be preoccupied with things over which I have no control."

Among the numerous advisory boards and councils that she serves on for colleges, industries, and service associations is the EPRI Advisory Council, a group of 25 individuals representing various segments of the public that advises EPRI on energy research programs. As a member of the Advisory Council, Wilson brings the black perspective on energy to the planning of R&D for the nation's electric utilities. It is a perspective that encompasses social, economic, political, and technical issues.

The economic agenda

"The most important thing to remember is that the agenda of blacks in this country is now an economic one," she begins earnestly. "We're still searching for economic parity."

Wilson and the NAACP have taken the position that this inferior economic situation must be rectified, and they believe that energy is the key.

"We know that this country grows and provides jobs when it has an abundant supply of energy," Wilson comments. "And we know that if we move away from that abundant supply, we are talking about limited growth, no growth, and a decline in productivity—all of which spells disaster for the agenda we're concerned about."

This link between energy availability, economic growth, and the black quest for parity explains in part the absence to date of blacks from the antinuclear ranks. Wilson was in Washington, D.C., on May 7, the day after a crowd of some 65,000 demonstrators had marched to the U.S. Capitol in an antinuclear protest triggered by the Three Mile Island accident. Newspapers that day were describing the protestors as predominately young, white, and middle class. Demonstration spokesmen were cited as admitting that as yet the antinuclear movement had attracted few from the minorities to its ranks.

Wilson addressed herself to this noted absence of blacks among antinuclear activists, as well as to other topics concerning the black community and the energy situation, during an interview with the *EPRI Journal* in Washington that day following the demonstration. As she explains, nuclear is "a pretty important part" of the energy mix in the country today that spurs economic growth and creates jobs.

"So while we're just as disturbed as any of those demonstrators about Three Mile Island and the implications of the need for a more careful scrutiny of the safety factors, we are not prepared to simply write off nuclear unless we have some assurances there are going to be some substitutes that will keep this country moving forward."

Fully one-third of black families in America today are still considered to be below the poverty line, she explains, and the unemployment rate for blacks is twice that of whites, approaching 50% for young black males. And although blacks

compose 11.5% of the U.S. population, "we own less than ½ of 1% of the business assets of this country."

Wilson's statements were buttressed later in the month by newspaper editorials and speeches by other black leaders on the occasion of the 25th anniversary of the Supreme Court's historic May 17, 1954, decision in *Brown* v. *the Board of Education*, which outlawed segregation in the nation's public schools. That decision had inspired hope within the black community that the dream of a better life would soon be a reality. Twenty-five years later, civil rights leaders proclaimed that the dream has not yet been realized by the majority of blacks in this country. For example, the distinguished economist Andrew Brimmer, persuaded by Wilson to head the NAACP's new Economic Policy Advisory Council, pointed out in a symposium in Washington, D.C., that "in 1978 blacks represented 11.9% of the labor force, but had 10.5% of the total jobs, [equivalent to] a shortfall of 700,000 jobs." He also noted that in 1978 there were 1.4 million blacks unemployed, which represented 23.3% of the total joblessness in the country, double their share of the labor force.

NAACP energy statement

The NAACP made headlines on January 9 of last year when it released a policy statement on the administration's energy plan, then winding its way through Congress. This was the first time that the national board had spoken out officially on energy matters. The statement criticized the administration's plan for its "overemphasis on conservation" and its "pessimistic attitude toward energy supplies for the future." Noting the historic correlation between economic activity and energy availability and consumption, the statement called for "a more vigorous approach to supply expansion and to the development of new supply technologies so that energy itself will not become a long-term constraint but, instead, can continue to expedite economic growth and development in the future."

In a reference to nuclear power, the NAACP statement said that this energy source, as well as the breeder, should be "vigorously pursued because it will be an essential part of the total fuel mix necessary to sustain an expanding economy." Although recognizing that nuclear does present environmental and safety concerns, the NAACP nevertheless expressed confidence in the ability of government, science, and industry to solve these problems.

"If we do not move ahead now with nuclear," the NAACP's statement declared, "the next generation is likely to be sitting around in the dark, blaming the utilities for not doing something this generation's officials would not let them do."

Newspaper headlines followed swiftly on issuance of the NAACP statement. "NAACP Takes Side of Oil Industry in Energy Struggle," read one; "Does Civil Rights Include Energy?" asked another; "Did the NAACP Board Know What It Was Voting For?" queried a third.

The NAACP knew exactly what it was voting for and in April of last year it reaffirmed its earlier statement. This year the board issued another energy statement, again acknowledging nuclear's contribution to the nation's electric power supply and expressing support for actions of the nuclear industry and the government in investigating the causes of Three Mile Island.

As chairman of the NAACP board, Wilson has been called upon to explain the NAACP's energy policy before numerous groups around the country. In one speech last year before the 69th annual convention of the NAACP in Portland, Oregon, she explained that by speaking out on energy, the NAACP was voting to add a new dimension to the historic struggle to better the conditions of blacks in American society, expanding it beyond those social, political, and legal issues traditionally regarded as civil rights, so that the "historic victims of racism can enter the mainstream of society on a permanent basis."

The first step, she told fellow NAACP members, is to realize that "the dominant dynamic today is economic. . . . It does little good for us to have the right to a suite in the Portland Hilton if we cannot afford the cost."

Pursuing the economy-energy connection, she stated, "Unless America is assured of ample and reasonably priced energy supplies in the future, the economy will not expand at the rate required to provide a job for every person willing and able to work." Proclaiming that a no-growth policy is not and never will be in the best interests of black America, she added, "It will only continue to foredoom millions of black Americans to the wastelands of idleness and poverty from which many of them are suffering today."

Civil rights heritage

The struggle to open new opportunities for blacks is a familiar one to Margaret Bush Wilson. In fact, she inherited a legacy of civil rights leadership from her parents, who worked to expand opportunities for blacks in her hometown of St. Louis, Missouri. Her mother, the former Berenice Casey, served on the Executive Committee of the St. Louis NAACP in the 1920s and 1930s. Her father, James

T. Bush, Sr., was a pioneer real estate broker and the moving force behind the *Shelley* v. *Kraemer* case, a housing suit that led to the 1948 landmark U.S. Supreme Court decision outlawing racially restrictive housing covenants. This is a story that his daughter Margaret delights in telling.

She explains that as a real estate broker, her father was acutely conscious of the limited amount of housing available to his black clients in the late 1940s and was continually trying to open a few more blocks where his people could live. The Shelleys, a black couple, were his clients. He sold them a house on Labadie Avenue in St. Louis that was owned by a white man. Although the house was covered at the time by a racially restrictive covenant (meaning it could not be sold to blacks), the owner wanted to sell it to whomever he could. Within a matter of days after the sale, the people in the neighborhood discovered that the Shelleys were black and filed a lawsuit in the St. Louis Circuit Court in an attempt to bar the family from moving into the house.

"A no-growth policy will only continue to foredoom millions of black Americans to the wastelands of idleness and poverty from which many of them are suffering today."

The Circuit Court ruled in favor of the Shelleys, stating that the restrictive housing covenant could not be enforced in court and was therefore invalid. The plaintiffs then appealed to the Missouri Supreme Court, which reversed the lower court's decision and ruled that the covenant was enforceable, a stunning defeat for the Shelleys and for James T. Bush, Sr.

"I can remember that day vividly," Wilson says. "We were sitting at the breakfast table, reading the morning paper and looking at that great big black headline: 'Missouri Supreme Court Overturns Housing Case.' And that was the first time I'd ever seen my father really look defeated. He was crushed."

Wilson credits her mother for spurring her father on to pursue the struggle. "She kept saying 'You can't give up now . . . You can't give up now,'" Wilson recalls, and that encouragement inspired her father, who "got up from that breakfast table, went to the telephone, and summoned all the black real estate brokers in St. Louis to a meeting at our house. And they formed the Real Estate Brokers Association of St. Louis on the theory that if they were going to take this fight on, they had to have an organization. They couldn't do it as individuals."

The association raised money, obtained lawyers, took the case to the U.S. Supreme Court, and won it. The Supreme Court ruled that racially restrictive housing covenants were unenforceable in the courts—a decision that affected the entire nation.

Wilson herself was tangentially involved in the *Shelley* v. *Kraemer* case. Just a few years out of law school and in private practice at the time, she was hired by the newly formed brokers association to obtain its corporate charter.

Wilson had attended public schools in St. Louis and had received a BA in economics, cum laude, in 1940 from Talladega College in Alabama, a college community she describes as "a little bit of New England transplanted to the South." Talladega College was one of the schools founded by the American Missionary Association in the South immediately after the Civil War and was integrated racially from its beginning. Wilson calls it an oasis in a state otherwise surrounded at the time by "rigid, ugly segregation."

The college gave her a fine liberal arts education, she notes, but had nothing to do with her becoming an attorney. "I'm a lawyer by pure accident," she admits, smiling sheepishly. "I was one of those youngsters who went to college not knowing what I wanted to be, but knowing what I did not want to be—a school teacher, a social worker, a nurse—all the female stereotypes. And I figured the best way to keep from becoming any of those things was not to take any courses that would qualify me to do so. So I went through college and I didn't take any education courses, so I couldn't teach. I didn't take any sociology courses, so I couldn't be a social worker. When I got home from college, I had a fancy degree in economics and a minor in mathematics."

A few days later she met a friend who was attending the Lincoln University School of Law that had been established for black students (today it is part of the University of Missouri School of Law) and the friend suggested that she apply for law school. "That was just the wildest idea," she recalls thinking at the time. But she nevertheless decided to pursue it. "What could I lose?"

Today she laughs when recounting the experience of her law school interview.

"I really don't believe that I was quite as arrogant as I seemed then. I walked into the dean's office, sat down, and introduced myself. And I remember saying 'I will *consider* going to your law school *if* you provide me with a scholarship that will take care of my books and tuition, and a part-time job that will take care of my spending money.' And he looked at me and said, 'Young lady, if you have enough nerve to walk in here and ask me, I have enough nerve to give it to you.' And that's how I got started in law school."

It was a small class—15 students—and only 2 were women. But it took Wilson

only one week to decide that she "had stumbled on her calling."

Work with rural utilities

After graduating with her LLB in 1943, Wilson served as an attorney with the Rural Electrification Administration, which at the time was headquartered in St. Louis. In her position she gave legal advice to rural electric cooperative utilities, some 260 of which are today members of EPRI. She feels proud of the role that she played in this "very creative period" in U.S. history.

"We lighted up the farms, in a sense, and now some 3% of the population produces food for over 200 million people in the United States and another 300 million around the world. And putting electricity in was the start of it. So I feel, in retrospect, that it was a very important part for me to play—small, but significant."

Throughout her professional career as an attorney, including many years in private practice as well as public service, Wilson has held positions that have made her instrumental in aiding minorities in housing, education, and legal services. She has served as assistant attorney-general of the State of Missouri; legal services specialist in the State Technical Assistance Office, which was part of the War on Poverty; administrator of the Community Services and Continuing Education program under Title I of the Higher Education Act of 1965 in the Missouri Department of Community Affairs; and acting director of the St. Louis Model City Agency. She also served as assistant director of St. Louis Lawyers for Housing, a program sponsored by the American Bar Association during the Johnson administration that sought to demonstrate how the role of lawyers could be significant in increasing the supply of low- and moderate-income housing. The group was successful in getting a substantial amount of housing on the drawing board, as she explains it, but the final commitment to build the units was withdrawn at the last minute during the Nixon administration.

"I was sick about it," she recalls today, "and my credibility [with some inner-city people in St. Louis] will never be retrieved." She had pursuaded some of the angry and frustrated urban blacks who wanted to "burn this city down" that they should work within the system, play by the rules. They did, but their efforts, in this case, for decent housing were "cut at the bud," she says with deep regret.

In 1970 Wilson returned to private practice and established a law firm with a long-time family friend, Wayman F. Smith, III.

Along with her professional career, Wilson has always taken an active role in NAACP affairs. In 1956 she became a member of the Executive Committee of the St. Louis NAACP and Secretary of its Job Opportunities Council. In 1958 she was elected the first woman president of that local branch; in 1962, the president of the Missouri State Conference of Branches; and in 1963, a member of the national Board of Directors. In 1975 she was elected chairman of the board, the first black woman to hold this position in the organization's history. (A white social worker named Mary White Ovington, one of the NAACP founders, served as its board chairman in 1913.)

Role for private industry

As chairman of NAACP's board, Wilson is a spokesperson for the black community and logs many miles each year articulating the black perspective before industry, service, and government groups throughout the country. Invariably she emphasizes in her speeches the crucial role of private industry in helping black people move into the mainstream of society in all areas, particularly in the economic sector.

"I keep reminding our people that 9 out of 10 jobs in America last year came from private industry," she says. "This is why it is so important that we not lose sight of the fact that while there is an important role for government in the area of providing appropriations for training programs and the like, there must be a significant role for private industry."

To her way of thinking, this role is a broad one, particularly as it applies to the various sectors of the energy industry. This role not only means industry must strive to ensure an ample supply of energy to keep the economy moving but also includes enhanced communications activities, more support for education and training for blacks, and increased efforts to recruit more minorities into jobs within industry.

In terms of communicating with the black community, Wilson notes that she has observed a higher level of sensitivity lately within the energy industry and a "perception that [ours] is a constituency they must be more conscious of and direct efforts to meet [our] needs in a more effective fashion." She insists that the urgent need right now is to address the sense of alienation that exists, especially among young people from deprived families who have the feeling that no one in the country cares about their future or their fate. This kind of attitude leads to much of the crime in the nation's urban areas, she comments, and she believes that private industry can make a significant contribution by reaching out

to these young people and opening new opportunities for them.

"To the extent that you can get responsible corporate entities in these communities to begin to open up in some way to give [these young people] some hope and a sense of appreciation and concern, then I think industry will make a major contribution."

She believes that increased education and training is an important aspect. "Ours is a highly technological society," she reflects about the United States, "but many of our black people are unskilled and simply do not have the education and competence that is needed in many industries. We really do have a job to do in our education programs. We must get our young people better trained and skilled."

> "The dominant dynamic today is economic. It does little good for us to have the right to a suite in the Portland Hilton if we cannot afford the cost."

In her addresses to professional groups around the country, Wilson has pointed to the paucity of black representation in the technologial disciplines. Only 1% of blacks hold engineering jobs, she has noted.

"We are aware of the dearth of black technicians across the board—engineers, scientists, nuclear physicists, and other experts in technology," she told the National Conference on Energy Advocacy and the Nuclear Option in Washington last February. "The majority of black college graduates historically have been, and continue to be, in the softer professional fields, especially teaching and religion. Few are in economics, accounting, and other business related fields . . . yet these are the areas where better job opportunities abound." She exhorted the energy community to train and recruit promising minority candidates for middle- and top-management positions.

She also believes energy companies can be of help by providing scholarships and assistance in developing technical education programs for black students. A mechanism for bringing this about, and one advocated by NAACP's executive director Benjamin L. Hooks, might be a joint effort of the NAACP, the black colleges in the nation, and the National Alliance of Business—each providing its own unique expertise. "The NAACP because traditionally we have been in the business of the advancement of black people," Wilson explains, "the black colleges because they have a way of channeling opportunities to young people, and the National Alliance of Business because it reflects and is representative of this important business community—where the jobs come from."

As a part of this effort, she insists that a need exists to convince young blacks that careers in science and technology can be exciting and rewarding ventures. One way to do this, she maintains, is to help build pride within the black community about the contributions that blacks have made in these fields. Among noted black scientists in history that she points to are Lewis H. Latimer, a member of Thomas Alva Edison's research team who also served as one of the chief witnesses called in court challenges over Edison's patents, and Elijah McCoy, who invented the lubricating cap, which made possible automatic oiling and revolutionized the machine industry. That device became so popular, as the story goes, that people inspecting new equipment would ask if it contained the "real McCoy," creating the American expression still used today.

"It's important that our young people are exposed to this kind of information about their heritage," Wilson observes. She credits the Department of Energy for aiding in this effort by publishing a booklet on black contributors to science and energy technology.

Challenges ahead

Margaret Bush Wilson is a person accustomed to challenges and is genuinely excited by them. From civil rights to energy, she tackles the problems head-on, never hesitating to take the initiative but always eyeing the situation with a practical and realistic attitude. Such is her view of new energy sources.

"Everybody is excited about solar," she comments. "We'd all love to have the energy that comes from the sun or from seawater, but we have not yet perfected the technological breakthroughs that will make that feasible and cost-effective so people can afford it. To me that's the challenge, and it's as exciting as going to the moon. Maybe more so."

She insists that R&D is a key element in meeting that challenge and advocates increased federal spending in this area. "If we put it to a referendum in this country," she reflects, "I bet the vast majority of Americans would vote for us to spend the money for this."

But solar, seawater, and the like are not today's reality for Wilson and the black community she represents. To them, reality is not yet being part of the economic mainstream of this country, and the immediate challenge is keeping the country moving forward to provide the jobs and entrepreneurial opportunities that will allow blacks to obtain that equal status. Adequate energy, including nuclear energy, is the driving force, and that is the thrust of her philosophy.

"The dominant dynamic is economic," she says. "We can't afford to have a no-growth economy. We've still too many people to push upward." ■

Synfuel Hearings

This was the summer that Congress and the president made synfuel a household word. Amid the flurry of legislative and administrative activity to promote synthetic fuel development, EPRI officials were called upon to discuss technical aspects.

BALZHISER

SPENCER

The *Washington Post* termed it synthetic fuel fever: that rush of activity in Washington, D.C., this summer to expedite the commercialization of synthetic fuels as alternatives to the nation's unhealthy dependence on imported oil.

It was first manifested in Congress by a spate of synfuel legislation. By some estimates as many as 40 bills were introduced from March through July.

Then the focus shifted to the president, whose rallying energy messages July 15 and 16 made synthetic fuels and other alternative energy sources a centerpiece of his $142 billion plan to move the nation toward "energy independence" and combat a growing "crisis of confidence." Carter not only proposed creation of an independent energy security corporation that would invest $88 billion in the production of synthetic fuels but also called for an energy mobilization board to cut through red tape and ensure the construction of critical energy facilities.

Federal action in the synthetic fuels area is of direct interest to EPRI. The Institute supports active research programs on processes to produce clean liquid, solid, and gaseous fuels from coal for electric power production. EPRI has spent over $70 million on R&D to produce synthetic liquid fuels from coal; additional expenditures of $220 million are planned for the next five years.

EPRI Testimony

EPRI technical expertise in the synfuel area was tapped on a number of occasions this summer by congressional committees holding hearings on key synthetic fuel bills. Appearing before the House Subcommittee on Energy Development and Applications on June 6, Richard E. Balzhiser, director of EPRI's Fossil Fuel and Advanced Systems Division, underlined the utility industry's

continued need for liquid fuels and suggested that the industry might provide an early and stable market for synthetic liquids.

Even though electric utilities have made a major commitment to reduce their consumption of liquid fuels, Balzhiser noted that "utility planners still see the need for liquid fuels to meet a portion of the customers' requirements most economically."

He explained that utilities deliver electricity instantaneously, at the flick of a switch, and must have enough capacity on hand to do so, even though customer demand varies according to the time of the day and season of the year. To provide this service most economically, utilities rely on a mix of power plant types that result in cost trade-offs. Some plants have high capital costs and low fuel costs and operate nearly full-time. Others have low capital and high fuel costs and operate only during periods of peak demand. Still others have moderate capital and fuel costs and operate part of the time.

Utilities currently rely on liquid fuels to fire the combustion turbines and steam plants that meet peak demand and some of the intermediate demand. Balzhiser pointed to EPRI studies that indicate the consumer would pay more if these options are foreclosed. One study shows that consumers would pay some $6 billion (in 1978 dollars), or $95 per household in the year 2000 alone, if combustion turbine capacity is eliminated in favor of coal-fired plants with higher capital costs. Clearly, Balzhiser indicated, utilities will continue to require liquid fuels for the future, probably on the order of 2–2.5 million (10^6) barrels per day.

First Market

Balzhiser suggested that the electric utility industry may have an important role to play in the development of a synthetic fuel industry, providing perhaps the first and most stable market for refined shale or coal liquids.

"The processes for converting oil shale, coal, and to some extent, solid waste and energy crops yield liquids that are not directly usable as transportation fuel without further refining," he noted. "However, several of these processes do produce a synthetic boiler fuel that can be substituted directly for petroleum-derived fuels with minimum modification to existing boilers." Referring to an EPRI-sponsored test burn at Consolidated Edison Co. of New York last fall of 4500 barrels of liquid produced from coal by the solvent-refined coal process SRC-II, he stated that "no major operational problems were encountered and the environmental standards for firing coal-derived liquids were met.

"Since utilities are potentially large users of liquids and use life-cycle accounting," Balzhiser suggested, "they might enter into long-term contracts to purchase the output of the first synthetic liquid plants, even if the price is higher than petroleum, to assure themselves of adequate fuel for their existing capacity." He also noted that such a commitment would reduce the risk to the builder of a synthetic fuel plant, who in order to produce transportation fuels would have to provide additional capital for a fuel-upgrading section and then deal with "a much more diverse and potentially volatile—although ultimately much larger—market."

Diversity of Requirements

Enlarging on Balzhiser's comments, Dwain Spencer, EPRI's director for Advanced Fossil Power Systems, appeared before the House Committee on Interstate and Foreign Commerce in late June and noted a number of other ways that utility industry needs are compatible with synthetic fuels. One such need is for "a broad range of fuel qualities to substitute for natural gas, distillate, and residual oil," he said.

"This places the electric power industry in the unique position of being capable of accepting either neat or blended synthetic fuels, with minimal additional processing or cost. The only additional upgrading required may be to meet federal or state emissions control requirements."

Spencer also pointed to utility industry compliance with the power plant and industrial Fuel Use Act (FUA) of 1978 as an important incentive for synthetic fuel development. That legislation prohibits the addition of any new oil- or gas-fired power plants for other than peaking purposes unless certain key exemption bases can be justified. It also calls for phasing out natural gas use for power generation by 1990.

"Our evaluation of the act and initial proposed rules by the Economic Regulatory Administration indicate that the most likely exemption basis acceptable to the government will be the early substitution of synthetic fuels or mixtures of synthetic and natural fossil fuels," Spencer stated. "In our view, the FUA stimulates, if not necessitates, an aggressive program to utilize synfuels in the electric power industry."

Spencer's testimony also referred to utility use of synthetic gas produced from coal. "Results from EPRI's studies have also shown that coal gasification–combined-cycle power plants offer an economically competitive, environmentally attractive power generation option for baseload utility applications," he said. "We have also been evaluating the potential for retrofitting existing gas- and oil-fired boilers with syngas produced from coal. Although there is no clear-cut economic advantage for retrofitting boilers, with intermediate BTU gas, re-

motely sited gasification units may be an important option in locations where coal transportation and siting limitations preclude new coal plants."

Technology Offensive

In July EPRI's Balzhiser was called back to Capitol Hill to testify before the Senate Energy Research and Development Subcommittee on Title III of Senator Henry Jackson's omnibus energy bill. This was the same day President Carter detailed his new energy plan in his Kansas City speech before the National Association of Counties.

In his testimony Balzhiser outlined a program to put U.S. technology "on the offensive once again, provide Americans with an assured supply of energy, and improve the competitiveness of U.S. technology in foreign markets." To do this he called for initiation of a government-industry partnership approach to the development and demonstration of a "rapid and continuous stream of new technology responsive to national needs."

Balzhiser's testimony included general observations about the government's role in large pilot and demonstration projects designed to speed commercialization of new technologies, as well as recommendations for principles to guide legislation authorizing government funding of such projects.

He identified three government procurement and contracting practices he sees as impeding rapid commercialization of new technologies: requirements for single, competitive solicitations for project proposals; patent and data rights provisions that eliminate commercialization incentives; and insistence on government management of projects in return for funding.

"Many promising energy technologies are highly proprietary and result from years of corporate effort," he noted. "They mature at different times, and thus single, competitive solicitations often attract inferior or premature proposals. . . . Further, the patent and data rights provisions discourage utilizing government support for highly promising proprietary technology, with the net result that government solicitations seldom attract the most advanced projects. Finally, few companies are willing to make significant cost-sharing contributions if management resides solely with the government."

Balzhiser suggested the following principles for government-supported pilot and demonstration projects for which immediate commercialization of new technologies is sought.

- Proposals would be considered at any time.
- Significant industry cost-sharing would be required in all phases of the work.
- Financial incentives, such as tax credits, accelerated depreciation, and loan guarantees, would be considered.
- Patent and data rights would be negotiated to protect proprietary information. Reasonable licensing requirements would ensure eventual competition.
- Management responsibility would reside with the contractor.

Balzhiser noted that such a program could be administered by the Department of Energy or by a board created specifically for that purpose (such as the president's proposed energy security corporation).

Of specific technology candidates for accelerated development and demonstration, he said that:

- Oil shale is certain to be the most cost-competitive of the synthetic liquid options and commercial-scale projects should be high on the priority list for funding.
- Gasifier development is the cornerstone of a synfuels program because it offers multiple synfuels and power generation options.
- Demonstration proposals for the Exxon Donor Solvent process and the H-Coal liquefaction process should be encouraged immediately to minimize lost time in utilizing pilot plant results for demonstration projects.
- Conventional pulverized-coal plants will continue to be the workhorse for the next several decades, but EPRI strongly supports accelerated development of gasification–combined-cycle and fluidized-bed combustion power plants for introduction into utilities in the mid to late 1980s because of inherent environmental and cost benefits.
- Now is the time for commercial-scale demonstrations of compressed-air and underground pumped-hydro projects for energy storage.
- Coal/oil slurries do not offer significant potential for displacing oil in utility boilers.
- A method of utilizing geothermal energy for power production, called the binary cycle, is ready for immediate demonstration and is expected to bring a major portion of the geothermal resource base across the threshold of economic viability.
- Government support for a $3\frac{1}{2}$-year, $40–$50 million program is needed to commercialize fuel cells for power production.

"It is imperative that the adversary relationship between government and industry be reversed and a partnership evolve that permits U.S. industry to meet its societal needs, as well as to compete effectively with industry–government partnerships abroad," Balzhiser concluded.

At the Institute

BOARD APPROVES ADDITIONAL FUNDS FOR COAL CLEANING

In an effort to help utilities keep pace with stricter environmental regulations, the EPRI Board of Directors approved spending more than $10 million on finding better ways to clean coal.

Meeting in Denver, Colorado, the EPRI board voted to boost funding for the previously approved coal-cleaning test facility, to be built in Homer City, Pennsylvania. The objective of the project, which will be conducted jointly by Pennsylvania Electric Co. and New York State Electric & Gas Corp., is to design, construct, and operate for at least five years a 20-t/h coal-cleaning test facility.

The facility will be used by utilities to test the technical feasibility of cleaning different kinds of coal under varying conditions prior to the construction of large-scale coal-cleaning plants.

Although the project was approved for a total of $5.9 million last August, three recent events increased the importance of coal cleaning for the electric power industry.

- A slowdown in the licensing of new nuclear plants, which will shift some new generating capacity to coal
- The recent large increase in foreign oil prices, which will increase the use of existing coal plants and may also cause a shift from oil to coal in some boilers
- Revised environmental regulations on air quality and solid wastes, which appear to encourage use of coal cleaning.

In other action the Board voted to increase R&D funding at EPRI to a level of $232 million next year. This is an increase of 14.3% (just slightly higher than the current rate of inflation) over the 1979 funding level of $203 million.

Australian Visit

General interest in EPRI's research program, particularly work under way on air pollution control, brought the chairman of the Electricity Commission of New South Wales, F. Brady, to EPRI recently for discussions with (from left) Owen Tassicker, EPRI technical specialist; Walter Piulle and Robert Carr, EPRI project managers; F. Brady; and Kurt Yeager, EPRI director of the Fossil Fuel Power Plants Department. The commission is the main electricity supplier for Australia.

Calendar

For additional information on the EPRI-sponsored/cosponsored meetings listed below, please contact the person indicated.

OCTOBER

16–18
Second National Symposium on Environmental Concerns in Rights-of-Way Management
University of Michigan
Contact: John Huckabee (415) 855-2589

22–23
Nuclear Nondestructive Evaluation Program Workshop
Palo Alto, California
Contact: Gary Dau (415) 855-2051

25–26
Topical Conference: Particulates
St. Louis, Missouri
Contact: Guy Farthing (415) 855-2392

NOVEMBER

8
Regional Review: Fossil Fuel Programs
Westboro, Massachusetts
Contact: William McKinney (615) 899-0072

MARCH 1980

9–13
Second International Symposium on Gaseous Dielectrics
Knoxville, Tennessee
Contact: Don Bouldin (615) 574-6200

Comprehensive Look at Coal-Burning Efficiency

A 10% improvement in the performance of new coal-burning electric generating plants is the goal of a new $1.2 million EPRI study to be performed in two separate, competing projects by Westinghouse Electric Corp. and General Electric Co.

Each of the two contractors will work independently to stimulate innovative design. This project is especially important at this time because coal-based technologies are expected to play an increasing role in new electric generating capacity in the United States at least through the end of the century.

Most of the recent design changes made to conventional coal plants have emphasized installation of environmental controls and dealt with the problems of burning lower-quality coals, both of which tend to reduce efficiencies and add to plant complexity. In this new effort, EPRI contractors will look for ways to improve thermal efficiency in every aspect of plant design and operation, including environmental controls. Primary attention, however, will be focused on the power generation equipment, such as the steam turbine, the boiler, and related auxiliary systems.

Four electric utilities will participate with each of the contractors. Philadelphia Electric Co., Pennsylvania Power & Light Co., Minnesota Power & Light Co., and Texas Utilities Co. will assist Westinghouse; Boston Edison Co., New England Gas and Electric Association, New England Power Co., and Jacksonville Electric Authority will work with General Electric.

In addition to utility participation, a steam generator manufacturing firm and a private engineering firm will also participate in each of the two study segments. Combustion Engineering, Inc., and Gilbert Associates, Inc., are participating with Westinghouse, while Babcock & Wilcox Co. and Stone & Webster Engineering Corp. are working with General Electric.

Dan Giovanni and John Dimmer will manage the project for EPRI in their capacity as cochairmen of a special review committee of engineers representing a broad cross section of the nation's electric utility industry.

"The individuals selected by EPRI to work on the research teams will possess a full range of skills needed to study all aspects of power plant design, construction, operation, and performance," according to Giovanni. "We're hoping to provide the engineering detail needed to define the critical research requirements, and costs, of developing more efficient and reliable coal plants."

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

FLUE GAS DESULFURIZATION

The overall objective of the Desulfurization Processes Program is to provide support to the utility industry in identifying and developing the most cost-effective flue gas desulfurization (FGD) technologies that can satisfy regulatory requirements through the next two decades. In the program's first two years, this objective has been pursued through evaluation of established technology as it is practiced in the industry, testing of advanced technologies at the prototype scale, and economic evaluation of current and future FGD processes.

To comply with clean air and water disposal regulations now being implemented, utilities with FGD systems already installed must continually upgrade and optimize system performance with regard to operability, energy consumption, water consumption, and by-product quality. Utilities planning new FGD installations must base their sulfur oxide emission control strategy on the most advanced existing technologies, even though some of these have been demonstrated only at relatively small scale. In addressing these utility needs during the past 12 months, EPRI has compiled design guidelines presenting the best information available for planning and specifying lime/limestone scrubbers; conducted pilot and prototype evaluations of advanced scrubber concepts; and carried out a series of economic evaluations of advanced and commercially available processes.

Design guidelines

As of mid-1979 lime-based FGD systems accounted for about 40% of the FGD capacity installed or under construction in the United States. Consequently, a large body of information is becoming available, but until recently it has not been organized and compiled in a format that would be readily available and usable by the utility industry. *The Lime FGD Systems Data Book* (FP-1030) integrates and summarizes the combined experience of utilities, architect/engineers, process and equipment suppliers, EPA, and EPRI in lime scrubbing technology. The result is a stand-alone document that provides (1) detailed guidelines about design factors, equipment specifications, and selection criteria for lime scrubbers and (2) specific procedures for determining which design parameters are critical in a site-specific situation.

The major benefits from these guidelines and procedures in specifying a new lime FGD system are increased reliability and availability and decreased maintenance needs, leading to significant savings—up to one-third—in the cost of maintenance on the scrubber system. Significant savings can also be realized with existing systems through the use of optimal operating procedures. *The Lime FGD Systems Data Book* was prepared by EPRI with participation by EPA. A similar guideline document covering limestone FGD systems is being prepared by EPA with EPRI participation.

Disposal of fly ash and SO_2 scrubber sludge has become a major power plant siting issue since implementation of the Resource Conservation and Recovery Act. Another guidelines document, the *FGD Sludge Disposal Manual* (FP-977), provides detailed information about design features, equipment selection, and critical site parameters of scrubber by-product disposal systems. A procedure is given for estimating the cost of a waste disposal system. The base capital cost will usually be in the range of $15–$30/kW, and multipliers are given for adjusting the base cost for each of several site-specific factors.

Chiyoda prototype

The Chiyoda Thoroughbred 121 process uses limestone as a scrubbing reagent and incorporates forced oxidation to produce by-product gypsum (calcium sulfate) instead of hard-to-dewater calcium sulfite sludge. The process accomplishes limestone dissolution, SO_2 absorption, oxidation of sulfite to sulfate, and by-product gypsum crystallization, all in one vessel. The projected operating costs for this technology appear comparable to or lower than the costs of conventional limestone scrubbing.

An eight-month prototype test program was recently concluded in which the operating characteristics of a 23-MW-equivalent Chiyoda system at Gulf Power Co.'s Scholz plant were evaluated (RP536). The prototype system, designed to scrub flue gas containing 2000 ppm SO_2, was operated under both design and off-design conditions. A number of preliminary results are described below.

SO_2 removal efficiencies in the range of 90–95% were observed under design conditions. The scrubber averaged 90% removal of SO_2 at inlet concentrations above 2000 ppm. The high SO_2 levels were produced by a combination of burning higher-sulfur coal and spiking the flue gas with SO_2 from a tank car. No conclusions were reached from these tests as to the upper limits of SO_2 removal or SO_2 inlet concentrations.

Limestone utilization was high—over 98% throughout the test program. Limestone grind appeared to have no significant effect on the utilization.

High concentrations of chloride in the limestone slurry (up to 6000 ppm, achieved by spiking the slurry) had no adverse effect on SO_2 removals.

Varying the oxydation air between four and eight times stoichiometric oxygen also had no effect on SO_2 removals or the absence of sulfite in the by-product gypsum.

High loadings of fly ash in the slurries, created by shutting off the power plant's electrostatic precipitator, appeared not to affect the scrubber chemistry adversely.

Some gypsum scale built up slowly on the outsides of the sparger tubes below the liquid level in the absorber vessel. This scale was $\frac{1}{16}$-in thick or less and resulted partly

from intentionally operating the scrubber at conditions beyond the design range. Soft gypsum deposits on the mist eliminator were easily removed by washing twice a month with pond supernatant.

Stacking of the by-product gypsum is being evaluated as a disposal technique. The physical stability and permeability (leachate penetration) of the stack appear good. The stacking tests will continue through mid-1980.

Economic evaluations

Several economic evaluation projects are in progress in EPRI's FGD research program. One of the earlier ones has recently been completed: a comparison of six advanced sulfur-recovery FGD processes with four processes that have achieved commercial or semicommercial status (RP784). Conventional limestone scrubbing is included as one of these four as a base case. The cost estimates (Table 1) were based on a hypothetical new 500-MW power plant located in Indiana and burning coal containing 3.5% sulfur. The costs are presented in first-quarter 1977 dollars. The economics are based on EPRI economic criteria, and in some cases the results are sensitive to these criteria; therefore, the costs shown should not be taken as applicable to any generalized installation. Process suppliers were given an opportunity to take exception to the cost estimates, and their comments will be included when the report is published. *Program Manager: George Preston*

Table 1
CAPITAL AND REVENUE REQUIREMENTS FOR FGD PROCESS
(first-quarter 1977 $)

Process	Supplier	Total Capital ($/kW)	Levelized Revenue Requirement (mills/kWh)
Activated char–Resox	Bergbau-Forschung GmbH; Foster Wheeler Energy Corp.	132	12.5
Absorption–steam stripping–Resox	Peabody Engineering Corp.; Foster Wheeler Energy Corp.	121	9.6
Ammonia	Catalytic, Inc.; Institut Français du Pétrole	170	11.3
Carbonate	Conoco Coal Development Co.	197	12.9
Dry bicarbonate	Rockwell International Corp.	211	13.9
Aqueous carbonate	Rockwell International Corp.	212	14.2
Magnesia	Various	136	10.3
Wellman Lord–Allied Chemical	Davy Powergas	126	10.5
Limestone	Various	94	10.0

Note: This information is from 1977 EPRI research by Stone & Webster Engineering Corp. (RP784-1). Note that these estimates are based on a new 500-MW baseload midwestern power plant burning 3.5% sulfur coal. Many assumptions and design concepts were used that affect absolute and relative costs, such as spare equipment, contingency, and credit or debit for by-products.

ENERGY UTILIZATION AND CONSERVATION TECHNOLOGY

Faced with rapidly rising energy costs, serious constraints on the availability of oil and gas, and the prospect of delays in the construction and operation of key energy facilities, the nation's utilities and their customers are now searching out ways to use energy more effectively and efficiently. This strategy can be expected to significantly extend the ability of existing and proposed energy resources and delivery systems to serve growing energy needs.

Utilities and energy conservation

Utilities have been traditionally concerned with, and highly successful in, increasing the efficiency of generation, transmission, and distribution of electricity to minimize costs and conserve resources. At this time, better utilization of electric energy offers the greatest potential for improvements in overall energy system efficiency. Electric utilities are being increasingly asked to assume major responsibilities in achieving national conservation goals through increased efficiency of energy use and improved management of electric loads. Utilities have yet another nationally important responsibility in energy resource conservation: to help substitute electricity generated from coal and nuclear plants for scarcer resources, especially for fuel oil and other petroleum-derived fuels.

In discharging these responsibilities, electric utilities must be concerned with managing the associated changes in operations, equipment, and procedures wisely so that these changes result in mutual benefits: for utilities, improved operations and financial health; for the consumer, low-cost energy and security of supply. Active involvement of the electric utility industry (through participation of individual utilities in significant conservation programs and through an effective EPRI R&D program in key areas of energy end use) is required if the utilities are to make the contributions expected of them in achieving national energy policy goals, while solving pressing energy supply and cost problems.

EUCT program

EPRI's Energy Utilization and Conservation Technology (EUCT) Program, established in 1976, is an industry response to the country's need for better use and conservation of energy and capital resources. The major objectives for this program are derived directly from the industry's national and regional responsibilities in energy conservation.

- Assessment, selective development, and demonstration of techniques and equipment designed to improve energy end-use efficiency
- Evaluation, selective development, and demonstration of thermal storage and other promising load management technologies and systems
- Identification, selective development, and demonstration of practical electric transportation modes and of other technologies and processes that permit efficient substitution of electricity for scarce fossil energy resources

Besides availability of funding, key considerations in selecting development and demonstration projects for support are the following.

- National and regional significance of specific energy end uses and the potential for

conservation-induced changes in those uses

- Probable or potential conservation impacts on utilities and consumers and the potential for favorably affecting such impacts through better information, technologies, and systems
- Logical roles for EPRI and the energy end-use R&D programs of individual utilities, the federal government (especially DOE), manufacturers of energy-using equipment, and operators of energy-intensive processes
- Desirability of working closely with individual utilities and equipment manufacturers to ensure timely utilization of R&D results

These considerations continue to govern the EUCT program that has emerged, with extensive industry advice, during the last few years. As initial results from the program's projects are becoming available, the resource conservation potential and likely utility impacts of energy efficiency, load management, and substitutions by electricity are being established, and opportunities for improvements through technology development are being defined and implemented. The challenge for the EUCT program is to adequately cover, as yet with a relatively small program, the enormously broad range of energy-using equipment and processes over which energy savings and utility impacts will aggregate.

End-use efficiency technology

Efficiency improvements can make major contributions to keeping electric energy costs down and freeing energy needed to help meet increasing loads, with the goal of maintaining electricity as a competitive and secure supply option for energy users.

The strategy in EUCT's end-use efficiency subprogram is to concentrate, in each of the major energy use sectors (residential, commercial, and industrial), on developments that have significant but as yet inadequately characterized and explored potential for energy conservation and impacts on utilities. An additional strategic goal is to explore the potential for increases in overall energy efficiency by utilizing the reject (waste) heat available from electrical equipment. Significant R&D is now under way in several areas.

Heat Pumps Design and field validation of heat pumps that offer improved seasonal coefficient of performance (COP) are the major objectives of a project cofunded with Niagara Mohawk Power Corp.; Carrier Corp. is the contractor (RP789). The project's emphasis is on reducing the contribution of heat pumps to the peak demand of utilities in northern climates. Some design improvements have already been incorporated in compressor designs, with further improvements to be field-tested in a planned follow-on effort. Hybrid heat pumps (i.e., combinations of heat pumps with an existing oil or gas heating system) are being assessed as a possible solution to seasonal winter-peaking problems (RP1201-6). Expansion of heat pump R&D will focus on the next generation of improved-COP air source heat pumps, advanced heat pumps using low-grade heat sources, and high-temperature industrial heat pumps.

Energy-Use Management in Buildings Air infiltration is recognized as a major contribution to energy losses from electrically heated buildings. Johns-Manville Corp. and Public Service Co. of Colorado are determining the magnitude of these losses and testing the effectiveness of an air infiltration barrier applied to a statistically meaningful sample of residences near Denver, Colorado (RP1351). A new residential systems study is being initiated to develop an improved understanding of energy flows in residential structures, both to evaluate the residence as a system and to determine what additional R&D is needed to improve efficient use of energy in residential applications (RP1701). This project is being defined in cooperation with the Demand and Conservation Program of EPRI's Energy Analysis and Environment Division; its results will be important in setting R&D priorities and technology targets for energy conservation in building management.

Waste Heat Recovery and Reuse Over 0.5×10^{15} Btu of energy from air conditioning and refrigeration has been identified as recoverable in the residential, commercial, and industrial sectors: one-half of that heat is recoverable from the commercial area with an economic payback of less than four years. Further, recovering and managing this heat could reduce peak load electricity demands (RP1087). Project emphasis is now shifting from assessment to the development of technology application guides for use by utility representatives to assist customers, primarily in the commercial sector. Seattle Department of Lighting (SDL) and Rocket Research Corp. are developing a generic heat recovery system that will permit recovery of heat rejected from large substation transformers without impairing their reliability (RP1274). SDL plans to demonstrate this technique for at least one substation location.

Dual Energy Use Systems (DEUS) A methodology is being developed that should permit utilities to assess opportunities for integrating DEUS—energy systems delivering both electric and useful thermal outputs—into utility systems. Survey work on both industrial cogenerators and utility-owned district heating systems is under way. When these surveys are completed, system analyses and conceptual design efforts will begin, with the objective of identifying systems capable of providing benefits to utilities and energy users (RP1276).

Assessment of Energy-Saving Technologies The EUCT program has the capability of quickly evaluating new energy-saving technology options in response to industry questions and concerns (RP1201). Radiation curing, light pipes, and voltage surge suppressors are among the items undergoing preliminary evaluation at this time.

Electric load management technology

Conservation of generation and system capacity will result from improved load management options that can increase utilization of utility plant and system potential. This, in turn, will lower electricity costs and defer capital requirements for new facilities. The EUCT load management effort is focused on the evaluation and development of equipment and systems that are, or have potential to become, electric loads lending themselves to effective control by utilities, while providing users with economic and reliable energy supply.

Thermal Storage Utilities have identified cool storage on the customer side of the meter as having excellent potential for reducing peak loads in summer-peaking systems. Similarly, load management via heat storage has been judged very important for winter-peaking systems.

A number of residential cool storage prototype units have been installed and instrumented to collect data over two summer seasons (RP1089). Data collected from 16 cool storage sites during the summer of 1978 are now being analyzed. Preliminary results indicate that relatively simple cool storage systems using fairly conventional refrigeration components and ice as the storage medium can give comfort with high reliability. Tests indicate that peak load (daytime) energy use could be reduced 50% and daytime power demand, 75%.

Data collected during the winter of 1978–79 from 17 instrumented heat storage systems will be analyzed later this year (RP1090-1). In a second heat storage project, five identical buildings at one location (one with conventional electric heating to serve as a baseline and four buildings, each

with a different heat storage system) will be monitored to evaluate currently available heat storage technology and to identify systems compatible with utility operations (RP1090-2).

Industrial Load Management The potential for managing the electric load presented by the refrigeration system of an industrial production facility is being analyzed (RP1088). A minute-by-minute simulation of electricity consumption has been used to develop a control strategy for the refrigeration system, and plant personnel are now implementing the strategy to validate its potential for load management. The project methodology should be applicable for identification of practical load management strategies in other industrial operations.

A preliminary assessment of opportunities for load management in the major electrolytic processes (aluminum and chlorine production) has been completed at EPRI, and the potential for realizing such opportunities through changes in process technology is now being assessed as part of EUCT program planning. In the agricultural sector, an assessment is under way to identify the potential for developing and implementing utility-compatible load management, conservation, and cogeneration technologies and systems (RP1466).

Load Management and Energy Conservation Survey A survey of utility-sponsored load management, thermal storage, and conservation projects was carried out in 1978 (TPS78-807). The study briefly described 70 utility conservation projects, 63 communications and load management projects, and 71 thermal storage projects. Approximately 20 of the projects, identified as typical examples of utility conservation efforts, will be described in depth for expanded utility use. This project is being entered into EPRI's research and development information system (RDIS) to provide utilities with access to the information.

Efficient substitution technology

Major national and international concerns over growing U.S. dependence on imported oil are prompting a thorough examination of how this dependence can be lessened by shifting from an oil-based to a coal/nuclear-based electric energy system. Significant shifts will occur only where substitution is an economically sound move; moreover, such shifts are likely to place added pressure on electricity supply. Thus, the national strategy and the economic problems of promoting shifts to electricity greatly increase the need for utilities to assist as much as possible in advancing more efficient energy use and load management. Accordingly, the strategy of the EUCT efficient substitution technology projects is to identify and stimulate developments that will permit substitution of electricity for oil and (where appropriate) gas in a manner consistent with the objectives of efficient and economic use of electric energy and utility energy equipment.

Industrial Electrification Electrification and energy management in industrial processes are one current focus in the area of efficient substitution technology. Charles A. Berg Associates is identifying trends and the technoeconomic potential for electrification of industrial processes and is characterizing technical responses appropriate for utilities (RP1275-3). United Technologies Corp. has begun a detailed assessment of concepts for industrial heat storage and recovery, which would be based on commercial or near-commercial hardware (RP1275-1). Projects to examine and develop the technology base for industrial uses of high-temperature heat pump and thermal storage systems are in the planning stage.

Electrified Transportation The transportation sector accounts for half the U.S. consumption of petroleum-derived fuels. The substantial oil savings that could be realized if coal and nuclear energy were used to provide transportation energy on a large scale have created renewed interest in electric vehicles (EVs) and other electric transportation modes. A national commitment in this area is beginning to emerge, motivated in part by the Electric Hybrid Vehicle Act of 1976 (PL94-413).

Establishment of timely and effective utility participation in this national effort is a primary goal of EPRI's electric vehicle demonstration project (RP1136). Such participation will ensure that EV technology and associated electricity uses will be compatible with future utility planning and power supply. Southern California Edison Co. is testing and evaluating electric vehicles that are candidates for the EV demonstration activities carried out by TVA, which is cofunding the project. In addition to the demonstration of up to 20 EVs at TVA, arrangements are being made for EPRI to provide a standard data-gathering package for some of the DOE-funded EV demonstrations at Long Island Lighting Co. and Consolidated Edison Co. of New York. The purpose is to develop the broadest possible EV information base on technology status, energy and power use, and utility interface.

Preliminary planning has begun to examine the R&D implications of a broader and more intensive involvement of EPRI and the industry in the development and implementation of EVs and other electric transportation modes (TPS79-737). This technical planning study should result in a comprehensive EPRI plan for R&D activities in electrified transportation.

Future challenges

EPRI's RD&D in energy end use includes contributions from utilities, large government-funded R&D programs, present and potential manufacturers, and various trade associations. To be successful in achieving its objectives, EPRI must cooperate with each of these groups. Energy utilization and conservation are extremely broad in terms of end-use applications and technological implications and opportunities in the major application sectors. Significant savings in energy use will result only from the aggregation of small savings from many needed technologies; accordingly, even a modest EUCT program must be broad in scope. The EUCT challenge is to have sufficient breadth to cover all potentially effective options and still produce practical results. This challenge must be approached by adding the unique perspective of the electric utility industry to the large national programs. *Program Manager: Orin F. Zimmerman; Project Manager: Robert L. Mauro*

COAL LIQUEFACTION

Control over the hydrogen transfer reactions that occur in a coal liquefaction reactor has long been an objective of researchers in the field. Over the last five years, a number of findings and miscellaneous clues from EPRI-sponsored research on the laboratory, bench, and pilot scale, have indicated that a real potential for controlling these reactions exists. A theory has evolved that suggests specific coal product liquids with relatively high boiling points have unique hydrogen-transferring abilities. Techniques have been developed to increase the concentration of these materials in the liquefaction reactor. New tests have been developed to measure the effectiveness of these materials. These concepts will be optimized during the next few years in bench-scale operations and then tested in the 6-t/d solvent-refined coal (SRC) pilot plant at Wilsonville, Alabama.

Liquefaction of bituminous coals (Kentucky, Illinois, Pittsburgh, and Indiana seams) has been shown by Mobil Research and Development Corp. to occur rapidly (RP410). Typical reaction times of 1–5 minutes achieve over 90% conversion in the pres-

ence of recycle solvent (process-derived) and hydrogen at temperatures of 427–454°C (800–850°F) and pressures of 8.27–17.2 MPa (1200–2500 psig) or below. Conversion is defined here as dissolution of coal products in a convenient solvent, such as cresol, pyridine, or tetrahydrofuran; more precisely, conversion is measured by the amount of the organic matter in the original coal that remains insoluble in the test solvent.

It was determined that at these short reaction times, a significant portion of the process-derived solvent combined with the coal or initial liquefaction products to form a nondistillable product. In addition, pure compounds with functionalities typical of chemical types found in coal-derived solvents were shown to have the ability to either donate or abstract hydrogen from coal liquefaction products. The rate at which they were capable of doing this varied substantially and was not associated specifically with the relative amount of donor hydrogen that the specific molecule contained.

Heavy liquids

In parallel projects, carried out in support of the SRC project at Wilsonville, a strong correlation was noted between the presence in the recycle solvent of nondistillable heavy liquids recovered from the process and higher levels of conversion (RP389, RP779-4, RP779-6, RP779-7). Other published information indicates a relationship between the distillate yield and the use of high-boiling-point nondistillable liquids as part of the slurrying oil recycled to the reactor in the SRC-II and H-Coal processes (RP238). One could surmise from this evidence that the presence of heavy liquids in the recycle solvent promotes both coal conversion and the formation of lighter products.

There are several mechanisms that have been proposed to explain this effect. In the case of SRC-II, the higher distillate yields were attributed at least in part to the increased presence in the reactor of mineral matter that was contained in the heavy liquid recycled to the reactor. In the H-Coal process, it was proposed that a higher concentration of heavy oil in the reactor made a higher proportion of the oil available for cracking to lighter products by particulate catalysts.

The potential role of the heavy liquids in promoting hydrogen transfer had not become apparent in the previous work noted above. This work had indicated that maintaining a process in solvent balance at short reaction times would be impossible because of solvent reaction with initial coal liquefaction products. Therefore, while coal could be converted at mild conditions, a continuous process was not possible because the net distillable solvent yield was negative for each pass. Such a process could operate for only several cycles before the initial solvent was consumed. The ability to recover nondistillable solvent from coal liquefaction products was necessary for the success of these short-residence-time (SRT) processes.

One of the options available for removing ash and unconverted coal from coal liquefaction products is the Kerr-McGee critical solvent de-ashing (CSD) process. This process can also be extended to fractionate coal liquefaction products by molecular type into a number of products.

It was agreed in 1977 that Kerr-McGee would ship a unit, built and owned by them, to the Wilsonville SRC pilot plant, primarily for testing as a de-ashing device (RP1234). EPRI added another stage to the unit shortly after its installation at Wilsonville to accomplish product fractionation (RP779-15). In tests conducted at Wilsonville during 1978, it was demonstrated that both distillable solvent remaining from vacuum distillation and nondistillable solvent could be recovered from SRC products.

A complex project set up to simulate this operation involved test programs at both Conoco and Kerr-McGee (RP1134-1 and RP1134-2). In essence, coal was liquefied in a bench-scale unit at Conoco's laboratory in Library, Pennsylvania, using solvent recovered from Wilsonville. The vacuum residue product was then forwarded to Kerr-McGee's laboratory in Oklahoma City and fractionated. Nondistillable solvent was recovered there and sent back to Conoco. This cycle was repeated several times and demonstrated that an SRT process could be kept in solvent balance.

It should be pointed out that an SRT process can operate at a lower pressure and temperature than conventional SRC processes. Some savings in product cost should occur because hydrogen consumption is minimized. Previous studies have shown that the replacement of filtration with CSD would be economically advantageous in its own right (RP832-2).

One of the subtasks of RP1134-1 at Conoco was initiated to establish criteria for solvent effectiveness. Specific tests were set up to determine the ability of the solvent both to carry donatable hydrogen and to transfer hydrogen from the gas phase to the initial coal liquefaction products. It has long been postulated that coal initially liquefies by thermal rupture and that hydrogen, transferred to the coal from the solvent, stabilizes the fragments and prevents their recombination. It has been shown, first in these laboratory tests and then in continuous bench-scale operations, that part of the SRC product that can be recovered by CSD fractionation promotes hydrogen transfer and thus enhances solvent effectiveness markedly.

Two-stage process

Another development of interest involves the upgrading of SRC recovered by CSD (RP361-2). The petroleum-refining industry uses a similar technology called propane deasphalting to separate residual oil into two fractions. It has been demonstrated that the lighter fraction can be upgraded by hydrogenation much more easily than the entire residuum. The CSD process is somewhat similar in that it rejects some heavy coal liquids with the ash. Therefore, SRC deashed with CSD does not contain some of the heavier liquids that filtered SRC contains. As a result, hydrotreating this material has been demonstrated to be much easier than treating the filtered SRC—that is, substantially milder conditions are used that lower hydrogen consumption and reduce catalyst fouling rates.

The net result of this development may be a two-stage liquefaction process that operates at relatively mild conditions to produce a high yield of high-quality utility fuel products. Three elements are necessary:

- A relatively mild noncatalytic coal conversion operation
- Preparation of a selective recycle solvent stream with simultaneous rejection of solids
- A mild catalytic hydrotreating operation

While apparently more complex than existing single-stage processes, the two-stage process may prove to be more economical because operating conditions are milder and hydrogen selectivity is improved.

A comprehensive five-year program at the 6-t/d Wilsonville pilot plant, including a major investigation of this approach, has recently been approved. The other major element of the program at Wilsonville will involve support of the 6000-t/d SRC-I demonstration plant. In order to optimize the use of experiment time at Wilsonville, a continuous bench-scale unit that contains all three process elements—liquefaction, selective solvent preparation, and de-ashing and hydrotreating—will be set up (RP1715). *Program Manager: Ronald Wolk; Project Managers: Norman Stewart and Howard Lebowitz*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

HIGH-TEMPERATURE FILTRATION FOR RADIATION CONTROL

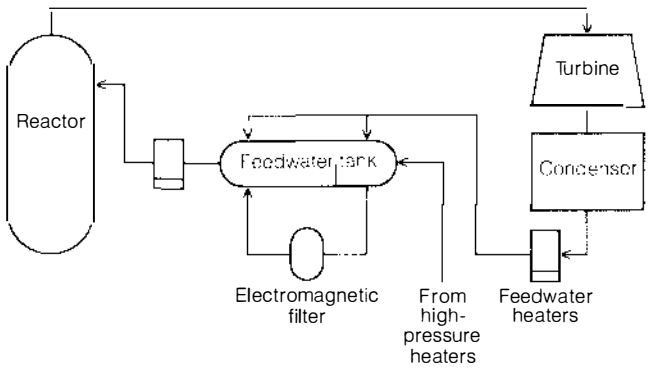
A program of testing has been developed to assess the ability of electromagnetic high-temperature filters (HTFs) to control the buildup of radiation fields in LWRs. Large-scale testing in both a BWR and a PWR is planned to evaluate operational and system characteristics and to determine the effects of the removal of corrosion products by such filters on the buildup of radiation fields.

Radioisotopes formed from corrosion products are the dominant source of radiation fields associated with the reactor coolant loop in LWR nuclear power plants. These corrosion products are formed by the extremely slow, generalized corrosion of the surfaces in the reactor coolant circuit and are released from these surfaces to the reactor coolant in ionic, colloidal, and/or particulate form. From the reactor coolant, in which their concentrations are expressed in parts per billion (10^9), corrosion products are deposited on fuel surfaces, which leads to the formation of radioisotopes, particularly cobalt-60. The subsequent release of these radioisotopes from fuel surfaces to the reactor coolant makes them available for incorporation into the corrosion film on reactor coolant system surfaces (such as coolant piping and pumps and steam generators).

LWR plants use ion exchange resins in low-flow bypass loops to remove corrosion products from the reactor coolant. These resins are capable of removing all forms of corrosion products in varying degrees, but require substantial cooling of primary water to avoid resin degradation. HTFs offer the opportunity to significantly increase purification flow rates without the thermal penalty associated with the use of resins. HTFs take a variety of forms—beds (including magnetite and graphite), etched-disk filters, and electromagnetic filters (EMFs).

The ability of HTFs to control radiation fields in LWR plants is difficult to assess, partially because it is not clear which form

Figure 1 Electromagnetic (high-temperature) filter as installed at the Isar BWR.



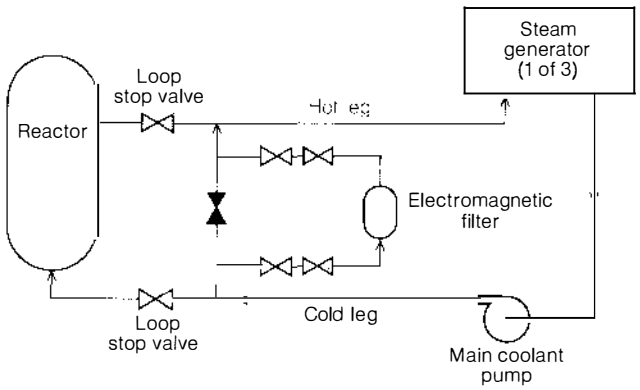


Figure 2 Planned PWR installation of electromagnetic (high-temperature) filter.

of corrosion products—ionic, colloidal, or particulate—has the greatest effect on radiation field buildup. In general, HTFs will be effective for removing particulates, less effective for colloids, and relatively ineffective for ions. Nevertheless, confidence in the influence of HTFs on radiation buildup has been great enough to warrant a project to test HTFs in LWRs. The decision was made to test large-scale HTF systems. Small-scale tests measure the capability of HTFs to remove corrosion products; large-scale testing permits this measurement plus determinations of HTF influence on radiation fields throughout the reactor coolant circuit and of the operational characteristics and performance of large HTFs.

Two organizations have been selected for this project—Kraftwerk Union (KWU) for the BWR application and Westinghouse Electric Corp. for the PWR application (RP1445). Each application will use an EMF as the HTF. The BWR testing will be performed by KWU at Isar, a German plant that has been on-line since September 1978. The EMF was a part of the original plant installation at Isar. As shown in Figure 1, this 1500-m^3/h filter processes one-third of the total feedwater flow entering the feedwater tank. The drains of the high-pressure heaters (not shown in Figure 1) are forward-pumped into the right-hand side of the baffled feedwater tank, which is the side from which the inlet to the EMF is drawn. At Brunswick-2, the high-pressure heater drains have been shown to contain a much larger amount of corrosion products than the low-pressure heater effluents (RP819-1).

Westinghouse has proposed the configuration shown in Figure 2 for installation at a PWR plant. Here approximately 0.5% of the reactor coolant flow will be passed through two EMFs via reactor coolant loop bypass lines on each of two steam generator loops.

Extensive testing and evaluation programs are being developed for each of these applications. Inlet and outlet sampling will be conducted to determine EMF removal capabilities for particulates and nonparticulates, and elemental and radioisotopic analyses will be performed. The frequency at which backflushing is required and its effectiveness will be assessed, together with the general operational requirements of the EMF. The influence of the additional burden on the radwaste processing system from EMF backflushing will be evaluated. Finally, tests will be performed to evaluate the most important (and most difficult to assess) feature—the influence of the EMFs on plant radiation exposure.

The patterns, trends, and characteristics of radiation field buildup in LWRs are being studied in several other projects (RP404-2, RP819-1, RP825-1, and RP825-2). Results of these projects will be valuable in comparing the HTF study plants with similar plants to attempt to discern the field and exposure effects of these HTFs.

Which techniques are most appropriate for effective radiation control should be much clearer within a few years, whether they are in the area of materials selection, coolant chemistry control, high-temperature filtration, decontamination, or a combination of these. *Project Managers: Robert Shaw and Michael D. Naughton*

PRACTICAL INELASTIC ANALYSIS

Computer-based stress analysis is a process in which solution accuracy trades off directly with computer operating cost. A recently completed project explored methods for obtaining a more favorable accuracy-cost trade-off. Methods of estimating accuracy bounds were also investigated.

A substantial fraction of the cost of many EPRI structural reliability projects goes to operate the computer while it performs finite element stress calculations. The cost of analyzing a three-dimensional, inelastic structure is presently prohibitive; this is unfortunate since real structures are, in fact, three-dimensional and often fail only after significant inelastic deformation. A coordinated study combining the research performed under RP971-3, RP1242-1, and RP1242-2 has been aimed at inventing more cost-effective computer algorithms for inelastic problems. It has also explored the closely related problem of error estimation.

Computer-based stress analysis involves a direct trade-off between computing costs and error reduction; refinement of the finite element mesh results in decreased error and increased computing costs. Determination of the optimal trade-off requires that information be available on error magnitudes. This information is not, however, supplied by the current generation of finite element codes. Thus in the worst case, the code user could complete his study with a solution that is both costly and of dubious accuracy.

Investigation reveals that high costs are primarily associated with the need to solve large sets of simultaneous algebraic equations. Costs can be minimized either by minimizing the solution time for a particular equation set or by minimizing the number of equations used to represent the structure. Use of both possibilities in tandem can yield very large savings.

The number of computer operations needed to solve the finite element equations is given by the following formula: cost = $ke^{\beta\alpha}$, where e is the error in the structure's strain energy, β is a measure of the efficiency with which the equations are solved, α is a measure of the efficiency with which each equation is used in approximating the structure, and k is a constant. Costs are minimized for a given error toleration by minimizing β and maximizing α.

Ordinary general-purpose equation-solving subroutines available on most computing systems give a β of 3. Finite element codes employ equation-solving subroutines that give a β of 2 by exploiting certain features of the finite element equations.

Work by two of the project contractors attacked the problem of reducing β further toward a goal of 1 or less. Entropy Limited concentrated on transferring to the area of solid mechanics a great deal of technology developed over the past decade for the transient analysis of nonlinear electronic networks. The identification in this project of a formal mathematical correspondence between the equations of finite element analysis and the equations of network analysis makes this transfer possible. Nonlinear networks can frequently be solved today with a β value of less than 1. The correspondence also facilitates the use of adjoint error propagation methods, well known to circuit analysts but previously unexploited by finite element practitioners.

Work at SRI International focused on application to stress analysis of a computational scheme known as the fast Fourier transform (FFT). The FFT is presently used to improve computational efficiency in a number of scientific fields. SRI found that an FFT-based code could be developed to give β equal to 1 but that applications would be limited to elastic bodies with rectangular or circular geometries. Irregularly shaped boundaries would raise β to 1.5. Cost characteristics for inelastic problems were not addressed by SRI because of lack of time.

Washington University focused on the problems of maximizing α and of estimating local strain energy error. The study showed that α can be doubled under many circumstances if one adopts the error reduction method of increasing the degrees of freedom per element while holding the number of elements constant; this contrasts with the more orthodox error reduction method of increasing the number of elements while holding the degrees of freedom per element constant. Work on local error estimation is

part of an envisaged computer code architecture that would minimize the number of simultaneous equations by adding local degrees of freedom adaptively in response to local accuracy demands.

An algorithm that exploited these techniques could offer substantial projected cost savings. If, as seems to be possible, β is reduced from 2 to 1 and α is simultaneously increased from ½ to 1, cost is reduced by a factor of 1000 for 10% error and 1,000,000 for 1% error. The project participants recommend that these techniques be first applied as an improvement to an existing stress analysis code. *Project Manager: S. T. Oldberg*

MONITORING BWR WATER CHEMISTRY

In an effort to better understand the environmental conditions in BWRs, a research program was initiated to monitor BWR water chemistry. These measurements have thrown new light on the way general laboratory studies of intergranular stress corrosion may apply to BWRs and have also helped develop a simple BWR startup procedure that minimizes the ability of the reactor environment to facilitate intergranular stress corrosion.

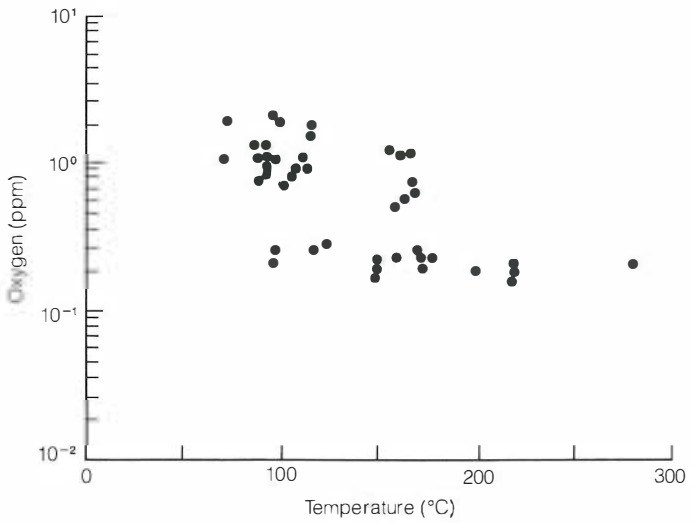
Between January 1971 and June 1977 approximately 3% of all BWR outages lasting longer than 100 hours were related to pipe cracking (RP705). Although pipe cracking is responsible for only a small percentage of total outages, the related fuel replacement costs are estimated to be $12 million per year (based on the total installed capacity in 1978). If nothing is done to protect future plants from pipe cracking, the associated fuel replacement costs could more than triple as additional plants are put into service.

Thus, it is not surprising that extensive research has been initiated to discover the causes and potential remedies for the pipe-cracking phenomenon.

The cracking occurs predominantly in weld-sensitized and furnace-sensitized type-304 stainless steel and has been clearly identified as intergranular stress corrosion cracking (IGSCC) (RP449-2). The simultaneous occurrence of three conditions is essential for IGSCC in BWRs: a critical level of stress, a sensitized microstructure, and an environment that promotes IGSCC.

Various remedies for IGSCC have been developed that are based on modifying one or more of the essential conditions. As part

Figure 3 Typical temperature-oxygen combinations during startups of three BWRs.



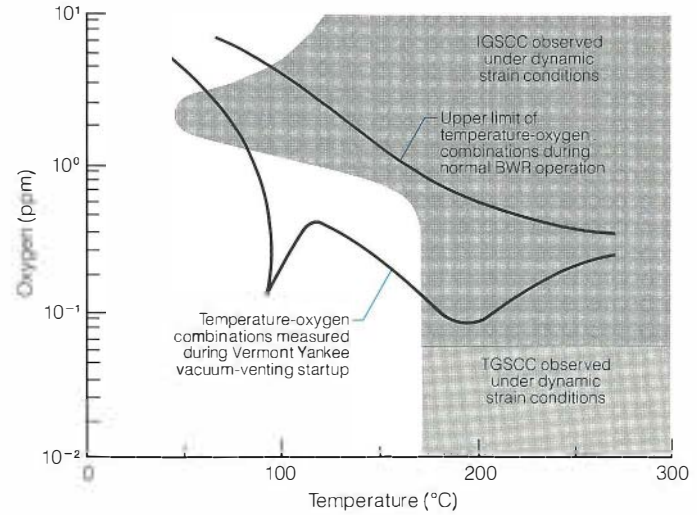


Figure 4 Experimentally determined environmental temperature-oxygen regions that are capable of facilitating intergranular and transgranular stress corrosion cracking (IGSCC and TGSCC) are superimposed on the temperature-oxygen combinations likely to occur during normal BWR startups. The lower bound on the BWR startup conditions represents the vacuum-venting startup procedure demonstrated at the Vermont Yankee nuclear power station.

of this effort, EPRI has initiated research focused on obtaining a better understanding of the third of these conditions—environmental conditions that promote IGSCC.

In the initial phase of this study undertaken by Nuclear Water & Waste Technology Inc., water chemistry was monitored during steady-state and transient BWR operating conditions (RP449-3). This research revealed valuable information about the levels of dissolved oxygen and hydrogen peroxide produced during BWR startup and shutdown operations. Figure 3, for example, illustrates the combinations of temperature and oxygen levels measured during startups of three BWRs: Brunswick-2, Monticello, and Vermont Yankee. Such in-plant measurements produced two fundamental stepping stones toward a better understanding and control of IGSCC in BWRs.

First, they helped put a new perspective on laboratory studies of IGSCC, showing the relationship between laboratory results and measurements made of the environments in actual BWRs. One such relationship is illustrated in Figure 4.

Second, the in-plant measurements helped to identify a simple procedure to minimize the concentration of dissolved oxygen during a BWR startup and thus reduce the ability of the startup environment to facilitate IGSCC. This oxygen control procedure, known as vacuum venting, was demonstrated at the Vermont Yankee nuclear power station. As Figure 4 shows, this startup procedure minimizes the temperature-oxygen trajectory within the IGSCC-susceptible region. Avoiding an environment that can facilitate IGSCC may be especially important during a BWR startup because the dynamic stresses and strains that occur during startup are believed to contribute to IGSCC.

Recent activities related to the monitoring of BWR environmental conditions have been expanded to include the measuring of electrochemical potential (RP706-1-2). These measurements, made possible through the continued cooperation of Vermont Yankee, have led to the improvement of in-plant measuring techniques. Current research on BWR environments is focusing on the relationships between electrochemical potential, oxygen concentration, hydrogen peroxide concentration, temperature, and IGSCC. *Program Manager: Richard E. Smith; Project Manager: Michael J. Povich*

CRACKING AND HEALING OF UO_2

The ceramic UO_2 pellets that form the heart of LWR fuel rods sometimes fracture in service as a natural result of high thermally induced stresses. Experiments traced the fracture process and subsequent motion of the pellet fragments—links in a mechanistic chain that sometimes leads to stress corrosion cracking of the fuel rod cladding tube (RP508).

During power increases in LWR fuel rods, pellet-cladding interaction (PCI) occasionally results in stress corrosion cracking of the Zircaloy cladding. Reducing the rates of power change in an attempt to lower interaction stresses decreases plant capacity. Thus, a significant economic incentive exists to understand the phenomenon and mitigate its effects. RP508, recently completed, investigated certain rate-limiting mechanisms in the UO_2 pellet that are associated with the failure process.

UO_2 fuel pellets are inherently brittle. Also, the low UO_2 thermal conductivity gives high center-to-surface temperature drops under powered operation. These two characteristics result in extensive pellet cracking even at low power. So long as the cracked pellet remains unfragmented and deforms elastically, its behavior is quite predictable: deformation is reversible under thermal cycling, and the pellet envelope returns to its as-fabricated dimensions on reactor shutdown.

Under certain conditions, however, a number of phenomena combine to produce that irreversible expansion in the pellet envelope known as relocation. The operative phenomena include fission product swelling, creep, and crack healing. They also include pellet fragmentation and such subsequent misalignment of the fragment fracture surfaces that the assemblage of fragments occupies a greater volume than before. In modeling the PCI failure phenomenon, one wishes an accurate description of the kinetics of relocation and the radial compliance of the as-relocated pellet. If a fragmented pellet has relocated in snug contact with the cladding, a power increase may (depending on the compliance) impose significant stresses in the cladding and thus set up one of several preconditions for stress corrosion cracking of the cladding.

The RP508 experiments used the direct electric heating (DEH) apparatus (Figure 5) at the Argonne National Laboratory to gather data on at-power pellet column behavior under laboratory conditions. Joulean (electric resistance) heating of the pellet material replaced fission fragment heating. The exterior was cooled by helium gas flow. Experiments were run both with unclad pellet stacks and with single-crystal Al_2O_3 tubes instead of the normal Zircaloy tubes. Instrumentation included an optical diameter-measuring device, an electromechanical length-measuring device, acoustic crack growth detectors, and optical pyrometers for measuring center and surface temperatures. Additional sensors monitored electrical variables and coolant conditions. Cladding tests featured strain gages applied

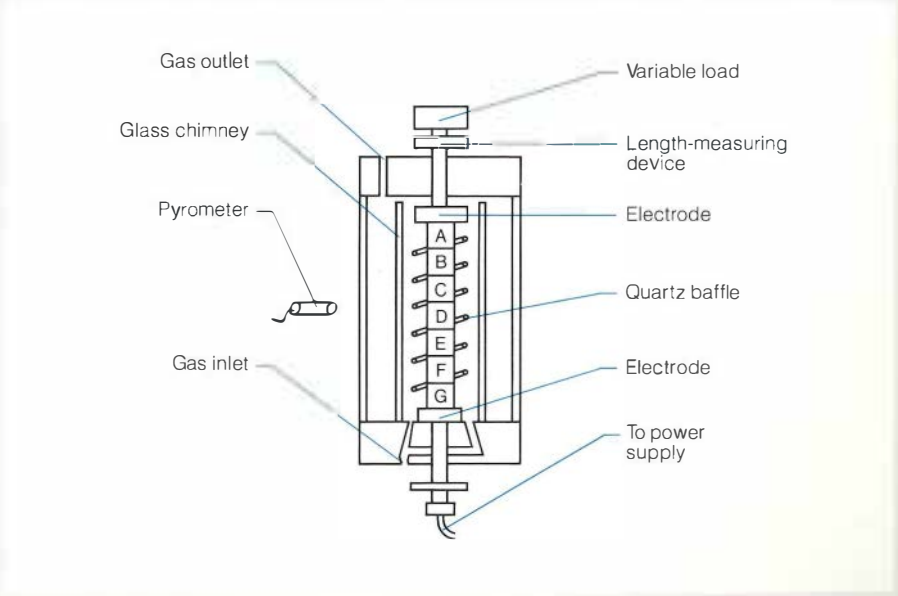


Figure 5 UO_2 pellet stack test chamber, part of the direct electric heating apparatus at Argonne National Laboratory. The pellets, labeled *A* through *G*, are powered by electric resistance heating and cooled by flowing helium gas.

to the cladding tube exterior to measure pellet compliance during PCI.

The DEH experiment included three series of tests. The 15 A-series tests were made on unclad stacks of about seven pellets subjected to single up-hold-down power cycles. The 5 B-series tests featured unclad stacks given up to four power cycles. Finally, the 4 C-series tests had Al_2O_3-clad stacks given one or two power cycles. Throughout the experiments, fuel surface temperatures were maintained at 400–600°C (752–1112°F). Fuel center temperatures extended up to 1830°C (3326°F). Although long-term tests had originally been planned, several experimental difficulties prevented test durations greater than 25 h.

The data base from tests on unclad pellet stacks comprises more than 13,000 events obtained by sampling sensor information at 12-s intervals. The picture of the relocation process that emerges from this mass of data is very complex, and it is possible that some effects are artifacts of the laboratory setup. However, the following findings stand out as being both technologically important and of probable applicability to real in-reactor behavior.

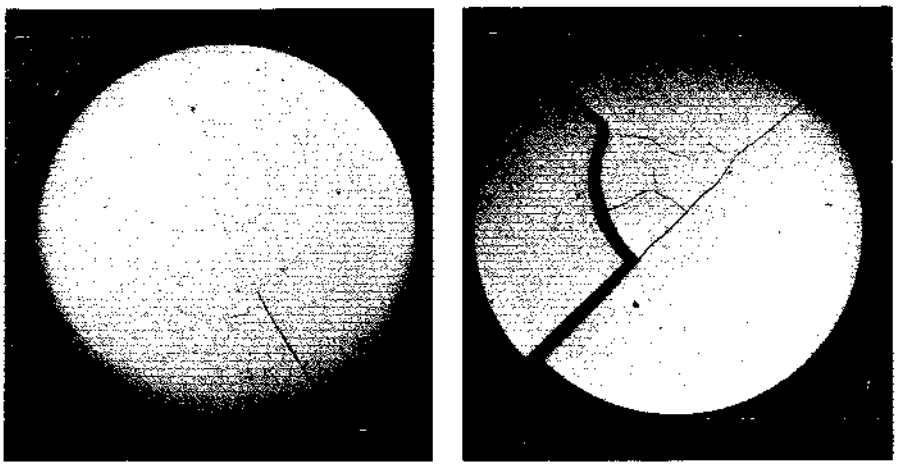
- Power and power ascension rates have thresholds below which the pellet cracks but does not fragment and exhibits essentially reversible thermoelastic behavior (Figure 6). These thresholds, which lie, respectively, at equivalent nuclear power ratings of 25 kW/m and 185 kW/(m·h), fall within the range of fuel rod operating conditions and are thus of practical interest.

- Above one or the other of these thresholds, the pellet separates into two or more fragments and the pellet fragments readily relocate outward.

- Irreversible increases in pellet diameter are highly correlated to decreases in fuel column length but are unrelated to time at power. Thus it appears that relocation is not controlled by thermally activated diffusive processes, such as crack healing and creep. Rather the mechanism appears to be a slight slumping of the fuel column downward and outward with motion along fracture surfaces, which act as shear planes. This motion is promoted by gravity and by power cycling and is inhibited by coulomb friction between the fragments.

Data from tests on clad pellet stacks led to the following key conclusions. In short-term tests (only several hours in duration) conducted above the relocation threshold, pellets relocate across prototypic pellet-cladding gaps. These relocated pellet fragments exhibit noncompliant behavior when they are in contact with the cladding, even though the tests are too short for the fragments to sinter. Stresses above the Zircaloy yield point are generated in the cladding during power ramping. This observation of substantial relocation behavior, in combination with noncompliance of the relocated fragments, suggest a key role for fragmentation and relocation in the phenomenon known to the fuel industry as deconditioning. Deconditioning refers to the propensity of fuel operated at low powers to gradually lose its ability to operate reliably at higher powers unless it is conditioned by a very gradual stress-relaxation ramp up to the higher power level. *Project Manager: S. T. Oldberg*

Figure 6 Pellets tested in direct electric heating apparatus. The cracked but not relocated pellet on the left was operated below a power of 25 kW/m. The fragmented and relocated pellet on the right was operated above that threshold.



DEPOSITION OF CORROSIVE SALTS IN STEAM TURBINES

Corrosion of turbine blades and disks caused by deposition of dissolved salts carried by dry steam is a recurring problem in both fossil and nuclear power plants. Accurate determination of salt solubilities at plant operating temperatures and pressures is important in developing systems to avoid this corrosion. New research on salt solubility and adsorption has led to a discovery of great potential value for corrosion control.

A reproducible and reversible adsorption process between an Inconel 600 surface and sodium chloride dissolved in dry steam has been observed in a study performed at the University of Georgia (RP969). The phenomenon may be highly significant to corrosion processes in dry-to-wet transition regions of steam power systems. Although this adsorption phenomenon has been studied only for a single salt on one alloy and at one temperature, it is believed to be a general phenomenon.

Important applications for the handling of superheated (dry) steam in thermal power plants are possible.

- A steam-purifying filter could be based on this principle.

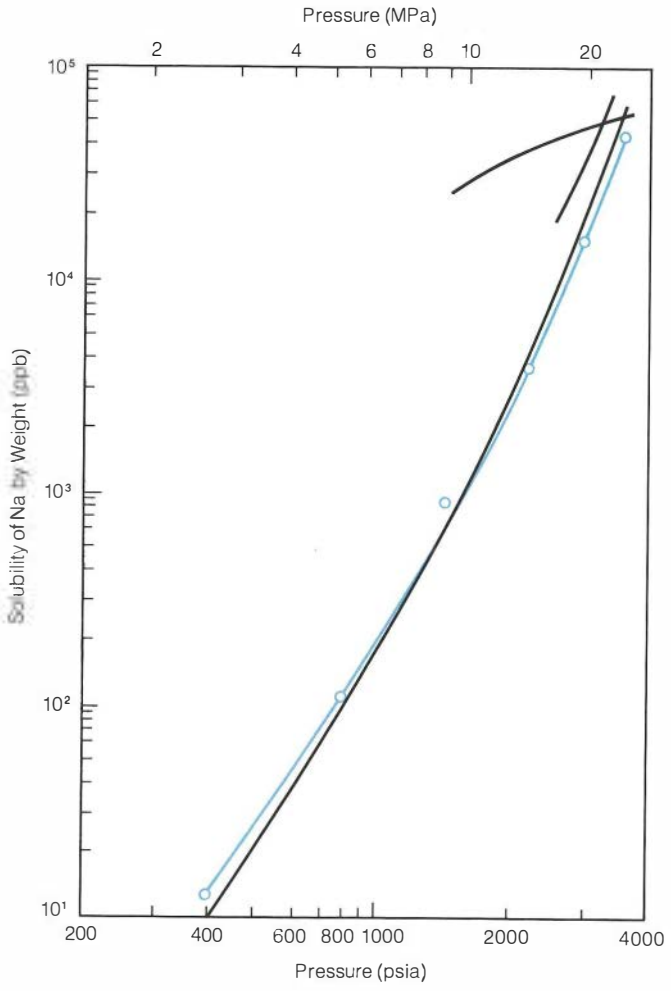
- Turbine damage observed near the Wilson line (the dry-to-wet transition region) might be related to similar adsorption processes.

- The principle could be related to corrosion in steam piping.

The adsorption phenomenon was discovered while attempting to accomplish the primary objective of RP969: to determine how much salt can be carried through the turbine in the steam phase without depositing and eventually forming a possibly corrosive solution on turbine internals. Accomplishments toward this primary objective are shown in Figure 7. Shown for comparison are measurements made in other studies; clearly the University of Georgia results are in good agreement with most previous work.

Information on this adsorption phenomenon is already being used at the University of Georgia in chemical analysis. Salts dissolved in steam are preconcentrated prior to analysis so that solubilities below current sensitivity limits can be measured. With this technique, the determination of solubilities below 1 part per trillion (10^{12}) is anticipated. *Project Manager: Thomas O. Passell*

Figure 7 Amount of sodium carried in solution by dry steam is shown as a function of steam pressure. The University of Georgia measurements (color) are generally in agreement with results from previous studies (black). The higher solubilities shown by the top curve probably resulted from particulate carryover, a mechanism that was carefully avoided in the University of Georgia study.



R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

UNDERGROUND TRANSMISSION

Flexible gas cable

The objectives of the flexible gas cable project are to develop, manufacture, and test a 345-kV flexible, compressed-gas-insulated cable capable of being placed on a reel for shipment in long lengths (RP7837).

When this project was first reported on (*EPRI Journal,* April 1978, p. 59), a prototype (300-mm-diam, 100-m-long) flexible compressed-gas cable fabricated by Kabelmetal of Hannover, West Germany, was undergoing a 300-kV withstand test while on its shipping reel. Subsequent to that successful test, the cable was pulled into a trench, which essentially formed a loop that came back on itself and included one S-bend. The main purpose of pulling the cable into the trench was to gain more knowledge of its mechanical characteristics. The system was then joined at the ends with a tap to high voltage, and another 300-kV withstand test was successfully completed.

The cable used in the trench test did not contain the optimized or final design insulator or conductor. Building on this success, however, a six-month test of overvoltage and cyclic loading was undertaken to gain as much information as possible about the system. This test is nearing completion.

As noted in the 1978 status report, a fabricating machine was ordered from Kabelmetal for production of 345-kV systems in the United States. This machine was successfully demonstrated at Kabelmetal in Hannover during the last week of March 1979 (Figure 1). Part of the demonstration consisted of the manufacture of three 10-m-long samples for electrical testing in the United States. In addition, one 10-m-long section was mechanically tested in Hannover. All the samples were 390 mm diam, which should be sufficient for 345-kV operation. In the Hannover mechanical test, one of the sections was bent around a 3.4-m-diam hub. Subsequent dissection of this sample showed that no insulators had been damaged mechanically. A hub of this dimension would result in a total shipping diameter of 4.27 m (14 ft) or less.

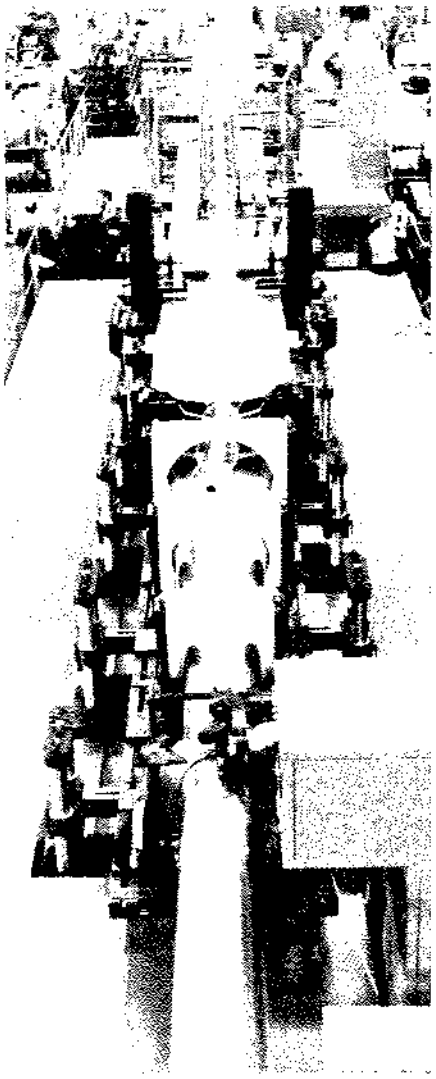


Figure 1 Machine for fabricating flexible, gas-insulated cable, under test by the manufacturer, Kabelmetal. The aluminum strip material moves toward the viewer through the forming tools and welding station (center) as the conductor with insulators is inserted.

The machine has been shipped to Bridgeport, New Jersey, to be installed in a facility leased by Gould–Brown Boveri Inc., the prime contractor. Production of a full reel of 345-kV flexible gas cable in the United States is scheduled for the first quarter of 1980. *Program Manager: Ralph Samm*

Contaminated-pellet detector

The development of equipment to effectively exclude contaminated pellets from being incorporated into extruded dielectric insulation was described in a recent report (*EPRI Journal,* December 1978, page 61). This work is being pursued by Reynolds Metals Co. (RP7865). Since the last report, the detector has been installed and is in operation at Reynolds' Malvern, Arkansas, plant to demonstrate feasibility under real-world operating conditions.

Setting up the detector in line at the manufacturing facility involved supplying a platform, power, an air supply, and a handling system (hopper, feed belt, and supports). In addition, since the unit sensitivity is temperature-dependent, it was found that circulation of cool air was required while the detector was operating, particularly in warm weather. Typical maintenance procedures were employed during operation.

Over a period of approximately six months, Reynolds processed over 63,000 lb (28,500 kg) of cross-linked polyethylene pellets. The total amount of rejected material over this period was relatively small—about 35 lb (15.9 kg). This represents only about 0.06% of the total material inspected. Further, less than 1% of the total pellets rejected were truly contaminated; the re-

mainder were "good" pellets rejected with the bad. These results indicate that the total number of contaminated pellets present in commercially available lots is extremely low —less than 0.0005%. (A similar result was observed in evaluation of a small quantity of high-molecular-weight polyethylene pellets toward the end of the project.)

It was found that the rejected contaminated pellets fell into five categories.

- Pellets possessing an embedded black mass
- Pellets possessing a solid shiny mass, presumably metallic in nature
- Pellets possessing foreign organic matter, such as wood
- Pellets that were colored (e.g., black)
- Pellets possessing black surface contaminants (called riders) that could be removed by rubbing

In addition, a relatively large number of free contaminants not associated with pellets were rejected (these were not counted).

The pellets with riders were found to be the most prevalent of those rejected, by a wide margin. All other types of contamination were found to a much smaller extent. Nevertheless, since any contaminant is detrimental to cable integrity, and since the contaminant nature influences the magnitude of the detrimental effect, all the results are highly significant. The results indicate that procedures for handling and packaging materials and for processing cable require review.

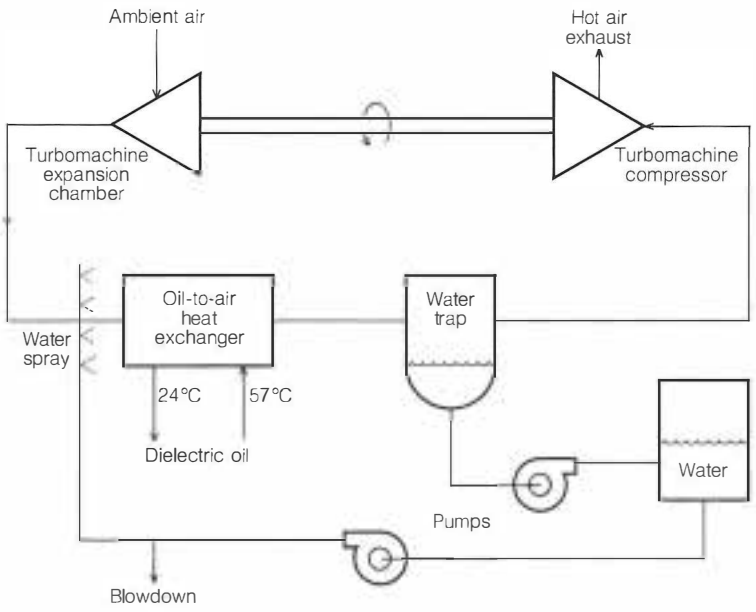
Prior to the completion of the work, a cable was prepared entirely from pellets that had been through 100% inspection, an achievement outside the scope of the original project goals. This cable will be installed by Florida Power & Light Co.

It is expected that the developments from this project will be pursued directly by materials suppliers and cable manufacturers and that an optical detector that can operate closer to standard production speeds will be forthcoming. *Project Manager: Bruce Bernstein*

Air-cycle cooling cables

Refrigeration and auxiliary equipment needed to force-cool an underground, high-pressure, oil-filled cable circuit is expensive. Also, existing conventional vapor-cycle units with their precoolers and cooling towers require large plots of land. Since land is costly in urban areas and land taxes are high, the present value cost of refrigeration is $1565–$1926/t of cooling installed

Figure 2 Air-cycle cable-cooling system. Cooling occurs because the ambient intake air does work on the turbine blades, causing the pressure to drop to approximately 33 kPa (4.8 psi). This air is then forced through an oil-to-air heat exchanger where its temperature is raised by extraction of the heat from cable oil. As the air exits, a turbomachine compressor containing a turbine compression wheel pressurizes it to slightly above ambient pressure and exhausts it through a duct. A water circulation system increases the cooling efficiency.



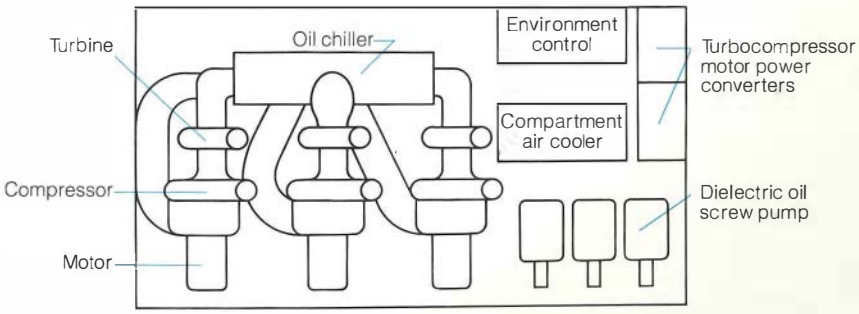


Figure 3 Anticipated packaging arrangement for a utility-size refrigeration station (10 × 5 × 3 m) rated at 600-t capability, with 300-t standby.

($445–$548/kW). EPRI is therefore seeking alternative methods and equipment to cool underground cable. One such alternative is air-cycle refrigeration. Results of a research project with the AiResearch Division of Garrett Corp. so far show a 35% reduction in capital costs, land requirements, and maintenance charges over the life of the equipment (RP7866).

The air-cycle refrigeration equipment being developed for cable cooling does not use a closed refrigerant loop. The working fluid is not Freon but air, which is taken in at ambient temperature and expelled to the atmosphere along with water vapor. The cooling cycle is called a subatmospheric Brayton cycle. Expansion of ambient air is the first operation, accomplished with a turbomachine expansion chamber containing a turbine wheel. Cooling occurs because the intake air does work on the turbine blades, causing the pressure to drop to approximately 33 kPa (4.8 psi). This air is then forced through an oil-to-air heat exchanger, where its temperature is raised by extraction of heat from the cable oil. On exiting, a turbomachine compressor containing a turbine compression wheel pressurizes the air to slightly above ambient pressure and exhausts it through a duct (Figure 2).

To make the system practical for utility applications, a water circulation system has been introduced. This system has a purpose similar to that of the precoolers in vapor cycle units—to reject or cool most of the heat generated by the cable before using Freon chillers or, in this case, the turbomachinery.

Cooling capacity is increased by using the latent heat of vaporization of water (540 cal/g; 2.26 MJ/kg). A spray system connected to the water system keeps a constant film of water blowing across the heat exchanger. Approximately 50% of the water is vaporized and exhausted with the hot air. The blowdown, which is recycled, accounts for the other 50%.

One of the benefits of using a utility-designed, 300-t (1.06-MW) capacity air-cycle system instead of a conventional system is its compact size—so compact that manhole installation is possible, should it be required. Figure 3 shows three 300-t units installed in this manner. One is a standby unit; the other two cool their own respective circulation loops.

With 100% load and an associated 100% cooling requirement on hot summer days, the following operating parameters would apply.

- Motor speed: 9500 rpm
- Amount of cooling: 1055 kW
- Amount of water: 30 m^3/12-h day (7925.4 gal)
- Turbomachine power: 261 kW
- Ancillary power: 4.25 kW
- Oil temperature in/out of heat exchanger: 58/25°C
- Water evaporated: 1.34 m^3/h (5.9 gal/min)
- Water recycled: 1.16 m^3/h (5.1 gal/min)
- Amount of cooling by H_2O evaporation: 841.1 kW
- Amount of cooling by absorption: 242.3 kW

Certain assumptions had to be made (based on a typical utility's yearly load fluctuations) to accurately assess and compare a utility vapor-cycle refrigeration station to a conceptual, manhole-installed, 300-t-capacity air-cycle system. The electric input and cooling requirements were based on the operating criteria shown in Table 1. With this loading used to determine yearly cost of electricity and expendables (water), the capital costs of equipment and installation and yearly operating costs shown in Table 2 were calculated for a utility-size system (two cooling loops).

On the basis of the above assumptions and a conceptual design, preliminary estimates show air-cycle cooling to be approximately 35% less expensive than a conventional unit for the first year of operation.

A 45-t (158-kW) demonstration unit is to be tested at the Waltz Mill cable test facility for long-term durability in the fall of 1979,

Table 1
OPERATING CRITERIA: AIR-CYCLE COOLING SYSTEM

	Summer (122 days)		Spring; Fall (152 days)	
	Day	Night	Day	Night
Transmitted power (%)	100	80	76	70
Oil cooling load (%)	100	50	40	25
Ambient temperature (°C)	29	18	18	7
Electric energy (MWh)	388	179	196	130

Table 2
CAPITAL AND OPERATING COSTS: UTILITY-SIZE AIR-CYCLE SYSTEM
($)

	Vapor Cycle	Air Cycle
Capital component	418,173	325,250
Land taxes or rental (annual)	37,500*	3,366**
Installation	151,250	25,500
Maintenance (annual)	13,000	3,500
Expendables (annual)	0	1,534
Electricity (annual)	18,372	53,573
Total	638,295	412,723
Cooling per ton	1,064	688

*Land taxes, based on $6.50/$ft^2$ in New York City.
**Rental of manhole, based on $0.60/$ft^3$.

and a final report covering this phase of the project is anticipated at that time. *Project Manager: Thomas Rodenbaugh*

SUBSTATIONS

Transformer hot spot detector

EPRI has funded a project to develop a passive device that can be used to measure the temperature of a transformer winding. By fastening a temperature sensor directly on the conductor of a transformer winding, the winding temperature can be measured directly rather than estimated, as is the practice today.

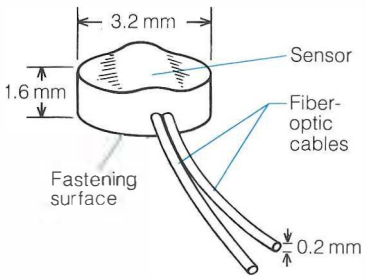


Figure 4 When placed in direct contact with a transformer winding, a tiny selenium ruby glass sensor indicates winding temperature via two fiber-optic cables. The sensor transmits less light with increased temperature, and the attenuation of light transmitted through the fiber-optic cables is converted to a temperature value by an electronic device outside the transformer.

The project employs a technique developed by Sigma Research, Inc., and uses a tiny selenium ruby glass sensor that transmits less light with increased temperature of the sensor (RP1137). This sensor is connected to an electronic device by two fiber-optic cables (Figure 4). The degree of attenuation of the light through the sensor is calculated in the electronic device and converted to a temperature value for the sensor. When a sensor is placed in contact with a transformer winding, the electronic device gives a reading of the winding temperature.

Additional work is planned to stiffen the fiber-optic cables (to prevent breakage) and ensure compatibility and reliability in the transformer environment. When this work is completed, the detectors will be placed in subassembly coils for further long-term testing. *Project Manager: Edward Norton*

POWER SYSTEM PLANNING AND OPERATIONS

Numerical simulation methods

A research project with Boeing Computer Services addresses both the efficiency and the reliability of present methods for simulating dynamic power system performance (RP670). The project is also developing the capability to perform the more complex simulations anticipated for the future.

Fundamental performance characteristics of each of the dynamic power system models commonly used in stability programs were identified. The interactions between these characteristics and various solution algorithms (procedures) were then investigated. After the performance characteristics of the individual methods were analyzed for efficiency, reliability, and numerical stability, a diagnostic transient stability program was developed for testing individual solution algorithms. In addition to performing transient stability computations, the diagnostic program provides performance timings on the numerical methods employed.

The diagnostic program is currently being used to investigate parameter tuning involving step-size control, methods of prediction, and convergence criteria. The time typically required for the stability computation portion of the diagnostic program has been reduced by 30% and several numerical instabilities have been eliminated. The results of the parameter tuning are being applied in other EPRI projects. For example, in the project on extended dynamics stability analysis, using advanced techniques (RP1208), the resultant transient-midterm stability program is being tuned to optimize the solution procedure. A user's manual has been prepared and the diagnostic program is currently available from the Electric Power Software Center.

Boeing Computer Services is also investigating numerical procedures involving high-performance processors, such as the array processor. Two solution procedures for sets of sparse linear equations are currently being developed and tested. The first of the procedures is for such arbitrary sparsity patterns as machine equations, and the second is for patterns that occur in the network equations. The resultant solution methods will be applied in conjunction with the procedures commonly used for large sets of sparse linear equations.

Parallel to this effort, the basic building blocks of generator control equipment (including exciters and governors) are being studied, and a data structure is being designed that will allow the rapid evaluation of machine equations by means of array processors. *Project Manager: John Lamont*

DISTRIBUTION

Horizontal boring equipment

Improved boring systems for small bores 5–15 cm (2–6 in) in diameter and up to 300 m (1000 ft) in length are needed to provide a practical and economical alternative to present boring methods. EPRI has a four-year project under way with Flow Industries, Inc., to develop and test improved boring equipment (RP1287).

A review of currently available systems showed that existing impact boring devices are generally used for short bores because they are convenient, inexpensive, and can be used without extensive operator training. However, impactors cannot penetrate difficult soils like clay and hardpan, have no provision for direction control, and are limited in distance capability.

The concept of impacting has several advantages—the bored hole is compacted and will stay open, and no material need be removed. Since the tool is generally accepted by the industry, modifying it to compensate for its shortcomings appears to be the best way to produce a general boring tool.

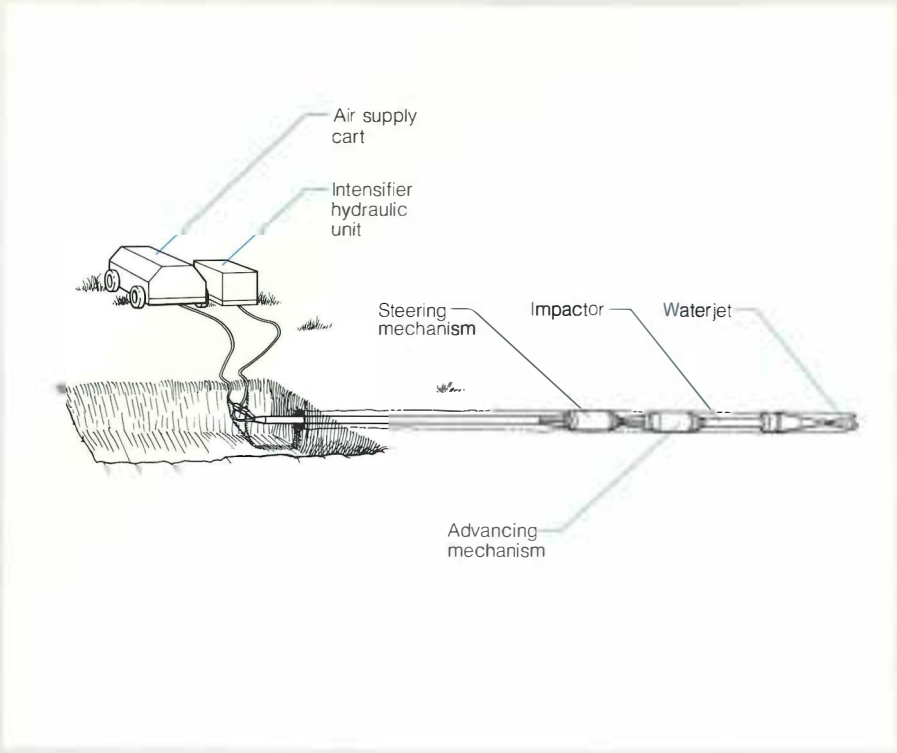
The system under development is a waterjet-assisted impactor (Figure 5). By using a waterjet in conjunction with an impactor, a tool can be designed that will use less energy to attain acceptable advance rates without the danger of penetrating nonmetallic gas pipes. Still, a waterjet will penetrate scattered rocks by hydro-fracturing the rock. Since most of the boring is done with the impactor, the hole size is controlled and there are very few cuttings to be removed.

Steering of the waterjet impactor will be accomplished by an inflatable steering system located at the rear of the impactor. The inflatable system is smaller than a mechanical steering system would be and has no exposed sliding surface. Additionally, an inflatable steering system can conform to an irregularly shaped hole.

All boring systems require an advancing mechanism, which consists of either an external pusher or an internal device. An internal advancing mechanism for the waterjet impactor is now in the prototype state. If successful, it will be much simpler than the conventional external systems now used.

Utilities anticipate that they will have an increasing need to replace existing direct-buried cable. In these instances, it would be helpful if the existing cable could be used to guide a boring tool. Flow Industries is there-

Figure 5 Waterjet-assisted impact boring device under development that will increase the length and accuracy of the bore without increasing energy requirements. The steering mechanism would be combined with an internal advancing mechanism.



fore investigating a method of removing the soil around the cable with a waterjet device that self-advances along the cable. After this device reaches the end of a cable run, the old cable could be removed and a new cable installed. Because of the potential use of such a cable follower and the simplicity of such a system, EPRI set a high priority on the design and fabrication of a prototype.

The cable-following device has been designed and fabricated. Initial testing started in July to assess its ability to advance along a cable, to determine the minimum radius it can negotiate, to optimize its power requirements, and to establish optimal arrangement of the jet nozzles. The advancing system for the cable follower is adaptable to a boring tool and will be considered for the second-phase design of the waterjet-assisted tool if the cable-follower test is successful. *Project Manager: Thomas Kendrew*

Lightning discharge current distribution

During thunderstorms, clouds become charged to very high potentials that are opposite in polarity to the charge on the earth. When the potential difference between cloud and earth becomes great enough (millions of volts), a lightning stroke develops. As the cloud-earth gap is bridged by the stroke, thousands of amperes flow to equalize the electric charges.

A certain number of strokes inevitably terminate on power lines. Since these lines are insulated from earth, a stroke may spark across line or equipment insulation to reach earth, causing a service-interrupting power fault. To reduce the number of such service interruptions, surge protection engineers specify using surge arresters on all overhead line equipment and sometimes on the lines themselves as well.

The function of a surge arrester is to provide a convenient path for the lightning current to travel from power line to ground and at the same time to prevent the continued flow of power current to ground. The modern surge arrester can perform this function very well, but in recent years there has been considerable discussion among surge protection engineers about the magnitude of lightning current that an arrester should be designed to discharge. Present national standards specify 65,000 A as the high-current discharge capability for distribution-class arresters, but evidence presented by some protection engineers has indicated that this current may be too low a design value. Consequently, EPRI undertook a research project to determine the statistical distribution of lightning currents discharged through distribution surge arresters (RP1141).

The accurate measurement of lightning currents is not an easy task. One needs a sophisticated instrument capable of performing its function in the hostile environment that exists at the end of a lightning stroke. Then one must install the instrument and wait for lightning to strike so that its characteristics can be recorded. The time needed to accumulate statistically valid data would naturally depend on the number of instruments used, but a minimum of several years would be needed to accumulate sufficient data from an economically reasonable number of recorders.

At the inception of RP1141, the above procedure could not be implemented because a suitable recording instrument was not available. Although a DOE research project was developing a surge recorder, it could not have been available soon enough to fill the immediate needs of industry. Therefore, a methodology that would produce the best possible data within the shortest time at reasonable cost was sought.

When lightning discharges through a surge arrester, it leaves its track on the arrester gaps. Such tracks have long been used to estimate the characteristics of the strokes that caused them. Although "reading gaps" is far from being an exact science, this method of determining discharge currents was the most reasonable approach for the project. Gaps from arresters that have been in service on utility systems can be read by a comparison with reference gaps, which are prepared by subjecting clean gaps to known discharge currents in the laboratory. The gaps from approximately 2500 arresters that have been in service for eight years would need to be examined to provide statistically valid data.

A project based on this methodology was designed, and The Detroit Edison Company was selected as the contractor. The study included the following.

- Preparation of reference gaps, using 8 × 20-μs waves (with and without follow current) and longer-duration square waves (The range of surge currents was 1000–100,000 A.)
- Examination of the gaps from over 2800 arresters provided by 14 utilities
- Analysis of the variable data to establish correlations (The variables included discharge current, discharge energy, iso-

keraunic level, arrester spacing, and geographic environment.)

- Production of a final report

Figure 6 illustrates the cumulative distribution of discharge currents and energies resulting from the examination of arresters that together experienced over 30,000 years of service and discharged 2420 strokes.

The naturally marked gaps were compared initially with reference gaps marked by 8 × 20-μs waves. Comparison with this single wave shape introduced a degree of uncertainty because lightning wave shapes probably exist in infinite variety. This uncertainty became evident during the course of the project, as many of the gaps removed from arresters exhibited markings atypical of 8 × 20 markings. This development led to a second categorization of the gaps—estimation of the stroke energy in coulombs.

Another source of uncertainty was the judgment of the gap examiner in interpreting and estimating current or coulomb values. This uncertainty was minimized by having all gaps interpreted by the same examiner.

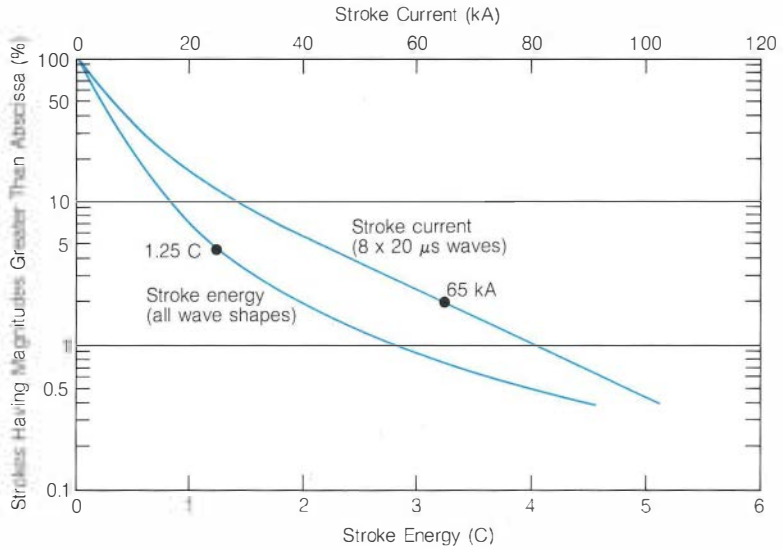
Using the frequency distributions of Figure 6 and other statistical data, the curves of Figure 7 were derived. By referring to these curves, one can estimate how often an arrester can be expected to discharge a given current. For instance, if the strokes recorded in the gap examination are assumed to have been 8 × 20 waves, an arrester would discharge a 20-kA stroke every 120 years.

The illustrations are but a sample of the data contained in the final report (EL-1140), now available from EPRI's Research Reports Center. Despite the methodologic drawbacks, this report is probably the best reference on the subject published to date. It will be of use to both the surge protection engineer and the surge arrester designer. A more definitive study can be made only after many years of data collection with sophisticated surge recorders. This course may eventually be pursued, but the results of this project will serve in the interim. *Project Manager: Herbert Songster*

HVDC insulator contamination and flashover

Insulators on direct current (dc) lines behave quite differently from those on alternating current (ac) lines. This has been observed on operating lines for many years. Up to now, almost all transmission lines have been ac; therefore, the performance of insulators on dc lines has not been given the same attention as those on ac lines. Today, the increasing use of interconnections, the

Figure 6 Statistical distribution of stroke current and stroke energy experienced by distribution-class surge arresters that had accumulated 32,808 years of service. The stroke current is assumed to have an 8 × 20-μs wave shape in all cases; the energy curve is based on consideration of additional wave shapes, such as 200-μs and 400-μs square waves, as well as 8 × 20-μs. Only 2% of all strokes exceed the arrester design standard of a 65-kA, 8 × 20-μs wave, but system designers should recognize that about 5% of all strokes contain energy greater than 1.25 C, which is the content of the standard 65-kA wave.



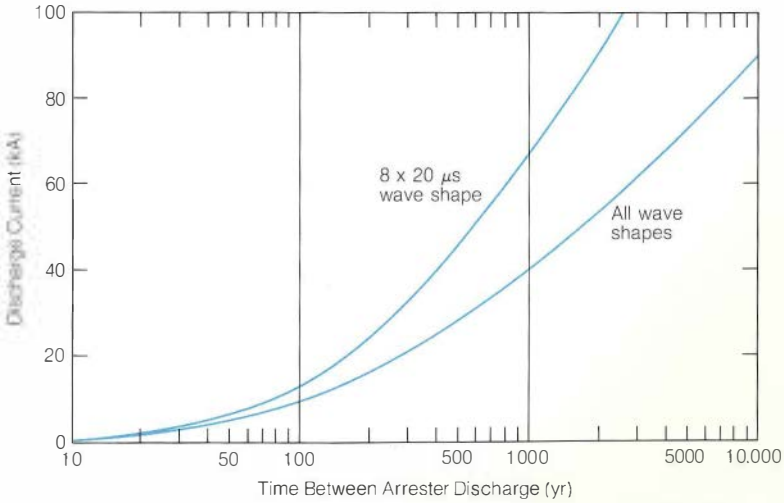


Figure 7 These curves show the average time between discharge of a given current experienced by the arresters examined. When stroke currents are interpreted as 8 × 20-μs waves, the average stroke current is higher than when other wave shapes are also considered. This can be observed in the divergence of the curves as current increases.

prospects of minemouth generating plants located far from load centers, and the siting of nuclear power plants in remote locations have generated renewed interest in dc transmission (RP848).

To better understand exactly what happens when insulators on dc lines become contaminated, EPRI is sponsoring a project at the University of Southern California to observe how insulators become contaminated under actual operating conditions; to perform laboratory tests, using controlled contamination; and to explain the process of dc insulator contamination and how contamination affects flashovers.

As part of the study, a test facility was built at the converter station at the south end of the 850-mile, ±400-kV Pacific HVDC Intertie line that runs from the Columbia River in northern Oregon to the Los Angeles area. This location offered two important advantages: The test insulators could be connected electrically to the operating transmission line; and the test insulators were subjected to typical contamination conditions of dew, fog, and airborne products of industry and agriculture.

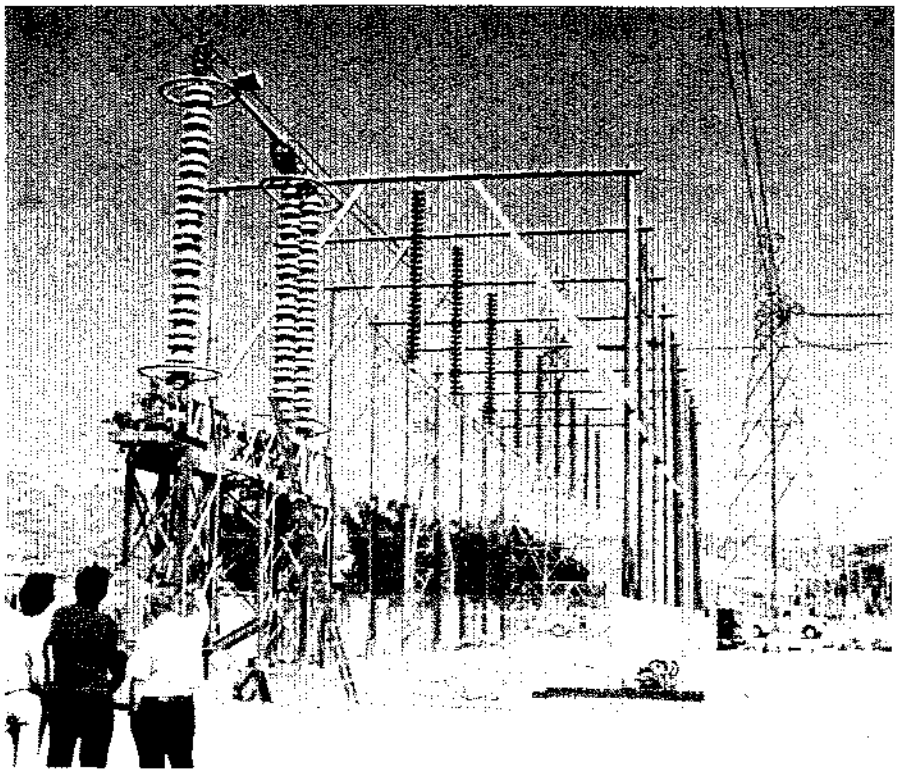
The test facility contains nine insulator strings directly energized by a tie to the operating dc line and two strings that are not energized (Figure 8). A weather station is located on the site to record conditions of wind speed and direction, temperature, humidity, and precipitation. Leakage current is also continuously monitored.

During the first two years of this ongoing project, observations have been made of the nature, rate of accumulation, and type of contamination experienced; the effects of wind, humidity, and rain; and the differences in the amount and location of contamination between insulators under electrical stress and those not under stress.

In addition to the field tests, laboratory studies of insulators have been conducted, using controlled contamination. The results show that the dc flashover voltage is considerably lower than the ac (rms) flashover level under the same conditions.

Two interesting phenomena were observed in the laboratory flashover experiments: a clean zone that forms on the insulator and the corrosive effects of nitrate contamination on glass insulators. The formation of dry zones on the surface of insulators has been well established for both ac and dc conditions. A similar phenomenon observed was the formation of a clean zone produced by electrostatic forces. The clean zone is electrically similar to the dry zone in that both are areas of high resistance and each plays an important role in the flashover process.

Figure 8 Field-test rack for contamination studies of dc insulators at the Sylmar Converter Station near Los Angeles. The operating Pacific HVDC Intertie transmission line is in the background; the switch connecting the test insulators to the dc line is at left, foreground.



The detection of the corrosive effect of nitrates on glass insulators was significant because many existing dc transmission lines use glass insulators. During tests with nitrate salt contamination, arcs cut $\frac{1}{32}$-in-deep (0.79-mm) grooves in the glass surface. It has been theorized that the surface of the glass is destroyed at the arc tips in an area of high field strength. Under actual field conditions, this phenomenon would not occur except after many years of service in extremely contaminated areas (the laboratory test was performed with very high levels of contamination, which accelerated the corrosion process).

This project will continue through the summer of 1980. Observations of field-experienced contamination will continue, and experiments with controlled contamination in the laboratory will be performed. It is hoped that these efforts will lead to a better understanding of the mechanics of contamination and its effect on dc flashover. *Project Manager: John Dunlap*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

ELECTRIC UTILITY RATE DESIGN STUDY

The Electric Utility Rate Design Study (EURDS), through advisory groups, consultants, and EPRI staff, has produced over 60 research reports on various aspects of load management (RP434). This nationwide effort was in response to a request by the National Association of Regulatory Utility Commissioners (NARUC) in 1974 to examine ways of controlling the growth in peak demand and its impact on electricity prices. Additional research on time-of-use rates and load controls continues in 1979. This report discusses Reference Manual and Procedures for Implementing PURPA, *a special report prepared by EURDS for NARUC.*

The National Energy Act (NEA), enacted after many compromises, brought into law five separate pieces of legislation. One of these, the Public Utility Regulatory Policies Act of 1978 (PURPA), was of particular concern to state regulators and to utility executives.

PURPA requires regulators to examine on a utility-by-utility basis in their own states most of the load management issues that were analyzed more generally in the Rate Design Study. Because of the experience gained in almost five years of research, NARUC asked the Rate Design Study to analyze PURPA and to see if help could be provided to the regulator. Specifically, the objectives were to suggest ways state regulators might cope with the issues raised in the new law and to determine how regulators might use the information in the 60 research reports previously generated by the Rate Design Study.

To understand PURPA, it is helpful to know the purpose of the NEA, which was described by DOE Secretary James Schlesinger as erecting a policy framework for decreasing oil imports by the following means.

- Replacing oil and gas with abundant domestic fuels in industry and electric utilities
- Reducing energy demand through improved efficiency
- Increasing production of conventional sources of domestic energy through more rational pricing policies
- Building a base for the development of solar and other renewable energy sources

PURPA has three purposes of its own, which generally complement the objectives of NEA: conservation of energy by consumers of electricity, optimization of efficient use of facilities and resources by electric utilities, and establishment of equitable rates for consumers of electricity.

PURPA imposes on state regulators (and on executives of certain publicly owned utilities) three primary responsibilities, which have great significance for the electric utility industry.

- Deciding whether or not to implement six ratemaking standards regarding cost of service, declining block rates, time-of-day rates, seasonal rates, interruptible rates, and load controls
- Deciding whether or not to adopt five standards of regulatory practice regarding master metering, automatic adjustment clauses, customer information, termination of service, and advertising
- Deciding whether or not a lifeline rate should be implemented

Many of these issues raised by PURPA standards were analyzed in the Rate Design Study. To make it easier for regulators to track down such information, the Rate Design Study has prepared a special seven-part PURPA report for NARUC, *Reference Manual and Procedures for Implementing PURPA.*

Part 1 of the manual briefly describes the three major determinations that each state regulatory commission must make and calls attention to particularly important aspects of the commissions' responsibilities, authority, and procedures in responding to PURPA requirements. Certain fundamentals are emphasized in this section. For example, PURPA mandates that a state regulatory authority must consider the various standards (including ratemaking standards) and lifeline rates under certain tests and procedural rules, but the decision on whether or not to implement such standards and lifeline rates rests with the state commissions.

Part 2 provides an outline of procedures for considering and implementing Title I of PURPA, which focuses on retail regulatory policies for electric utilities. This part contains four schematic diagrams that show the procedures state commissions might use in considering the various load management issues raised by PURPA. In addition, this section lays out the procedures step-by-step and suggests a course of action for state regulators. Such a course would take advantage of earlier hearings (grandfathering) and incorporate information from the Rate Design Study.

Part 3 is a detailed section-by-section analysis of PURPA. This discussion examines each subsection of the law, adds relevant information gained in the Rate Design Study, and cites (by page number) sources of additional information contained in the Rate Design Study research reports.

Part 4 includes a concise issue-by-issue discussion of load management, as well as cross-references to both the research reports and various sections of PURPA. This part of the manual, prepared by Resource Planning Associates, Inc. (RPA), describes the major alternative rate designs (e.g., time-of-day rates based on marginal costs) and load controls (e.g., radio-controlled residential water heaters). In addition, RPA provides a brief review of the questions that should be considered in the design and implementation of time-of-use pricing. Approaches and techniques for evaluating the

costs and benefits of proposed load management techniques are also discussed.

Part 5, prepared by Elrick & Lavidge, Inc. (E&L), a market research consulting firm, describes the results of a survey of state commissions that was conducted by E&L in January 1979. This survey is the third in a series done for the Rate Design Study to assess load management practices. The 1979 poll, for example, found that in 60% of the states, a utility had adopted permanent (not experimental) time-differentiated rates, either time-of-day or seasonal, between July 1977 and January 1979. On the other hand, only five states had adopted lifeline rates as described in the E&L poll.

Part 6 is a facsimile of the PURPA law itself, and Part 7 is a copy of the request from NARUC to perform the analysis.

PURPA hearings have started in several states, and additional hearings should occur before November 1980. The special PURPA manual for NARUC and forthcoming additional research reports represent the latest thinking on many of the issues of load management. To facilitate the transfer of this information to the public, copies of the PURPA manual, a guide to the research reports, and the reports themselves are available from EPRI by written request. Certainly the objective of the original 1974 NARUC request (to find ways of slowing the upsurge in consumers' electricity bills) is consistent with the three purposes of PURPA. Moreover, because these three purposes—conservation, efficiency, and equity—supplement (but do not supplant) each state's traditional objectives of rate design, the stage is set for a reasoned and reasonable determination of which PURPA standards should or should not be adopted for each utility by each state commission. The Rate Design Study will contribute to this process by providing timely and objective information for the public debate on load management. Determinations of the state commissions are expected by November 1981.
Project Manager: J. Robert Malko

TOXIC SUBSTANCE RESEARCH: THE MICROCOSM APPROACH

One of the more important environmental assessment problems facing the industry is the development of tools for rapid and inexpensive screening of ecological effects resulting from fossil fuel use. The probable future emphasis on coal combustion and conversion as a source of electric power will increase the introduction of by-products into aquatic and terrestrial ecosystems. The Ecological Effects Program has initiated a major effort to develop methodologies by which effects can be identified and quantified in less time and at less expense than can be accomplished by field evaluations.

A microcosm is a laboratory environment set up to simulate, as closely as possible, a part of an aquatic or terrestrial ecosystem. The idea of studying laboratory ecological systems that include more than a single species or groups of single species is intuitively appealing; most ecologists believe that the use of the microcosm approach, with its greater complexity, would lead to more meaningful interpretation of interrelationships and community interactions when testing subtances for potential toxicity. The state of the art in microcosm research is quite primitive, however. Therefore, EPRI-sponsored studies in this field are not only satisfying an industrial need but also contributing to the development of an important aspect of the science of ecology. The microcosm project is being carried out by six contractors working on separate issues in the development and application of microcosms (RP1224).

Lawrence Berkeley Laboratory, working on optimal designs for lake water-column microcosms, has developed a strategy for dealing with the problems of size and algal side growth without sacrificing the replicability of the water column (RP1224-1). Chemical changes as well as changes in phytoplankton and zooplankton numbers and species distribution are being monitored. The water column of an actual lake has been successfully tracked for a short period with a microcosm inoculated with water from that lake. A quantitative framework for indicating the stability of an aquatic system is also being developed. It is expected that the final report will recommend aquatic microcosm designs that will optimize replicability for evaluating effects of coal conversion effluents. Previous work by Lawrence-Berkeley was the basis for the present research (EA-936).

The second contract under the microcosm project, a study of lichen and moss microcommunities, is being carried out by the University of Cincinnati (RP1224-2). These plants harbor a variety of microscopic animals (tardigrades, nematodes, rotifers, and others), which could serve as early-warning indicators of pollutant effects. The research team will explore the feasibility of using bark-inhabiting lichen and moss microecosystems for atmospheric pollution studies. The investigators are surveying potential sample sites in the Cincinnati region to determine rates of sulfur deposition on tree bark. This will enable them to select the best sites from which to collect samples of moss and lichen. Progress has also been made on the development of a valid and reproducible technique to extract the microfauna from these samples. This work is at the forefront of methodology development for pollution indexes.

Another microecosystem of interest to the industry is one comprising blue-green algae, bacteria, grazing flies, and associate microfauna in thermally enriched water such as that found in cooling ponds. The University of Georgia is developing a microcosm and a simulation model of a hot spring microcommunity (30–55°C) in Yellowstone National Park (RP1224-3). The model will be used to assess the probable effects of various perturbations caused by thermal change and will be tested against actual experimental manipulations of the thermal microcosm. Experimental laboratory apparatus consisting of incubators and growth chambers for the algae and the flies has been constructed. Systems ecologists and industry biologists are looking forward to the development of this simulation model as a simple and cost-effective way of predicting the ecological effects of temperature variation.

Chlorine is used extensively in electric power plant cooling systems to reduce biofouling. Battelle, Pacific Northwest Laboratories is using a flowing seawater microcosm system to investigate chlorine stress on the establishment and development of communities of attached marine organisms (RP1224-4). Raw seawater will be passed through the experimental tanks, and eggs and larvae of marine organisms in the water will attach themselves to the substrate. These flowing seawater microcosms will then be perturbed with different chlorination regimes, and the populations of barnacles, mussels, and other sessile organisms will be monitored to assess effects and recovery from chlorination. At present, the experimental tanks are in place, and artificial substrates of poured concrete with a rough finish have been prepared to serve as colonizing sites. The substrates have been conditioned with seawater, and some diatomaceous colonization is now apparent.

Excised agricultural (managed alfalfa) microcosms are the fifth type under investigation (RP1224-5). A methodology for applying coal combustion deposits to these microcosms and to field plots will be the first product of this research. Ranges of concentration and application rates of dry deposits that might affect agricultural systems will be determined. In addition, transport of

Figure 1 Agricultural microcosm system used in toxic substance research.

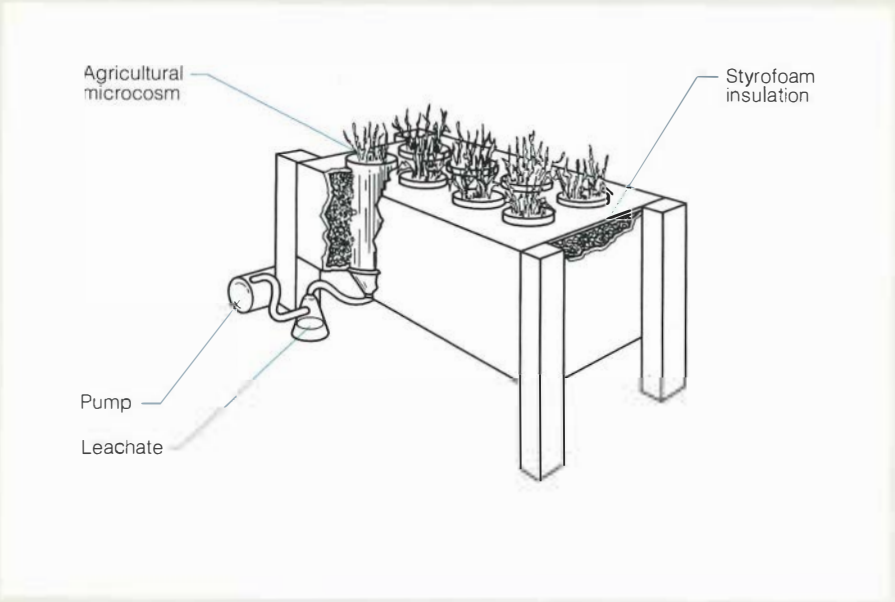


Figure 2 Structural makeup of microcosm.

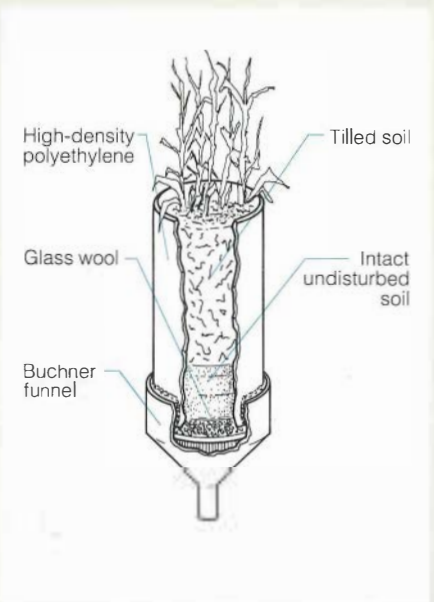


Figure 3 Field plots being prepared for applications of fly ash.

these deposits and their effects on field plots will be compared with microcosm analogs.

Setup of the microcosm in a greenhouse at Battelle, Columbus Laboratories is well under way (Figures 1 and 2). High-pressure sodium vapor lamps are being employed. Rainwater is being collected and used weekly for leaching the microcosms. Field plots have been established and are being prepared for application of fly ash (Figure 3). Fly ash, representative of the material that would escape a power plant and be deposited on the landscape, is being collected from stacks at Virginia Electric Power Co.'s Mt. Storm, West Virginia, power plant by arrangement with the company.

Many researchers feel that for some materials and subsequent investigations, only large-scale microcosms can adequately simulate effects on a natural system. Therefore EPRI is funding an evaluation of the feasibility of using large-scale aquatic microcosms to address ecological problems of the industry (RP1224-6). Lawler, Matusky & Skelly Engineers will be identifying problems that show the greatest potential of being addressed with large-scale microcosms. They will be characterizing the physical, chemical, and biological requirements for such a large-scale facility and will subsequently develop design concepts for large-scale aquatic microcosms. This research has just begun, with the final result expected in late spring 1980.

As indicated by the six projects discussed above, the multitude of conceptual, theoretical, and empirical considerations in environmental toxicology make complex ecological toxicity testing varied and difficult. While EPRI cannot address all the questions that must be answered, these projects should be sufficiently varied in objective and scope to provide a basis for evaluating microcosms as a tool for industrial toxicity testing.

During the spring of 1980 EPRI will conduct a workshop on the integration and synthesis of RP1224 research. It is anticipated that the results of this workshop will establish the direction of future ecological toxicity evaluation at EPRI. *Program Manager: Robert W. Brocksen*

New Technical Reports

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

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ELECTRICAL SYSTEMS

Proceedings: Transmission Static VAR Systems Seminar

EL-1047-SR Special Report (WS78-108)

The use of a VAR source with a smooth and rapid response to provide voltage support to transmission systems was the subject of a seminar on October 24, 1978, in Duluth, Minnesota. One of the principal questions discussed was how to determine which of the four basic types of static VAR systems to use in a given situation. This report by the Minnesota Power & Light Co. contains papers presented at the conference. Specific topics include the theory, application, and field experience of static VAR systems on utility networks. *Editors: John Marks and Gilbert Addis, EPRI; Ivars Vancers, MP&L*

Cost Components of High-Capacity Transmission Options

EL-1065 Final Report, Vols. 1 and 2 (RP568-1)

Commonwealth Associates, Inc., investigated the cost of various high-capacity transmission options to determine in-place component costs for transmission systems to be installed between 1985 and 1990. The results are presented in two volumes. By developing costs on a component basis, a flexible method is provided that allows the user to make changes in design and cost components. Common design criteria assumptions are established, specific transmission systems considered are described, and systems with relatively high economic potential are identified. Major cost components of specific transmission systems are identified to highlight areas where further research may bring about cost reduction. *EPRI Project Managers: F. J. Sherman and P. M. Anderson*

ENERGY ANALYSIS AND ENVIRONMENT

Independent Assessment of Energy Policy Models

EA-1071 Final Report (RP1015-1)

The Energy Laboratory of the Massachusetts Institute of Technology conducted a prototype model verification and assessment to test the practicality and usefulness of third-party model analysis. The Baughman-Joskow Regionalized Electricity Model (REM) and the Wharton Macroeconomic Energy Model were assessed and the case study experiences were analyzed. *EPRI Project Manager: R. Richels*

Dynamic Energy System Optimization Model

EA-1079 Final Report (RP442-1)

The Dynamic Energy System Optimization Model (DESOM) was developed at Brookhaven National Laboratory to investigate the roles of different technologies in the U.S. energy system over an extended period of time. It can be used to study such topics as the impact of new energy technologies, interfuel competition, and conservation strategies. This report describes how an earlier version of DESOM was modified to make it more useful to the utility industry: the most efficient solution algorithms were determined, software was improved, the electric sector of the program was modified to make it more realistic, and DESOM was transferred to EPRI. *EPRI Project Manager: D. M. Geraghty*

Right-of-Way Ecological Effects Bibliography

EA-1080 Topical Report (RP855-1)

Asplundh Environmental Services developed this annotated bibliography on the ecological effects of overhead transmission line rights-of-way for use by researchers and utilities. It contains 824 citations of documents that cover the published state of the art through 1977. It is indexed by author, subject, and ecological region. *EPRI Project Manager: R. A. Goldstein*

Biofouling Control Investigations: 18-Month Summary Report

EA-1082 Interim Report (RP1372-1)

This report by Marine Research, Inc., summarizes continuing research into alternatives to chlorination for the control of biofouling in power plant cooling systems. Promising alternatives that are evaluated include continuous low-level chlorination, dechlorination, condenser antifouling treatment optimization, toxic coatings, and freshwater ozonization. Follow-up efforts on chlorine optimization to prevent intake fouling, additional chlorination/dechlorination tests, and slime measurement correlation will be reported at a later date. *EPRI Project Managers: R. K. Kawaratani and J. Z. Reynolds*

Design for Coal Supply Analysis System

EA-1086 Final Report (RP1009-1)

This report by Charles River Associates Inc. contains the system design for a coal supply analysis system developed for EPRI's Energy Supply Program. The system contains procedures and data bases for use in developing domestic regional coal supply functions for coal studies. Procedures focus on methods of estimating available coal resources, coal mining input prices and availability (land, labor, capital, equipment), coal extraction costs, and coal supply functions. For each procedure, the report specifies the processes modeled, inputs and outputs, and proposed methodologies. The report also specifies the content of the data files and suggested data sources. *EPRI Program Manager: Milton Searl; EPRI Project Manager: Thomas Browne*

FOSSIL FUEL AND ADVANCED SYSTEMS

Electric Utility Solar Energy Activities, 1978 Summary

ER-966-SR Special Report

This report contains the results of the fourth EPRI survey of U.S. utility-sponsored solar energy projects and updates EPRI-649-SR. It includes brief descriptions of 600 projects being conducted by 165 utilities, as well as lists of information contacts and addresses, locations by state, projects by categories, and available project reports. The report may be used to facilitate the exchange of information between utilities, assist EPRI solar energy managers in their program development, and inform individuals, government agencies, and commissions on current utility solar project demonstrations. *EPRI Project Manager: John Cummings*

Development of a Standard Methodology for the Correlation and Extrapolation of Elevated Temperature Creep and Rupture Data

FP-1062 Final Report, Vol. 2 (RP638-1)

This report by the Metal Properties Council, Inc., describes in two volumes the newest available techniques of extending creep rupture data to times and temperature of interest to utility application and concludes that the attempt to standardize the technology of evaluation is worthwhile. Volume 1 provides the state-of-the-art critique of methodologies and a summary of workshop results. Volume 2, a compendium of workshop manuscripts summarized in Volume 1, is intended for the specialist. *EPRI Project Manager: K. R. Kinsman*

Environmental Assessment Methodology: Solar Power Plant Applications

ER-1070 Final Report, Vols. 1–4 (RP551)

This project with Woodward-Clyde Consultants developed a methodology for assessing the environmental impact of solar central power stations. The methodology and computer program were developed and exercised to compare two sites for solar-thermal central receiver power plants. Volume 1 provides the environmental impact assessment methodology and instructions for

its use. Volume 2 contains the methodology for assessing industrial implications and secondary impacts and the computer model for estimating these impacts. Volume 3 defines the methodology used to compare two sites for solar-thermal power plants. A computer program to assist in the implementation of the methodology is presented in Volume 4. *EPRI Project Manager: J. E. Bigger*

Concept Screening of Coal Gasification CAES Systems

EM-1077 Final Report (RP1199-1)

United Technologies Research Center explored the prospective performance and economics of various plans to substitute a clean-burning, coal-derived fuel gas for natural gas or petroleum as a plant fuel in advanced compressed-air energy storage (CAES) power plants. The thermal characteristics of selected coal gasification and fuel gas cleanup systems were matched to the requirements of CAES systems, and the integrated system configurations were studied. Capital and operating costs were calculated and compared with alternative power plant costs. These results led to recommendations on the direction of future coal gasification/CAES investigation. *EPRI Project Manager: William Stevens*

Rheology of Concentrated Suspensions and Their Settling Characteristics in Vessels Having Inclined Walls

AF-1085 Final Report (RP314-1)

In two parallel investigations, Stanford University studied the fundamental behavior of solid particles suspended in Newtonian liquids: the enhanced sedimentation in vessels with inclined walls and the rheology of concentrated suspensions. A sound theory was developed that describes all the various flow phenomena that occur in inclined settling. The experimentally tested theoretical predictions explain past observations and provide a framework for the investigation of new sets of operating conditions. The rheology of concentrated suspensions of monodispersed solid spheres under a variety of flow configurations was experimentally studied to ascertain whether such systems are Newtonian or whether they obey a more complicated constitutive relation. A new equation was developed that treats the suspension as a fluid with structure and accurately models the experimental data. *EPRI Project Manager: R. H. Wolk*

An Assessment of the Use of Chemical Reaction Systems in Electric Utility Applications

EM-1094 Final Report (RP1086-1)

In Phase 1 of this project, Gilbert Associates, Inc., studied chemical reaction systems (CRSs) that involve conversion of thermal energy to chemical energy for storage/transportation, with subsequent reconversion to thermal energy and/or electricity. Twenty-four high-temperature CRSs and 17 low-temperature CRSs were analyzed to determine which could be beneficially used in electric utility applications before the year 2000. A method was developed that resulted in the selection of four applications for conceptual design and equipment cost estimate: two systems were for on-site storage of thermal energy and two were for transport of thermal energy between locations 25 miles apart. The technical feasibility of selected CRSs to transport energy over 25 miles was established. *EPRI Project Manager: B. R. Mehta*

Fuel Cell Power Plant Integrated Systems Evaluation

EM-1097 Interim Report (RP1085-1)

This interim report describes the work by General Electric Co. on two advanced fuel cell power plant types employing molten carbonate technology—small (5-MW), dispersed, oil-fueled power plants and large (675-MW) coal-fueled power plants. The project goals were to establish component and subsystem definitions, configurations for reference plant selection, plant performance costs and availability goals; and to evaluate reference configurations for potential success. Included are general design requirements for the two power plant types, system analytic techniques and methodologies, and configurations for seven coal power plants and one oil power plant. The project focus was to optimize the thermal integration in order to minimize the power plant heat rate. Three of the coal-fueled cases met the heat rate goal, and a means is discussed for more closely approaching the goal in the oil-fuel case. *EPRI Project Manager: A. P. Fickett*

NUCLEAR POWER

Analytic Models and Experimental Studies of Centrifugal Pump Performance in Two-Phase Flow

NP-677 Final Report (RP493)

The Massachusetts Institute of Technology developed a new method to predict the two-phase performance of reactor coolant pumps for steady-state and transient conditions when the pump geometry, operating characteristics, and single-phase liquid data are known. Existing data for centrifugal pumps were reviewed, and a short survey was made of previous work on the modeling of two-phase pump flow. The new method of modeling the two-phase performance of pumps was applied to existing data. Using the new method, the first-quadrant, two-phase performance of a new pump was predicted with accuracy. The method remains to be tried out on and compared with actual two-phase performance of general centrifugal pump data. *EPRI Project Manager: Kjell Nilsson*

EPRI–CURL Dynamic Analysis of Loop-Type LMFBRs

NP-1001 Final Report (RP352-1)

Cornell University developed a computer program that simulates transient behavior in a loop-type LMFBR power plant. Transient analysis studies determined that the program is capable of economically simulating operational and accidental transients. A set of mathematical models was developed and used to simulate operational, incident, and accident transients. The models developed are described, and a user's guide is included. In a related project (RP1381) the validity of the numerical models used is being studied. Development of a computer program for transient analysis use in pool-type LMFBRs is in progress. *EPRI Project Manager: E. L. Fuller*

Refueling-Outage Water Clarity Improvement

NP-1081 Final Report (TPS78-790)

NUS Corp. studied the problem of water turbidity during refueling. Causes and corrective actions are identified and evaluated. Temporary devices used, chemical considerations, and potential permanent system modifications are discussed. Additional areas for R&D are defined, and engineering guidelines and cost estimates are included. The report is an information source for the implementation of improvements to operating practices or the correction of system design deficiencies. Two corrections offered are the installation of auxiliary systems and the addition of a system directly provided for water clarity improvement. *EPRI Project Manager: T. W. Libs*

Nuclear Waste Management, Status and Recent Accomplishments

NP-1087 Final Report (RP SIA78-414)

This report by Battelle, Pacific Northwest Laboratories reviews the status and progress of nuclear waste disposal and highlights progress made from 1976 to 1978. It is an extension of a previous project, NP-44-SR. The report emphasizes the disposal of high-level waste and spent fuel, with brief coverage of other wastes. Systems that are closer to implementation receive fuller treatment than second-generation systems. High-level waste solidification and geologic disposal system processes that are the most advanced in terms of readiness for full-scale U.S. demonstration are discussed in detail. *EPRI Project Manager: R. F. Williams*

GLASS II—Global-Local Finite Element Analysis of Structural Systems

NP-1089 Interim Report (RP299-1)

In this report the University of California describes the computer program GLASS-II, which is based on the global-local finite element methodology where both finite element and classic Rayleigh-Ritz approximations are simultaneously employed as solutions for problems that are of industrial interest. Developed to improve the organization and capability of GLASS-I and to be user-oriented, the code is part of on-going research for an efficient solution algorithm for linear fracture mechanics and seismic wave propagation in the soil-structure interaction area. The report describes the GLASS-II computer code, the library of elements, and instructions for programming global functions. A user's manual (Appendix I), example problem, and the source listing (Appendix II) are also included. *EPRI Project Manager: H. T. Tang*

Probabilistic Accident Analysis—ATWS

NP-1090 Interim Report (RP1233-3)

Babcock & Wilcox Co. (B&W) analyzed a number of EPRI methods of predicting system response to anticipated transient without scram (ATWS) events. This is the seventh report in a series that describes the probabilistic basis for the regulatory question of ATWS. The analysis in this volume uses input values derived from actual plant experience at Oconee and is applicable to B&W reactors. Included are estimates of anticipated transient frequency, probability of scram system failure, and probability of excessive peak pressure. The result is a best-estimate probability of 0.18 that an allowable pressure of 3750 psia would be exceeded if an ATWS occurred and 0.6 that 3200 psia would be exceeded. The frequency of significant ATWS events is smaller than 1.1×10^{-6} per reactor per year; thus compliance with the ATWS safety goal of approximately 10^{-6} per reactor per year is demonstrated. *EPRI Project Manager: G. S. Lellouche*

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September 197