Fusion: Capturing a Star

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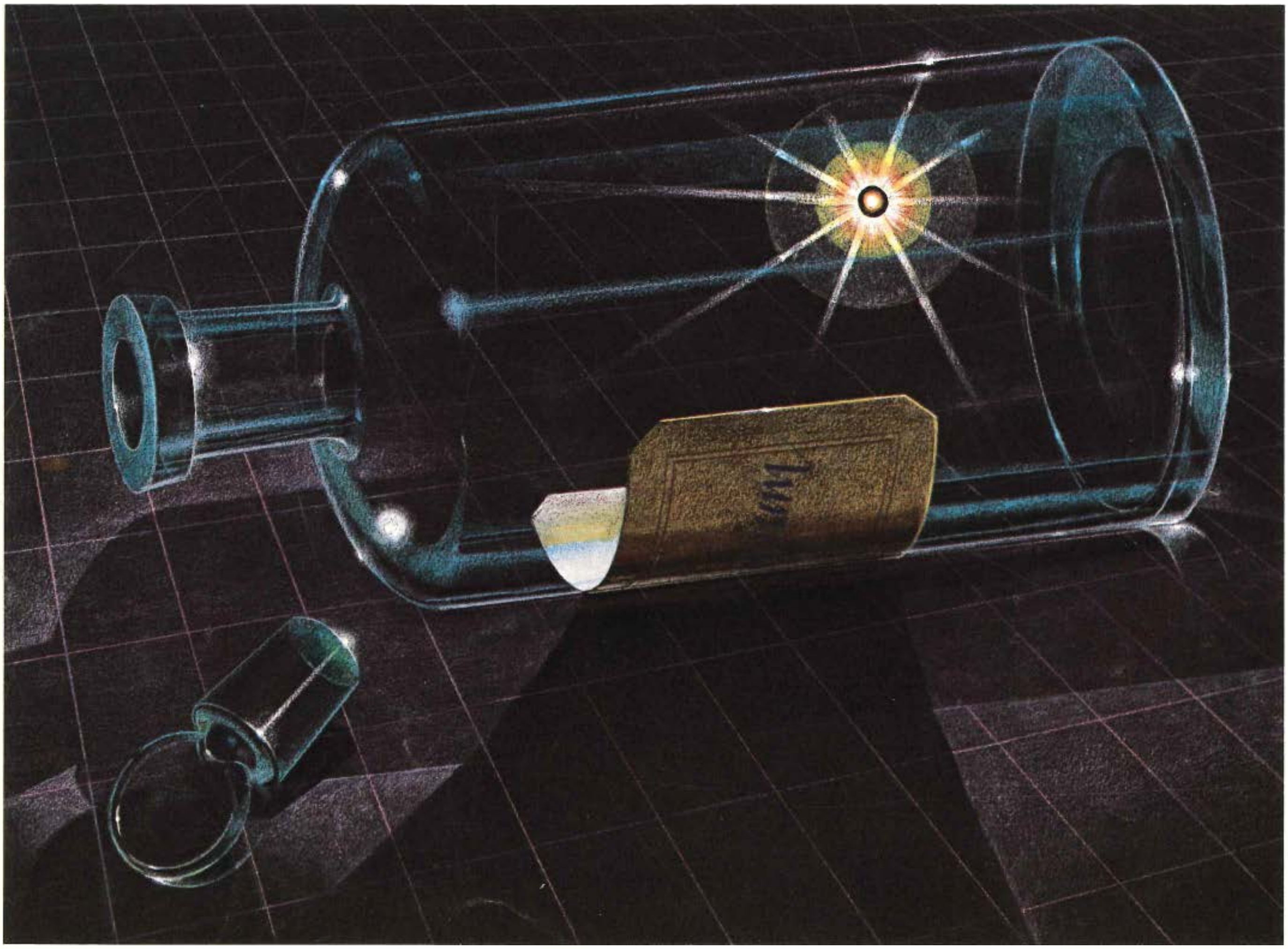

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Cover: Capturing the fusion reaction of a star within a magnetic "bottle" is one of humanity's brightest hopes for the twenty-first century.

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Fusion Power: Time for Recognition

While Nero fiddled, Rome burned—and so it may be with society as we know it today—Washington fiddles over control versus deregulation, tax incentives versus taxes, and so it goes. While there is ample need for concern over energy supply in the next decade or two, it is equally imperative we recognize that as of now we have no option we are confident will be deployable in sufficient quantity to meet United States needs as early as the year 2000.

EPRI analyses identify the need for significant contributions early in the next century from new technologies, even given significantly reduced demand growth as a result of conservation. With lead times of 10–15 years required for new plants utilizing commercialized technologies, one should quickly recognize that utility planners will be making decisions in the next decade on what they must order to meet needs in the year 2000.

Coal and LWR power plants appear the only options, but neither is assured. Resource availability and/or environmental problems could limit the extent of either's contribution. Uncertainties associated with both are simply too great for us to be sure that either will be available to the extent required.

Of the so-called long-term options, only the breeder and fusion appear capable of meeting the nation's needs on the scale and with the geographic deployment flexibility required. To be sure, each has its potential liabilities as well, but these *do not include resource limitations.* While other difficulties, hopefully, can be engineered around, an inadequate resource base cannot.

My purpose here is not to argue the case for the breeder as the earliest alternative to coal and LWR; that fact is not disputed among knowledgeable energy experts. It is rather that the EPRI analysis concludes that even with coal, LWR, and the breeder, we will begin experiencing generation shortages early in the next century. Simple wisdom requires that we not only move aggressively with breeder technology development but also maintain a concerted effort to harness the potential of fusion. With the many uncertainties relating to resources, environmental impacts, and technology, it seems imperative that we not depend entirely on one or even two long-term options. Diversity is essential, and fusion clearly offers the potential of another option; in the more distant future, it is perhaps the ultimate option.

My conviction reflects the rapid scientific progress that has been made in fusion research in recent years—leading, I believe, to what will be a cascading of results over the next 5 years. But these results will represent only the first milestone, the so-called scientific breakeven. Even more important is the recognition of the enormous technological barriers that must yet be overcome before fusion power can seriously be considered by energy suppliers. The time and cost required to resolve these challenges are substantial; let's not deceive ourselves in that respect.

Demonstration-scale projects are likely still 20–25 years away. The ultimate fusion option, a neutronless fuel, is undoubtedly further away, but the incentive here is so large that we simply cannot ignore it, particularly with the ray of light that has emerged in this area in EPRI studies over the past year. We must recognize that even after more than 25 years of research, fusion is still an infant. We must avoid prematurely foreclosing different approaches that could ultimately prove most attractive to the user and yet initiate development of an applied thrust that begins to provide the engineering design base for power-producing systems.

Fusion lacks a Rickover or a mission with the popular appeal of the space program. For this reason it is entering a precarious stage within the federal R&D program. It is too long-term for today's politicians and too costly, risky, and long-term to survive normal discounting practices, even in the government's economic analyses. Utilities, the principal users eventually, are so preoccupied with current problems and so unfamiliar with fusion's status and uniqueness that as an industry they have largely ignored it to date. True, some utilities have actually supported fusion work and EPRI has an active program in this area, but what is needed is industrywide recognition that fusion is a must sometime in the next century, perhaps earlier than it is now possible to achieve, even with an all-out effort. Fusion requires both the support and the direction of utilities as it enters the technology phases. User input is essential to the physics community if user criteria are to properly influence the continued research and the emerging development and power reactor phases.

Fusion is not without its potential Achilles' heel, just like each of the other alternatives, but its potential problems are fundamentally different from those that could constrain coal, LWR, and breeders. Most importantly, fusion problems are susceptible to technical resolution. Resolution will not be simple, cheap, or even assured, but the risk of not sustaining an aggressive program is simply unacceptable, given the future as I see it. To rely *solely* on the breeder as our long-term option, or to naively assume that solar can meet the nation's electricity needs, is playing Russian roulette with our children's future.

Richard E. Balzhiser, Director
Fossil Fuel and Advanced Systems Division

Authors and Articles

We all talk earnestly about technology transfer—not just getting R&D findings into a notebook or report but getting them into daily use somewhere. The task is hard enough when the research is incremental: a new component for a familiar process. It is awesome when an entire technology is involved, as is now the case with nuclear fusion power: 25 years in research already, and at least 20 more to go. But such is the timetable of technology R&D; no wonder we are uneasy about the optimism that so often attaches to conceptual thinking about new energy fuels, processes, and machinery.

Fusion is a prime example. Ever since the H-bomb in 1952 it has repeatedly been bannered as *the* breakthrough that would replicate the energy process of the sun. It would be fueled by an easily accessible and minute chemical fraction of the world's oceans. It would free us forever from the need to carve up the earth's surface—and its innards—in pursuit of inevitably limited resources. All this and no radiation hazard, either.

Intuitively, we know these to be overstatements or, at least, oversimplifications. But how can we lay out the promise and the problems of fusion power for those who look to us for knowledgeable answers? In this case, the first-priority problem of technology transfer is just to communicate basic understanding of an esoteric subject, so that its useful implications can even begin to be considered. And the fact is, fusion isn't thoroughly understood in the utility community.

■ This month's lead article could be a benchmark in the kind of technology transfer that is most needed. To begin with, **"Capturing a Star: Controlled Fusion Power"** (page 6) is an orderly logical glossary of concepts, fuels, processes, and structures. But it is more. It links these parts forward and backward with the research problems in engineering, materials, environment, and economics that define the state of the art in nuclear fusion today.

The article was written by John Kenton, EPRI's communication specialist in nuclear technology. Moving beyond his 17 years with *Nucleonics, Nucleonics Week,* and the Atomic Industrial Forum, Kenton updated his knowledge this year at AIF's Denver meeting, the American Nuclear Society annual meeting, the fusion research facilities of Princeton University and Lawrence Livermore Laboratory, and, finally, EPRI's utility executive seminar on fusion just two months ago.

■ From a section leader on the Manhattan Project in the mid-1940s to the spearhead of a citizens' group that recently created a marine park along the San Diego coastline, William Nierenberg has made his mark. Now director of the Scripps Oceanographic Institution at La Jolla, California, this physicist-turned-environmentalist is also a member of EPRI's Advisory Council. **"William Nierenberg: Blockbuster"** (page 17), by JOURNAL staff writer Stan Terra, compresses a wide-ranging interview into focused opinion on institutional blocks to energy solutions, on methanol as a substitute for fossil fuels, and on the need for a balanced approach to the environment.

■ Long-term energy supply solutions like controlled fusion, and even Bill Nierenberg's speculation about methanol, are different indeed from the specifics of U.S. energy demand in the interval from 1985 to 2000. **Robert Crow's "Demand 77"** (page 20) cites three scenarios of demand progression and reviews the sector-by-sector rationale behind them in studies conducted and sponsored by EPRI's Demand and Conservation Program.

The numbers themselves are interesting today. Even more intriguing is the prospect that annual refinements of the demand-modeling process will yield ever sharper forecasts for use as utility R&D and system planning tools.

Robert Crow has headed the Demand and Conservation Program since he came to EPRI in July 1974 after four years on the School of Management faculty of the State University of New York at Buffalo. His major research interests are econometric demand analysis, regional growth, and the theory of consumer behavior. Crow's article on behavioral considerations in energy conservation appeared in the June-July 1977 issue of the EPRI JOURNAL.

■ Process. Pattern. Population. Assessing energy use by process is easy. Just hang some instrumentation on it and measure it. Assessing energy use by patterns—say of sectors or regions—is another matter. As portrayed in "Demand 77," the ever-changing interactive factors of economic supply and demand get in the way, not to mention purely behavioral and policy influences.

Assessing energy use, and especially the needs of the future, by population projections provides another approach. This is the way of demographer **Everett Lee,** writing in **"Energy for What?"** (page 24). Lee's treatment is qualitative but it clearly identifies three pressure points for gauging energy needs—jobs, housing, transportation—in terms of demographic trends that are measurable today.

Everett Lee developed his interest in demography in a logical sequence that began with his BS in biology from the University of Pennsylvania in 1949. Biology led to biochemistry and, in turn, to genetics. After that, with MS and PhD degrees in sociology (also from Pennsylvania), it was only a short step to demography. University teaching and research have been Lee's focus: four years as chairman of sociology and anthropology at the University of Massachusetts and six years as a professor of sociology, his current post, at the University of Georgia.

Lee directed a section of the International Biological Program for six years (1969–1975) under National Science Foundation auspices, and he continues his participation today in the UNESCO Man and Biosphere program. For the past three years he has been an invited speaker at the Aspen (Colorado) Institute conference of EPRI's Advisory Council. "Energy for What?" is adapted from his talk there last August.

Crow

Lee

Capturing a Star: Co

If the energy that powers the stars could be harnessed on earth, we could solve the world's energy problems, perhaps for all time.

□ An EPRI state-of-the-art feature

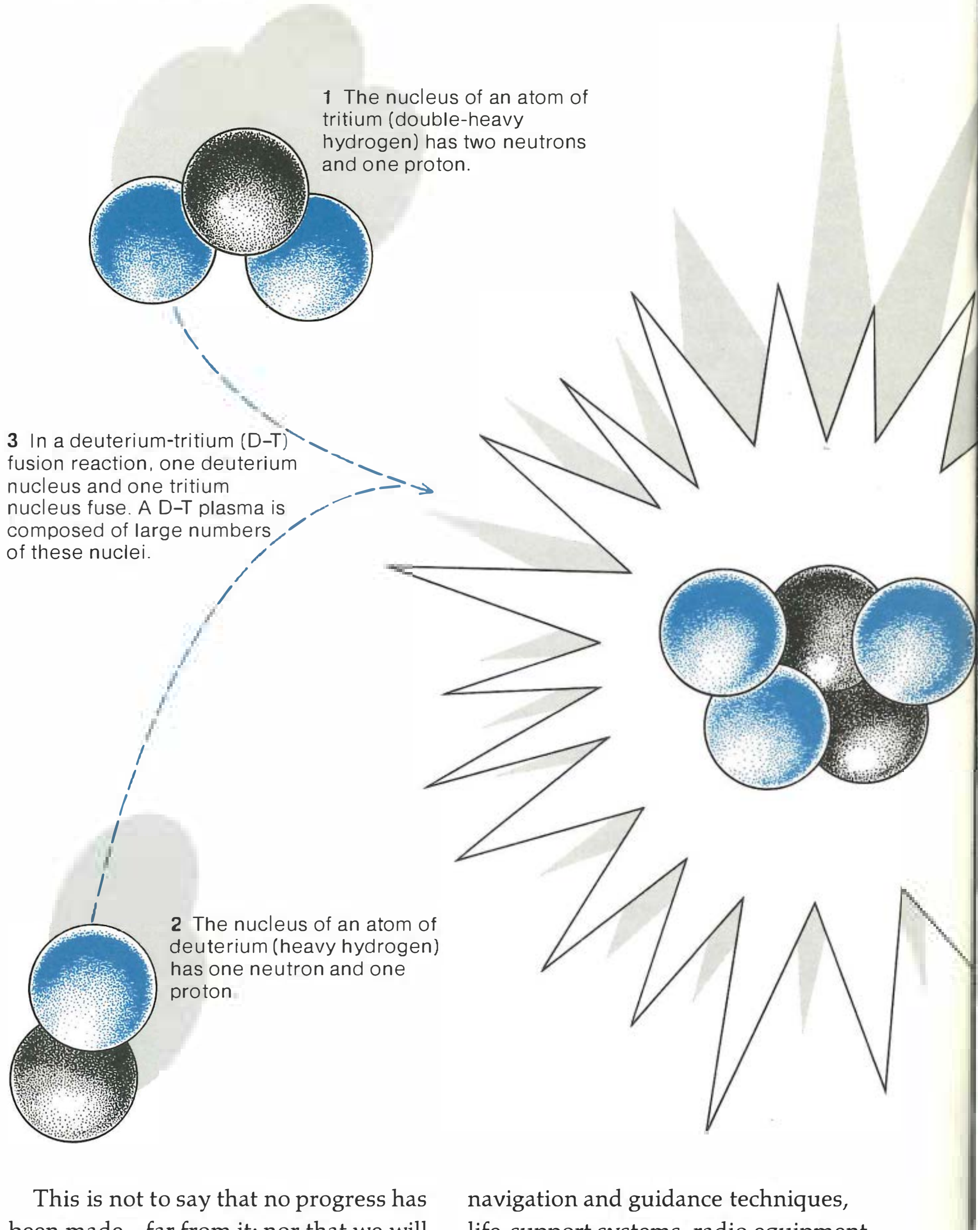
Few people are aware that a glass of ordinary water (H_2O) contains a fuel that if burned at 10% efficiency is the equivalent of 30 gallons of gasoline. The fuel is deuterium, a variant or isotope of the hydrogen atom, one of the most abundant elements on earth. In fact, one in every 6700 atoms of hydrogen is "heavy hydrogen," or deuterium.

Unfortunately, we are not likely ever to be able to pour a glass of water into our automobile fuel tanks because the conditions for using the vast energy potential of deuterium are very demanding. So demanding, in fact, that we must reproduce the temperature of the sun to be able to liberate that energy. Astrophysicists have determined that the heat and light of the stars, including our sun, are produced by the fusion of deuterium nuclei. So to harness fusion energy for useful purposes we must, in essence, try to create, confine, and control a miniature star on earth.

The liberation of fusion energy has been demonstrated, in an uncontrolled fashion, in the hydrogen bomb. The question how soon man will pacify, tame, and harness its power for generating civilian electric power has been a matter of conjecture since the United States first disclosed its fusion research program in 1958, at the second Geneva Atoms for Peace Conference.

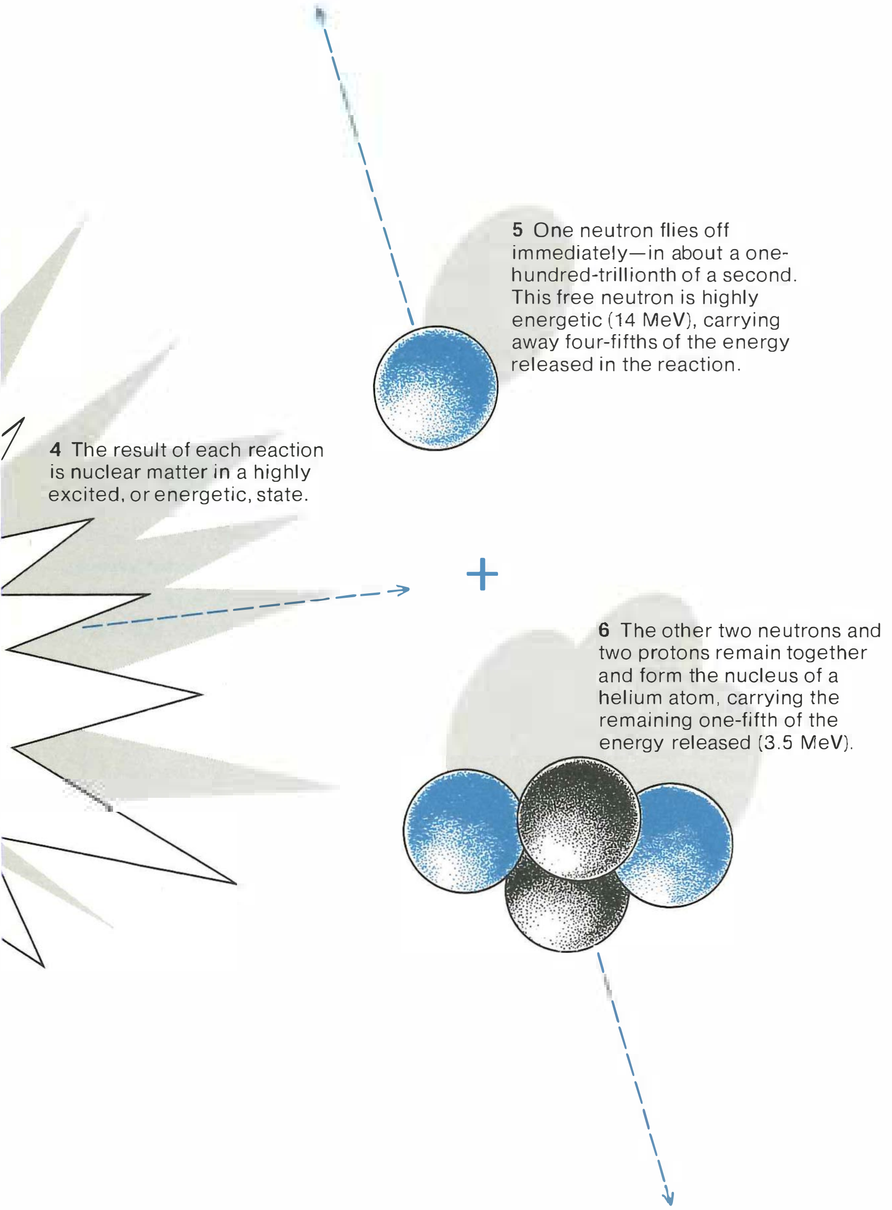
On the eve of that conference, the late Homi J. Bhabha, distinguished physicist and head of India's Atomic Energy Commission, was asked when, in his opinion, electric power from fusion would be available. "In about 20 years," he replied. Six years later, at the third Geneva conference, when the world's nuclear scientists again gathered to review progress, Bhabha was asked for a new estimate of the time when fusion power would be practical. Grinning broadly, Bhabha shot back, "In about 20 years."

Today, although the United States spent $325 million in FY77 on civilian fusion research, not even the most enthusiastic fusion power expert could give an estimate of less than 20 years in answer to the same question.



This is not to say that no progress has been made—far from it; nor that we will not achieve fusion power. What it does illustrate is the almost inconceivable difficulty of this research effort, which can be said to be far more difficult than landing men on the moon and bringing them safely home. The development of higher-thrust launch rockets, celestial navigation and guidance techniques, life-support systems, radio equipment to span the distance between Earth and moon, and all the other feats of technology that had to be meshed into one smoothly working system, difficult and unprecedented though they were, were only extrapolations of known engineering principles. But to create and maintain

trolled Fusion Power



a fire of 100 million degrees Celsius and use it to make electricity like a firebox under a boiler is another matter. It involves so many new scientific principles, which must be integrated into one maintainable system, that after 26 years of effort the demonstration of the scientific feasibility of generating power by fusion still lies before us.

Some insight into the relative difficulty of harnessing nuclear fission and nuclear fusion may be gained from the following chronology. It was only 6½ years after the first fission explosive device was detonated at Alamogordo, New Mexico (July 16, 1945), that generation of a token amount—100 watts—of electricity by fission power was first achieved at the experimental EBR-1 reactor (December 20, 1951). And it was but an additional 6 years until the pioneer Shippingport nuclear power plant first reached full power of 68 megawatts (December 23, 1957). Thus, the elapsed time to bring fission nuclear power to commercial reality was less than 13 years. By contrast, the first fusion explosive device was fired October 31, 1952; yet today, 25 years later, we are still (by common estimate) another 20 years away from seeing the first token electricity flow from a fusion reactor and at least an additional decade or more from the first utility fusion power plant. The director of the main federal fusion R&D effort recently defined the aim of the U.S. program as perfecting and introducing into commercial use safe, economic, and environmentally sound fusion reactors "sometime early in the next century."

The difference, the promise

What is fusion? How does it differ from fission? Why bother with it if it is so much more difficult to achieve?

Reduced to simplest terms, both nuclear fission and fusion depend on the paradoxical fact of nature that a vast release of energy accompanies both the fissioning (splitting) of the nuclei of the heaviest elements and the fusing (uniting) of the nuclei of the lightest elements. However, the difficulty of creating the conditions in which the two processes will work may be compared to channeling water to run downhill versus pushing it uphill. The nuclei of the heaviest elements are so large they tend to be unstable and to throw off particles. (This is the natural radioactivity discovered by Henri Becquerel and Marie Curie in the 1890s.) Among the lightest elements, there is no such naturally occurring radioactivity. Fusion is not the way materials want to behave on earth.

To make the fusion reaction work, we must begin with temperatures exceeding those of the sun. Then, once a reaction is under way, in fusion as in fission, energy is released in the form of heat generated by the unimaginably rapid motion of nuclear particles freed in the reaction. The problem, then, is to control these reactions, capture the heat, and make it do work.

One may well ask why so much money and effort are being expended, so much hope attached, to capturing this star, controlled fusion. Put most simply, it is because deuterium is so plentiful on earth. Deuterium from ordinary water can be isolated by simple processes with which we have decades of experience and whose cost would be a negligible factor in a fusion economy. ERDA (now DOE) has calculated that if fusion power were a reality, the total future world supply of deuterium fuel would last 64 billion (10^9) years at current world consumption rates.

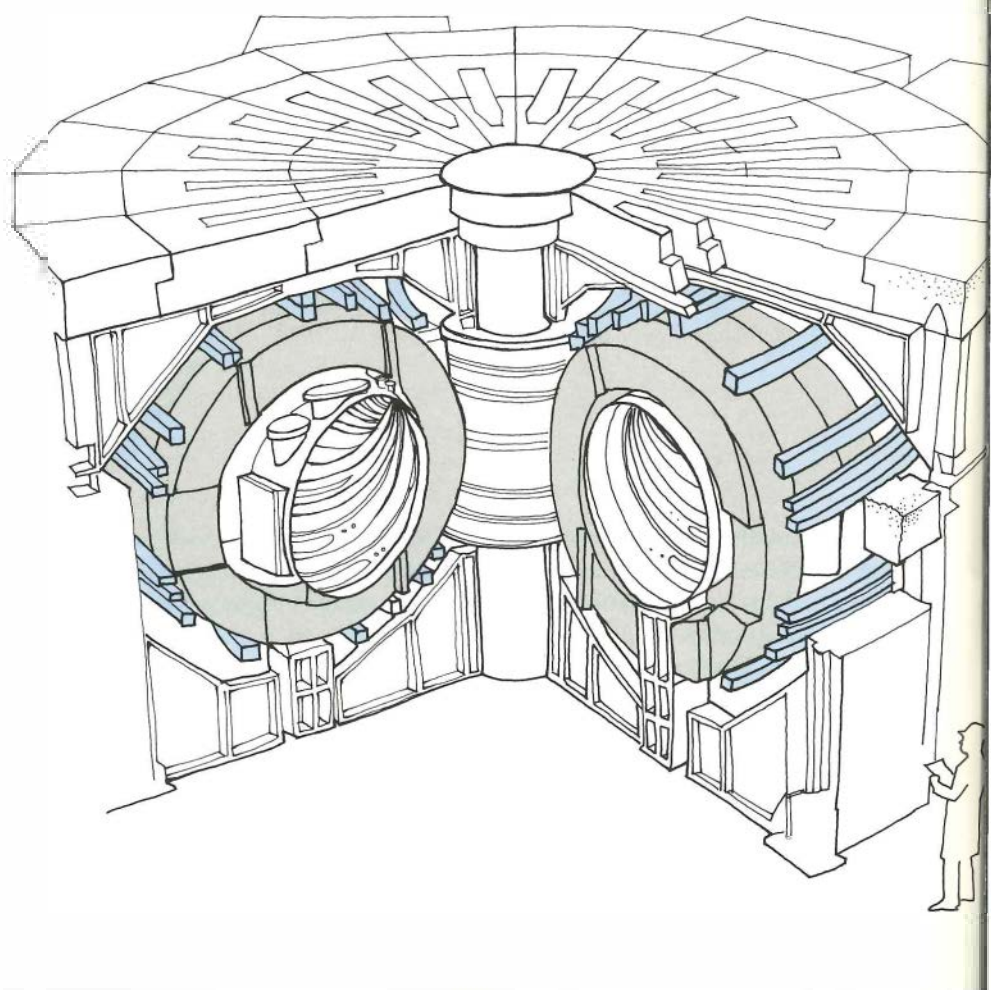
Moreover, the fail-safe nature of controlled fusion processes and their potentially slight environmental impact are further incentives for assigning a high priority to fusion research.

Requirements

To be able to fuse, nuclei of atoms must be heated to extremely high temperatures. The hotter they are the faster they move, and they must be made to move rapidly enough that the nuclei overcome their electrostatic repulsion and approach close enough to make fusions likely. In such an ionized state, the dissociated nuclei and electrons are called plasma. Plasma doesn't behave like a gas but has characteristics of its own (it has been called the fourth state of matter, beyond solid, liquid, or gas). Since the start of the civilian fusion power program, a tremendous amount of research has been concentrated on the properties of plasmas and a whole new science, plasma physics, has come of age.

For fusion reactions to take place in a controlled environment, the plasma must be held at certain minimum conditions of temperature, density, and confinement time. These have been established by the British physicist J. D. Lawson as being plasma confinement for at least one second at 100 million degrees Celsius and at a density of about 100–1000 trillion (10^{12}) particles (nuclei) per cubic centimeter—far less than the density of air, but high enough for a plasma. Under these conditions, a substantial number of nuclei in the plasma would collide and fuse, releasing clouds of neutrons and new helium nuclei—the fusion products—whirling around in the plasma at 10–20% the speed of light. Their energy of motion (heat) could then be extracted by loops of circulating lithium, helium, molten potassium, flibe (molten fluorine, lithium, beryllium salts), or other appropriate fluid passing through a "blanket" around the plasma chamber and heated by fusion reactions.

How to contain a plasma of 100 million degrees Celsius long enough so that by successive fusion reactions more energy can be released than the energy needed to create and heat the plasma is no simple task. Obviously, any material known to man will vaporize at 100 mil-



lion degrees Celsius. The best-known fusion reactor, our sun, uses gravity for plasma confinement—which we on earth clearly cannot. Magnetic fields were soon seen to be the best possibility when civilian fusion research began. (More recently, lasers have made possible an alternative to magnetic confinement: inertial confinement.) As all particles composing a plasma carry an electrostatic charge, their direction of motion can be influenced, or restrained, magnetically, like a magnet acting on iron filings.

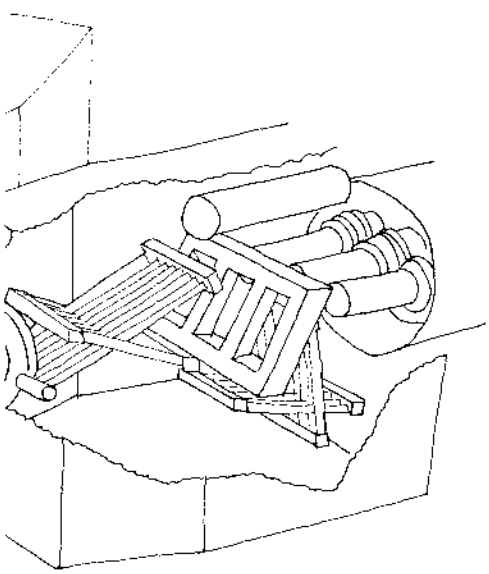
How do we fashion a magnetic bottle to contain this star? From the outset of the U.S. fusion power program in 1951, it was obvious that science had to go back to fundamentals in learning about plasmas. For if the hot plasma (the fuel) comes into physical contact with the walls of the vacuum chamber in which it is confined, it cools prematurely and quenches itself. Therefore the magnetic field—the nonmaterial furnace liner between the plasma and the chamber wall—must hold the plasma stable and confined. During the 1950s and 1960s, fusion researchers learned how to design magnetic fields to control the wriggly instabilities in a magnetically confined plasma. Many experimental devices of different configurations in ever-larger sizes were built in the United States and abroad in quest of stable plasma and threshold conditions for fusion.

Tokamaks, mirrors, and other concepts

In 1971, the fusion program leaders in AEC (later part of ERDA, now of DOE), seeking greater funding to expand the program, selected one promising device, the tokamak, as the object of stepped-up development and as the vehicle for attempting to show scientific feasibility. (To some, this means energy breakeven, or as much electric power produced as is required to operate the device; to others, it means net energy or a surplus of salable power; to still others, a controllable burn of fusion fuel.)

As a result, the most advanced device today for confining a plasma is the tokamak, which was developed in 1969 in the USSR. (*Tokamak* is a Russian acronym for current and magnetic chamber.) It is a torus (doughnut-shaped) chamber, not unlike earlier U.S. plasma devices—with strong magnets around the vacuum chamber to compress the plasma inside—but with the added feature that a strong electric current is induced in the plasma itself and combined with the external magnetic field to cause the total field to assume a helical (spiral) form. This has the advantage of heating the plasma with the electric current at the same time as the current is helping to stabilize the plasma.

Tokamaks now constitute the main thrust of the U.S. (and worldwide) magnetic confinement program. Second are magnetic mirror machines in which the plasma is made and confined in a straight rather than a toroidal vacuum chamber. To keep the plasma from hitting or escaping through the ends of the straight



Cross section of the TFTR (tokamak fusion test reactor), on which construction has just begun at Princeton Plasma Physics Laboratory, suggests its almost unbelievable complexity. The plasma is contained in the doughnut-shaped vacuum vessel (seen open in two cross-section cuts). It is confined centrally, away from the chamber walls, by the toroidal field coils (shown in gray). A second magnet system, the poloidal field system, is composed of three subsystems (shown in blue): ohmic heating coils to help heat the plasma, equilibrium field coils, and variable curvature coils to locate and stabilize the plasma. The main source of heat to the plasma are four neutral beam injectors, one of which is shown in the cross section at right.

tube, the magnetic bottle is crimped by increasing the magnetic field strength at both ends so that the plasma is reflected back in the other direction.

A major variant of the tokamak concept is the doublet machine conceived and being developed by General Atomic Co., with utility support. Here the toroidal plasma is magnetically constricted at the equator of a cross section through the plasma doughnut so that the cross section is kidney-shaped rather than circular. The purpose is to make more efficient and economic use of the magnetic field and thereby, eventually, to reduce the cost of the magnet system—one of the most expensive components of a fusion device.

Present state of research

International cooperation in fusion research has been superb and noteworthy. The USSR has been conducting a very aggressive fusion program, as have Britain and France.

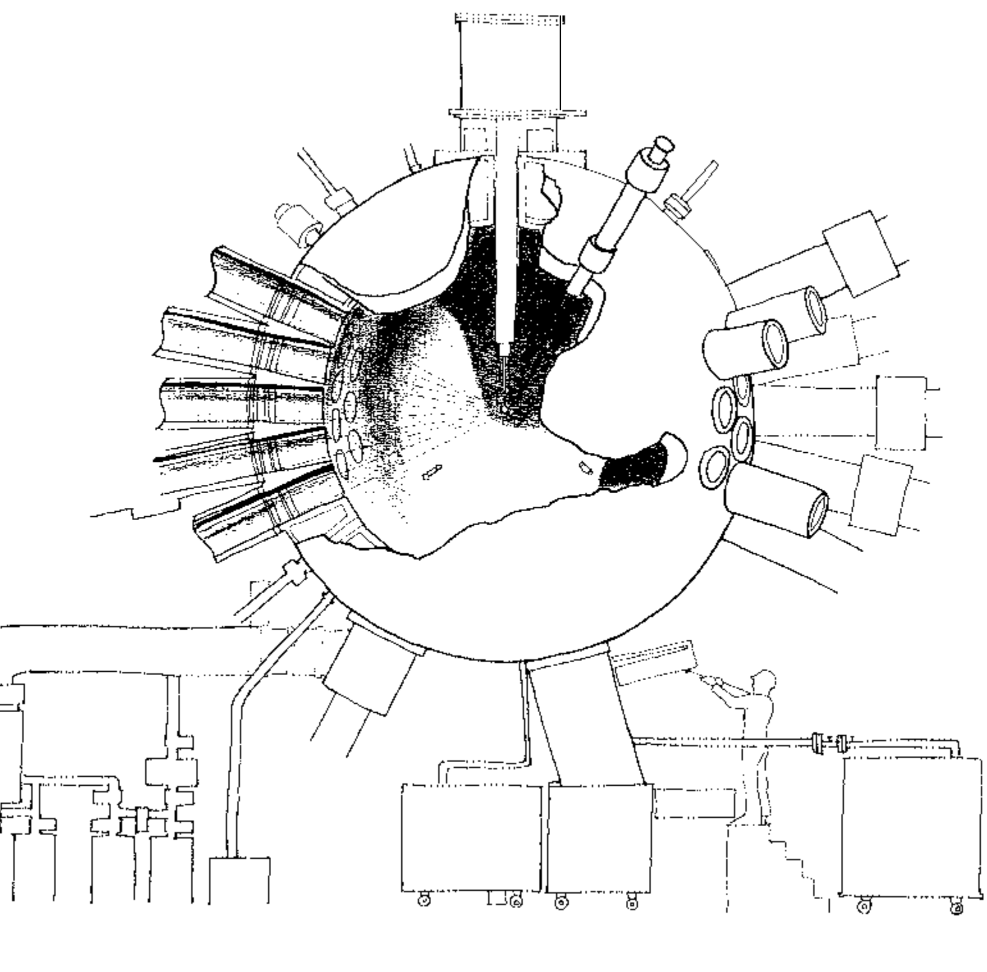
In the United States, tokamaks are currently in operation, as well as in the construction and planning stages, at Princeton University Plasma Physics Laboratory (PPPL), Oak Ridge National Laboratory (ORNL), and General Atomic Co. (GA). Mirror devices are being developed principally at Lawrence Livermore Laboratory (LLL) and ORNL.

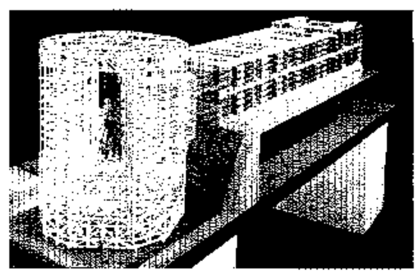
At PPPL, one of the two largest tokamaks in the world, the $14 million Princeton large torus (PLT), has been in operation for two years. PLT has demonstrated that plasma confinement time improves substantially as the thickness of the plasma doughnut is increased. The unit is providing a means for further study of various methods of heating a plasma: ohmic, radio frequency, and injection of high-energy deuterium atoms whose electrostatic charge is first neutralized (neutral-beam heating).

Another and larger device under construction at PPPL will be used to develop and test techniques for reducing the amount of impurities and foreign materials that get into the plasma from the chamber wall and cause energy loss. This is the $19 million poloidal divertor experiment (PDX) to be completed in 1978. Its aim is to show that plasma impurity levels can be reduced tenfold by modifying the magnetic field configuration.

Next at PPPL will come the far more powerful tokamak fusion test reactor (TFTR), the most exciting project currently under way in the fusion program. It will be the largest device yet built anywhere and the first in which fusion fuel will be burned, thus permitting physics and engineering studies to be conducted under actual fusion reactor conditions. It will have a vacuum chamber more than twice the size of PLT's. Construction is scheduled to start by the end of 1977 on this $228 million facility, which is slated to become operational in June 1981. TFTR may become the world's first fusion device to demonstrate energy breakeven, if not net energy. However, TFTR will be able to ascertain this milestone, if reached, only by instrumentation because it will not be equipped to generate electricity.

In the meantime, other devices are





The target chamber of a laser fusion power device (left) must be able to withstand microexplosions equivalent to about 20 kg of high explosive, which occur at frequent intervals. Tiny pellets of deuterium or deuterium-tritium are dropped into the chamber from the top with such precise timing that when centered in the chamber they are struck simultaneously by the light energy from 40 lines of high-powered lasers. The chamber walls are of a fiber-reinforced epoxy plastic.

A model of the Shiva laser fusion device now operating at Lawrence Livermore Laboratory (above) shows the vibration-free frame on which the laser lines are mounted. The target chamber is within the cylindrical frame, the lasers on the straight part. Like the TFTR, Shiva is a research tool and cannot generate power.

seeking to demonstrate the ability to burn fusion fuel under controlled conditions.

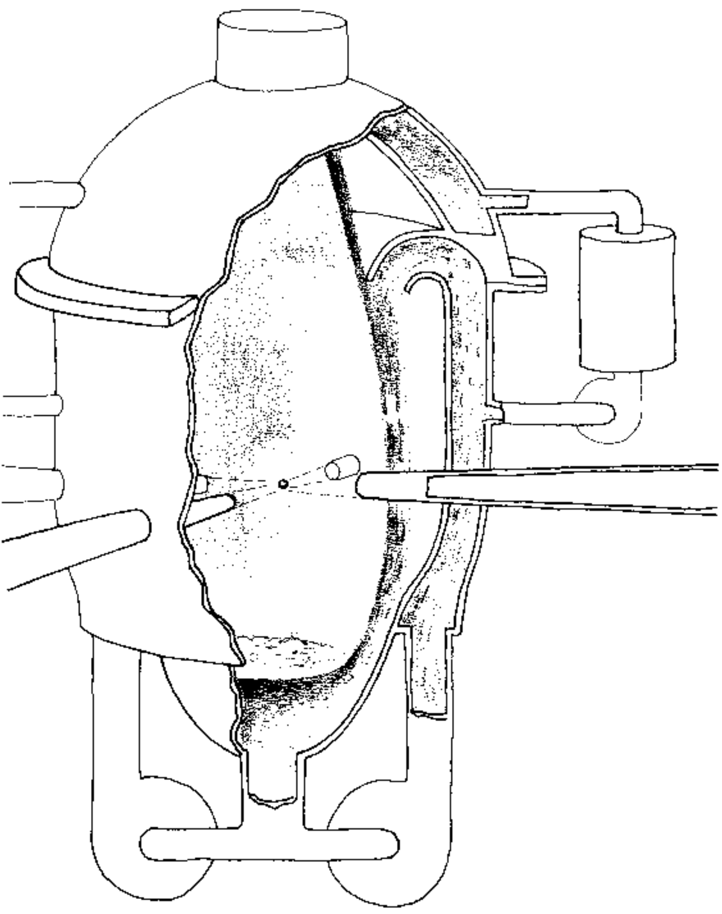
Once these goals are achieved, it will still be necessary to design a machine that can produce an economic surplus of power and can be built and operated at competitive cost. Early fusion reactors are expected to be driven systems, which means that external heating will be required during operation to maintain the plasma at thermonuclear temperatures. A surplus of net energy is possible with a driven system, but another scientific plateau beckons: attainment of conditions for ignition—when there are so many fusion reactions going on in the plasma that the heat the reactions produce is sufficient to maintain the plasma at the required temperature. The reaction thus becomes self-sustaining, and external heaters can be shut off while the fusion burn continues, saving input power and making for a more efficient machine. (Of course, power to the magnets that confine the plasma is still required.) Overall, achieving ignition conditions remains a formidable task because we have yet to show that we can control such a self-sustaining burn.

Fusion fuel

Aside from the multiplicity of confinement schemes, there are a dozen or more possible fusion reactions, as well as a half dozen possible fuels. Among the fuels, the only ones considered for first-generation fusion reactors are the two hydrogen isotopes: deuterium and tritium. Deuterium (heavy hydrogen) is twice the weight of ordinary hydrogen because its nucleus contains a neutron in addition to the single proton found in common hydrogen. On the other hand, tritium (double-heavy hydrogen) consists of a nucleus of two neutrons and one proton and is thrice the weight of common hydrogen. Fusion reactions involving the next heavier elements, helium, beryllium, lithium, and boron, are more difficult to sustain but promise improved performance in the future.

The easiest of these reactions to work with, relatively speaking, is the deuterium-tritium (D–T) reaction, in which a deuterium nucleus and a tritium nucleus fuse to form a helium atom, releasing a fast neutron and 17.6 megaelectronvolts of energy. Of this energy, 80% (14 megaelectronvolts) is carried out of the plasma by the fast neutron, and the rest remains to deposit enough energy within the plasma to maintain its temperature against radiation loss.

The deuterium-deuterium (D–D) reaction is more difficult but more desirable to work with than the D–T reaction for several reasons. Deuterium is abundant, whereas tritium does not exist in nature but must be bred from lithium. Moreover, unlike deuterium, tritium poses a potential biological hazard. However, the probability of a D–D reaction's occurring is less than that of a D–T reaction, and the energy released per fusion event is less. To attain energy breakeven with D–D fuel requires more demanding conditions of temperature, plasma core density, and energy confinement time.



A microballoon containing deuterium and tritium for use in Shiva experiments is shown magnified on the point of a needle.

One possible configuration of a power-generating laser fusion device, called the lithium waterfall reactor. Here a laser fusion target chamber like that of Shiva has molten lithium introduced at the top. It flows down the entire inner surface of the chamber, picking up the heat energy of the fusion reactions. The hot lithium is collected at the bottom, pumped through a heat exchanger, and then back into the top of the chamber. The heat exchanger would permit immediate commercial application, using the steam cycle and standard turbines.

Engineering problems

Early in the 1970s researchers began to make preliminary evaluations of the engineering, maintenance, safety, environmental, and cost aspects of a conceivable fusion power plant. Although it is much too early to do more than conjectural work of this nature, the emphasis has been steadily shifting from scientific research to engineering and technology. Much of this work is aimed at probing for generic defects in any of the various types of devices and at defining R&D needs for the support technology that each will require.

A number of subspecialties have emerged in the course of this effort, such as designing magnet systems for fusion reactors. Superconductive magnets are being developed for large-scale magnetic confinement fusion devices.

In the meantime, present fusion devices through the TFTR use conventional copper electromagnets, but even their size and field strength are among the largest ever attempted. PLT has eighteen 6-ton toroidal field coils with a field strength of 4.5 tesla (45,000 gauss), plus two other subsidiary electromagnet coil systems, requiring a cooling-water flow of 700 gallons a minute (0.044 m^3/s). The problems in designing the structural support for the weight of the coils, vacuum chamber, and machine frame (150 tons) fade beside the problem of designing the support and frame to withstand 54 million pounds of centering force (240 MN) from the toroidal field coils alone. This is in the PLT, which is less than half the size of the TFTR—and the TFTR is still only a research tool, not yet an operating fusion power plant. This points up the fact that the size and complexity of tokamaks are their greatest drawbacks.

TFTR's three magnet systems will contain almost 400 megagrams (323 tons) of copper, and require 8000 gallons a minute (0.505 m^3/s) cooling-water flow and about 950 megawatts input power during operation.

A magnetic confinement fusion power plant will also require a number of auxiliary systems unfamiliar to conventional power plants. In addition to the plasma heating, impurity control, tritium control, and magnet systems, these auxiliary systems will include a high-vacuum system to keep the plasma chamber evacuated, a cryogenic system to keep superconducting magnets at their operating temperature of −270°C, a continuous fuel injection system, and a large, complex power supply to the magnets and heaters. Moreover, design work on the reactor blanket will require some innovation. It will serve as the heat dump from which the energy of the fusion reaction can be extracted for useful purpose, and possibly also as the region where tritium fuel can be produced from lithium.

Another major problem is that of selecting a material to line the inside of the vacuum chamber nearest the plasma, which is called the first wall. The irradiation of the first wall by the plasma gives rise to materials problems of swelling, blistering, embrittlement, and other surface damage. The first wall may be expected to undergo fierce neutron bombardment, and various metals and alloys as well as graphites are under study for the first wall. While it is too early to be certain, it is possible that the first wall may have to be replaced as often as every 2–3 years if radiation-resistant materials cannot be developed. If the first wall does require periodic replacement, it would have to be snaked out of the plant by remote handling methods. As it could be several times more radioactive than a spent fuel bundle from a fission reactor and many times larger, it would also present a major disposal problem. Other ideas for designing around the problem have been put forward. One avenue being pursued is the possibility of bringing to earlier fruition more advanced fusion fuel cycles in which there is no large-scale production of energetic neutrons, thus avoiding or minimizing the problem of radioactive damage to the first wall.

In any event, if fusion reactors are to become conventional utility plants, ease of maintenance will be a major design requirement.

Safety and environmental aspects

It has frequently been stated that fusion is safer than fission because the process is self-limiting and because there is no radioactive waste to dispose of. This statement is only partially accurate. It is true that fusion reactors, unlike fission plants, leave no waste from the fuel used. However this overlooks the fact that there will probably be other highly radioactive, nonfuel wastes associated with the operation of fusion reactors, such as the worn-out first walls mentioned above.

Similarly, it is true that a fusion reaction cannot get out of control because if any of the systems maintaining power level should malfunction, the level would drop and the reaction would stop. But it is not inconceivable that the vacuum vessel might rupture, releasing the tritium in the system to the reactor building. Although tritium is considered a radioactive material of relatively low hazard because it emits only low-energy electrons (beta radiation) and its bodily retention time is brief, it is capable of diffusing through construction materials, including metals and alloys, ceramics, plastics, shaft seals, gaskets, piping, tubing, and containment walls. Therefore, not only a sudden release but also a steady, constant permeation during operation must be guarded against.

To make sure that tritium containment and cleanup technology is abreast of the need, a tritium systems test assembly is to be built to develop and demonstrate tritium control systems.

Also under way or planned are a number of research programs to examine the environmental and biological effects of other potentially hazardous materials that may be associated with fusion devices, such as lithium and beryllium. Another potential hazard receiving close attention is the possibility of liquid lithium spills or lithium fires.

A source of environmental concern totally new to power plant design is the biological implications of high magnetic fields, and assessments of these implications are being made. Additional studies must include effects on longevity, tumor incidence, behavior, various physiological systems, reproduction, and development.

Cost projections

In a real sense, asking today what the capital cost and generating cost of fusion power will be is like asking Wilbur and Orville Wright on their touchdown at Kitty Hawk what the passenger-mile cost of a 747 jet flight would be. On the other hand, there are enough data available to have permitted some serious and thorough cost studies.

One such detailed cost study, which is based on a conceptual design of a large tokamak power plant, points out some of the cruel trade-offs that must be made to make fusion power cost-competitive.

Because the useful energy of fusion must be gathered for extraction outside the reacting plasma region, the radioactivity shield must also serve as the heat collection region. This requires design of a thick complex blanket structure to serve as shield, heat collector, and in some devices, also as a tritium factory. The size and complexity of this blanket, which in turn controls the size and cost of the confining magnets, create a great incentive to reduce reactor size for any given power output. But directly counter to this is a minimum size limitation set by the requirement to remove the heat produced.

To illustrate the magnitude of projected costs, the study showed that if the blanket for a 1500-megawatt tokamak were made of type-316 stainless steel, 50,000 tons would be required. At today's prices, this amount would, by itself, exceed the total cost of a present-day fossil or fission power plant of equivalent output.

While the design used as the basis of this study is too early for more than taking a bearing, it is felt to represent a realistic case, arriving at numbers only slightly higher than those of another study. For the 1750-megawatt unit, assuming 35% average power conversion efficiency, the vendor estimated direct construction costs of $6.82 billion. Adding $1.77 billion for interest during construction, the total capital cost was $8.59 billion in 1977 dollars. This works out to $4910 per kilowatt; omitting operating and maintenance costs but assuming an 80% plant factor and 17% amortization, this is 11.9¢ per kilowatthour.

Amid this welter of problems and complexities, what is already clear to utility people is, as one put it, "What we don't need from fusion is . . . huge complicated nuclear plants that will probably cost $10 billion each and require restructuring the energy industry to provide and use them." Said another utility man, "Don't give us a white elephant."

Inertial confinement

As a result, a number of groups—EPRI among them—have been looking elsewhere than to the tokamak for the eventual utility fusion plant. A number of alternative magnetic confinement schemes are being probed, including variants of the mirror machine, such as the spherical mirror, field reversal mirror, and other devices with exotic names—linear theta pinch, elmo bumpy torus, multipole, electromagnetic cusp, Z pinch, and surface magnetic confinement. Each has its own difficulties and its own special promise.

Other researchers are following an entirely different avenue, an alternative to magnetic confinement. This is inertial confinement, popularly called laser fusion. This concept, on which work began in 1962, is being pursued at LLL, LASL, Sandia Laboratories, and KMS Fusion, Inc. It involves compressing and heating a tiny pellet of fusion fuel within an extremely short time, typically much less than a billionth (10^{-9}) of a second.

Thus the deuterium and tritium in the pellet are compressed and heated to thermonuclear temperature so rapidly that fusion reactions take place. The glass pellets, called microballoons, which are so small that it takes 500 to equal the volume of one grain of rice, are now commercially available.

Precisely focused and convergent beams of light from high-power lasers are used in experiments to attain fusion reactions. In this approach plasma instabilities, though different in nature from those in magnetic confinement, must still be overcome. And although inertial confinement holds promise of avoiding the high cost of magnet coil systems, it brings with it the cost of very sophisticated and powerful lasers. Fueling and heat extraction in a laser fusion device are still open questions.

EPRI's role

Where does EPRI fit in, and what is EPRI doing in what is inherently a high-budget pursuit? (Altogether, nearly $1.5 billion has been spent to date by the federal government.)

Thus far, EPRI has completed 7 fusion studies and has 22 projects under way. Their subjects include assessment of the status of both magnetic and laser fusion; evaluation of plasma heating methods, first wall and other materials, fusion instrumentation, and advanced fuel concepts; cost-benefit studies; feasibility studies; and simulation experiments—to cite a representative few.

Overall, EPRI sees its role as being able to look further ahead than the fusion laboratories concerned with demonstrating scientific feasibility; that is, to try to identify what features an eventual fusion power plant must have to respond best to the needs of the utilities, and above all, to make sure that no promising avenues are closed prematurely because of early commitment to one type of device. EPRI is concerned that the field of fusion reactor concepts not be narrowed too soon, that alternative fuel cycles be kept alive, that someone work backward from the commercial fusion power plant so that R&D decisions may be channeled in the direction of what is most practical, what is most needed.

Industry Leaders Briefed at EPRI Fusion Seminar

Research leaders from many fields get a crash course in the state of the art of fusion power to satisfy the need for communication among utilities, government, laboratories, and universities.

Cosponsored by EPRI and DOE, the first Executive Seminar on Fusion attracted about 90 participants to San Francisco in mid-October. They included representatives of utilities, manufacturers, architect-engineers, universities, consultants, and federal energy agencies. In two days of briefings and a half-day tour of Lawrence Livermore Laboratories' (LLL) fusion power facilities, the participants received a crash course in the basics of fusion processes, science, and technology, as well as an updating on the present status of the numerous federal and private programs seeking to harness the power of fusion energy.

Cohosted by Pacific Gas and Electric Co. and LLL, the first-of-its-kind meeting was arranged to satisfy the need for communication and feedback among utilities, government, and the scientific community about fusion R&D, the state of the art, and the directions the national program appears to be taking.

In addition to reports of significant progress in all major areas of peaceful fusion work, research was described on the possibility of bypassing the steam cycle, which is already being done at LLL. More than any other energy source, fusion appears to be suited to direct conversion to electricity, thus eliminating steam generators and turbines. This is not likely to be developed for the first generation of fusion power plants, but its promise enhances the already great potential of fusion. That potential was well described by Dr. Richard F. Post, deputy associate director of LLL, in the following analogy: If a 45-cm (18-in) water main, at ordinary municipal water-supply pressure, fed a heavy water separation plant continuously, the trickle of product heavy water from that plant would contain enough heavy hydrogen to supply the present energy needs of the entire world.

The role of utilities in the coming stages of fusion research and development was a recurring theme of the seminar. A number of speakers expressed a view that was well summed up by Dr. John P. Holdren of the University of California at Berkeley when he said, "Rushing commercialization may promote the wrong choices. Here is where you [utility leaders] as users can exert your influence.

"It would be nice," he continued, "to avoid stainless steel structures, liquid lithium coolant, machines that have to be big, weapons-relevant inertial confinement schemes, and hybrid fusion-fission systems based on the plutonium cycle."

Preparing for the opening session in San Francisco of the first EPRI Executive Seminar on Fusion are (from left): Harold W. Sonn, senior vice president, Public Service Electric & Gas Co.; Nolan H. Daines, vice president, planning and research, Pacific Gas and Electric Co.; and Richard E. Balzhiser, division director responsible for EPRI's Fusion Program.

A panel of four utility officials discussed the role of utilities at the concluding session of the seminar. They were Robert A. Bell, director of research, Consolidated Edison Co. of New York, Inc.; Harold W. Sonn, senior vice president, Public Service Electric & Gas Co.; Carl M. Podeweltz, research manager, Tennessee Valley Authority; and W. B. Bechanan, vice president, Kentucky Utilities Co.

The consensus of the session was that the appropriate contribution of utilities at this stage of fusion development is not direct financial support but rather information on utility requirements, training and preparation for this new energy source, and strong support to sustain the required long development effort. "Our role," commented a utility man in the audience, "is to interpret, educate, and communicate in the political arena and to the man in the street what is coming." The assignment of utility engineers to fusion laboratories for training was seen as desirable. The suggestion of a reverse flow of laboratory personnel going to work in utilities to get utility experience was hailed by a member of the panel as "a superb idea."

Holdren declared, "Fusion is absolutely essential to the future well-being of mankind. Therefore an aggressive, vigorous program is essential—but it's not the only game in town."

"Don't overplan or try to design too closely at this stage," urged Con Ed's Bell. "The major utility role is to demonstrate new technology as the last step before commercialization. But don't oversell fusion—we have to worry about the total energy program. The consequences might be support for only a short term."

Official Start of BEST Facility

Shovels and speeches signal the first site work on the utility industry's national center for testing one-tenth-capacity scaled prototypes of load-leveling storage batteries.

Among all the possible storage options, batteries stand out by offering potential for several particularly attractive features, among them closeness to the loads served, excellent electrical response, and rapid first installation and capacity increase.

EPRI's Fritz Kalhammer reminded his audience of these motivations for utility load-leveling batteries as ground was broken on October 6 for a national center that will test prototype modules of new storage batteries when they become ready early in 1980.

The director of EPRI's Energy Management and Utilization Technology Department was one of six speakers at the site of the Battery Energy Storage Test (BEST) Facility in central New Jersey, midway between New York and Philadelphia.

Host for the BEST project is New Jersey's Public Service Electric & Gas Co. The utility is building the facility at a cost of nearly $2 million on 7 acres of its Sunnymeade Road Substation site in Hillsborough Township, 13 miles north of Princeton. EPRI and the U.S. Department of Energy (DOE) are sharing equally the remaining project cost—perhaps $9 million—for the battery testing systems and their instrumentation.

Kalhammer underlined the significance of beginning construction of the BEST Facility, calling it a commitment and saying, "It reflects substantial confidence on the part of the major funding agencies and battery developers that several new battery types capable of meeting future utility requirements will become available within 10 years."

The BEST Facility will accommodate multicell battery banks up to nearly 2-MW capacity—about one-tenth the size of eventual commercial designs for utility service, which will last for thousands of charge-discharge cycles over their 10–20-year lifetimes. The most nearly comparable batteries today are the 1.5-MW uninterruptible power supply units in telephone and computer systems, but they cannot be cycled continuously.

Success with load-leveling batteries will permit electric power produced by large, efficient nuclear or coal-fired plants to be stored during periods of low demand and released at times of peak requirements. For electric utilities, this would mean reduced reliance on generating units that require increasingly scarce and costly oil.

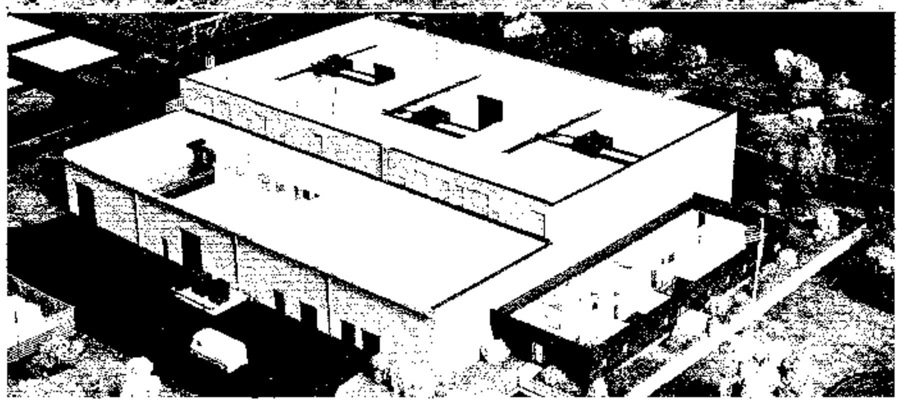
In addition, battery installations at decentralized points (substations, for example) will increase system reliability and defer the need for new transmission and subtransmission facilities. Finally, batteries offer environmental advantages: they're clean, quiet, and nonpolluting.

At the BEST Facility groundbreaking, Kalhammer cautioned that battery development still involves risk and uncertainty as to technical success, cost, and utility acceptance. The new test facility and its initial 10-year program of tests should serve as a focal point for evaluating and resolving these points, Kalhammer said.

EPRI is managing a substantial R&D program aimed at increasing the options for energy storage by electric utilities. An EPRI-funded study completed last year indicated that storage installations could eventually provide up to 5% of U.S. electricity consumption and up to 17% of utility generating capacity (if sufficient nuclear and coal baseload capacity is available to charge the storage facilities). The study concluded that underground pumped-hydro, compressed-air, and thermal storage are most likely to become feasible first. Batteries look attractive after 1985, if present trends continue.

PSE&G Research Corp., a new subsidiary of the New Jersey electric utility, holds the contract for design, construction, and acceptance testing of the BEST Facility. Arrangements have not yet been made for facility management and operation during battery tests.

Cooperative auspices of the utility industry's new storage battery test center are symbolized by the officials participating in the October 1977 groundbreaking: Harold Sonn, president of PSE&G Research Corp.; Patricia McKiernan, mayor of New Jersey's Hillsborough Township; Joel Jacobson, New Jersey state energy commissioner; Robert Smith, Public Service Electric & Gas Co. board chairman; Eric Willis of DOE; and Fritz Kalhammer of EPRI.



Three battery test bays (with overhead cranes) dominate the 29,000-sq-ft BEST Facility. A single converter area is at far left of the lower section, and the adjacent space is divided for a computer, a control center, shops, and utilities. Management offices and conference rooms for battery test participants are in the contiguous building at right.

William Nierenberg: Blockbuster

A respected scientist is bent on breaking through the institutional blocks that prevent application of some available energy solutions.
□ An EPRI interview

Those who know William Nierenberg say he's brilliant. His mind rushes and he speaks in a tumble of words, racing to transmit a chain reaction of ideas. A physicist-turned-environmentalist, Nierenberg was a member of the fateful Manhattan Project team that ushered in the atomic age in the mid-1940s. More recently, he spearheaded a citizens' group that got city and state sanction for a marine preserve that extends some six miles along the San Diego-La Jolla coastline in California.

Nierenberg was named director of the world-renowned Scripps Institution of Oceanography in 1965 after 15 years as a physics professor at the University of California at Berkeley. Known chiefly for his work in low-energy physics while at Berkeley and at the university's Lawrence Livermore Laboratory, he has since gained recognition as a leading expert in oceanographic research. Nierenberg holds a professorship in physics and is vice chancellor of marine sciences at the university in addition to heading Scripps. And among the numerous government, civic, professional, and educational committees and boards he serves on, here and abroad—including the White House Office of Science and Technology Policy—is EPRI's Advisory Council. This year he became chairman of the Council's committee on power sources and uses.

Nierenberg took time out recently from his crowded schedule for a JOURNAL interview. The setting was his knotty-pine-paneled office at Scripps with sliding glass doors opening on the beach and gently rolling surf. In his characteristically forceful manner, Nierenberg talked about the need to break through social and institutional blocks to achieve acceptance of available technical solutions to energy problems, about methanol as a desirable substitute for fossil fuels, the need for a balanced approach to environmental concerns, and the effectiveness of EPRI's Advisory Council.

Nierenberg is impatient with what he sees as the "social and institutional blocks" that stand in the way of using available technical solutions to many of our energy problems. About two years ago, after reading an article on methanol in *Science* that got him "thinking and working" on it, Nierenberg decided that "methanol was the best wedge I could find to try to penetrate this institutional blockage and help break it apart." He adds, "I think it's really working." He points out that a committee chaired by Commissioner Alan Pasternak of the California Energy Resources Conservation and Development Commission held hearings earlier this year in connection with the feasibility of using methanol in a proposed combined-cycle plant of Pacific Gas and Electric Co. in the San Francisco Bay Area. The Commission's ruling on whether or not to require PG&E to burn methanol instead of distillate oil in the plant is expected by the year's end.

EPRI has about a half-dozen research

projects under way on various aspects of the production and use of methanol as a power plant fuel. Nierenberg, however, takes no credit for influencing EPRI's entry into methanol research.

Nierenberg notes that methanol (wood alcohol) has been used widely in Europe for years. He recalls as a student in Paris in the late 1930s the "sweet-smelling exhaust from the Parisian buses fueled by methanol." And he reminds us that a large number of the German combat machines in World War II were powered by methanol. Several experiments are being conducted in the United States on using pure methanol or a methanol-gasoline blend as a fuel for automobiles and other vehicles.

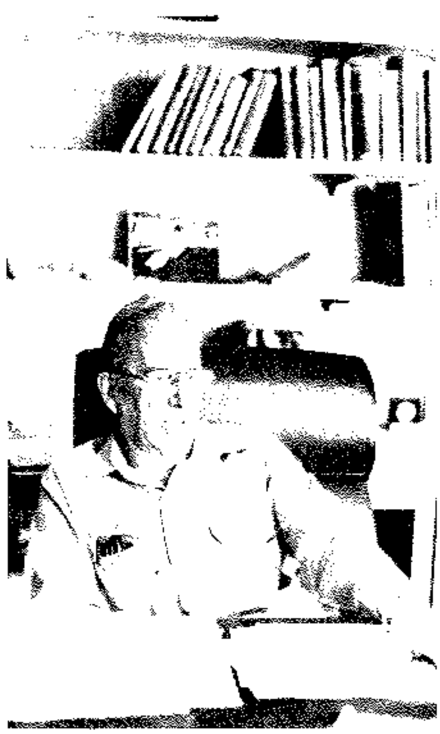
Wanting further documented evidence to bolster his advocacy of methanol, Nierenberg raised $25,000 to fund a study of the fuel under the auspices of the Foundation for Ocean Research, of which he was president. The results of the study by William Barr and Frank Parker of the American Energy Research Co. in McLean, Virginia, were published last year: *The Introduction of Methanol as a New Fuel into the United States Economy.*

In the foreword to the report, Nierenberg states: "The hard fact seems to be that the problems of introduction of new energy sources on a large scale are more formidable than the technological problems. Therefore, commitment to an energy solution that requires large investment in research and development before facing the problems of introduction is, in effect, a delaying action."

He goes on to say: "We must seek a fuel based on known domestic sources and on an existing acceptable level of technology. If R&D then can benefit efficiency of production and cost, it can proceed in parallel with solving the problem of introduction. Complete national dependence on new continuing R&D has no more place in a completely rational national energy program than does continued reliance on a diminishing, finite, world petroleum resource."

Nierenberg itemizes methanol's attributes. It's not a new fuel, having been produced since the turn of the century. So the technology is in hand. It burns cleaner than gasoline or distillates, leaves virtually no deposits, and increases the power and improves the mileage of automobiles. It has handling, storage, and distribution properties equal or superior to those of gasoline. Its drawbacks as a vehicle fuel—lower energy content than gasoline, lack of lubricity, relatively high vapor pressure when mixed with gasoline, tendency to phase-separation at lower temperatures, and cold-start problems—are "amenable to straightforward engineering and/or chemical solutions," Nierenberg's methanol report contends.

"Methanol was the best wedge I could find to try to penetrate this institutional blockage and help break it apart."



Methanol's use to utilities is seen as a clean-burning substitute for low-sulfur oil to fire gas turbines that handle peak and intermediate power loads. In the past, utilities have not warmed to methanol because it is higher priced than fuels now being used and its supply is limited. Nierenberg dismisses the higher-price–unreliable-supply objections as "extremely bad engineering," pointing out that "the cost of materials produced drops quite rapidly with the amount produced." He adds, "The scale factor is very important. If we operate on the same scale that we're operating atomic energy, coal, and oil today, then the cost of methanol is comparable."

Estimating methanol production costs is a slippery exercise at best, with figures ranging from $2 to $7 per million Btu. Factors accounting for the cost differences include the feedstock and process selected, construction costs, plant siting, and financing methods. Nierenberg maintains that methanol can be produced for about $2 per million Btu. EPRI's studies indicate the cost would be closer to $7. And everyone making such estimates questions the other person's figures.

Nierenberg proposes that at first methanol be made from coal, then various biomass materials, such as forest and agricultural products, wastes, and residues, be gradually phased in as the feedstock source. Production would be in regional processing plants and the methanol shipped to the markets in each region. In this way, he explains, control of emissions that result from converting coal into methanol would be the responsibility of the processing plants. As it is now, he notes, each power plant that burns coal has that responsibility, which would be eliminated with the switch to methanol.

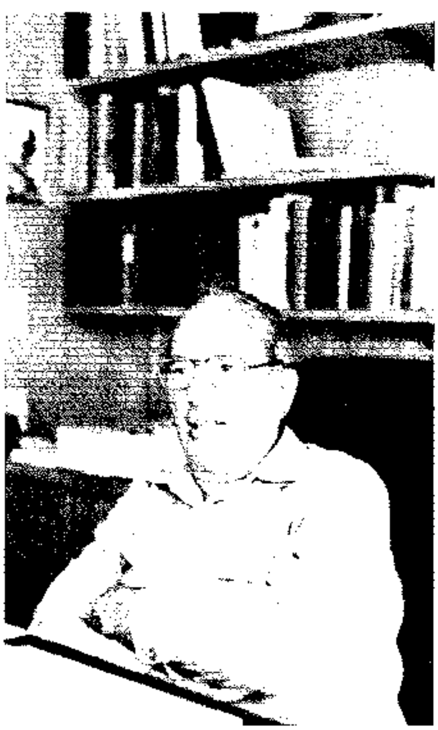
Nierenberg has an interesting notion for combating the carbon dioxide (greenhouse effect) problem by using pine and eucalyptus trees as a source for methanol. "Pine trees can now be cut after about six years and eucalyptus regenerate in about four," he says. "We are now getting tremendous rates of wood production that is ideally suited for methanol." With the present controls on the cutting of timber, Nierenberg notes, the amount of forest remains fairly stable. And should clean-burning methanol gradually replace much of the fossil fuels now being used, the photosynthesis process of the forests would tend to keep the lower-level carbon dioxide at a somewhat constant rate, he explains.

Nierenberg makes clear that he doesn't view methanol as the energy fuel panacea. "The solution eventually is going to be typical of most of our solutions," he says, "a mixture of a lot of things." He sees methanol as an important element in a mix of fuels that would include coal, nuclear, solar, and other renewable forms of energy.

Solar energy is taken in its broadest sense by Nierenberg. "The sun makes the winds and the winds make the waves," he points out. "So the winds and the waves are solar energy, too." Motioning at the waves washing ashore outside his office, Nierenberg observes, "There is a great deal of energy stored in waves." And he notes that energy can be extracted from the 15°C temperature difference in the upper layers of the ocean—what's known as ocean-thermal energy conversion. Nierenberg recognizes, however, that these forms of energy are "rather far down the line."

As one of the environmentalists on EPRI's Advisory Council, Nierenberg calls for a balanced approach. "The environment is a much more complicated affair than even the most ardent environmentalists realize," he says. He notes that while he was instrumental in getting legislation enacted to protect California's coastal zone, "I lobbied like hell against the nuclear moratorium initiative in the state last year." He does not want to see the nuclear option foreclosed, and among his colleagues, he says, "I find the more sophisticated the scientists are about the environment, the more they are into this balanced approach. They've seen too much damage done in the name of the environment."

"If we operate on the same scale that we're operating atomic energy, coal, and oil today, then the cost of methanol is comparable."



Nierenberg feels that the Advisory Council "is more effective than I would have expected." He views the members as "quite sophisticated," part of whose function is to serve as "an elite sounding board against which EPRI can try out its ideas." Conversely, the Council functions as "a connecting link to the outside world, helping explain what EPRI is doing."

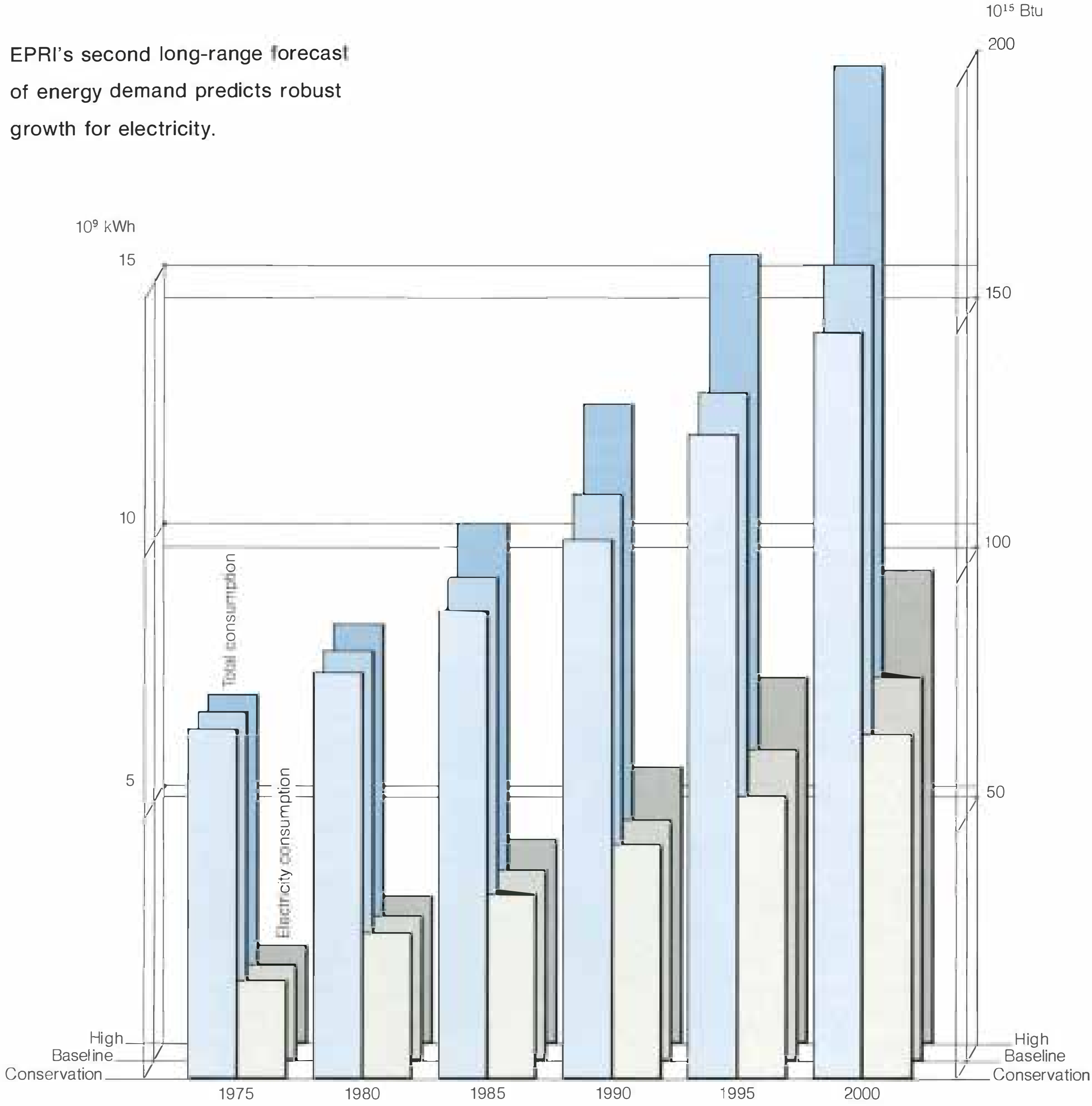
He considers the environmentalists on the Council "a pretty well-balanced group," and he senses that "they have been sobered by their practical discussions with EPRI staff members." Council members "are getting to know one another better, what their talents, limits, strengths are, and are working more effectively now," Nierenberg says. And as chairman of the Council's committee on power sources and uses, "I expect to work much harder on that," he adds.

In his role as environmentalist, Nierenberg is especially proud of an accomplishment within a sand-dollar's throw of his office. Walking over to the sliding glass doors, he points to the La Jolla marina and explains, "That's a look, no-touch preserve now. The marine life there is coming back like mad—abalone, fish, all the rest." The marina is only part of a six-mile marine park stretching along the San Diego coast that through the efforts of a citizens' group led by Nierenberg is now preserved under city and state jurisdiction. "It's working like a charm," he smiles. "We're very proud of it."

Demand 77

by Robert T. Crow

EPRI's second long-range forecast of energy demand predicts robust growth for electricity.



Demand 77 forecasts substantial growth in electricity for all three scenarios. In each scenario, the rate of electricity growth is higher than that of total energy. Electricity's share of total energy also will continue to grow, but at a declining rate.

Energy consumption in general—and electricity use in particular—appear likely to regain and maintain a rather robust growth rate. This is one conclusion that emerges from *Demand 77: The EPRI Energy Consumption Model and Forecasts,* a two-volume report that will be published shortly.

It thus appears unlikely that President Carter's energy proposals, even if all are enacted, will limit the annual increase in energy consumption to the desired 2%. However, it does appear that the same policy proposals may be successful in shifting fuel consumption from petroleum to coal, thereby reducing oil imports from the level they would otherwise reach.

These and other findings were developed from forecasts that cover each sector of the U.S. economy. *Demand 77* is EPRI's second work of its type. The first was *A Preliminary Forecast of Energy Consumption Through 1985* (EPRI SR-37), published in March 1976. In both reports, the forecasts are conditional on a number of alternative assumptions concerning national economic growth, energy prices, other prices, and energy policy.

The forecasts also encompass forms of energy other than electricity, so that account may be taken of the larger picture of which electricity is a part. Although the forecasts proceed through time in one-year increments, their primary focus is on the period from 1985 to 2000.

The long-run nature of the forecasts is particularly important to EPRI's internal R&D planning, given the long lead times between research and commercial operation and the long useful lives typically associated with electrical equipment. In addition to EPRI's internal use, the forecasts also augment the general state of knowledge of possible U.S. energy growth.

Demand 77 forecasting model

The forecasts in *Demand 77* are based on an econometric model of energy consumption behavior. They consist of a series of equations relating the energy consumption of various classes of users to those variables expected to have a major influence on consumption. It is important to note that this approach emphasizes how people actually *do* use energy rather than how they *could* or *should* use it.

One critical assumption behind such an approach is that the primary motivating factors are measurable variables, such as income, prices, and weather. It does not make allowance for such nonprice factors as an energy conservation ethic or other intangible changes in values or tastes. So far, this assumption is consistent with postembargo consumption experience. Whether it will remain so is unclear. A related but somewhat different assumption is that the response of energy users to these measurable variables does not change markedly over time. In other words, changes in the explanatory variables themselves, rather than changes in the way people react to them, cause changes in the consumption of energy.

Demand 77 illustrates the eclectic approach to forecasting adopted in the Demand and Conservation Program. We selected what appeared to be the best methods from EPRI-sponsored research and other research. Each equation in the forecasting model is treated as a module that may be replaced by a superior equation when it becomes available. Thus, *Demand 77* retains several features of last year's forecasts, while incorporating major innovations in most of the forecasting model structure.

An important goal is to increase the model's ability to assess the implications of a variety of potential changes, such as drastically different public policies, technological breakthroughs, a renewed oil embargo, and other examples of serendipity or catastrophe. This implies that the forecasts must become more detailed.

Residential sector

In modeling residential electricity consumption, we relied on the work done in RP431 (*1*). In this model, residential kilowatthour sales are related to personal income, electric utility rates, natural gas prices, population, and climate variables. Its major innovation is its treatment of the declining-block structure of electricity rates, permitting a more precise estimate of the responsiveness of consumption to the way electricity is actually priced and also providing a means to assess the impact of different rate structures on kilowatthour sales.

The residential model also takes into account the fact that electricity consumption does not adjust instantaneously to changes in income and prices. The fact that people have ingrained consumption habits and have acquired houses and appliances that were more suitable for a former income and price situation implies that adjustments to new circumstances take place only gradually. It is unlikely, for example, that "inefficient" refrigerators will be replaced by "efficient" ones until the former have ended their useful life.

Commercial sector

There has been little work done on the commercial sector. Perhaps the best work on electricity to date is that by Timothy Mount, Duane Chapman, and Timothy Tyrrell, of Oak Ridge National Laboratory, which was reestimated and evaluated along with other state-of-the-art electricity consumption models in RP333 (*2*). Like the residential model, it consists of a single equation relating kilowatthour sales of the price of electricity, the price of natural gas, personal income per capita, and population. Another similarity to the residential model is that it takes account of the time lags in adjustment of consumption to changes in explanatory variables. There is much work to be done in the commercial sector, perhaps the least explored of all of the energy consumption sectors. We expect that the results of a study on analysis of demand for energy in the commercial sector (RP662) will be a major improvement and will be ready for incorporation into *Demand 78.*

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Demand 77 has combined the residential and commercial sectors in dealing with petroleum and natural gas. Our forecasts are taken from FEA's *National Energy Outlook, 1976.* Although the model used in that document was not directly linked with our own, care was taken to ensure that its forecasts were compatible with the remainder of *Demand 77.*

It is important for the electric utility industry to have a good understanding of these markets, since shortfalls of natural gas availability and increased prices of both may have important implications for shifts to electricity. Also, of course, the consumption of these fuels by end users is a major determinant of how available they will be to the electric utility industry.

Industrial sector

Industrial energy use is treated as a derived demand for factors of production. The manufacturing sector is disaggregated into nine industries modeled separately. The industrial model proceeds on a two-step basis. The first step is separate forecasting equations for electricity and fossil fuels, derived from a formal representation of cost-minimizing behavior for a given level of output (*3*). The second step is a split of the fossil fuel total among natural gas, petroleum, and coal. Both electricity and fossil fuels are taken as functions of the level of output and the relative prices of all factors of production: electricity, fossil fuels, capital, labor, and materials. The fossil fuel split model estimates relative shares as a function of relative prices.

Transportation sector

The demand for gasoline uses a model developed by James Sweeney for FEA (*4*). It takes account of total vehicle miles traveled, average miles per gallon in the fleet of all gasoline-powered vehicles, and differences in mileage for vehicles of different vintages. The model also takes account of the retirements of vehicles over time and forecasts miles per gallon of new cars as a function of the price of gasoline and legislated efficiency standards. Other transportation energy consumption is carried over more or less intact from EPRI's 1976 forecasting effort.

Demand 77 forecasts

The *Demand 77* model forecasts have in common the same forecasts of economic growth and nonenergy variables from the Wharton Econometric Forecasting Associates' annual model. Also, all energy prices are based on forecasts of EPRI's Supply Program. In addition, the Supply Program furnished estimates of natural gas availability at the forecast price levels. Our assumptions concerning natural gas curtailment are that electric utility use will be phased out by 2000 and that when the demand for natural gas exceeds supply, 10% of the shortfall will be allocated to the residential and commercial sector and 90% to the industrial sector. It is assumed that 65% of the shortfall in each of the sectors will be taken up by petroleum, 15% by coal, and 20% by electricity. It is assumed that one Btu of electricity at the point of final consumption substitutes for two Btu of natural gas.

The baseline scenario used the Supply Program's energy prices without modification. The high energy consumption scenario modifies prices to make them similar to the high electrification, $8 per barrel oil case of FEA's *National Energy Outlook, 1976.* This scenario approaches the upper bound of plausibility. The energy conservation scenario is based primarily on the objectives and policy enunciated in President Carter's energy message. Although most observers of energy analysis and policy would not regard this as being as much an "outside" representation of conservation as the high electricity consumption scenario is of high consumption, it is of interest to real decisions now being made. Account has been taken of different prices and a number of legislative standards that do not have their impact through the pricing mechanism.

Baseline results

As the figure shows, at the most general level, total energy growth is forecast to lie between 3.2% and 3.5% annually for each of the five-year periods, slightly less than the 3.6% rate of the 20 years before the 1973 oil embargo. This leads to total energy consumption of 159×10^{15} Btu by the year 2000. In the case of electricity, growth is postulated to be fairly robust during the next five years, gradually falling off to a rate of less than 5% per year in the 1990s. Although the growth rates are much lower for fuel (from 1.6% to 2.4%), it is interesting and somewhat disconcerting to note that the rate accelerates in the future and that the most rapid growth (from 29×10^{15} to 54×10^{15} Btu in the 1975–2000 period) is in the consumption of petroleum, which pulls the growth rate for total energy up between 1990 and 2000 compared with the 1975–1990 period.

In examining this case by sector, it appears that the most vigorous growth for fossil fuel consumption is in the industrial sector, in spite of the curtailment of natural gas. Electricity growth is forecast to be especially robust in the residential-commercial sector.

High consumption results

In the high electricity consumption case, the growth rate in total energy consumption is never less than 4% per year for any period after 1975–1980. The total energy consumption of 196×10^{15} Btu is definitely in the high range of energy consumption forecasts. Electricity consumption under this scenario repeats the pattern of a high growth rate in the initial years and a gradually declining rate throughout the period. Unlike the baseline case, however, the projected annual growth rate of electricity consumption is almost 6% well into the 1990s. The general pattern of growth in fuel also follows the baseline case. Most of the growth to 2000, of course, is accounted for by petroleum, since natural gas is restricted to grow only by about 27% over this period, whereas petroleum is forecast to be approximately $2\frac{1}{2}$ times its 1975 consumption. As in the baseline case, the direct consumption of coal grows relatively slowly.

Conservation results

The implications of this energy conservation scenario are to drop the rate of growth of total energy consumption to approximately 3% annually between now and the year 2000. The underlying patterns of this scenario are familiar: relatively high rates of electricity growth from 1975 to 1980 (which would be little affected by the conservation policy in any case), dropping through the remainder of the period to something over 4% in the 1990s. Fuels also show the familiar path of relatively low rates of growth in the first part of the period and increasing growth rates in the latter part, but in no case do they approach the rate of growth of electricity. A major difference, however, between the energy conservation case and the other cases is that coal consumption is roughly 4.5 times its 1975 level by the year 2000, whereas in the baseline case, the level of consumption in 2000 is approximately 1.7 times 1975 consumption. It is also interesting to note that natural gas never has to be curtailed in the energy conservation scenario.

EPRI made many assumptions on the way in which President Carter's policy would affect consumption. These might differ from those made by the administration. Thus, it cannot really be interpreted as a definitive test of the implications of the Carter policy. Two principal difficulties in quantifying the president's policy are assessing the effects of standards and assessing the effects of incentives to invest in new capital equipment and such improvements as insulation. Also, energy prices will have an impact on consumption whether or not the president's program is adopted. Thus, it is necessary to estimate how much conservation would be a result of government action and how much would have taken place in the market without any further incentive than increased energy prices.

Our approach to estimating the impact was to take the best engineering information available on the potential of the Carter policy to reach its objective and apply it, along with a subjective assessment of how much adjustment would take place without the policy. Of course, many of the president's policy recommendations would have a direct impact on energy prices. These were reflected as adjustments to the baseline energy prices provided by the Supply Program.

The figure indicates the increase in the share of electricity in total energy consumption. The fact that it increases at a declining rate is to be expected. If it increased at a constant or increasing rate, sooner or later it would account for more than 100% of all energy.

Generally, but not consistently, our results tend to be somewhat higher than forecasts of others—for both electricity consumption and total energy growth. Of course, it must be recognized that none of these results are completely comparable because they all involve somewhat different assumptions on the rate of economic growth, levels of energy prices, and the role of energy policy.

What *Demand 77* tells us

In addition to the demand forecasts themselves, the work behind *Demand 77* taught us (or in some cases confirmed) a good deal about our future research priorities in the Demand and Conservation Program. It can be said that three major issues leaped out at us: the need for functional disaggregation; the importance of sectoral disaggregation; the need for additional work on nontransportation natural gas and petroleum consumption.

In assessing the energy conservation scenario, many of the actual and potential policy proposals concerning energy conservation are addressed to specific activities of a sector, such as heating and cooling, rather than to a sector as a whole. This implies that we should investigate a level of functional aggregation below the level of sector and subsectors.

The second issue, the importance of disaggregation by industry, was particularly important in the industrial sector, where many forecasts of electricity consumption have been surprisingly low, considering the problem of availability and the cost of petroleum and natural gas. However, when disaggregated results are examined, one reason for the relatively low growth is clear: those industries that have traditionally consumed the most electricity are projected to grow rather slowly compared with other manufacturing industries. Disaggregation is also desirable for analysis of residential consumption by demographic classes and for the commercial sector, which comprises extremely heterogeneous groups of industries.

Natural gas and petroleum consumption in the residential and commercial sectors and the impact upon the electricity consumption of restrictions on natural gas availability need careful attention. With respect to the residential and commercial sectors, we feel uncomfortable with the results of the FEA analysis, particularly the counterintuitive results concerning the decline of natural gas consumption. One important aspect of this problem is that the situation differs between regions. Thus, even in our national forecasting efforts, we are forced to pay close attention to regional phenomena.

While much remains to be done in forecasting national energy consumption, we feel confident that *Demand 77* has made major strides in advancing the state of the art and fully expect *Demand 78* and subsequent efforts to establish a tradition of improving the accuracy and meaningfulness of national energy consumption forecasts.

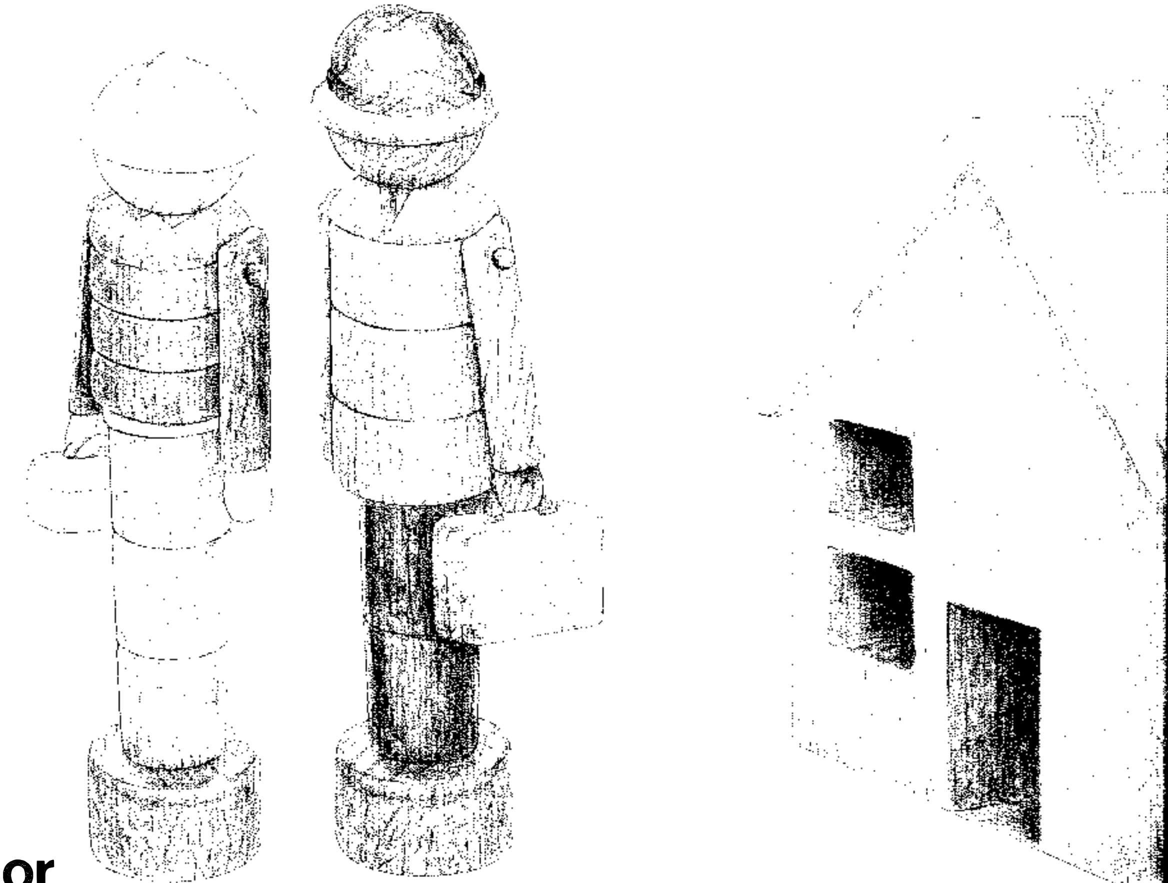
References

1. *The Residential Demand for Energy.* Final Report for RP431, prepared by Data Resources, Inc., 1977. EPRI EA-235, Vol. 1.

2. *Models of Demand for Electric Energy.* Final Report for RP333, prepared by Charles River Associates Inc., 1976. EPRI EA-221, Vol. 1.

3. *Industrial Energy Demand Models.* Final Report for RP433-1, prepared by Econometrica International, 1976. EPRI EA-242.

4. James Sweeney. "U.S. Gasoline Demand: An Economic Analysis of the EPCA New Car Efficiency Standard." In *Advances in the Economics of Energy and Resources,* Vol. 1, edited by Robert Pindyck. Greenwich, Conn.: JAI Press, forthcoming.



Energy for What?

by Everett S. Lee

A job. A house. A car. Just these few specific needs will have substantial implications for U.S. energy demand in only a generation or so. The

A job. A house. A car. Basic needs. Perhaps individually modest. What meaning does any of them hold for the shape and pace of energy policy or technology? As a basis for considering these needs individually, we should delineate the population for which they must be provided, not only in terms of numbers but also in terms of the kinds of people included.

Population projections

What we so devoutly wished for a decade ago has occurred. The growth rate of U.S. population has fallen so low that it is rapidly nearing zero. A fifth or more of the increase in population today is through immigration, and women entering the childbearing age are projected to average only 1.7 children instead of the 2.1 necessary for replacement. As recently as 1960 the figure was 3.5. By this index the fertility of American women has fallen more than 50% in 17 years.

In 1965 a population of 300 million was projected for the year 2000. Two-thirds of the total was foreseen to live in metropolitan areas and perhaps half in just three great complexes centering on New York, Chicago, and the Pacific Coast. Today the best guess is between 250 million and 260 million, and there is now an inverse relationship between population growth and size of area. What more could conservationists desire?

We are abandoning the great cities that were anathema to most planners, and millions are achieving a closer union with nature by resettling in smaller places. As a striking example, the outflow of population from the 22-square-mile island of Manhattan has been so great that only half as many people live there now as in 1910. This migration is bolstered by a natural decrease in numbers. There are now more deaths than births in Manhattan, and many cities will soon experience a similar occurrence—at least for whites.

But there are marked changes also in the structure of population. For example, between July 1960 and June 1961 the national population grew by 1.7%—over 3 million. By 1975–1976 the increase was

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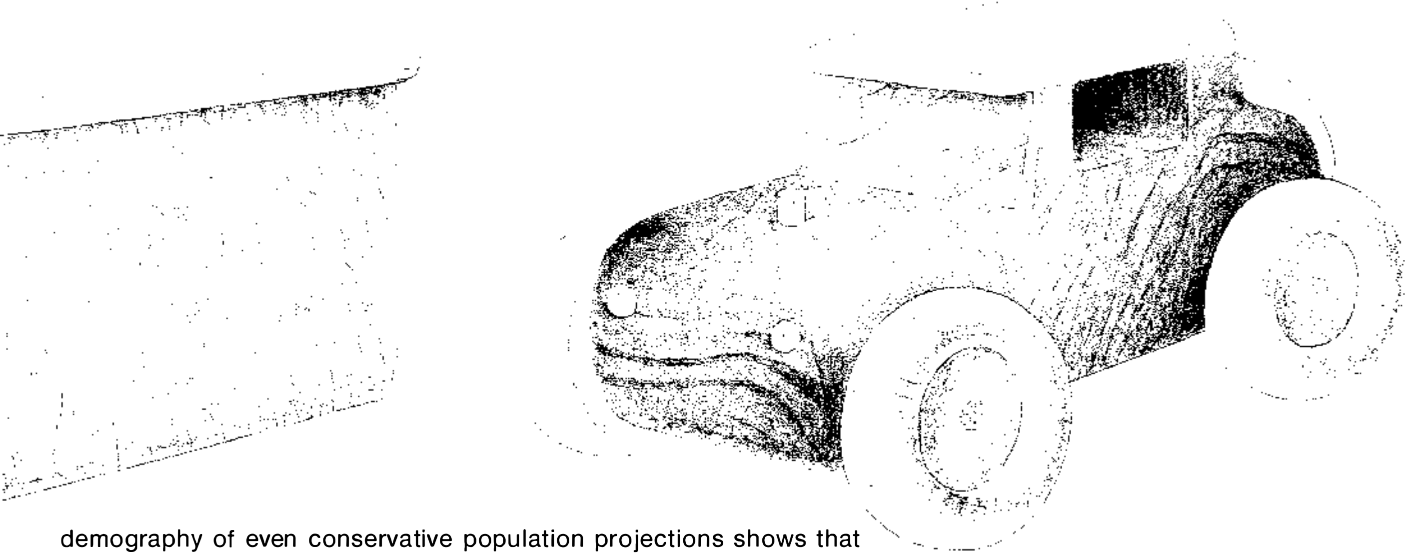


demography of even conservative population projections shows that relatively modest private aspirations may add up to a severe public problem.

only 0.6%—a little over 1.5 million. In the earlier period, whites accounted for 83% of the growth, blacks 14%, and other races 3%. In the more recent period, only 66% of the growth was attributed to whites, and the proportions accounted for by blacks and other races were 21% and 13%, respectively. Moreover, 23% of the total 1975–1976 population increase consisted of immigrants, of whom 49% were white, 12% were black, and 39% were of Asian stock. Therefore, the pressure most necessary to reckon with is the aspirations of minorities for jobs, housing, and transportation—and for the energy increment that makes those possible.

Even more important is the change in the age composition of population. For a long time death rates for persons 35 and over decreased only moderately, by less than 1% per year between 1960 and 1973. But since then the annual rate of decrease has been 4–6% annually. This trend will not produce marked effects by the end of the century, when the population aged 65 and over will have moved from today's 11% to perhaps 12–13%. But by 2040, when today's babies are ready to retire, the senior population will be 18–23%.

Though the number of persons 65 and over will increase by 7 million by the year 2000, the number under the age of 18 may decline by as much or more. Thus nearly all the growth in population (about 20%) will be of persons of labor-force age, between 18 and 65.

Job opportunity

What do these demographic trends foretell about the need for jobs—and what must be the productivity of those jobs if economic activity is to meet the growing aspirations of the most needful segments of our population?

With a 20% increase in the labor force (and possibly 15% in total population) by the year 2000, we need no increase in labor force participation rates or rates of employment to maintain the current standard of living. Indeed, with full employment and a modest 1% annual increase in worker productivity, we could easily achieve an average increase in gross national product per capita of 35% or so by the end of the century. And a 2% increase in productivity, which we have averaged for a very long time, would yield a 70% increase in GNP per capita.

But the Secretary of Commerce, concerned about the financial state of the Social Security system, has recently proposed that the retirement age be raised from 65 to 68. If we thus increase the length of working life (by 2 years or so, given present mortality rates), we will experience in time a 4–5% increase in the labor force. Add to that another 5% from increased participation of women, and still another 5% from reforms in education, and we are faced with a possible 35% increase in the labor force—as against a population increase of only 15%.

We must increase production in order to increase employment. We are now familiar with the correlation between the use of energy and gross domestic product, as well as between employment and the use of electricity. Thus, even with a slowly growing population, energy conservation and full employment are at odds. Long-term acceptance of a 7% unemployment rate is hardly credible. That overall level has traditionally meant a 14% unemployment rate for blacks, a 15–20% unemployment rate for youths, and a 30–40% unemployment rate for black youths. We should not expect that an increasingly educated, increasingly articulate, and increasingly organized minority, which is growing faster than average, will tolerate this. If the system cannot accommodate itself to them, they will work to change the system. The primary demand over the next few years—probably over the next few decades—will be jobs, which means production and, in turn, consumption. An increasing number will therefore put the provision of energy, which is becoming equated with jobs, above conservation.

Housing

Next to jobs, housing is high on the list of private aspirations and public concern. What kind of housing, and where? The preference is for a detached single home, located in a suburb or less urban area, convenient for commuting to work. In general the occupant wants to own his house rather than rent, and he wants the full complement of mechanical and electrical appliances.

Confusion about housing needs stems from misunderstanding of household types. The total number of households increased by 20% from 1960 to 1970 and by 15% from 1970 to 1976, as against 13% and 6% increases in population. Average household size now stands at 2.9 persons —down 8% since 1970.

Husband-wife families, however, increased no more rapidly than population. Of the 73 million households in 1975, only 47 million, or 65%, were husband-wife families. The great changes have been in households where broken families live, where persons live alone, or where nonrelatives live together. From 1970 to 1976 the number of households with families headed by women increased by one third, to 7 million; and the number of men and women living alone more than doubled, to 15 million. In addition there are many informal arrangements: Of the 1.5 million two-person, non-husband-wife households, 44% are composed of two persons of the opposite sex.

From these trends we may draw two important conclusions about housing. One is that the number of households requiring small dwellings has increased much more rapidly than the number that opt for single-family homes. The rise in apartment living is evident. The other conclusion is that divorce or separation usually impoverishes one or both spouses and removes them from the market for the single-family detached home.

Table 1
HOUSING TRENDS IN THE UNITED STATES

	New Households (000)	*New Dwelling Units (000)*
1950–1960	1,466	4,171
1960–1970	2,640	4,741
1970–1976	3,413	4,159

Who chooses to live in apartments? Largely, the young and the old, the poor, and recent migrants. In large cities there are always a number of young middle-class people, some living alone, others who are couples without children. For the poor the principal ways of lowering the cost of housing are to live in slums or in very little space. Well-to-do older people find an advantage in being near services and entertainment. Migrants into an area often rent apartments for a time while they explore their surroundings.

Despite the inflation in housing costs, the number of new nonmetropolitan dwelling units constructed since 1950 has exceeded the number of households formed (Table 1). This excess has permitted substandard dwellings to be abandoned, a major factor in the improvement of the U.S. housing stock. More people own these homes, too. In 1950, 55% of Americans owned their homes; by 1975 the proportion was 65%. Furthermore, they own better homes, the number judged substandard having fallen from 35% in 1950 to 5% in 1975. At the earlier date, 15% lived in dwelling units where there was more than one person per room. That proportion also fell to 5%, while the proportion living in units with central heating rose from 50% to 70%.

Of the owner-occupied dwellings in 1975, almost 90% were conventional single dwellings and 6% were mobile homes. In renter-occupied dwellings the reverse was true. Only a third of rented dwellings were single homes, and two-thirds of renters lived in structures that contained two or more units. By 1975 almost half of the renters of metropolitan dwelling units were in structures with five or more units, up from a third in 1950.

These differences are important in revealing the directions of migration. When families have children, they usually move into single homes if they can afford them. And for many, this is accompanied by movement from city to a sub-

Table 2
VEHICLE OWNERSHIP IN THE UNITED STATES

Annual Income ($)	Percent of Households: One Car	Percent of Households: Two or More	Annual Mileage (000): Per Car	Annual Mileage (000): Per Household*
<3000	35.2	11.0	9.2	5.7
3000–5000	48.2	16.1	8.9	7.5
5000–7500	53.3	26.2	10.9	12.2
7500–10,000	52.1	36.2	12.4	16.3
10,000–15,000	40.4	53.5	11.5	18.5
15,000–20,000	28.8	67.9	11.7	21.4
20,000–25,000	24.3	73.1	12.9	25.5
>25,000	19.6	77.6	13.5	28.7
All	38.7	45.1	11.8	16.8

Source: *Statistical Abstract of the United States, 1976*, page 597.

*Includes households owning no car and therefore driving zero miles.

urb or nonmetropolitan area. Wherever household migration has occurred, it has been eased by the virtually complete electrification of the United States, which in turn has encouraged ever-higher norms for labor-saving but energy-using electric appliances. Figures for 1975 show the percentage of U.S. homes so equipped:

Television sets	99.9
Refrigerators	99.9
Clothes washers	69.9
Ranges	68.5
Clothes dryers	57.7
Room air conditioners	52.8
Water heaters	40.4
Dishwashers	38.3

Figures such as these surely characterize the energy component of U.S. housing today, and they suggest what will be needed to meet the aspirations of a growing population and its disproportionately greater number of separate households.

Automobiles and commuting

Because the newer and better houses—and particularly those equipped with the full complement of electric appliances—are easiest to obtain outside large cities, millions of Americans find that their residence and place of work are increasingly separated and unlikely to be connected by reliable public transportation. The automobile, therefore, is essential to most working Americans, not only for commuting but also for shopping, which increasingly is done in shopping centers. Indeed, the American's way of life revolves around a car, and even the poorest person is forced to buy one (Table 2).

It seems almost incredible that 11% of households with annual incomes of less than $3000 have more than one car—and that these households average over 9000 miles per vehicle. Certainly, average unit costs of vehicle ownership and operation do not apply here—17.9¢ a mile for new cars, according to the Federal Highway Administration, and 19.9¢ for those over five years old. This accounting would apply more than half the lowest incomes to automobile costs alone.

More realistic estimates are obtained for households with higher incomes. Those with annual incomes of $20,000 to $25,000, for example, average 25,500 miles per household at a total cost of $4559, roughly a fifth of the total income. Thus, regardless of income level, vehicle operating costs are substantial, and increases considerably affect family budgets. People with low incomes are obviously forced to cut costs by eliminating insurance, garages, and maintenance as much as possible.

Still, the car is a necessity for most Americans. It has made the suburbs possible. Indeed, most of us travel to work by car and, except for those who live where there is good public transportation, there is no alternative. Thus, were it not for the car the distribution of population would be quite different from what it is.

But while the car has permitted local decentralization, it has not motivated an overall spreading of population. On the contrary, the U.S. population has become concentrated in a very small part of its total area. Over half of Americans now live within 50 miles of the Atlantic, Pacific, and Gulf coasts or the Great Lakes. About 60% live in urban areas, the less than 1% of U.S. land area that centers on cities of 50,000 or more. Furthermore, about 90% live within commuting distance of those cities.

In short, we have arranged our lives around the automobile, in part because we want to live in a suburb—or even more rural area—and remain within easy commuting distance of our work. We have done this by living near cities or in the transportation corridors that connect them. Until recently much of the rest of the country got emptier and emptier, and that tendency will probably be resumed soon because so many people now living in the countryside are old and will soon die. A similar situation prevails, at least for whites, in central cities, where births are relatively few.

The cost: energy versus change

We have a growing need for jobs. And we have fixed ideas on housing and transportation. All are expensive in terms of energy but changing our perceptions and our systems would be enormously costly in dollars and completely disruptive of our way of life. Thus, we know what we need energy for. The problem is to develop it and apply it shrewdly—even conservatively—within a slowly growing population so as best to serve the essential aspirations of those groups that most need its benefits.

At the Institute

Washington Public Power Supply System Joins EPRI

Utility industry support for EPRI received a boost with the recent addition of Washington Public Power Supply System (WPPSS) and its participating utilities. WPPSS has now begun membership payments on behalf of Pacific Northwest cooperatives and public power agencies that are designated preference customers of Bonneville Power Administration (BPA).

WPPSS acts as a joint operating agency for 115 participating utilities located principally in Oregon, Washington, Idaho, and Montana. In addition to its existing generating capacity, WPPSS has five nuclear plants under construction, with a total planned new capacity of more than 6 million kilowatts. WPPSS-generated power is distributed through the BPA system.

With an initial payment of $3 million for 1977, the WPPSS action represents support for EPRI from 103 additional utilities. Twelve Northwest municipal utilities and cooperatives are already EPRI members.

Utilities Must Move on Technology Development

The electric utility industry cannot afford to play research roulette, believes Frank M. Warren, chairman of EPRI's Board of Directors. Warren recently told the Annual Management Conference of the Iowa Utility Association that the industry cannot afford to place one favored technology into the race now with the assumption that other entries could be added later if the leader proves unsatisfactory. Why? Warren, chairman of the board of Portland General Electric Co., explained it's because of both the long lead time required to develop major new technology options and the difficulty of forecasting what conditions will be like when the technologies are available.

"The only prudent procedure is to move ahead on a number of promising technology fronts," he maintained. He told his audience that forms of energy malnutrition have cast their "ominous shadows" over the United States and the rest of the world, causing the industry's electric power research and development to play a strenuous game of catch up.

The question Warren believes we should ask is "Are we catching up?" In a socioeconomic environment that is all too often unfriendly, uncooperative, and unrealistic, we are going to be hard pressed to generate the technology needed to meet future electric power needs.

For the balance of the century, Warren said, the United States will need more usable energy sources, more energy technology, and all the scientific talent possible. But even more important than this, the general public, and particularly the nation's decision makers, must have accurate energy information on which to base decisions.

"Too few people realize the time and investment required to bring major new energy options into commercial use," he stated. "It took a quarter of a century and billions of dollars' worth of research, development, and demonstration to make nuclear reactors a commercial reality, and we are still encountering serious setbacks in our nuclear power timetable because vocal and politically influential segments of our public are not convinced that it is a good, clean, safe, and economic way to go."

Other factors compounding the energy problem, according to the EPRI chairman, include the general distrust of many public and private institutions and the conflicting, confusing, and frequently inaccurate statements about energy that are often made.

"The problems facing the electric utilities are great," Warren said, "but substantial progress is being made toward developing important new technology options for electric power production, transmission, and distribution."

He told his audience that much of this progress is coming from research at EPRI. "Results already are pointing toward a research program that is becoming cost-effective and that soon will be saving utilities many times more than it is costing them," he said.

He concluded by saying that the most important service of developing new energy technologies is to ensure a continuation of uninterrupted electric service without undue insult to the nation's environment or pocketbook.

International Comparisons of Energy Consumption

Does the United States consume more energy per capita than Sweden? or Germany? or Japan? If so, and these countries enjoy a standard of living similar to ours, does that mean that the United States is inefficient in its energy use? Can such comparisons be validly made or is it like comparing apples and oranges? And what implications do the findings have for future U.S. conservation strategies?

These were some of the questions examined during a workshop sponsored by EPRI and Resources for the Future, Inc., (RFF) at the Brookings Institution in Washington, D.C., September 15–16. Entitled "International Energy Consumption Comparisons," the workshop drew more than 30 economists and energy specialists from the U.S. government, foreign countries, universities, private industry, and research institutes to discuss an issue that has engendered considerable public debate on both domestic and foreign fronts.

EPRI President Chauncey Starr launched the discussion with a paper emphasizing the complexity involved in comparing countries and their respective energy uses. He pointed out that there are many variables that affect energy use: a country's resource endowment, its industry mix, its geography and climate, population density and lifestyle, and relative energy costs. Starr argued that these factors should be considered in light of well-publicized aggregate numbers that show "for some comparable total bundle of goods and services, energy used in a number of European countries is less than in the United States."

The complexity and diversity involved in such comparisons was also underlined by RFF's Joel Darmstadter, who presented the findings of a recently completed study on the subject conducted by RFF for EPRI. The study will be published by Johns Hopkins University Press toward the end of 1977.

Darmstadter argued that because of the many factors involved, variations in ratios between energy use and economic output among countries should not in themselves be viewed as indicators of either economic efficiency or energy efficiency. He warned that the United States should not "be too much transfixed by a foreign yardstick that, while intermittently revealing, can also be illusory."

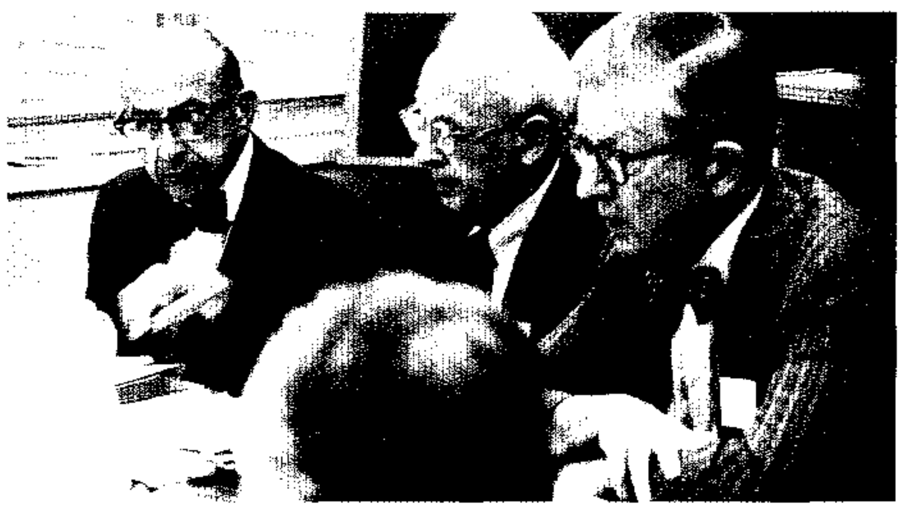
He did point out, however, that in breaking down economic activity and energy use in each country into consuming sectors (residential-commercial, transport, industry), the study revealed that the greatest international difference in energy/GDP (gross domestic product, a measure of economic output) ratios is due to transportation.

"Not only are American passenger cars about 50% more energy-intensive (in terms of fuel per passenger mile) than European cars, but relative to income levels, Americans travel a lot more than Europeans."

Another key difference was in space conditions, and the EPRI–RFF study points out that "more economic automotive practices and space conditioning improvements seem clear-cut candidates for enhanced energy utilization."

Other workshop participants presented papers comparing U.S. energy use with that of Sweden, Japan, and Germany, while further sessions examined such topics as energy use in key societal sectors (building, transport, industry), energy policies, and technical and methodological problems in international comparisons.

The proceedings of the workshop are now available, WS-77-29.



At a workshop held in Washington, D.C., in September to examine international energy consumption patterns are (from left) EPRI President Chauncey Starr; Sam Schurr, codirector, Energy Policy Center, Resources for the Future (RFF); and RFF President Charles Hitch.

Utility Representatives Discuss R&D Management

"We're concerned about the future because we expect to spend the rest of our lives there."

The words are Mark Twain's, but the speaker who quoted them before more than 100 utility representatives at a conference in Washington, D.C., this fall was J. M. Pennebaker, R&D manager, Texas Electric Service Co. Although Pennebaker was referring to specific problems faced by his company in converting from oil and natural gas to other fuels, the general concern he enunciated was clearly a predominant theme of the two-day conference on R&D management sponsored by EPRI's Research Advisory Committee (RAC) this October.

It was the second such conference held under RAC auspices. The first one (two years ago) had been so successful, according to RAC Chairman L. F. Lischer in his opening address, that another was planned to allow "the same beneficial opportunities for each of us to become acquainted with others who manage or coordinate R&D to discuss common problems and exchange information—all with the view of making our R&D efforts as productive as possible."

The conference was held at a time in Washington when energy was the leading item on the government's agenda. The proposed energy program was on the floor of the U.S. Senate and DOE had just come into official existence. Amid this atmosphere of urgency and change in the federal energy program, the utility representatives met to discuss the evolving role of their own internal R&D efforts and to be briefed on recent developments at EPRI and DOE.

The first part of the conference examined internal R&D programs: the way in which they are organized (centralized, decentralized, single-manager) and problems that are encountered. Several themes seemed to run through the discussion. Those present seemed to agree that a strong commitment from senior management was necessary for a successful R&D program. They also agreed that it was important for the R&D group to be integrated with the other working units in the utility, particularly the operating groups.

Discussing the session's topic "Commercialization of Technology" are utility R&D managers (from left) F. M. Staszesky, Boston Edison Co.; Dwain Spencer, EPRI; Walt Esselman, EPRI; V. T. Huckleberry, Oklahoma Gas and Electric Co.; and D. E. Wooldridge, Ohio Edison Co.

Several speakers discussed the relationship of their R&D programs with the national program conducted by EPRI. The feeling was expressed by some that as EPRI's workload grows, internal R&D at local utilities may shift toward more specific and specialized problems.

The utility managers indicated concern for the future direction of R&D efforts and an interest in what EPRI and DOE would be doing in broader problem areas. The second half of the conference focused on those interests. Representatives from EPRI and DOE discussed the commercialization of technology, as well as developing programs in the use of coal, nuclear power, and inexhaustible energy resources.

Again, several common themes seemed to prevail: the need for government and industry to work closely together in bringing new technology to commercial readiness; the long lead times necessary for this to come about; and the urgency to begin now. Representatives from both

RAC Chairman L. F. Lischer, Commonwealth Edison Co., delivers the opening address at the two-day R&D Management Conference in Washington, D.C.

C. H. Daley and M. J. Mulcahy, Boston Edison Co., discuss the presentation on nuclear power research with EPRI's Ed Zebroski (right).

EPRI and DOE stressed that the utilities, as potential users of new energy technology, must have their needs and requirements known in the early stages of technology development. EPRI must continually have input from utilities to guide its program, and the electric utility industry as a whole must have constant interaction with federal agencies in the drafting of government programs.

The conference provided an opportunity for R&D managers to meet, discuss their concerns for the future, and in the words of Chairman Lischer, "help the electric power industry in its efforts to solve today's and tomorrow's problems."

Members of the panel on "Commercialization of Technology" field questions from the audience. From left are Richard E. Balzhiser, EPRI; David Israel, DOE; F. M. Staszesky, Boston Edison Co.; and H. M. Siegel, Exxon Research and Engineering Co.

Energy Technology Conference Planned

EPRI will join DOE, the American Gas Association, and the National Coal Association in sponsoring the nation's largest energy technology conference, which will take place in Washington, D.C., February 28–March 1, 1978.

"Challenges to Technology" is the theme of the 5th Energy Technology Conference & Exposition, which is expected to attract about 4000 energy leaders from government, private industry, universities, and the scientific community. The conference will give an overview of the total energy picture, examining electricity and all fuel sources (coal, oil, gas, nuclear, advanced options) from all points of view (technical, economic, environmental, and societal).

EPRI officials are actively involved in planning the conference, which is held each year in Washington, D.C., under the management of Government Institutes, Inc., an educational and publishing firm. Ric Rudman, director of the EPRI Planning Staff, and EPRI Washington Office Director Robert Loftness are serving on the executive committee that is guiding the general formation of the meeting. In addition, EPRI technical staff members are organizing conference sessions and will be appearing at the meeting as moderators and speakers.

Among the session organizers are: Milt Levenson, director, Nuclear Power Division, "Nuclear Fission and Breeder Technologies"; René Malès, director, Energy Analysis and Environment Division, "Energy Modeling"; Kurt Yeager, director, Fossil Fuel Power Plants Department, "Direct Use of Coal"; Dwain Spencer, director, Advanced Fossil Power Systems Department, "Coal Liquefaction"; Quentin Looney, acting manager, Energy Utilization and Conservation Technology Program, "Cogeneration, Waste Heat, and District Heating"; and Arnold Fickett, manager, Fuel Cells and Chemical Energy Conversion Program, "Fuel Cells."

Also among the EPRI speakers will be Robert Jaffee, technical manager, Materials Support Program; Fritz Kalhammer, director, Energy Management and Utilization Technology Department; Vasel Roberts, manager, Geothermal Program; and John Cummings, manager, Solar Program.

An exhibit highlighting EPRI projects will be part of the exposition accompanying the conference. The exposition will be open to the public.

Reducing Power Losses

The electric utility industry has always been conservation-minded in the best sense of the word, EPRI Electrical Systems Division Director John Dougherty told members of the National Rural Electric Cooperative Association (NRECA) at a recent energy conservation technology conference.

Noting that to the utilities, conservation means avoiding energy waste rather than avoiding energy use, Dougherty said EPRI's research program is carrying on in the same tradition, with heavy emphasis on development of more efficient components to minimize power plant energy losses.

"The electric utility industry is the largest energy user," he explained, noting that this is partly because of electric energy losses inherent in the operation of power systems. "Some 10% of all kilowatthours generated in the United States are consumed as losses in the power systems. This is equivalent to 300 million barrels of oil in 1976 alone." This is not because utilities are unconcerned about losses. Losses have always been carefully watched. In fact, Dougherty stressed that power systems are actually highly efficient and that the large losses are directly related to the massiveness of the national power consumption.

He further stressed that with a mature technology like the generation and distribution of electricity, huge improvements in cutting losses are unlikely, although in dealing with such a large quantity of energy, even a very small improvement in system losses would have a substantial impact.

Dougherty proceeded to cite a few examples of power losses, particularly those associated with transformers. "The typical kilowatt of electric power passes through four or five voltage transformations between the generator and the customer. Transformers, with a typical efficiency of 99%, are one of the most efficient devices in the power system. Still, after passing through five such step-up or step-down transformations, 5% of the generator output will have been consumed in transformer losses."

According to the EPRI division director, losses in the magnetic steel of the transformers make up an appreciable portion of the total losses. That is why during periods when transformer loads are light, such losses represent a much higher percentage of the actual power being handled. Much of the research under way at EPRI and DOE is aimed at reducing these core losses.

He said that both EPRI and DOE have been pursuing several promising concepts for reducing these losses, including the development of superconducting generators, which may reduce losses up to 50%. This reduction in generator losses is because superconducting generators can operate at lower temperatures.

Dougherty concluded by saying that utilities are not only urging their customers to conserve energy but are also making strong conservation efforts on their own and through EPRI, by reducing losses on power systems.

Possible Impacts of Electricity Shortages

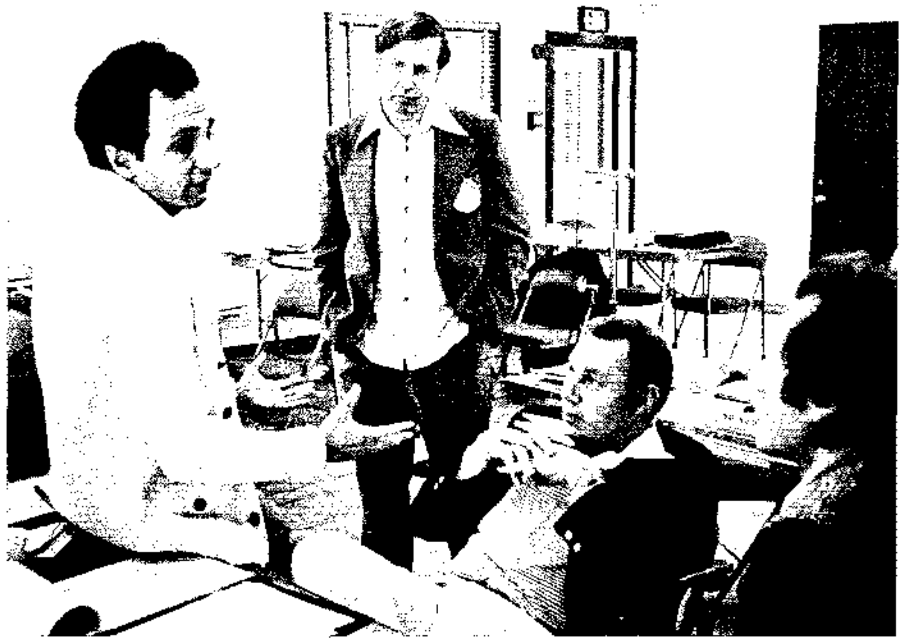
How much electricity will be required during the next few years? EPRI staff acknowledges that it's impossible to know for sure.

Higher prices, conservation efforts through regulation, and possible voluntary reductions in electricity use will tend to effect lower rates of growth in demand as compared with the past, members of the EPRI Energy Analysis and Environment Division believe.

Even with this uncertainty, however, utilities must make plans now for base-load units for the years 1985–1990 because of the long lead time required for licensing and construction. Further, some experts believe the demand for electricity will outstrip the utilities' capacity sometime during the next five years. Thus, possible consequences of such shortages should be evaluated and understood now.

The importance of this subject was highlighted recently at an EPRI workshop held in Pacific Grove, California. Specifically, the environmental and social impacts of electricity shortages were considered and areas of needed research identified. EPRI is now developing a program to evaluate the possible impacts of shortages.

Workshop participants discuss needs for research work on electricity shortages. From left are Frank Alessio, president of Criterion Analysis, Inc., of Dallas; Glenn Whan, associate dean of the College of Engineering, University of New Mexico; Richmond Hoch, president of Sigma Research, Inc., Richland, Washington; and Ronald Wyzga of EPRI's Environmental Assessment Department.



Participants included representatives from the electric utilities, universities, private research institutes, national laboratories, federal agencies, and the United Nations. During the first part of the workshop, they identified and characterized the types of electricity shortages that could occur. Then they examined the management procedures that are available to utilities, federal agencies, and consumers at the time of a shortage. Those procedures include voltage reductions, rolling blackouts, appeals for conservation, and restricted use of electricity.

The participants further examined the impacts that could result from the application of these procedures, while making specific suggestions for research that would provide estimates of the magnitude and type of impact that could occur under various conditions. Areas of needed research included institutional questions related to the management and prevention of electricity shortages. It was also suggested that alternative management tools be identified and their environmental, social, and economic impacts be assessed. In addition, existing methodologies for assessing the impacts of electricity shortages were reviewed and suggestions were made on ways to improve these methodologies.

Finally, it was suggested that a careful review of existing models on the subject be undertaken and that such models be improved and expanded.

Reactor Dosimetry Symposium

More than 100 engineers and scientists attended the second ASTM–Euratom symposium on reactor dosimetry, which EPRI hosted in October in Palo Alto. Symposium leaders were (from left) James Grundl, National Bureau of Standards; Philippe Mas, Commissariat à l'Energie Nucléaire, Grenoble, France; Ugo Farinelli, CNEN, Casaccia, Italy; William McElroy, Hanford Engineering Development Laboratory; Frank Rahn, EPRI; William C. Morgan (half hidden), Battelle, Pacific Northwest Laboratories; and Albert Fabry, CEN/SCK, Mol, Belgium.

As well as ASTM and Euratom, EPRI and the U.S. Nuclear Regulatory Commission cosponsored the meeting, which was held in cooperation with the International Atomic Energy Agency.

The measurement of radiation effects on fuels, cladding, and reactor structural materials was the theme of the meeting. Symposium sponsors expressed satisfaction with the high-level exchange of technical information, particularly on radiation embrittlement effects on reactor pressure vessels.

Energy Future Discussed

Will our energy future be an evolution or a catastrophe? René Malès, director of EPRI's Energy Analysis and Environment Division, believes the answer lies in our hands.

Speaking at the Rocky Mountain Electrical League Convention in Colorado recently, Malès said if our future is constrained to be a series of replicas of the past, but on a larger scale, we will reach catastrophe.

"There is no reason to believe, however, that man has lost the power to evolve solutions by using his ability to invent. The glimmerings of these solutions are evident, but they will take ingenuity, investment, and persistence, just as did the evolutionary technologies we are enjoying today."

Malès set the stage for a clearer understanding of the energy strategy we should follow by discussing the question of energy demand and supply and the impact of new technologies on our energy future. Without energy constraints, such as sharply rising prices and government-mandated curtailments, energy use would more than double by the year 2000, he said. Energy use efficiency and a slight decline in the rate of population growth may also play roles in curbing energy use.

Malès expects a 20–30% reduction in energy use because of the recognized decline in the availability of resources which, he believes, will bring about higher energy prices and a government commitment to more prudent management of resources. Some conservation enthusiasts believe that energy use can be reduced further without damage to the economy and American lifestyle. Malès maintains that conservation, or more appropriately, improvement in the efficiency of energy use, is reflected in his estimate of response to higher prices and government-mandated changes.

According to Malès, there are two ways to view the supply side of the equation. The geologist sees potential shortages of oil and gas because of the limit to the physical existence of the resources. The economist sees increases in the price of fuel as the way to encourage development of additional supplies and rationing of scarcer resources. But both are unsure about the exact amount of fuel that will be made available during the next 30 years.

"Some people say we don't have to worry about that," Malès said. "Some believe new technologies, such as solar, will make the energy future bright. But it takes a long time to develop new technologies and even more time to make them economical; therefore, it is risky to count on any one technology's being developed soon enough to replace dwindling fuel resources."

In conclusion, Malès said the national energy strategy has to be the encouragement of as much conservation as possible. But we should plan in such a way that if conservation does not reduce energy demands as much as we would wish, we can meet the higher level of resource needs.

In addition, we should allow prices to rise to encourage development of new fuel supplies and the efficient use of energy. Finally, we should follow many paths of technological development, recognizing that some may not be successful. The cost of being overprepared to meet demands is not terribly high and has been the way this country historically has ensured that energy insufficiencies would not be a constraint to its economic growth.

"On the other hand," he remarked, "not being able to meet future energy demands because of shortages of fuel or because technologies have not been developed could result in critical costs to the economy—unemployment, decreased income, and the inability to compete internationally."

Summaries of Technical Reports Available

In an effort to make information in EPRI technical reports more accessible to both utility and nonutility audiences, EPRI is now providing summaries of all technical reports.

The summaries are offered as alternatives to the complete reports for those readers who do not need detailed data. In this way, EPRI hopes to direct its full reports to those who actually use the data.

Clarification

In the foreword to the August 1977 JOURNAL article that summarized immediately applicable EPRI research results (page 20), two advanced energy storage technologies were described as being unworkable and therefore of no potential benefit. Clarification is in order.

Superconducting magnetic energy storage (SMES) is technically feasible, at least on the scale of present magnets. Research aimed at eventual electric utility application is under way at the University of Wisconsin and Los Alamos Scientific Laboratory (LASL), with sponsorship by the U.S. Department of Energy and a group of Wisconsin utilities. Although EPRI has not funded its own SMES research, it is monitoring the Wisconsin and LASL efforts; EPRI's future direct involvement remains an open question.

SMES is a long-term development. For utilities, the critical issues are the probable capital cost and the difficulty of scaling up to large storage capacity. Quite apart from utility system energy storage, SMES technology may become useful as a source of pulsed energy to drive the coils of controlled fusion reactors.

Flywheel energy storage was studied briefly under EPRI sponsorship but was phased out because of clearly prohibitive structural costs for systems that would fulfill utility operating requirements. However, flywheels are both workable and economical in specialized commercial apparatus—for example, to meet the starting surges of electric motors used in large excavating machines on small power systems.

Project Highlights

Ceramic Heat Exchangers May Save Petroleum and Natural Gas

Substantial amounts of petroleum and natural gas could be saved if EPRI tests show ceramics can replace some metals in gas turbine electric power plants. If the tests are successful, coal could in some instances replace petroleum and natural gas as the fuel for utility gas turbine systems. First, however, as Roger Richman, EPRI project manager, explained, the brittle but heat-resistant ceramic must show it is capable of withstanding system temperature changes and pressures.

Gas turbines are normally used during high levels of electricity use because they are relatively inexpensive and can be turned on and off rapidly. A major drawback is that the turbines require expensive, clean-burning, and scarce petroleum and natural gas because they cannot tolerate the contaminants in cheaper fuels.

According to Richman, coal could be used to heat the "working fluid" (clean air or helium) that would power the gas turbine if the turbine could be protected from the contaminants in the coal. A new technology being investigated by EPRI involving the heat exchanger concept may not only prevent contaminants from reaching the turbine but also increase the system's efficiency an estimated 10% or more.

Richman explained that the heat exchanger would be inserted between the burning fuel and the gas turbine. The flue gas from the coal would flow through one side of the exchanger and the clean gas to be heated through the other side. The heat exchanger would be ceramic because, unlike metal exchangers, it may be able to withstand the high temperatures and corrosive gases of gas turbines that use coal.

Sunlight is another possible energy source for the gas turbine power plant as long as sufficiently high temperatures can be achieved to make the system work efficiently. The solar gas turbine power plant being developed by EPRI would need to reach temperatures up to 1093°C (2000°F) to work efficiently. A ceramic heat exchanger, with its believed capability of increasing the solar heat to electricity conversion efficiency, may make that possible.

Feasibility has been demonstrated only for small-scale laboratory devices. The problem now is one of scaling up the ceramic heat exchanger to commercial size. According to Richman, EPRI is managing and funding two projects at a total of $500,000 a year to demonstrate full-scale systems.

AiResearch Manufacturing Co. of California, a division of Garrett Corp., is developing a coal-fired heat exchanger. Black & Veatch of Kansas City, Missouri, is experimenting with a heat exchanger for a solar-powered system.

"We know that in principle ceramics can withstand temperatures of up to 1650°C (3000°F), but can we fabricate them into useful shapes and can they withstand temperature changes and system pressures?" Richman asked.

According to the EPRI project manager, ceramics require a whole new design philosophy, fabrication technology, and field erection and maintenance procedure because unlike metals they are brittle. However, Richman said that if the technology can be achieved, the difference between EPRI's development approach to solar power plants and that of the federal program will be significant.

The federal solar energy research program is focused on using sunlight to heat steam power plants and therefore solar heat-to-electricity conversion efficiencies are less than 20%. If EPRI can demonstrate ceramic heat exchangers that operate at temperatures beyond that which conventional alloys can withstand, 870°C (1600°F), solar gas turbine systems may prove to be more efficient than solar steam systems.

"The higher the temperatures that can be achieved with any system, the greater its potential efficiency. Ceramics may give us the higher temperatures and efficiencies we need and make such systems competitive with existing technologies," Richman concluded.

Coal Gasification Test Facility Dedicated

The nation's largest test facility for turning coal into low-Btu gas by using an environmentally acceptable process was dedicated on October 18 in Windsor, Connecticut. The low-Btu coal gasifier was developed by Combustion Engineering, Inc. (C–E), and jointly funded by EPRI, C–E, and DOE.

Participating in the dedication ceremonies were Ella T. Grasso, governor of Connecticut; Eric H. Willis, deputy assistant secretary for energy technology, DOE; Seymour B. Alpert, technical director of fuels (Advanced Fossil Power Systems), EPRI; Howard M. Winterson, president, C–E Power Systems Group; and Donald E. Lyons, vice president, C–E Fossil Power Systems.

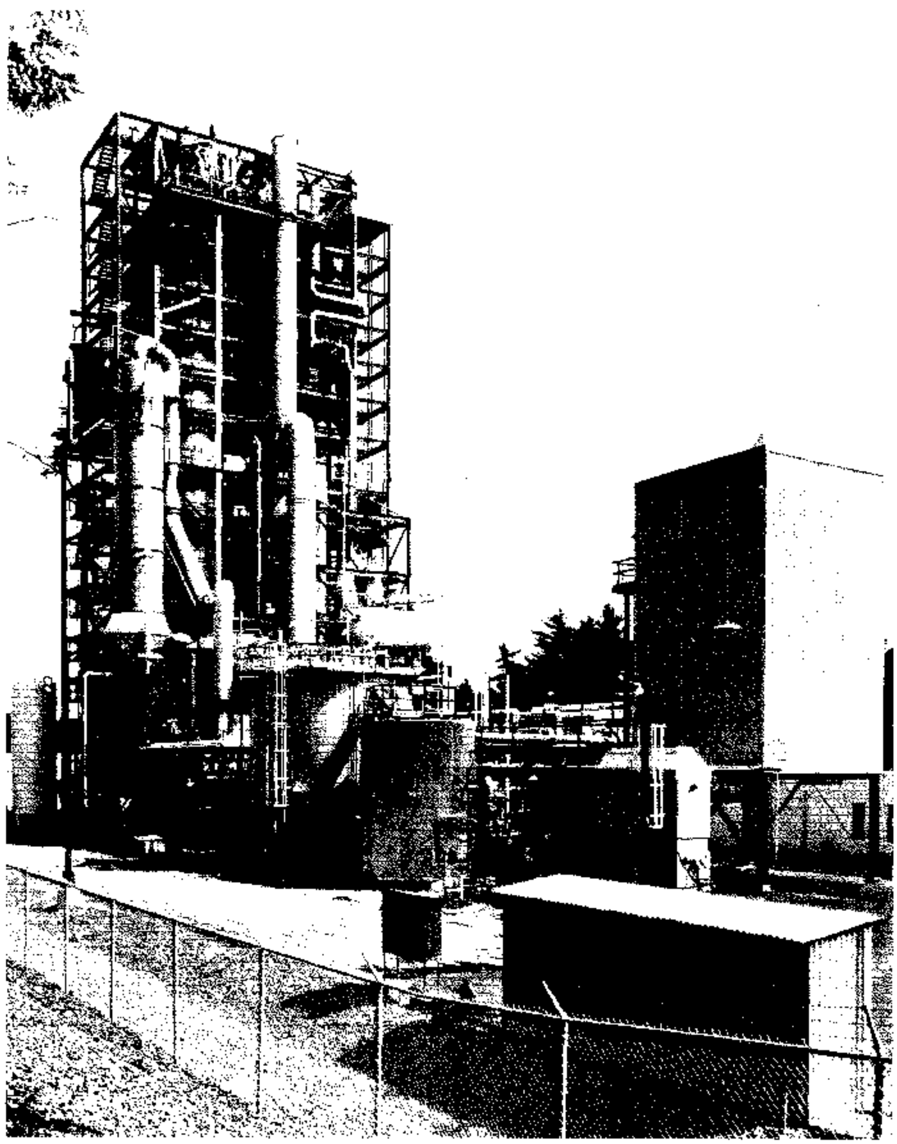
The gasifier was selected for development by C–E in the early 1970s after comparative design studies of alternative processes. It incorporates much of the equipment and many of the systems used in conventional coal-fired power plants.

The Windsor test facility is intended to demonstrate that an efficient, environmentally acceptable power generation system is possible with low-Btu gasification of coal. The clean fuel gas delivered by the gasification system can be used either as a power boiler fuel or as a combined-cycle fuel. In the latter, both gas turbine and steam turbine cycles are used to attain higher efficiency.

The two-stage, atmospheric pressure, entrainment-type coal gasification test facility was designed and constructed by C–E under a contract with DOE, with support from EPRI. C–E Power Systems was the prime contractor, with C–E Lummus providing detailed design and procurement under subcontract.

The central component of the facility is the gasifier. Coal and char are injected and burned in a combustor section to provide hot gases (1760°C, 3200°F). The hot gases rise through the reductor and gasify additional coal injected in this section. The gases produced by this process are then cooled before entering the cleanup systems.

Overall view of the low-Btu coal gasification test facility dedicated October 18. The largest of its kind in the nation, the facility was designed by Combustion Engineering, Inc.



Char and ash are separated from the product gas by a particulate removal system and are recycled to the combustor to ensure maximum carbon utilization. The coal's ash is withdrawn as molten slag from the bottom of the combustor. This slag is water-quenched, then ground to a gravellike consistency, and dewatered for landfill disposal. The sulfur in the product gas is captured in a liquid cleanup process and converted to commercial-grade elemental sulfur. This coal gasification system produces a minimum quantity of solid waste for disposal —inert slagged ash and elemental sulfur.

Including design, construction, and operation of the test facility, the entire program is valued at $25 million.

EPRI Negotiates 26 Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP653-2	Rock Brine Chemical Correlations	16 months	30.0	Stanford University *P. LaMori*
RP783-2	NO_X Control for Post-Fired Boilers: Engineering Feasibility of Post-Combustion Systems	12 months	150.0	Stearns-Roger, Inc. *D. Teixeira*
RP842-3	4.8-MW FCG-1 Fuel Cell Power Plan Demonstration	14 months	574.6	United Technologies Corp. *E. Gillis*
RP982-6	Engineering-Economic Study of Analyzer for Continuous Nuclear Assay of Coal	6 months	49.8	Food Machinery Corp. *O. Tassicker*
RP982-7	Laboratory Evaluation of Dry Alkalis for Removing SO_2 From Boiler Flue Gases	6 months	88.9	KVB, Inc. *N. Shah*
RP990-2	Application Survey and Evaluation of Gas Turbine Needs	6 months	24.7	Systems Control, Inc. *R. Duncan*
RP992-2	Ceramic Materials Application to Low-Activity Fusion Reactors	12 months	50.0	General Atomic Co. *R. Richman and N. Amherd*
RP1030-1	Agglomeration of Fine Coals	24 months	80.0	University of California at Berkeley *W. Slaughter*
RP(K)102-01	Geologic Assessment of Compressed-Air-Storage Sites in Kansas	10 months	75.0	Black & Veatch *T Schneider*
Nuclear Power Division				
RP403-2	Multifrequency Eddy-Current System Steam Generator Tubing Inspection	24 months	374.6	Battelle, Pacific Northwest Laboratories *R. Pack*
RP959-1	PWR Reflood Thermal-Hydraulic Tests	57 months	3913.7	Westinghouse Electric Corp. *T. Fernandez*
RP961-2	Validation of Real-Time Software in Nuclear Plant Safety Applications	15 months	109.0	Science Applications, Inc. *A. Long*
RP961-3	Validation of Real-Time Software in Nuclear Plant Safety Applications	15 months	59.1	University of California at Berkeley *A. Long*
RP965-4	Analysis of LOCA-Induced Fluid-Structure Interaction	11 months	130.0	Pacifica Technology *J. Carey*
RP1073-1	Determination of Building Effects on Dispersion of Effluent Plumes From Nuclear Power Plants	14 months	249.7	SRI International *H. Till*
Electrical Systems Division				
RP932-1	Magnetic Amorphous Alloys for Use in Power Transformers	18 months	99.0	University of Pennsylvania *E. Norton*
RP997-2	Synchronous Machine Study	33 months	125.0	Ontario Hydro *P. Anderson*
RP1047-2	Power System Data Management Requirements	15 months	60.0	Case Western Reserve University *C. Frank*
RP7865-1	Contamination Detector for Extrudable Dielectrics	16 months	152.8	Reynolds Metals Co. *B. Bernstein*
RP7867-1	Magnetic Refrigerator Development	18 months	180.0	ERDA *M. Rabinowitz*
Energy Analysis and Environment Division				
RP1061-1	On-Site Measurement and Chemical Speciation of Elements Discharged to the Environment Through Ash Disposal	11 months	150.0	Union Carbide Corp. *R. Perhac*
RP1098-1	Residential Energy Consumption Forecasting Models; Further Development	8 months	63.8	Data Resources, Inc. *J. Boyd*
RP1107-1	Cost and Benefits of Over- and Under-Capacity in the Generation of Electric Power	6 months	110.0	Decision Focus, Inc. *J. Karaganis*
RP1109-2	Ecological Effects of Acidic Deposition	29 months	240.1	University of Virginia *R. Kawaratani*
RP1110-1	Greenhouse Soil Heating for Improved Production and Energy Conservation: Work Statement	36 months	113.5	Ohio Agricultural Research and Development Center *R. Kawaratani*
RP1146-1	Geochemical Guides to Deep Uranium Resources	11 months	82.5	Scienterra Inc. *J. Platt*

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

UTILITY SOLAR RESEARCH

For the past three summers EPRI has surveyed electric utility companies in the United States for the nature of their involvement in solar energy research. Each year the number of participating utilities and projects has increased significantly: Between 1975 and 1977, the number of respondents tripled and the number of projects nearly quadrupled.

Preliminary analysis of the 1977 survey indicates that the projects fall into six categories (Table 1). Most of the activity is concentrated in the area of solar heating and cooling (SHAC). Nearly 85% of all utilities surveyed are sponsoring at least one SHAC project. Of primary concern to many utilities is documentation of the impact of these solar systems on the utility, development of special solar rates, and determination of the performance and cost-effectiveness of various SHAC systems and components with the intent of passing this information on to customers.

SHAC projects range from monetary support of university research to full sponsorship of design, construction, instrumentation, and evaluation of systems in residential or commercial buildings. For example, solar demonstration homes have been built by investor-owned, municipal, and rural electric cooperative utilities in California, Colorado, Georgia, Idaho, Kansas, Minnesota, Nebraska, New Mexico, New York, Ohio, Oregon, Pennsylvania, Texas, and Washington. Utility-sponsored demonstrations also involve the installation and instrumentation of residential and commercial solar hot-water heating systems, and solar swimming-pool heating systems. Other projects include offering technical assistance to do-it-yourself builders, monitoring private solar systems, performing system design studies, testing materials and components, developing computer simulations of SHAC systems, and conducting experimental rate design studies.

In many cases, utilities are working directly with EPRI and with federal agencies as project cosponsors, contractors, evaluators, and/or information suppliers. Many utility projects complement federal development and demonstration programs. For example, four companies in Indiana will monitor seven identical SHAC homes funded by the U.S. Department of Housing and Urban Development. Alabama Power Co., Basin Electric Power Cooperative (North Dakota), Reedy Creek Utilities (Florida), and the City of Santa Clara (California) have received grants from ERDA (now the Department of Energy [DOE]) to augment new utility office buildings with SHAC systems and to analyze the performance and utility impact of these systems. These individual utility activities are coordinated with EPRI's program to ensure that utility interests and requirements are integrated into the federal solar energy program. This is done by focusing effort not only on energy displacement but also on an overall economic approach to energy management and use.

Numerous utilities are directly involved in the EPRI program objective of identifying "preferred" SHAC systems. (A preferred system minimizes consumer cost while providing potential for utility load management and capacity credit.) Fourteen utilities have submitted system data for exercising computer codes to test methodology describing preferred systems for any service area (RP549 and RP926). EPRI is supporting instrumentation and monitoring projects on five utility-sponsored experiments (RPs 554, 649, 923, 924, and 925). In a more controlled and extensive experimental program, Long Island Lighting Co. and Public Service Co. of New Mexico are hosts for the construction of 10 experimental homes (RP549). In addition, EPRI will initiate a commercial SHAC experimental program, with 5 to 10 utilities as hosts for the preferred systems.

Activities in the remaining categories compose 24% of the total projects and involve 15% of the responding utilities. In most cases, several utilities are cooperating on three or four large projects. In the wind energy category, 17 utilities are participating in a DOE–NASA large-machine demonstration program. Three utilities have been selected as hosts for the construction of 200-kW wind generators on their systems. The rest are monitoring wind conditions for possible selection as hosts for the demonstration of two 1500-kW wind turbines. Individually, several utilities are sponsoring residential wind turbine generator

Table 1
ELECTRIC UTILITY SOLAR ENERGY PROJECTS—1977

Category	*No. of Projects*	*No. of Utilities Participating**
Solar heating and cooling	350	125
Wind	31	19
Solar data collection	21	21
Solar-thermal electric power	29	18
Photovoltaics	9	8
Other	22	15

*A total of 148 utilities are sponsoring projects in 1977.

UTILITIES ATTENTION!

Were you missed in EPRI's 1977 solar survey? Do you want to be included next year? If you are or will be conducting or sponsoring solar studies of any kind, please contact John Cummings at EPRI.

demonstrations or monitoring private installations.

In the category of solar-thermal electric power, again most utility activity is in several large projects that are cofunded by the federal government. Southern California Edison Co. and the Los Angeles Department of Water and Power are hosts for a DOE 10-MW solar-thermal power plant demonstration. The Southwest Project, which encompasses wind and photovoltaic energy application studies, involves 11 utilities working together to develop both technical and institutional strategies to integrate solar-thermal power plants into existing utility systems. The study is funded by several federal agencies.

On the other hand, solar data collection projects were found to be independent of federal programs. Activity is concentrated in the western states, with 13 of 21 participating utilities involved in the West Associates Solar Resource Evaluation Study.

The remaining 7% of the solar energy activities identified in the 1977 survey consist of photovoltaic and process heat projects, including solar crop-drying demonstrations and monitoring, boiler feedwater preheating studies, and public information programs.

Results of the 1977 survey of utility solar energy activities will be published by early 1978, and will be similar to the previous year's report, *Electric Utility Solar Energy Activities—1976 Survey* (EPRI ER-321-SR). A useful addition will be an estimate of the amount of money spent to date by all utilities on solar energy projects and the amount utilities have budgeted for 1977. Methodology to make these estimates is currently being developed, as well as plans to obtain more accurate and detailed information by a mail survey in 1978. *Program Manager: John Cummings*

ENERGY UTILIZATION AND CONSERVATION TECHNOLOGY

EPRI's major objective in the Energy Utilization and Conservation Technology (EUCT) Program is to help utilities stimulate more efficient energy management practices among end users. The program strategy is to identify opportunities for improved energy management, develop technical responses to those opportunities, and make the resultant practices or technologies available through utility channels. In some cases new technology can be implemented with the aid of designers or manufacturers of energy-using equipment, and the utility serves to create a "demand pull" for the technology transfer. In any case, the utility serves as a key agent.

Identifying opportunities

Recognizing that better end-use energy management will reduce the rate at which new utility capacity must be added leads to two areas of opportunity. The first is more efficient use of primary energy resources and electricity in major consumer sectors. The second is improved end-use load management to permit more economical production and use of electric power. The program addresses consumer energy demand in two subprograms dealing with improvement of end-use efficiency and improvement of electric load management, respectively (Figure 1).

End-use management of the load pattern (sometimes called demand management) can be accomplished in two ways—changing the timing of present electricity use and implementing new technologies, such as the electric vehicle, that can use electricity during off-peak hours. Because suitable equipment and appropriate rate structures are necessary to accomplish demand management and because neither is widespread in the United States today, the complexities of designing R&D programs in this area are great. Planning and conduct of this subprogram therefore will be an iterative process.

Electric vehicle technology is particularly intriguing because transportation is such a large demand sector (Table 2), but space heating also offers great potential for demand management. Together with air conditioning and water heating, it represents nearly one-fourth of energy end use. More important, these loads account for over half of all electricity use in residential and commercial buildings (Table 3) and are in many cases more easily shifted in time than are other loads.

The EPRI–EEI Electric Utility Rate Design Study, in a much more sophisticated and comprehensive way, has also identified space heating and cooling as the primary target for peak shifting. Since these are low-temperature processes, thermal storage systems could serve customer demand at all hours, thus permitting a major portion of building electricity load to be shifted to off-peak hours. Two pertinent EUCT projects (RP1089 and RP1090) are just getting under way. A third project has been developed: a field demonstration of electric vehicles designed to gather performance data and to develop a basis for estimating utility system impacts (RP1136). This work is being closely coordinated with the emerg-

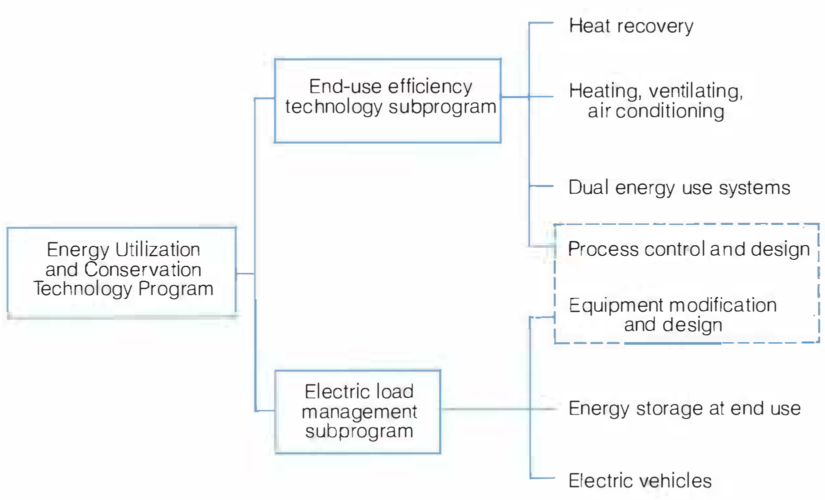


Figure 1 Representative technologies indicate the direction of energy utilization and conservation technology subprograms. Their range will broaden as potential cost and conservation potential become apparent.

Table 2
ENERGY END USE—1975

Sector	*%*
Transportation	26.2
Space heating	17.6
Process steam	16.0
Direct heat	10.4
Electric drives	8.2
Feedstocks	5.1
Water heating	3.8
Air conditioning	3.3
Commercial lighting	2.6
Refrigeration	2.4
Cooking	1.1
Electrolytic processes	1.1
Other	2.2
Total	100.0

Table 4
ENERGY USE: INDUSTRIAL PROCESSES
(10^{15} Btu)

Process	*Total*	*Electricity*	*Temperature (°C)*	*Temperature (°F)*
Thermal				
Drying	1.14	0.08	100	220
Distillation and separation	1.11	0.04	95–290	200–550
Cooking	0.19	...	120	250
Evaporation	0.19	—	95–150	200–300
Washing	0.11	—	40–90	100–190
Sterilization	0.10	—	65–120	150–250
Coking	0.99	—	1100	2000
Furnace	0.70	0.12	1000–1550	1800–2800
Bake oven heater	0.23	0.02	260–1000	500–1800
Annealing	0.01	...	800–1100	1500–2000
Thermal and/or Chemical				
Reactors with preheater	2.45	0.04	150–1500	300–2700
Electrolytic	0.29	0.29	NA	
Mechanical				
Mixing, crushing, grinding, separation	0.19	0.19	NA	
Compression	0.12	0.06	NA	
Refrigeration	0.10	0.05	NA	
Assembly	0.06	0.06	NA	
Extrusion and rolling	0.05	0.05	NA	
Filtration	0.04	0.04	NA	

Note: Data encompass the 16 heaviest energy-using, 4-digit SIC industries, plus the entire food industry. About half of all industrial energy use is represented.

Table 3
ENERGY END USE—1976
RESIDENTIAL AND COMMERCIAL
(10^{15} Btu)

Use	*Total*	*Electricity*
Space heating	13.16	0.70
Air conditioning	0.69	0.67
Water heating (residential)	1.63	0.67
Lighting	0.85	0.85
Refrigeration	0.29	0.29
Cooking	0.37	0.14
Other	1.57	0.47
Total	18.56	3.79

ing DOE-sponsored R&D program on electric and hybrid vehicles.

Planning for research on efficient end-use technology is more complex. This EUCT subprogram is emerging slowly because of the great range of opportunities available, evidenced, in fact, by the large amount of current work under other auspices. Some idea of the EUCT subprogram potential can be gained by extending the energy uses of tables 2 and 3 to include the industrial processes given in Table 4. Such factors as current efficiency of energy use, relevance to the utility industry, applicability of the technologies shown in Figure 1, and possible modifications in consumer preferences are being considered in developing the subprogram plan. Two EUCT projects are in progress: heat pump development (RP789) and industrial process control (RP1088).

Although the two EUCT subprograms are oriented toward different technologies, there are interdependencies. Thermal storage, for example, can capture residual process heat that may be useful again in another way at another time. This potential for beneficial overlap between subprograms is an important factor in project selection.

Technology development

Following is a brief status report on each EUCT project in progress:

▫ Utility-sponsored energy storage, load management, and energy conservation projects (TPS77-720). This is a survey by Energy Utilization Systems, Inc., under joint sponsorship by EPRI and DOE. It will aid both sponsors in their project planning (and supply electric utilities with a directory of ongoing projects). The energy storage portion is complete, having identified 19 utilities demonstrating cool storage systems and 25 demonstrating heat storage systems. Several utilities have projects of both types or of combination storage systems.

▫ Advanced northern climate air source heat pump development (RP789). Phases I and II of this joint effort (cosponsored by Niagara Mohawk Power Corp. and Carrier Corp. and carried out by Carrier) completed two heat pump system designs that increase system capacity at low northern climate temperatures and reduce individual residential peak demand (including supplemental resistance heat) from about 13 kW to less than 11 kW. Comprehensive instrumentation for monitoring field performance of residential heat pumps and a sophisticated data analysis center were also developed. This evaluation capability will be used during Phase III to test the performance of an advanced design prototype in four northern cities representing a range of winter weather severities.

▫ Cool storage and heat storage instrumentation and data verification (RP1089 and RP1090). These are separate two-year field-test projects (for cool and heat) designed to stimulate commercialization of thermal storage devices, to identify R&D needs, and to estimate potential impact on utility system loads. EPRI will supply instrumentation and will analyze data from storage equipment installed by individual utilities. Test sites are being selected primarily from among the ongoing projects identified through the survey described earlier. Data gathering from heat storage units should begin in January 1978 and from cool storage units in the spring of 1978.

▫ Load leveling on industrial refrigeration systems (RP1088). This project is designed to demonstrate the applicability of process control techniques to reduce peak electric demands in industrial plants. The demonstration is being done by the University of South Florida in cooperation with a food-processing plant in Tampa. Controls will be applied to the compressors on a refrigeration system not only to reduce peak demand but also to facilitate the reuse of heat withdrawn from the food to serve needs elsewhere in the process. The practice of heating and then (separately) refrigerating the same material is common throughout the food industry. A description of energy consumption patterns within the plant has been completed. A computer model, suitable for use in a low-cost microprocessor, is being developed to simulate the variation of electricity demand with time for the entire plant and for its 13 major subsystems.

Technology transfer

In the electric utility industry there is a vast resource of knowledgeable people who are in constant personal contact with energy end-users. Because person-to-person interaction is the most effective way to communicate—particularly to transmit information on unfamiliar technology—all EUCT projects are designed to use the utility service representative as an information and education link.

Another major transfer route is through designers and manufacturers of energy-using equipment. EPRI and the utility industry can stimulate the development and manufacture of energy-conservative and peak-shifting equipment by providing effective field performance testing. The testing capability developed through RP789, for example, will be made available for manufacturers to evaluate the performance of new heat pumps in actual service. *Program Manager: Quentin Looney*

HEAT REJECTION

As the least expensive and most efficient alternative, once-through cooling has been the historically preferred power plant cooling method. However, when thermal pollution came to be seen as a major environmental problem and as sites on water bodies affording withdrawals of several cubic meters per second became scarce, closed-cycle cooling became the primary cooling option. Before 1972, once-through cooling served about two-thirds of the installed capacity in the United States. Since then, it has been used on only about one-third of newly installed capacity. Projections indicate that this trend will continue.

The favored closed-cycle option, again from the standpoint of first cost and plant efficiency, is the wet tower of either mechanical or natural draft type. However, wet towers bring their own set of environmental impacts. Evaporative cooling of a 1000-MW (electric) plant with a heat rate of 10,000 Btu/kWh consumes approximately 0.5 m^3/s on a coal-fired plant and 0.6 m^3/s on a nuclear one. Vapor plumes and drift emissions are environmental effects that must be predicted and demonstrated as harmless. Cooling-circuit blowdown, required to maintain suspended and dissolved contaminants at acceptable levels, must be treated and disposed of.

All these wet-tower problems may be eliminated or alleviated, although at con-

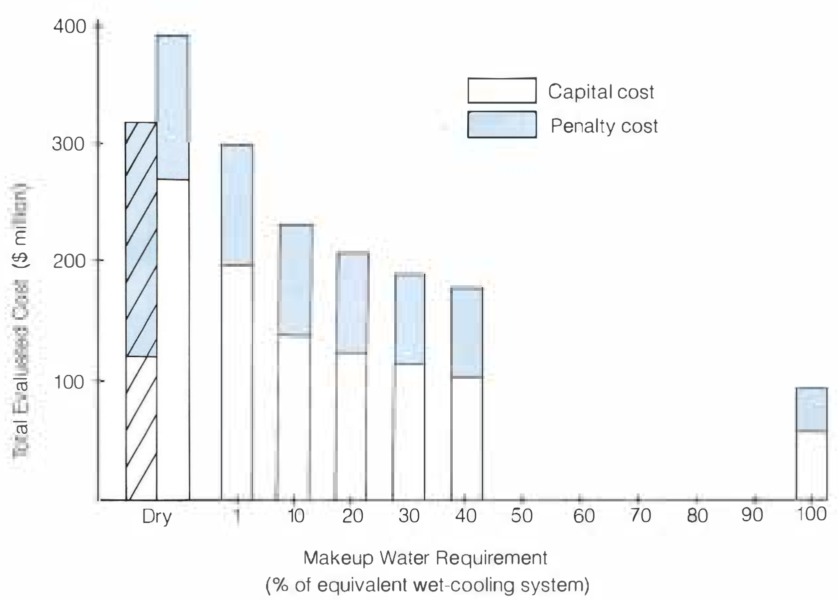


Figure 2 Dry cooling is costly, and substituting even a small proportion of wet cooling (combined system) affords substantial savings in design of a 1000-MW New Mexico nuclear power plant. For comparison with 100% wet cooling, the penalty increments represent the cost of extra generation needed to compensate for the less efficient dry cooling. The shaded bar at left shows an improved cost picture for a 100% dry-cooling system when coupled with a high-back-pressure turbine. Figures are projected in 1985 dollars. (Source: ERDA COO-2442-1, November 1976)

siderable cost, through the use of dry cooling—either all-dry systems or hybrid systems in which wet cooling is used occasionally to augment cooling capacity during hot, high-demand periods. Dry systems have been used in a few instances for many years, primarily in Europe and USSR. They are just now receiving serious consideration in the United States, with two major installations under construction: an all-dry tower at Wyodak (Wyoming) by Pacific Power & Light Co. and Black Hills Power and Light Co. and a wet-dry system at San Juan by Public Service Co. of New Mexico.

The trade-off between total evaluated cost and water consumption is shown in Figure 2. Wet cooling will continue to be the economic choice wherever water is available. In fact, considerable expense can be incurred in the transport and pretreatment of makeup water before dry cooling becomes economical. However, local conditions will surely require at least partial use of dry cooling in many instances in the future. To help the industry meet needs in the least costly way, the EPRI heat rejection subprogram has active research projects on all three types of towers.

Wet towers

Wet cooling is an established technology for which the thermodynamic and design principles are well understood. The primary problems are reliability, water treatment, plumes, drift, siting, and acceptance testing. Siting concerns are two-fold: to avoid interference and recirculation in which a tower ingests its neighbor's or its own exhaust plume, with a consequent fall-off in cooling capacity; and to prevent near-field plume effects such as fogging, icing, or corrosion of structures, transmission lines, or switchgear. Near-field plume behavior is dominated by local atmospheric aerodynamics, which in turn are determined by local structures, topography, and the presence of the tower itself. These plume flows are nearly impossible to model and predict analytically, but siting decisions, which can be crucial to tower performance, are irreversible with structures the size of a utility cooling tower.

An EPRI project is validating the use of physical models in a hydraulic flume at the University of Iowa's Institute for Hydraulic Research (RP732). Two sites have been modeled—Mississippi Power Co.'s Jack Watson Plant, equipped with mechanical draft towers of a new, round design; and Southern Electric Generating Co.'s Gaston Steam Plant, equipped with two rectangular mechanical draft towers. Near-field plume behavior at these prototype sites has been obtained from plume photographs under a variety of wind speeds, atmospheric conditions, and tower loads. Model runs simulating the range of field conditions under postulated scaling laws have been made. Model-to-prototype scale factors of 1:150 (undistorted) have been used. The models have ranged from simply a tower on flat terrain to a detailed configuration of structures and topography out to a (prototype) distance of several hundred meters, and results have been compared to determine the degree of detail required for adequate simulation (Figure 3).

The Gaston Steam Plant is also the site of a series of field tests by Environmental Systems Corp. to demonstrate an improved acceptance test methodology incorporating simultaneous readings of inlet wet-bulb temperature and air velocity at multiple locations on the faces of the tower (RP905). These data will help to account for the effects of recirculation and of variability in wind speed and direction. If taken over a range of atmospheric conditions, they will provide a sound basis for extrapolation to the design point. A final report on the instru-

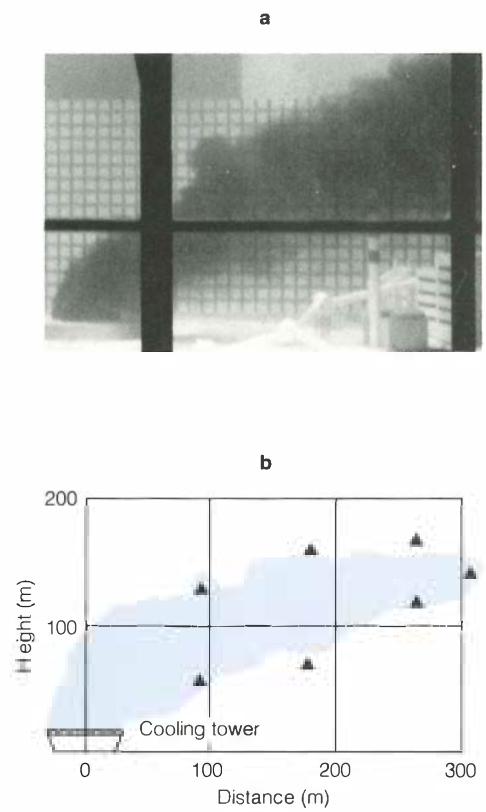


Figure 3 Typical plume (a) is made visible by dye injection in a hydraulic flume model of Mississippi Power Co.'s round cooling tower. Plotted boundaries (b) of an actual plume photographed and measured at the tower correspond closely to points scaled from a model photo made under the same wind and weather conditions.

mentation and procedures will be available in January 1978.

Dry towers

The use of dry towers to eliminate the need for water in plant cooling is technically feasible. It provides an attractive solution to many of the wet-tower environmental problems described earlier, but dry cooling is inherently costly for many reasons. The low heat capacity of air and low heat-transfer rates of air-cooled exchangers require large air volumes, large surface areas, and large, costly towers. Dry-bulb temperatures are both higher and more variable than wet-bulb values, forcing the plant to reject heat to a higher temperature sink, often significantly higher at times of peak power demand for most (summer peaking) utilities. If high-back-pressure turbines are used to reduce the hot-day capacity deficit, higher heat rates will be incurred during the remainder of the year. However, even though dry cooling will never achieve economic parity with wet cooling, it may well be imposed by legislation or because of lack of water in many regions of the country.

The EPRI program, in cooperation with DOE's Dry Cooling Tower Project, is working on the development and demonstration of an advanced dry-cooling system with the potential for significant cost reductions over conventional dry-cooling towers (RP422). From independent evaluation by DOE and EPRI, the most promising concept is a phase-change ammonia loop for transporting heat from the power plant condenser to the cooling tower. Where conventional systems use circulating water, which is heated in the steam condenser and cooled in the tower, this approach evaporates ammonia in the steam condenser and condenses it in the tower. Several factors should make for higher performance and lower cost:

- The isothermal phase-change loop eliminates the condenser range from the temperature difference between the condensing steam and the ambient dry bulb.
- The high heat capacity per kilogram of evaporating ammonia reduces the pumping power requirements for the circulating loop.
- The two-phase system permits the use of high-performance, augmented heat transfer surface on the transport loop side of the steam condenser.

Data from RP422 document technical feasibility studies and economic comparisons of ammonia phase-change systems with wet towers and dry towers of conventional design. The ability to optimize a phase-change system with a conventional, low-back-pressure ($\sim$16.9 kPa, or $\sim$5 in Hga) turbine instead of the high ($\sim$50.7 kPa, or $\sim$15 in Hga) or modified ($\sim$30.4–37.2 kPa, or $\sim$9–11 in Hga) turbine normally required for a minimum-cost dry-cooling system results in significant energy replacement savings over the life of the plant and reduces the total evaluated cost of dry cooling by approximately a factor of two below conventional designs.

Current activities include construction of a 2×10^6 Btu/h pilot facility at Union Carbide Corp., Linde Division laboratories in Tonawanda, New York, to obtain performance and design data for individual system components. In parallel with this effort, the planning, design, and costing of a demonstration facility in the 5–10-MW (electric) range is being carried on in cooperation with DOE through Battelle, Pacific Northwest Laboratories. Test plans are being reviewed with Pacific Gas and Electric Co. in consideration of using its Kern Plant at Bakersfield, California, as a possible test site.

Wet-dry cooling

As shown in Figure 2, using a small amount of water, perhaps 1–10% of the annual consumption of an all-wet system, can afford substantial savings from the cost of an all-dry system. The primary problems with wet-dry systems are variation in water consumption and the potential for control and maintenance problems. Water consumption must be predictable with sufficient precision to design and operate a system at nearly optimal power production cost within site-specific constraints of annual water availability, meteorology, and load demand. To these ends, EPRI is participating in a year-long field test of a single-cell (200×10^6 Btu/h) wet-dry tower at Southern California Edison Co.'s San Bernardino Steam Plant (Figure 4). Other sponsors include the Los Angeles Department of Water and Power, Tucson Gas & Electric Co., West Associates, DOE, EPA, the California Energy Research, Conservation, and Development Commission, and Ecodyne Cooling Products Co. Tower construction and instrumentation have been completed and shakedown tests begun. As part of the project a computer performance code for predicting water consumption has been prepared and will be verified against the field data to be obtained over the next 12 months. *Program Manager: John Maulbetsch*

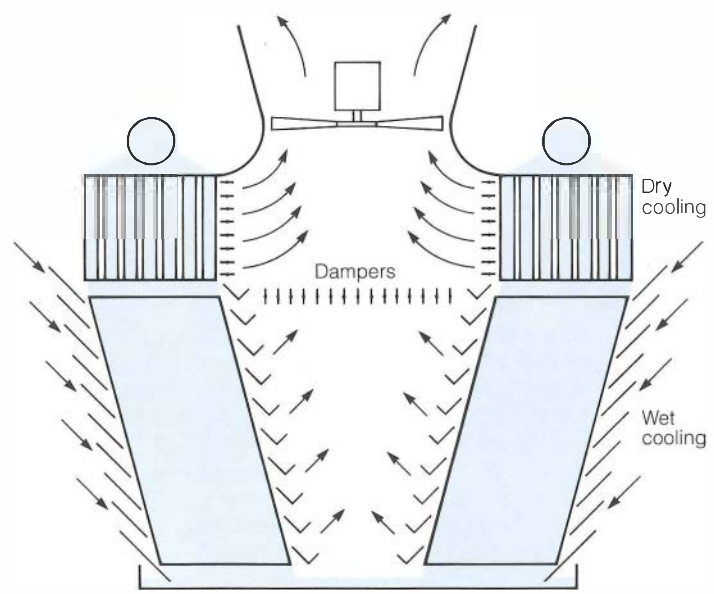


Figure 4 A single 200×10^6 Btu/h cell of this hybrid wet-dry cooling tower design will be field-tested at a Southern California Edison Co. plant for a year. Rotating dampers permit all-wet or all-dry cooling or any combination. Finned tubes provide dry heat exchange; wet tower fill provides evaporative cooling.

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

NUCLEAR PLANT SOFTWARE CENTER

A significant number of past, present, and future research projects supported by EPRI's Nuclear Power Division result in the development of computer codes that can provide new and improved analytic capabilities for the utility and nuclear industries (*1*). In addition, EPRI will generate computer-oriented data libraries for general use.

It is widely realized, however, that the development and validation of software is only the first step toward ensuring its usefulness. It is also necessary to provide for the routine distribution and maintenance of computer codes so that potential users can regularly use them on their own computer systems. Moreover, it is important for EPRI to have a focal point for correcting and improving codes on the basis of feedback from users or of new data.

EPRI has recently contracted with Technology Development Corp. (TDC) to establish a nuclear plant software center (NPSC) near EPRI's Palo Alto office. Under this contract, TDC will provide for the testing, maintenance, and distribution of nuclear codes and of data supplied by EPRI (Figure 1). An important aspect of this work will be the development of a record-keeping and updating system to assure users that the distributed codes are current.

TDC has initiated a phased program of assuming responsibility for the codes that EPRI is currently distributing. In addition, TDC will provide distribution packages for new codes to be provided by EPRI. (Table 1 lists the status of current EPRI codes.) Initially, EPRI will provide the financial support for these activities. Beginning in 1979, however, users will be charged for specific distribution services.

The NPSC manager is Leroy Krider, a member of TDC's software and information systems group. Krider's experience in the computer software field includes research in language design and implementation,

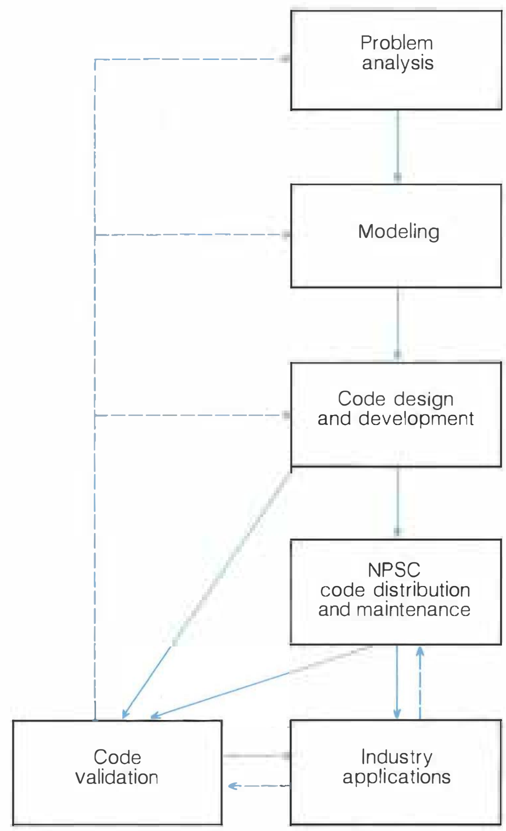


Figure 1 Flowchart shows the process of code development and distribution by EPRI and through NPSC and the use of feedback from code validation to update the codes or develop new codes.

Table 1
PROJECTED NPSC CODE DISTRIBUTION

Code	*Description*	*Distribution*
STEALTH	Structured analysis	Now available
COMETHE	Fuel rod modeling	Now available
MEKIN	Core transient analysis	4th qtr., 1977
ARMP	Fuel management and core analysis	4th qtr., 1977
MANAGE	Optimization of utility generation	4th qtr., 1977
UPRI	Uranium price behavior	1st qtr., 1978
COBRA/3C-MIT	Core thermal-hydraulic analysis	1st qtr., 1978
RETRAN	Reactor system transient analysis	3d qtr., 1979

operating systems, and multiprocessing. He has also been an instructor in numerical methods in the Department of Applied Science of the University of California at Davis (Livermore), where he also managed the department's computer facility. Krider has a special interest in making available the results of research and sees a rare opportunity to pursue this objective in NPSC.

TDC has been engaged in the fields of software design and implementation and the operation and management of facilities since its founding in 1971. Representative of its work is the design and implementation of systems and applications software for the Illiac-IV parallel processor at the Institute for Advanced Computation under contract to NASA, Ames Research Center. *Program Manager: Burt A. Zolotar*

ZIRCALOY INELASTIC DEFORMATION

The zirconium alloy Zircaloy in its two major variants, Zircaloy-2 and Zircaloy-4, is the major structural material used in the core of modern light water reactors. In a recently completed project, EPRI investigated the behavior of this material when it is stretched or compressed beyond the elastic limit (RP456). The end product was a mathematical model for the material behavior.

The equations making up the model are called constitutive relations. In concert with other equations describing the mechanics of solid bodies—in the form of a finite element stress analysis computer program, for instance—the equations predict the effects of fabrication and in-reactor duty cycle on stresses and distortions found in Zircaloy reactor components.

The immediate application is to the industry's current problems of premature fuel rod failure caused by pellet-cladding interaction and the life-limiting phenomenon of channel distortion in BWRs. In the longer term, it is hoped that a truer model for material behavior will aid core component designers in eliminating potential problem areas before they become costly to utilities.

Mathematical models of materials behavior, including the models produced in the above project, serve two basic purposes: First, they summarize the results of large and complex libraries of experimental data in the more compact form of a few equations. Second, they serve to extrapolate the results of those experiments to new, untested conditions in a manner found plausible by the materials scientist. A cleverly constructed model can save substantial experimental effort and cost by permitting extrapolation far from the conditions under which the data were taken.

The contractors were Stanford University, General Electric Co., and Massachusetts Institute of Technology (MIT). The Stanford investigators had the difficult task of developing a submodel for the behavior of the metal from room temperature to 860°C. Referred to as MATMOD, the submodel takes the modern approach of treating metal creep and plasticity within a single, unified framework.

One simplifying assumption made at Stanford was to ignore the directionality, or anisotropy, of Zircaloy strength characteristics. This function was performed by an anisotropic submodel developed at General Electric. This submodel describes the differences in yield strength dependent on the axis along which the metal is stressed and on whether it is stressed in tension or compression.

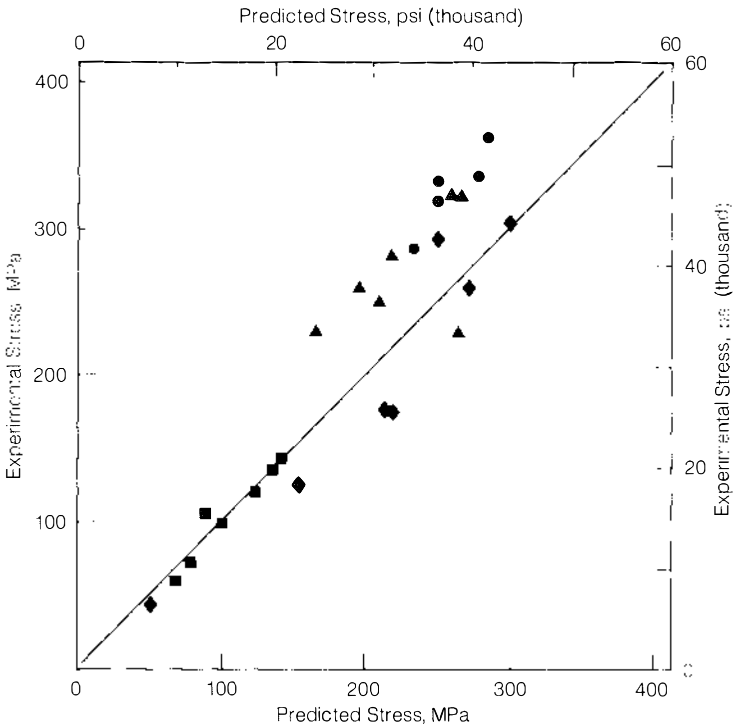
A key element in the project was the production of reliable creep, tensile, and compression test data on well-characterized Zircaloy material at MIT. Tests were performed at elevated temperatures and, in a few cases, under proton bombardment on otherwise unirradiated material. Together with data from the literature and from the other two contractors, these data were used in the development and the verification of the Stanford and General Electric submodels. The following indicates the scope of the combined Stanford–General Electric model.

- Temperature range from room temperature to β-phase transformation
- Short-time plasticity, including strain rate sensitivity and temperature sensitivity
- Long-time creep, including primary creep, steady-state creep, proper variation of steady-state creep rate with stress
- Cyclic stress-strain behavior, including Bauschinger effect, cyclic hardening and cyclic softening, shakedown to a saturated condition of constant stress and strain amplitudes
- Static recovery and dynamic recovery
- Dynamic strain-aging effects, including plateau in yield strength versus temperature, negative strain rate sensitivity
- Complex histories of stress changes, strain rate changes, temperature changes
- Irradiation effects, such as irradiation hardening, irradiation-enhanced creep, channeling (strain softening), swelling
- Anisotropy, including strength differential effect

The accuracy of Stanford's MATMOD is indicated by comparing strain rate change test results with MATMOD predictions. In these tests, the tensile strain rate pertaining to a particular strain increment was randomly varied within a range typical of reactor component operation. Figure 2 shows a comparison of predicted stresses with those measured. Average error for the annealed material is 5%; for the cold-worked, stress-relieved material, 17%. Use of the General Electric anisotropy submodel in conjunction with MATMOD would reduce these errors significantly.

In addition to the work on anisotropy, a portion of the General Electric effort was devoted to an integration between the Zircaloy model and a representative finite element stress analysis computer program called NONFIN. It was found that certain tricky characteristics of the equations impede a completely foolproof coupling. Thus exploitation of this powerful technology still

Figure 2 **Plot of stresses shows close fit between those predicted by MATMOD and the experimental stresses recorded. The results from the anisotropic submodel are not included.**



Material: Unirradiated Zircaloy-2 plate

● 350°C cold-worked, stress-relieved (tested 90° to rolling direction)

◆350°C cold-worked, stress-relieved (tested 45° to rolling direction)

▲ 425°C cold-worked, stress-relieved (tested in rolling direction)

■ 450°C annealed (tested 90° to rolling direction)

requires tailoring a solution to a particular problem's requirements; placement of a general-purpose computer program in the hands of casual users awaits future improvements in numerical methods.

Final reports for the General Electric and Stanford projects have been published: *Plasticity Theories and Structural Analysis of Anisotropic Metals—Zircaloys* (EPRI NP-500) and *Development of the Materials Code, MATMOD* (EPRI NP-567). A final report on the work at MIT will be published shortly. *Project Manager: Terry Oldberg*

TURBINE RELIABILITY VERSUS THE PURITY OF STEAM

Steam entering turbines is generally of very high purity as the boiling process is very effective in keeping dissolved salts in the liquid phase. However, pure as the steam is, there is a trace quantity of salts that dissolve directly in the steam vapor, especially at the higher pressures characteristic of modern steam generators. This is usually only in the range of 0.1–100 parts per billion (10^9) by weight, but it is sufficient to lead to serious corrosion damage in turbines under certain conditions.

The three major rotating parts of a turbine are the rotor, the disks, and the blades. All three have experienced cracking that has led to plant outages for repair or replacement. Several recent disk-cracking events occurred near a point in the turbine where deposited salts are located near the Wilson line (a point in the steam decompression cycle where moisture droplets appear). This suggests some connection between concentrated salt solutions and the cracking events.

One way to remove this threat is to remove one of the necessary ingredients for the cracking: the deposited salt. The existence of the Wilson line cannot readily be changed without paying an energy penalty. The salt deposition can be eliminated by purifying the inlet steam.

The obvious way to avoid salt deposits is to keep the impurity content of the salt below its solubility limit at all the conditions of steam temperature and pressure in the turbine cycle in which no liquid droplets are present. This is the reasoning behind the steam purity limits recommended by turbine vendors.

Such limits are not now based on measured values of steam solubilities but rather on numbers extrapolated from measured data. The uncertainty of such extrapolation is sufficient to have elicited a whole range of steam purity specifications from turbine vendors.

To correct this situation, EPRI has established two projects to measure the steam vapor solubility of three common salts or compounds thought to form aggressive solutions—sodium hydroxide, sodium chloride, and sodium sulfate—under conditions similar to those at the inlet to the low-pressure turbine. One project is at the University of Georgia (RP969). The second is wider in scope in that it includes detailed design and planning for dynamic salt deposit measurements in a laboratory turbine-simulator (RP1068). This is a joint effort between a steam generator vendor, Babcock & Wilcox Co. (B&W), and a turbine vendor, General Electric Co.

Supporting these projects with in-plant steam purity measurements is an important part of the strategy used to find ways to avoid turbine cracking damage. Two additional projects are under way to accomplish this: RP704-1 with Nuclear Water & Waste Technology, Inc. (NWT), and RP1124, a multicontractor effort that includes contributions from Westinghouse Electric Corp., B&W, NWT, and NUS Corp. Both projects will involve detailed chemical monitoring of steam and liquid phases in the secondary side of PWRs with once-through steam generators. Plants cooperating in this effort are Arkansas Nuclear–1, Crystal River–3, and Three Mile Island–1 and –2.

The objective of these in-plant measurements is to learn the realities of existing plant impurity levels, to find the primary sources of the more aggressive species, and to suggest practical ways of controlling the impurities so they can be held to benign levels. *Project Manager: Thomas O. Passell*

Table 2
UO_2–ZIRCALOY PILOT BUNDLE IRRADIATIONS
(by fuel irradiation cycle)

Plant	*Design*	*1975*	*1976*	*1977*	*1978*	*1979*
Calvert Cliffs-1	14 × 14	Load		1	2	3
Oconee-2	15 × 15	Load	1	2	3	

PILOT FUEL BUNDLE IRRADIATION STUDIES

A broad program of LWR fuel performance studies is under way at EPRI. The status of projects on BWR and PWR fuel surveillance was reported earlier (*2, 3*). In this last of three articles, the corresponding work on pilot bundle irradiations is described.

Projects in this category are studying the effects of fuel, cladding material, and design variables on performance. Material and design parameters are changed in a small number of rods included in an otherwise standard bundle design. These data will be used to develop a basis of comparison between modified fuel rod configurations and the standard design. Equally important, the data will be used to obtain information on the behavior of fundamental materials under prototypic conditions.

The current emphasis is on fuel and cladding modifications that will minimize or eliminate fuel rod bowing and pellet-cladding interaction (PCI) effects, as these two phenomena have potentially serious impact on plant availability.

Two projects address UO_2–Zircaloy behavior and two projects described earlier will study the behavior of $(U_9-Pu)O_2$, that is, mixed-oxide—Zircaloy (*4*).

The projects on UO_2–Zircaloy irradiations with Combustion Engineering, Inc. (C–E) (RP586) and with B&W (RP711) have been designed to be complementary. Together they expand the potential data base by studying both fuel and cladding variables under essentially the same power and exposure conditions. Table 2 presents the schedule for the two projects and Table 3 summarizes the test matrix.

C–E project

Task A in this project is the irradiation of test fuel rods in 14 × 14 assemblies. This comprehensive task is intended to evaluate the performance of fuel rods containing design parameter variables, Zircaloy clad creep, and growth of Zircaloy-clad fuel rods and components. The effort includes irradiation of three test assemblies with the same initial fuel-enrichment distribution. A total of 60 experimental fuel rods and 12 nonfueled rods will be examined. The three test assemblies are reconstitutible to facilitate easy removal of rods for interim and postirradiation examination.

One test assembly will be discharged at the end of each of three cycles. The test rods were characterized in detail for preirradiated clad OD and ID dimensions, ovality, and length. Selected fuel pellets, characterized by dimensional, density, and metallographic examinations, were placed in known axial positions in selected fuel rods (*5*).

The three test assemblies were inserted in Baltimore Gas & Electric Co.'s Calvert Cliffs-1 reactor in 1975; Cycle 1 was completed in January 1977. The operating conditions will be followed on a bundle-by-bundle basis for the three bundles and on a rod-by-rod basis for the test rods throughout all three cycles of operation.

The core average burnup at the end of Cycle 1 was approximately 17,000 MWd/tU. The peak pellet burnup in the high-enrichment test rods was calculated to be 21,730 MWd/tU. In the first interim examination started in February, the test assemblies were removed to the spent fuel pool, leak-tested, and examined visually. No defects or anomalies were observed. The lengths of the assembly and the peripheral rods were measured and rod-to-rod (i.e., channel) spacings were recorded to determine the extent of rod bow. Of the peripheral fuel rod channels examined visually, 99.7% showed ≤20% closure (1244 of 1248). Maximum observed channel closure was ≤40%.

A number of the test rods from the three-cycle bundle were removed for length and diameter measurements (profilometry) and eddy-current testing. No ID or OD defect indications were measured. While the rods were being removed, the withdrawal force of the rods was measured. The rods were then returned to the three-cycle bundle for further irradiation. A bundle will be removed at the end of each cycle (one bundle, from region A of the core, at the end of Cycle 1, and so on), and will be retained for detailed poolside examination during the following cycle. Data analysis is now under way. The next end-of-cycle examination is planned for January 1978.

B&W project

This project is divided into two phases: a creep-collapse test phase and a PWR demonstration irradiation phase. Both phases involve irradiation under typical PWR conditions in Duke Power Co.'s Oconee-2 reactor and both use the same lots of cold-worked and stress-relieved (CWSR) and recrystallized Zircaloy-4 cladding.

Phase I will provide information on the long-term, in-core compressive creep (collapse) and irradiation growth behavior of nonfueled Zircaloy-4 cladding (*6*). Precise measurements on all specimens will provide rod bow and distortion information in the absence of fuel interaction effects. Data are being generated for creep-induced ovalization, diametral creepdown, and irradiation growth and distortion as a function of differential pressure, temperature, and fast neutron fluence through three irradiation cycles.

Phase II will extend the experimental work on the four cladding types examined in Phase I by adding fuel interactive effects under typical power reactor conditions. The effect of pellet geometry is another added variable in these irradiations (*7*).

Rods representing each experimental condition were inserted in peripheral positions in each of two assemblies. Both of these assemblies were irradiated for two cycles in Oconee-2.

Poolside examination of the two fuel assemblies and four creep-collapse clusters

Table 3 TEST MATRIX FOR UO_2–ZIRCALOY SEPARATE-EFFECTS STUDIES

	UO_2 Fuel Parameters					
Experiment	*Theoretical Density (%)*	*Enrichment (%)*	*Length to Diameter*	*Dish (depth) Chamfer (°)*	*Densification Stability*	*Standard Product Line*
RP568 Combustion Engineering, Inc. Task A	93.0	2.45	1:7	–	no	yes
	93.0	2.82	1:7	0.015 in	yes	no
	93.0	2.82	1:7	0.015 in	yes	no
	93.0	2.82	1:7	—	yes	no
	93.0	2.82	1:7	–	yes	no
	95.0	2.33	1:7	–	yes	yes
	95.0	2.33	1:2	—	yes	no
	95.0	2.33	1:2	—	yes	no
	95.0	2.45	1:2	30°	yes	no
	93.0	2.45	1:7	—	yes	no
RP711 Babcock & Wilcox Co. Phase 2	93.5	2.67	1:2	fbs[c]	yes	no, Type L
	93.5	2.75	1:8	src[d]	no	yes, Type C
	93.5	2.67	1:2	fbs	yes	no, Type L
	93.5	2.75	1:8	src	no	yes, Type C
	93.5	2.67	1:2	fbs	yes	no, Type L
	93.5	2.75	1:8	src	no	yes, Type C
	93.5	2.67	1:2	fbs	yes	no, Type L
	93.5	2.75	1:8	src	no	yes, Type C

[a]Detailed out-of-pile measurements of mechanical properties available for all tests.
[b]Plus variable pressure; 468 psi, 64 rods in 4 assemblies.
[c]Flat bottom, side chamfer.
[d]Spherical radius 45° corner.
[e]Nuklearrohr Gesellschaft.
[f]Cold-worked and stress-relieved.
[g]Recrystallized.
[h]Plus variable texture and stress-relieving anneals, four types from three vendors, 4 per assembly.

was undertaken at the end of the first cycle (at 18,000 MWd/tU) in May 1976 (*8*), and at the end of the second cycle (26,200 MWd/tU) in July 1977. The procedures included gamma scanning of corner rods, water channel dimensioning, visual examination (TV and optical), and line scanning of fuel rods for diameter, bowing, and profile. Hot cell examination of the Zircaloy creep specimens was completed after one cycle of irradiation (*9*). One fueled assembly will be selected on the basis of the poolside examination for detailed destructive examination.

Results to date

Key results from data analyzed to date are:

▫ The visual appearance of the experimental fuel rods and assemblies at a peak burnup of 26,000 MWd/tU was excellent, with no obvious defects or anomalies.

▫ After burnups of 19,000 MWd/tU (2.5–5 $\times 10^{21}$ n/cm², 0.1 MeV), creepdown and ovalization were generally highest in the CWSR, 485°C (905°F), cladding and lowest in the recrystallized cladding. Rod bowing appeared to be least with the former and highest with the latter (*8*).

▫ The more cold-worked cladding exhibited the best combination of postirradiation tensile properties at 344°C (650°F) by retaining the highest strengths with the least loss of ductility. The largest changes in mechanical properties were measured in the recrystallized cladding where uniaxial and biaxial tensile strengths increased by 119% and 86%, respectively, and strains decreased by 82% and 71% respectively (*9*).

▫ Gamma scan traces of corner rods showed no fuel column gaps greater than 7.6 mm (0.3 in) (*8*).

▫ The linear profilometry of fuel rods showed some evidence of mechanical interaction between the cladding and type L pellets at the end of Cycle 1. In contrast, rods with standard commercial type C pellets generally showed larger ovalities but no indication of "ripples" that may be related to PCI (*8*). Preliminary data analysis at the end of Cycle 2 indicates that the rippling effect has not increased.

The Cycle 2 data are currently being analyzed.

EPRI has planned or has under way power reactor fuel surveillance projects with every major U.S. first-core and reload fuel vendor. This will substantially increase the amount of detailed data available to the utilities on fuel performance in large operating BWRs and PWRs.

Naturally, these projects on current fuel will be augmented in the future as new fuel

Zircaloy-4 Clad Parameters[a]			Fuel Rod Parameters				
Manufacturer	Standard Product Line	Nonfueled Tubes	No. of Assemblies	Fill-Gas Pressure, (psi)	Peak Linear Power (kw/ft)	Peak Linear Power (W/cm)	Burnup
Sandvik	yes	yes[b]	4	450	9	295.3	Three cycles: 15,000, 25,000 35,000 MWd/min; one assembly removed per cycle for NDE and PIE.
Sandvik	yes		1	300	12	393.7	
Sandvik	yes		1	450	12	393.7	
Sandvik	yes		1	300	12	393.7	
Sandvik	yes		1	450	12	393.7	
Sandvik	yes		4	150	8	262.5	
Sandvik	yes		2	300	8	262.5	
Sandvik	yes		2	450	8	262.5	
Sandvik	yes		2	450	9	295.3	
Sandvik	yes		2	450	9	295.3	
Sandvik	cwsr[f]	yes[h]	6–8	450	Cycle 1: 11	360.9	Two cycles, two bundles, NDT after each cycle. PIE at EOL: EOC = 18,800 MWd/t; EOC 2 = 26,200 MWd/t.
Sandvik	cwsr		6–8	450	Cycle 2: 7	229.7	
Sandvik	rc[g]		6–8	450			
Sandvik	rc		6–8	450			
NRG[e]	cwsr		6–8	450			
NRG	cwsr		6–8	450			
NRG	cwsr		6–8	450			
NRG	cwsr		6–8	450			

rod design concepts are introduced by the vendors. As soon as the vendor commits to a design change as part of a new product offering (for example, a concept to minimize PCI failures), EPRI plans to irradiate samples of the new rods in one or more lead test assemblies to provide semistatistical performance data for utility evaluation. *Program Managers: J. T. A. Roberts and F. E. Gelhaus*

References

1. W. B. Loewenstein and J. B. Moore. "Validated Analytic Codes for the Nuclear Electric Industry." *EPRI Journal*, Vol. 2, No. 7 (September 1977), pp. 47–50.

2. "Fuel Bundle Irradiation Studies." Nuclear Power Division Report, *EPRI Journal*, Vol. 2, No. 4 (May 1977), pp. 44–48.

3. "PWR Fuel Performance Surveillance Studies." Nuclear Power Division Report, *EPRI Journal*, Vol. 2, No. 7 (September 1977), pp. 44–46

4. "Plutonium Recycle." Nuclear Power Division Report, *EPRI Journal*, Vol. 1, No. 3 (April 1976), pp. 32–33.

Note: The following references may be requested from J. T. A. Roberts, EPRI.

5. Fabrication and Characterization of 14 × 14 Experimental Assemblies. RP586 Report, November 1975.

6. Pre-Irradiation Characterization of Test Specimens in the "Creep-Collapse" Program, LRC-4733-2, January 1977.

7. Pre-Irradiation Characterization of Test Specimens in the "PWR Demonstration Irradiation" Program. LRC-4733-1 (NP), November 1976.

8. Poolside Examination of PWR Demonstration Fuel Assemblies and Creep Specimens—End of Cycle 1. Key Phase Report No. 1, LRC-4733-3, May 1977.

9. Hot Cell Examination of Creep Collapse and Irradiation Growth Specimens—End of Cycle 1. Key Phase Report No. 2, LRC-4733-4, July 1977.

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

DISTRIBUTION

A project with United Technologies Corp. is concerned with the use of laser technology to detect voids and contaminants in solid dielectric cable insulation during the manufacturing process (RP794). This prospective quality control device would monitor high-molecular-weight polyethylene (HMWPE) and cross-linked polyethylene (XLPE) extrusion processes to locate and identify voids and inclusions, which often impair the dielectric strength of insulation and result in premature cable failure.

Phase I of this multiphase project has established the feasibility of real-time, in-process detection of voids and contaminants by using far-infrared (FIR) laser scattering techniques.

The basic system concept involves the detection of FIR light that is scattered by insulation imperfections. The source of the illumination is an FIR laser optically pumped by a CO_2 power laser. The FIR beam illuminates the test samples. A cryogenic (4 K) Ga:Ge detector, placed at the proper angle away from the forward beam direction, collects the scattered FIR "light." The illumination head is a solid polyethylene block with a cylindrical aperture through which the cable test sample passes. The annular space between sample and block is filled with an index-matching (index of refraction) fluid to minimize aberrations of the collumated beam of light. The best fluid to date has been common machine oil.

Output of the system has been optimized at a power level of 75 W and a wavelength of 119 μm. For 25-mil imperfections, an output signal-to-noise ratio of 5:1 has been achieved. The lowest size void to be reliably identified is 1 mil in a sea of microvoids ($\approx 10^6/cm^3$). Presently in progress is signature work to refine the detection and identification of light-scattered responses.

Phase II, an 18-month follow-on proposal, has been approved for funding. Based on successes to date, this continuing effort will be directed toward cable diagnostic studies in addition to the original real-time, quality control device. The results may provide a unique tool for investigation of the initiation and growth of trees under accelerated life testing. *Project Manager: J. H. Piscioneri*

Cable temperatures

Solid extruded dielectric cables normally operate at temperatures above ambient primarily because of losses generated in the conductor by the load current. Thermoset materials in common use today are cross-linked polyethylene (XLPE) and ethylene-propylene rubber (EPR). The maximum operating temperatures, in the 5–69-kV range, are defined by various industry specifications (AEIC, IPCEA). These are conventionally designated as the insulation temperature at the conductor, rather than at the cable surface, in the following manner: maximum normal operating temperature, 90°C; maximum emergency overload temperature, 130°C.

It is apparent that at the given conductor temperatures, the outer cable surface temperature will be lower than the interior temperature of the cable. These cable temperatures have been historically accepted.

In recent years, concern has developed about whether these generally accepted temperatures are quantitatively valid. This concern has become magnified as more systems are being designed to operate at or near the rated normal and emergency overload conditions. The reason for such concern is that when extruded dielectric cables operate in an emergency overload environment, changes occur in the insulation. For example, XLPE and EPR undergo thermal expansion; XLPE undergoes a primary transition and softens; and cable dielectric properties change and physical properties are reduced. Moreover, aging mechanisms may change, and due to thermal gradients, such changes are not necessarily uniform through the cable wall. While many of these basic materials changes have been noted in the polymer and chemical literature, no systematic evaluation has been performed of the significant changes in the total cable system.

Hence, EPRI has initiated a project with the Institut de Recherche de l'Hydro-Quebec (IREQ) to evaluate the effects of temperature on cable insulation (RP933). From the basic physical, chemical, mechanical, and dielectric changes that are found, the cable study will attempt to optimize the temperature ratings.

Laboratory methods have been developed for (a) precisely controlling the degree of cross-linking of cable materials within a narrow range; (b) improving the reliability of dielectric measurements by employing an electrode molded into a thermostat resin that holds the specimens flat; and (c) measuring conductivity as a function of temperature in a rapid, reliable fashion.

Some results to date show that breakdown strength of molded materials decreases relatively slowly with increasing temperature and that the elastic modulus of various insulation materials is different above and below approximately 100°C. *Project Manager: Bruce Bernstein*

Substations

Designing support insulators for gas-insulated equipment is made difficult by the requirement for small size and thus short creepage paths, as well as the difference between the dielectric constants of most solid insulating materials and gas.

A project at Gould, Inc. (I-T-E) has investigated sulfur hexafluoride (SF_6) epoxy foam, a novel material that consists of a highly electronegative gas, SF_6, confined in a network of closed epoxy cells (RP749). SF_6 epoxy foam can be prepared by mixing liquid epoxy and molecular sieves that have been previously loaded with SF_6 (molecular sieves adsorb approximately 25% by weight of SF_6). Molecular sieves are crystalline alumina silicates, commonly called zeolites. The crystal structures have large internal crystalline surface areas, which accounts for their gas-adsorption capability. The material is supplied as a fine powder so that it disperses evenly in the epoxy and is inert. When the mix is heated, the adsorbed SF_6 is released, thus foaming the epoxy. Subsequent curing traps the SF_6 in small, evenly distributed, closed cells.

Some of the measured properties of SF_6 epoxy foam indicate this unique material is suitable for high-voltage insulation. These properties include a low dielectric constant, a high dielectric strength, and the ability to regain dielectric strength if punctured by a low power source. The material does not require vacuum casting.

Since some of these properties can be directly attributed to SF_6, an analytic method was developed to determine if epoxy foams retained the SF_6 gas. Neutron activation analysis (NAA) was chosen because it is a nondestructive method. Consequently, after measuring a sample's initial SF_6 concentration, the sample could be aged and reanalyzed in order to measure changes in the SF_6 content.

The NAA data obtained on aged samples indicated that some materials retained SF_6 up to the point of thermal decomposition. Other formulations retained SF_6 provided the samples had not aged in excess of their glass transition temperatures. The retention of SF_6 by these foams suggest they will retain the properties attributed to SF_6 and that they can therefore be used as high-voltage insulation in either air or SF_6 environments. Gould, Inc., is continuing the development of SF_6 foam for potential product application.

The project is now complete and the final report, EPRI EL 520, is available. *Project Manager: Richard Kennon*

The use of SF_6-gas-insulated equipment in substations is gaining wide acceptance. For reliable operation of this type of equipment, it is important that the gas density be maintained within design limits and that the gas not be contaminated.*

The SF_6 gas itself is expensive, and therefore gas leaks should be detected as early as possible. It is also of interest to maintain the low humidity content of the gas. Humidity, which affects the integrity of the insulating materials within the gas-insulated equipment, would also react with the SF_6 gas if an electric arc developed within the SF_6 containment. It is therefore of interest to have an instrument that could be used for continuous monitoring of the gas. Such an instrument should be able to detect leaks in excess of 1–2% per year, as well as detect gas contaminants of significant levels.

Gages that are presently used arrive at the gas density indirectly. They measure the pressure of the gas, which measurement is then combined with a temperature compensation to compute the gas density. This method, of course, assumes that there are only insignificant contaminants (or none) in the dielectric gas itself.

EPRI is therefore sponsoring a project with Nucleonic Data Systems that has as its goal the development of an economical instrumentation system capable of measuring the SF_6 gas density within the 140–420-kPa (20–60-psia) range. The instrument is to be capable of measuring humidity content from a few hundred to a few thousand parts per million (RP656).

The project, which is now almost complete, has shown that it is feasible to directly measure the density of the SF_6 gas, as well as measure the gas humidity. The prototype instrument, however, is rather complex and most likely would be more expensive than the conventional pressure gages. In the course of the project, it was found that it is difficult to measure gases of low concentration with the same instrument used to measure the high-pressure SF_6 gas. This requires a high dynamic range in the instrumentation, with a resultant loss of resolution and accuracy. A technically better instrument could probably be built if the low-density gas component is monitored separately. However, this is beyond the scope of the study.

The experimental gage that was developed by the contractor uses the infrared absorption characteristics of the gases. A wavelength is chosen where the monitored gas absorbs strongly, but where interference from other gases is minimal. The photon absorption is approximately proportional to the density of the gas, which is also proportional to the dielectric strength of the gas. In order to overcome problems with stability or drift of components, a comparison is made at a second wavelength, which is relatively unaffected by the presence of the gases. By taking the ratio of the two signals, one can correct for variations in the pressure of other gases, changes in the infrared source intensity, small path length changes, and so on.

The wavelength selected for the gage is 2.7 μm for the moisture measurement, with a reference at 1.7 μm. For the SF_6 gas the selected wavelength is 5.8 μm, with a reference at 5.1 μm. This forces severe restrictions on the type of detectors that may be used in the system. Several different detectors were evaluated, and a pyroelectric detector was chosen for the experimental gage. The signal from the detector is processed by relatively conventional electronic devices. The measured values are then displayed for an operator, and alarm signals are activated when the measured values deviate from the expected value.

The experimental work is complete, and a final report is being prepared. Publication of this report is expected before the end of the year. *Project Manager: S. Nilsson*

To date, ac metering equipment has satisfied the needs for dc links. In many cases it may be desirable to have dc metering equipment directly on the dc line, but voltage and current transducers of the required metering accuracy are not yet available. They will, of course, be necessary in multiterminal HVDC systems that also require low-cost, reliable transducers for protection and control purposes. In recognition of these needs, EPRI has sponsored development of an electronic current transducer with the desired performance. The transducer is being developed by General Electric Co. (RP668).

The specifications of the transducer are equivalent to present standards for metering class C current transformers. However, the performance of the new transducer will exceed the specifications where this can readily be accomplished. For instance, a 3–5-kHz cutoff frequency has been established as a desirable target.

For this project, it was decided to rely on proven technology to the extent possible. A shunt was therefore selected as the primary current sensor because it was considered to be the best component to satisfy the requirements of accuracy and linearity.

Two different electronic system concepts have been studied as a part of the project. One was to use a current-to-voltage converter that would drive a light transmitter, thus producing a light signal proportional to the current. The light signal would be transmitted through an optical fiber from the bus-potential level to a receiver at ground potential, where it would be reconverted to an electric signal. However, this type of system would not by itself meet the linearity and

*"Improving Gas Dielectric Performance for Substation Design." *EPRI Journal*, Vol. 1, No. 6 (July-August 1976), pp. 20–25.

accuracy requirements. It needs the support of a high-accuracy, slow-information channel, using voltage-to-frequency and frequency-to-voltage converters for gain compensation of the amplitude-modulated system.

The other concept was an all-digital system and a selection was made between the two schemes prior to the construction of a prototype unit. It turned out that the two systems had almost identical performance, but with the use of a new, low-loss optical waveguide in the digital system, it was possible to defer the conversion of the light signal back to an electric signal. (This can be done first in the control room, thereby avoiding the electric magnetic influence problems associated with low-level electric signals through the yard.) It was therefore decided to implement the digital scheme, which is shown in Figure 1.

The electronics located in the head of the transducer next to the shunts requires a power supply for its operation. It was decided to use a 10-stage, 30-kHz cascade transformer power supply capable of providing about 100 W from the ground to the electronics in the top of the electronic current transducer (ECT). Thus, this serves to feed the power from ground level up to the transducer head. This would also supply necessary power for temperature compensation of the temperature-sensitive components in the measuring head. Ten stages would satisfy the basic insulation level required for the 400-kV operating voltage. The power supply will be approximately 80% efficient.

The optical guide communication link selected for the ECT is complete with the transmitters, receivers, and the fiber couplings required for the 300-m distance from the transmitter to the receiver in the control room. The estimated attenuation in the optical transmission system is about 6 dB or less. This link is manufactured by SIECOR.

The detailed design of the transducer is now almost complete, and most of the subassemblies have been built. The final assembly will be completed this year. The long-term accuracy of the electronics system will be evaluated by operating the unit outdoors in the Schenectady, New York, area throughout the winter. The laboratory tests will then be completed, just prior to shipment of the transducer for long-term testing in an operating HVDC system. This is expected to begin in August 1978, and the results of the tests should be available by mid-1979.
Project Manager: S. Nilsson

POWER SYSTEM PLANNING AND OPERATIONS

New data management problems have come into focus as a result of increased interconnections and additional computer control centers for operations. For instance, suppose a group of interconnected utilities wish to perform on-line power flow calculations. To do so, each needs real-time network data about its own power system, as well as real-

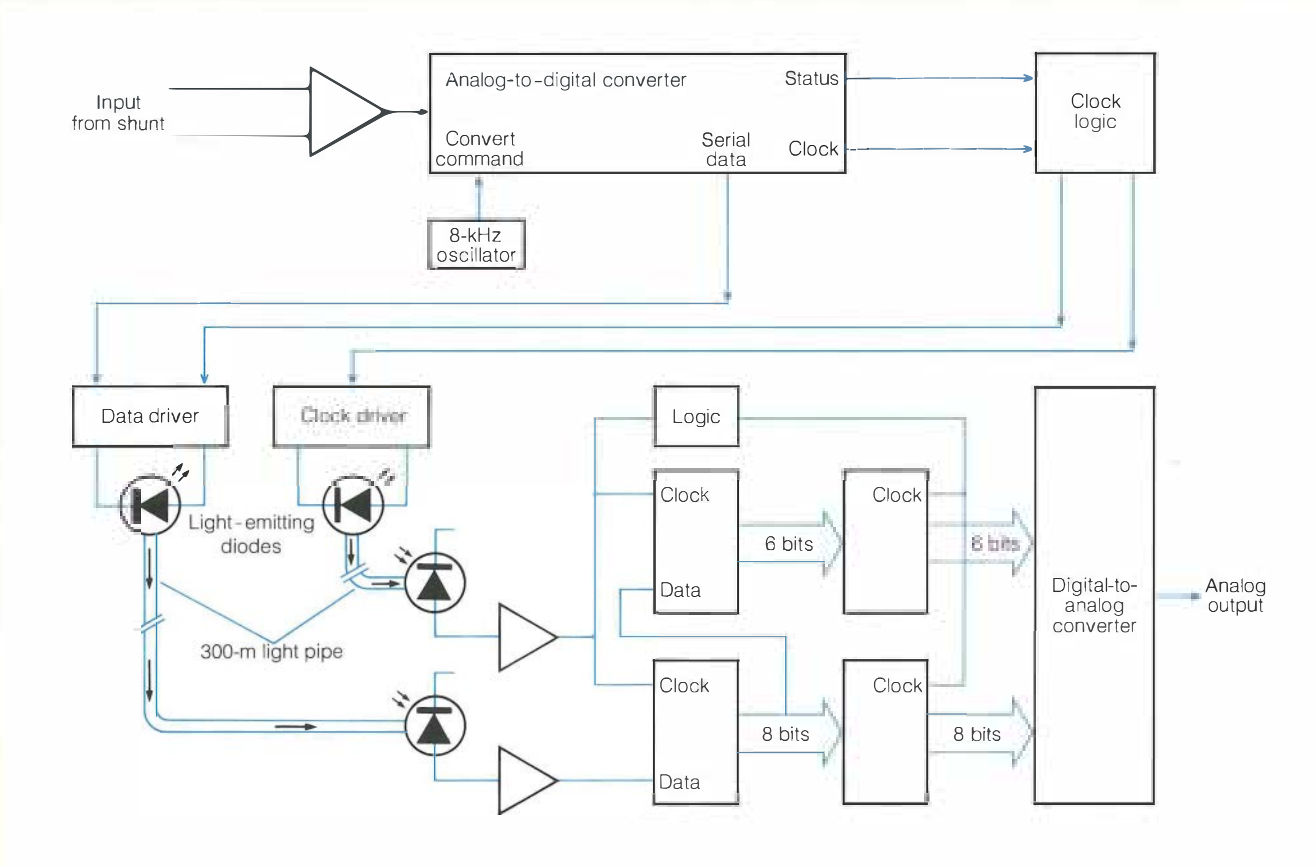


Figure 1 Block diagram of a digital electronic current transducer developed for dc power systems.

time network equivalents for each neighboring system. If each utility tried to share this data, every computer would spend most of its time gathering the required information and performing the network equivalence calculations. This data management problem can be reduced by instituting a central, higher-level computer to which all data are sent. The needed storage and computation can be carried out on this higher-level computer, with the appropriate results relayed back to the various utility control centers.

Figure 2 is an example of a multilevel, hierarchical control of power systems. This example points out how, at the power pool level, hierarchical control concepts may help relieve data management problems. At the other end of the data stream, techniques are needed to quickly digest the wealth of information that is currently available from a power system. Two ongoing research projects are intended to alleviate the data management problem (RP1047-1 and -2). The main theme in this research is to develop techniques to overcome the data management burden on current and proposed operational control centers.

The first project involves data management in a hierarchical control environment (RP1047-1). Our goals in this work are manifold: to determine what types of control and analysis computations should be performed at each level of computer hierarchy; to specify the data base and data flow requirements at each level; to determine the hardware required to measure and manage the data; and to determine the software and hardware requirements at each level.

The contractor, Computer Sciences Corp., will look at the information flow from the bulk power remotes, through the interutility regions of control, the company master control center, the pool central control computer, and, finally, to the multipool control center.

The second project in this group will concentrate on the large amount of data available from the bulk power remotes (RP1047-2). The contractor, Case Western Reserve University, will use a pattern recognition technique called associative memories to discern the similarities between a new set of real-time power system data and the remote terminals and reference sets of data. Stored in the computer memory are other sets of these data that correspond to widely different power system conditions.

As one potential application, Case Western Reserve will develop the stored pattern as well as the mathematical comparison techniques to indicate the degree of system stability represented by the new data. Because of the potential speed of computation of the associative memory techniques, a system operator would have a timely indication of system stability at his disposal. This contrasts with the present method of scanning a large data base to determine if there are any indications of changing system conditions. The contract with Case Western Reserve University will extend over two years. *Project Manager: Charles J. Frank*

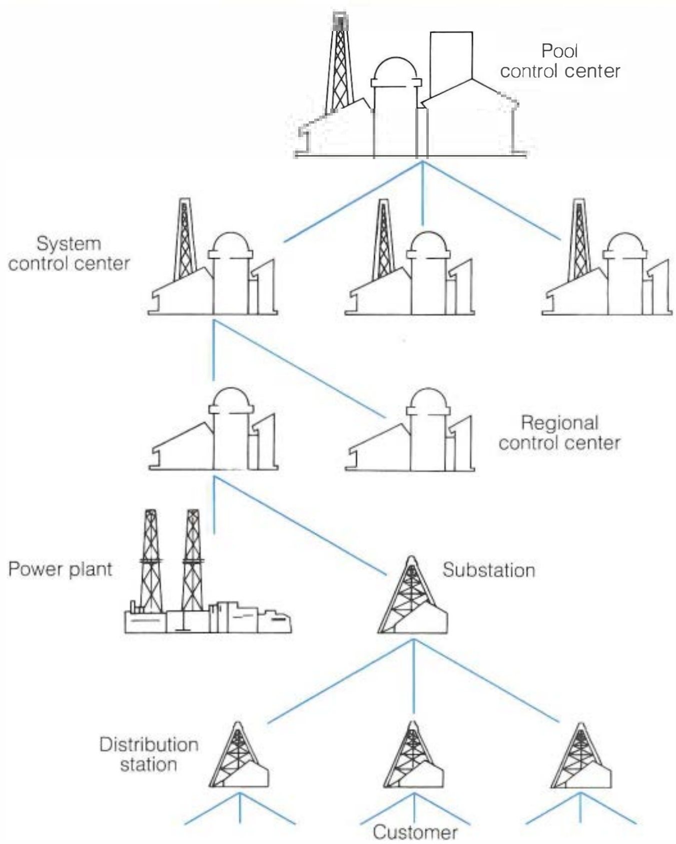


Figure 2 Example of multilevel control of power systems.

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

COMPUTERIZED SITING

In any attempt to assess the environmental impacts of various energy supply scenarios, there arises the need to predict likely locations for variable sets of energy facilities. In response to this need, the Applied Physics Laboratory (APL) of the Johns Hopkins University is developing a means to model alternative geographic distributions of energy facilities under constraints involving water availability, waste heat, air quality, population, and concentrations of generation (RP953-1).

The methodology is intended for application to any region. A mid-Atlantic region—Delaware, Maryland, New Jersey, Pennsylvania, Virginia, West Virginia, and the District of Columbia—served as the test region during methodological development. As currently formulated, the model is limited to nuclear and coal-fired electric generating plants. Extensions to other facilities, such as oil-fired electric generating plants, coal conversion facilities, oil refineries, and liquefied natural gas importing facilities, are possible.

The regional energy demand and the facilities needed to satisfy this demand are taken as input data. The demand for generating capacity is allocated among 36 load centers in proportion to population projections for the year 2000. Using linear programming, facilities are placed to meet demand and to minimize one of four objectives, which are based on transmission costs, fuel transportation costs, population density, and water requirements. The definition of load centers and the formulation of objectives are both accomplished with the assistance of planning staff from area utilities. Formulation of the coal supply is adapted from an EPRI-funded study on the coal transportation network (EA-237).

Each objective function leads to a different set of locations. Using special techniques and based on the four objectives, a "noninferior set" (NIS) of acceptable locations is generated, thus providing decision makers with useful trade-off information. Ultimately, decision makers may be able to assign subjective weights to the various objectives that would allow construction of a single objective function as a weighted sum of these objectives.

Other objectives can be incorporated into the model. Interaction with state, federal, public, and industry representatives will determine which objectives are ultimately used. From among the many objectives incorporated into the model structure, the users can select those that are most appropriate to their interests.

The set of constraints currently programmed into the model was formulated according to APL experience in power plant siting; state energy officials and EPA regional staff assisted in choosing initial values for constraint parameters and in some cases, helped to define the form of the constraints.

The method incorporates a manual screening step whereby some land areas are excluded from the set of possible locations entered into the linear program. The manual screening undertaken for initial model testing was accomplished with the guidance of the energy officials within the region.

The model has been exercised to generate NIS location solutions. These solutions have been mapped and presented to utility representatives and energy officials in a series of workshops held throughout the region. Initial utility reaction indicates the objective based on transmission costs is the most important in a large-scale analysis. Energy officials have suggested several changes in the values used for constraint parameters and screening factors. *Project Manager: Richard Richels*

TECHNICAL PERFORMANCE AND MEASUREMENT

The technical performance and measurement subprogram is a result of a recent reorganization of the Energy Demand and Conservation Program. Its role is to collect basic information on the physical and behavioral aspects of energy consumption. The subprogram is also responsible for engineering analyses of the energy-using performance of buildings and equipment. Such research will permit improved analyses of conservation technologies and government-mandated standards and their impact on electric utilities.

Research involves sampling and survey techniques and monitoring instrumentation to determine the energy-using characteristics of buildings and equipment. Simulation modeling, as well as statistical techniques, is employed in the relevant engineering analyses.

The data developed in this subprogram are of direct interest to electric utilities and will provide basic data for the analysis of energy consumption behavior in the Energy Demand and Conservation Program and information of value to the Energy Utilization and Conservation Technology Program of the Fossil Fuel and Advanced Systems Division.*

Currently, there are four major studies in this subprogram—two are nearing completion; two are just beginning. One study nearing completion has collected and analyzed detailed information from the characteristics of fuel utilization in residential heating and cooling (RP137). It covers the data and analysis for electric resistance, electric air-to-air heat pumps, and gas furnace systems. However, not included are furnace

*"The Heat Pump: Renewing an Option," *EPRI Journal*, Vol. 1, No. 8 (October 1976), pp. 20–25.

systems using heating oil, a shortcoming that will be remedied in future research.

In this study, Ohio State University has placed extensive comprehensive monitoring instrumentation on six single-family detached houses and two apartments in the Columbus, Ohio, area. This instrumentation collected data on the energy used by furnaces, on heat gain and loss through infiltration, on the heating loads carried by other appliances, and other variables of potential importance. These data, collected at 15-min intervals, were compiled and correlated with weather information on temperature, humidity, wind, and solar radiation. The data have been used to construct a detailed simulation model of energy use in heating and cooling for each of the Columbus houses. This model has since been generalized and simplified and, in future research, is to be validated on information from a sample of single-family detached houses across the country. Data on this sample have already been collected by Ohio State University and translated for further analysis under a separate contract. The final report is expected to be published before the end of 1977.

The instrumentation packages purchased for the field test in this project are being reassigned in further research. Several agreements with utility companies for small, jointly sponsored projects are under way. In these cases, EPRI's contribution is the use of the equipment. In return, EPRI will be able to disseminate the results of the studies.

Another study nearing completion is intended to determine the load and use characteristics of late-model residential heat pumps in actual operation (RP432). It is jointly sponsored by the Association of Edison Illuminating Companies and is being conducted by Westinghouse Electric Corp. The project is of particular importance because of the interest in heat pumps as efficient space-conditioning devices and the uncertainty about the impacts that widespread adoption would have on utility system loads. The instrumentation and measurement in this research are consistent with that of RP137 so that the combined data files may be analyzed in future research. Data have been collected, translated, and analyzed for 8–11 houses in each of 12 utility service areas—a total of 120 houses, representing a wide range in climate.

One new study (RP1100) uses data developed in RP432. It translates the data into a model of heat pump systems performance and analyzes it to determine the impact of alternative levels of heat pump saturation on electric utility loads for utilities that are different in customer composition, climate, and other relevant variables. This study will perform similar analyses on the annual cycle energy system. It will also investigate the interaction of preferred heat pump design and electric utility rates.

A second new study (RP1101) uses the monitoring and recording equipment from RP432 to measure the load and use characteristics of residential electric water heaters. In this study, water heater use is related to the usage rates of major hot-water-using devices, such as clotheswashers and dishwashers. A simulation model of water-heating use will be constructed and the impact of alternative levels of water heater saturation on electric utility loads will be analyzed. The study also will investigate the possible impact that solar water heaters might have on electric utility loads. *Program Manager: Robert Thomas Crow*

New Technical Reports

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

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

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ELECTRICAL SYSTEMS

Free and forced convective cooling of pipe-type electric cable systems

EL-147 Final Report (RP7821)

In this investigation, the University of Illinois at Urbana sought to develop methods for estimating the cooling obtainable for pipe-type electric cables by free and forced convective schemes and to provide reliable means for determining current-carrying limits of electric cables.

Specific objectives of the proposed research were: to investigate the flow and heat transfer mechanisms of the coolant, especially near the surface of the cable, and establish the governing parameters; to determine heat transfer coefficients and pressure drops as functions of relevant property, flow, and geometric parameters; and to correlate the results of this and other investigations to provide design methods for convectively cooled pipe-type electric cables.

Because of the geometric configuration of convectively cooled underground electric power cable systems, nonuniform cooling of the individual cables can occur. A numerical analysis was performed on the effect of nonuniform surface cooling on the temperature distribution inside and on the surface of the insulation of a single cable.

The effects of dielectric losses within insulation were also investigated. It was assumed that these losses vary inversely with the square of the radius. The results show that for the given total heat loss per unit length, the surface temperature profiles shift upward with no significant change in shape if part of the heating comes from dielectric losses. Thus, the most severe conditions occur when all heating comes from the electric conductor. *EPRI Project Manager: T. Rodenbaugh*

SF_6 foamed insulation

EL-520 Final Report (RP749)

This study by Gould Inc. describes sulfur hexafluoride (SF_6) epoxy foam, a novel material that consists of a highly electronegative gas, SF_6, confined in a network of closed epoxy cells. SF_6 epoxy foam can be prepared by mixing liquid epoxy with molecular sieves that have been previously loaded with SF_6 (molecular sieves adsorb approximately 25% by weight of SF_6). When the mix is heated, the molecular sieves release their adsorbed SF_6, thus foaming the epoxy. Subsequent curing traps the SF_6 in small, evenly distributed closed cells.

Some of the measured properties of SF_6 epoxy foam indicate that this unique material is suitable for high-voltage electrical insulation. These properties include a low dielectric constant, a high dielectric strength, and the ability to regain dielectric strength when punctured (by a low-power source); also, this material does not require vacuum casting. *EPRI Project Manager: R. E. Kennon*

Feasibility and viability study of an air-cooled, foam-insulated transmission system

EL-532 Final Report (RP7848-1)

This report describes an analytic study by Rensselaer Polytechnic Institute and General Electric Co. of the technical feasibility and economic viability of a novel underground power transmission system. The current-carrying conductors of the system are relatively large-diameter, thin-walled aluminum tubes, which are mechanically supported and electrically insulated from each other and from the ground by a closed-cell, polyurethane foam. The transmission line is cooled by passing ambient air through the pipes between blower and exhaust stations at intervals along its length.

A preliminary design for such a line was developed, taking advantage of the opportunities for trade-offs between electric, thermal, and mechanical requirements. This design was costed and compared with two existing technologies—high-pressure, oil-filled cable and compressed-gas-insulated bus.

There appear to be no clearly insurmountable difficulties in developing an underground foam-insulated line. The system has the potential of being a low-capacitance, high-ampacity alternative for EHV transmission circuits of lengths on the order of 100 miles, particularly in rural and semirural areas, where overhead lines are unacceptable. Typical ratings for the system are 1400 MVA at 345 kV and 4500 MVA at 550 kV. Preliminary designs show the economic and environmental aspects to be attractive.

Insulation and cooling are the most influential factors of the system. Specific recommendations are made for further evaluating the concept. *EPRI Project Manager: J. Dalzell*

Controlled-impedance short-circuit limiter

EL-537 Interim Report (RP654)

Continued growth of electric power systems and the consequent increase in fault currents have produced the need for current-limiting devices. Such devices allow high-power systems to be interconnected without increasing the short-circuit ratings of the installed equipment, including the circuit breakers. The objective of this study by Westinghouse Electric Corp. was to investigate the technical and economic factors associated with one particular fault current device—the controlled-impedance current limiter. With this limiter, a series-tuned inductor-capacitor circuit placed in the line has virtually zero impedance under normal operation; during a fault, however, the series-tuned configuration is rapidly altered into a high-resistive impedance. Five circuit variations of this limiter were examined.

Performance of the resonant circuit limiters was analyzed and evaluated by using a digital computer simulation and by performing tests on a scaled-down model. The computer simulation was based on a power system application having a throughput rating of 300 MVA at a nominal system voltage of 145 kV; the results of this study, however, are applicable for limiters in 69–345-kV systems. *EPRI Project Manager: V. H. Tahiliani*

Permanent magnetic field in large superconducting cylinders

EL-541 Final Report (RP798-1)

Research on magnetic field trapping has been conducted for EPRI by Battelle, Pacific Northwest Laboratories. The main objectives of this effort were to determine the effects of cylinder diameter and wall thickness on the maximum field that could be trapped and to evaluate superconducting materials used to produce the cylinders. A further objective was to develop a method for making large-diameter tubes for use in the cylinder-size scaling-law studies. In particular, high-rate sputter deposition was to be considered for making the large tubes.

Materials properties tests were conducted to support the work on cylinders. Specifically, pinning-force data were obtained on flat samples to evaluate relative suitability of candidate superconducting materials for the field-trapping tubes. Moreover, small tubes of a variety of superconducting materials were evaluated. The results of these tests were used to select materials for the tubes that were eventually used to empirically determine the scaling laws for field trapping in cylinders. *EPRI Project Manager: M. Rabinowitz*

Computer program for determination of earth potentials due to faults or loss of concentric neutral on URD cable

EL-545 Final Report (RP797-1)

Extruded solid dielectric cables with bare concentric neutral wires have received wide industry acceptance for underground residential distribution (URD) primary construction. The performance of this type of cable has been outstanding since the early 1960s. However, incidences of corrosion of the bare copper concentric neutral wires have caused the utilities to consider methods of mitigating the corrosion process. One method of corrosion control is to apply an appropriate semiconducting or insulating jacket over the neutral wires. However, the effects of the jackets on "touch-and-step" potentials during short-circuits has not been known.

Georgia Institute of Technology developed data on touch-and-step potentials for jacketed neutral cables subjected to short-circuit conditions at normal operating voltage, but these data are applicable only to the one set of system and environmental conditions that prevailed at the Franksville, Wisconsin, test site. This project was initiated to broaden the usefulness of the Franksville data. As a result, touch-and-step potentials can now be investigated at any location. The main objective was to develop a general computer program to calculate touch-and-step potentials, using the Franksville test data as a basis for verifying the program. An additional objective was to compute earth surface potentials resulting from operation with an open neutral. This report contains the details of the development effort. An appendix is available that contains the computer program and user's manual. *EPRI Project Manager: W. E. Shula*

Exploring applications of parallel processing to power system analysis problems

EL-566-SR Special Report

This report offers the formal presentations given at an EPRI seminar on defining an orderly approach to the entire scope of computer applications for large-scale power systems. The ideas in these presentations and the informal responses of the audience, which included computer and power engineers, will greatly influence future planning at EPRI and may have some influence on computer methods developed for the industry.

Large-scale power systems analysis is approached from two levels: engineering analysis and system control. Engineering analysis is an off-line activity and is usually carried out on a utility corporate computer, often in a batch mode. System control is conducted in a real-time environment wherein analysis and control computations are arranged by priority, with computing tasks distributed between the active control computer and a backup machine. In some cases the same or similar analysis programs are run to determine the network solutions under a given condition.

In recent years, a great deal of emphasis has been placed on coding large-scale digital methods of network solution under various steady-state or transient conditions. Since even straightforward steady-state network solutions involve solving nonlinear algebraic equations, a number of solution techniques have been examined, and notable gains have been recorded. Similar improvements have been made in the speed, accuracy, and fidelity of transient solutions of very large systems. *EPRI Project Manager: P. M. Anderson*

ENERGY ANALYSIS AND ENVIRONMENT

Fuel and energy price forecasts: quantities and long-term marginal prices

EA-433 Final Report, Vol. 1 (RP759-1)

EPRI and the electric utility industry require fuel price forecasts for use in planning. EPRI's Energy Analysis and Environment Division has a contract research program under way to develop information on which to base such forecasts. Work is being conducted to improve data, to design and develop improved methods of forecasting energy prices, and to reduce the margin of error in such forecasts. This is a joint effort by three programs in the Energy Analysis Department—Supply, Demand and Conservation, and Systems—with assistance from the Environmental Assessment Department. Since it is a long-range program involving considerable fundamental work in energy economics and analysis, major results will not be available for some time.

In the meantime, EPRI has required energy price forecasts for R&D planning and other purposes. Therefore, to assist the Energy Analysis and Environment Division staff in the preparation of interim price forecasts, the Supply Program contracted with SRI International and Foster Associates, Inc., to prepare independent price forecasts to the year 2000.

While this study prepared by SRI was designed primarily to aid the Energy Analysis and Environment Division staff, in accordance with EPRI policy, it is being published so that it may be used by electric utility staffs and others. *EPRI Project Manager: T. E. Browne*

Airborne monitoring of cooling tower effluents

EA-420 Final Report, Vols. I–IV (RP484)

Stringent thermal discharge limitations established by EPA in accordance with sections 301 and 306 of the Federal Water Pollution Control Act Amendments of 1972 have led to an increased use of cooling towers by utilities as one alternative to once-through cooling for steam electric power plants. Cooling towers have potential impacts that should be evaluated along with engineering, economic, and social implications when selecting cooling systems for proposed new electric power plants.

As part of the Chalk Point Cooling Tower Project (CPCTP) in Maryland, EPRI and EPA have sponsored an airborne monitoring program at the world's largest operating brackish-water natural-draft cooling tower. The overall objective of the CPCTP is to characterize all emissions from the cooling tower and assess their impact on the surrounding environment. Specific objectives of this study by Meteorology Research, Inc., were to characterize the downwind transport of water vapor and salt drift in the cooling-tower plume, investigate chemical interactions of the cooling-tower and combustion stack plumes under merging conditions, and evaluate the potential hazards of turbulence, icing, and impaired visibility to aircraft that may travel through the plume.

This report represents the most complete and detailed data base on natural-draft cooling-tower plume characteristics available in the open literature. As such, it should be of considerable value to the scientific community, utility companies, and regulatory agencies for testing cooling-tower plume models, planning future cooling-tower applications, and evaluating attendant environmental effects. *EPRI Project Manager: C. Hakkarinen*

FOSSIL FUEL AND ADVANCED SYSTEMS

Alternate concepts in controlled fusion

ER-429-SR Special Report

Commercial feasibility of new technologies applicable to electricity generation, including system performance, cost, availability, and reliability, is a major concern of electric utility executives. In the case of fusion power, tokamak and magnetic mirror concepts are receiving the bulk of the national research effort leading toward scientific demonstration.

However, recently completed designs of power plants based on those concepts have shown the potential for operation difficulties resulting from plant size, cost maintainability, and construction. The role of the designs was to point out the technological problem areas so that R&D could be directed to the regions that most critically affect commercial application. Redesign of the tokamak and mirror concepts to achieve improved characteristics is certainly possible. On the other hand, new fusion reactor concepts, as well as ones that have not been so fully investigated, should be scrutinized for potential advantages in operation characteristics.

As this report shows, there is an abundance of ideas in the fusion community for novel types of fusion reactors. Success in fusion requires vigorous pursuit of at least one reactor concept; but at the same time, a search must be made for alternative approaches that may be more suitable for eventual commercial application. Choice selection that includes user's requirements as part of the selection criteria makes fusion more attractive to the electric utilities and hence fosters the commercial development of the technology.

It was with this viewpoint that EPRI decided to make a study of alternative fusion reactor concepts that could lead to more practical systems—if not in the first generation of reactors, then in the next. A series of four workshops was organized on this subject, and the results were written in three parts. Fusion-fission hybrid and inertial confinement reactors were not covered in this study. *EPRI Project Manager: N. Amherd*

Solvent refining of West Kentucky 9-14 coal

AF-499 Final Report (RP779-6)

Hydrocarbon Research, Inc. (HRI) was contracted by EPRI in 1974 to conduct experimental studies to provide background information on the solvent-refined coal processing of West Kentucky coal. The data obtained from this research were used in kinetic analyses to explain the difference in performance between the Wilsonville and Fort Lewis plants. However, the data produced in 1974 did not cover the range of dissolver temperatures and space velocities required to explain the difference in performance between the two plants.

An experimental program to generate data that cover the extended range of temperatures and space velocities was funded and carried out for EPRI at HRI's Trenton Research and Development Center.

The bench-scale runs were conducted with Kentucky 9-14 coal containing 1.57 wt% organic sulfur. Unmodified hot contactor slurry was recycled directly from the contactor outlet to the contactor inlet without depressurizing the stream in order to simulate the backmixing effect that might occur from turbulence in large-diameter equipment. The remaining conditions were carried out in a plug flow system. The first six conditions were at a 3:1 solvent-to-coal ratio. The last two conditions were at a solvent-to-coal ratio of 1.6:1. The solvent for this operation was a vacuum distillate obtained by vacuum-distilling the contactor slurry effluent.

This report summarizes product distribution data at each operating condition; hydrogen consumption data; elemental analyses of products and product fractions for sulfur, nitrogen, carbon, and hydrogen; and solvent analyses. The principal results and product properties are correlated with operating conditions. *EPRI Project Manager: R. Wolk*

Improved cathodes for phosphoric acid fuel cells

EM-505 Final Report (RP634-1)

The objective of this project by Case Western Reserve University was the identification and characterization of promising nonnoble metal electrocatalysts for O_2 reduction as alternatives to the high-area platinum now used in phosphoric acid fuel cell cathodes. Particular attention was focused on transition metal macrocyclic complexes.

It became increasingly evident from the research that it is not likely to find transition metal macrocyclics that are superior to platinum in terms of activity and lifetime in phosphoric acid at temperatures above 150°C. Consequently, the objectives of the research were broadened to include the identification and optimization of the various factors controlling the catalytic activity of platinum for O_2 reduction in phosphoric acid. *EPRI Project Manager: A. P. Fickett*

Screening evaluation: synthetic liquid fuels manufacture

AF-523 Final Report (RP715)

Methanol and Fischer-Tropsch liquid products are potentially attractive fuels for power generation because of their favorable storage characteristics and their compatibility with environmental standards. As part of a continuing program to evaluate synthetic fuels from coal, EPRI contracted with The Ralph M. Parsons Co. to perform a screening study of processes for the production of methanol and Fischer-Tropsch liquids. These synthetic liquid fuels are produced from synthesis gases that are generated by the gasification of coal. The scope of this study is limited to a screening evaluation of several gasification processes combined with methanol and Fischer-Tropsch synthesis processes. The level of detail used in the screening study is not sufficient to allow comparison with more detailed studies on other fuels.

In an effort to evaluate a total plant concept for the production of liquid fuels from synthesis gases, facilities for coal gasification and syngas purification are included. The evaluation is based on a comparison of five cases; in four of the cases, methanol is produced by the Chem Systems process, and in the remaining case, Fischer-Tropsch liquids are produced. For methanol production, four gasification processes are used: Foster-Wheeler, slagging-gasifier (British Gas Corporation–Lurgi), Koppers-Totzek, and Texaco.

For Fischer-Tropsch products, the slagging gasifier system was selected. *EPRI Project Managers: S. A. Vejtasa and N. Korens*

Thermal and kinetic analysis of the pyrolysis of coals

AF-528 Final Report (RP368-1)

Thermal analysis has long been used to characterize coals according to rank or identification and to study the kinetics of the carbonization reactions. Basically, there are two techniques for thermal analysis. The first method is thermogravimetric analysis, in which either weight changes or the rate of weight change is recorded with respect to time or temperature at various heating rates. This analysis, when made in the absence of air, yields information on the temperatures at which the sample starts to decompose, reaches a maximum, and then terminates. The results of these thermogravimetric analyses can be used to obtain the reaction kinetics for the sample. Most kinetic analyses reported in the literature on the thermogravimetric data of pyrolysis of coals have assumed a first-order behavior for the decomposition reactions. However, it has been recognized for some time that the complex reactions, such as those occurring during coal carbonization, cannot be described adequately by overall first-order kinetics.

In the second method, called differential thermal analysis (DTA), the sample is compared with a reference material whose decomposition behavior is known and whose thermal properties are similar to the test material. The sample and the reference are placed in identical containers, and the temperature differential between them is recorded while both holders are heated at a constant rate. Alumina or coke (pyrolyzed coal) is used as the reference material for a DTA on coal pyrolysis. *EPRI Project Manager: M. J. Gluckman*

Evaluation of intermediate-Btu coal gasification systems for retrofitting power plants

AF-531 Final Report (RP203-1)

This study was undertaken by Tennessee Valley Authority to extend the investigation of coal gasification systems for retrofit application in electric power generation to include two alternative systems for producing a clean, intermediate-Btu fuel gas.

The previous study included only low-Btu gas production. The oxygen-blown Lurgi and Koppers-Totzek gasifiers were considered in this extension of the study. For the removal of hydrogen sulfide from the fuel gas and subsequent production of sulfur, a commercial Benfield H_2S removal process with a Claus sulfur recovery unit is used with Lurgi gasification, and a commercial methyldiethanolamine H_2S removal process with a Claus sulfur recovery unit is used with Koppers-Totzek gasification. Auxiliary units, such as oxygen production, heat recovery, tar removal, waste water treatment for by-product recovery, and power recovery from depressurizing the fuel gas, were included in the complete system evaluation.

The primary objectives of the study were to describe and to estimate the cost of two gasification systems for producing clean, intermediate-Btu fuel gas and to compare these estimates with the previous estimates for producing clean, low-Btu fuel gas by six fixed-bed gasification systems. The economic premises used in both studies are sufficiently similar so that meaningful comparisons are possible. *EPRI Project Manager: R. A. Loth*

Fusion reactor control study

ER-533 Annual Report (RP546-2)

The Charles Stark Draper Laboratory, Inc., has undertaken a study of control requirements for experimental power reactors. As part of this effort, a digital simulator for tokamak EPRs and their control systems is being designed and implemented. The simulator will be used as a design tool in investigating control laws and developing control requirements. This report on the first year's work includes a description of the simulator and a description of potential tokamak EPR control problems. Also included is an analysis of algorithms for the control of plasma major radius. *EPRI Project Manager: N. Amherd*

Proceedings of the review meeting on advanced-fuel fusion

ER-536-SR Special Report

This report comprises papers presented at the Review Meeting on Advanced-Fuel Fusion held in Chicago in June 1977. (A few articles that could not be presented at the meeting are also included.) As the first extensive report devoted to advanced-fuel fusion, the proceedings provide an important background for continued planning of EPRI research.

Potentially, advanced-fuel fusion can provide a major contribution to our long-term energy resources and simultaneously offer the most favorable fusion conditions possible in terms of minimizing radioactivity and maximizing efficiency. The main difficulty with the advanced fuels is that they require even higher fusing temperatures and better plasma confinement than D–T fuel. However, the advantages are important enough to excite the scientific community. In fact, the attitude toward advanced-fuel fusion has changed remarkably in the past few years as a larger segment of the fusion community has recognized the importance of advanced-fuel fusion as an ultimate goal. Because individuals still disagree on how this goal should be achieved, the meeting had three important objectives: to review the present status of advanced-fuel fusion; to discuss the role of advanced-fuel fusion in the overall development of fusion power; and, with conclusions from the first two objectives in mind, to consider how and at what pace advanced-fuel fusion should be developed.

To achieve these objectives, the meeting was a mixture of presentations, panels, and workshops; participation in the panel and workshop discussions was designed to provide all attendees with an opportunity to contribute views and ideas. Over 60 participants from a wide range of backgrounds attended. *EPRI Project Manager: R. Scott*

High-thermal-efficiency, radiation-based advanced fusion reactors

ER-544 Final Report (RP645-4)

Advanced fusion fuels offer the possibility of nearly neutron-free electric power production with the advantages of greatly simplified reactor maintenance and a reduction of the radiological hazards normally associated with other nuclear technologies. However, these neutron-free fusion reactors will generally be marginal power producers unless a very efficient energy conversion process can be found.

In this study, a new energy conversion scheme is explored that has the potential of achieving thermal cycle efficiencies high enough (e.g., 60–70%) to make advanced-fuel fusion reactors attractive net power producers. In this scheme, a radiation boiler admits a large fraction of the X-ray energy from the fusion plasma through a low-Z first wall into a high-Z working fluid, where the energy is absorbed at temperatures of 2000–3000 K. The hot working fluid expands in an energy exchanger against a cooler, light gas, transferring most of the work of expansion from one gas to the other. By operating the radiation–boiler–energy exchanger as a combined cycle, full advantage of the high temperatures can be taken to achieve high thermal efficiency. The existence of a mature combined-cycle technology from the development of space power plants gives the advanced-fuel fusion reactor application a firm engineering base from which it can grow rapidly. What is more important, the energy exchanger essentially removes the peak temperature limitations previously set by heat engine inlet conditions, so that much higher combined-cycle efficiencies can be reached.

This scheme is applied to the case of an advanced-fuel proton–boron-11 fusion reactor, using a single reheat topping and bottoming cycle. A wide variety of working fluid combinations are considered, and specific cycle calculations for thermal efficiency are presented. The operation of both the radiation boiler and the energy exchanger is described. Material compatibility, X-ray absorption, thermal hydraulics, structural integrity, and other technical features of these components are analyzed to make a preliminary assessment of the feasibility of this concept.

Although a number of unique components require engineering development, the proposed energy conversion scheme has some very attractive characteristics and no obvious technological barriers. Its dissimilarity to other fusion concepts makes further exploration of this approach particularly desirable. *EPRI Project Manager: N. Amherd.*

NUCLEAR POWER

Rod bundle test facility instrumentation—description, calibration, and uncertainty analysis; PWR blowdown heat transfer project

NP-112 Final Report (RP289)

A major consideration in the design of engineered safety systems and licensing of LWRs is that sufficient cooling capability be provided to keep reactor core fuel element clad temperatures below specified values, even for a postulated break in principal coolant loop components, such as the main recirculation loop pipe. Therefore, it is necessary to be able to predict reactor system performance in such a LOCA and to take steps toward the prevention and/or mitigation of accidents when designing the system. As a part of the continuing effort to improve and advance safety technology, the EPRI–Combustion Engineering, Inc., effort on PWR blowdown heat transfer is designed to provide basic data on the reactor core thermal-hydraulic performance under LOCA conditions. Information on these conditions is, of course, not obtainable from actual reactors, and an engineering test program such as this is necessary to provide the required data base.

The scope of the work is limited to the time period extending from the break occurrence through transient critical heat flux. The accident situation receiving the most attention in this investigation is the double-ended cold leg break, with discharge from both ends of the pipe break.

This report presents the instrumentation and measurement system used in all rod bundle tests. The project is one part of EPRI's work in the program area of LWR safety. The instrumentation used during the rod bundle blowdown heat transfer tests, conducted at the Heat Transfer Research Facility of Columbia University, are described, and measurement uncertainty analyses are performed. The uncertainty studies are generally based on single-phase, steady-state instrument performance; two-phase characteristics are discussed, and limiting errors are estimated. Where possible, steady-state steam-water data are used to substantiate theoretical uncertainty bounds. *EPRI Project Manager: K. A. Nilsson*

Rod bundle blowdown heat transfer tests simulating PWR LOCA conditions

NP-113 Final Report (RP289)

Experiments were conducted by Combustion Engineering, Inc., to investigate transient critical heat flux (CHF) in PWR cores during a hypothetical LOCA. Twenty-seven powered blowdown transients were performed in the testing. Loop and test section parameters were selected to simulate predicted average reactor core blowdown thermal-hydraulic conditions. All experiments were performed with a 25-rod-bundle test section having a uniform axial heat flux profile. The rod bundle had an active heated length of 4 meters (12.5 feet). The test results are discussed, including the experimentally determined times and locations of CHF. *EPRI Project Manager: K. A. Nilsson*

PWR and BWR radiation environments for radiation damage studies

NP-152 Final Report (RP304-1)

A knowledge of the effects of radiation in nuclear reactors is important for safety and reliability. For the purpose of assessing radiation-induced degradation of performance for nuclear components, it is necessary to have a complete description of the neutron fields around these components—particularly the pressure vessel, which is one of the primary containment boundaries in nuclear systems. Primary reliance is placed on a combination of analytic calculations that predict integrated fluence over plant lifetime and a series of metallurgical surveillance specimens in accelerated flux positions that can be used to monitor changes in material properties with exposure. The underpinning of this strategy depends on the ability to validate the calculations through dosimetry and to correlate changes in material properties with the characteristics of the radiation field, namely the flux and spectrum.

Science Applications, Inc., performed calculative analyses of the radiation environments that are most critical for radiation embrittlement. The studies focus on areas close to the core, at the beltline of the pressure vessel, and near regions of material discontinuities. Both axial and azimuthal variations in the radiation fields, important to consider in commercial LWRs for determination of maximum fluence locations, are considered. Spectral variations are analyzed to help correlate the results of surveillance specimens and dosimeters with material effects. *EPRI Project Manager: F. Rahn*

Fission product data for thermal reactors: parts 1 and 2

NP-356 Final Report (RP453)

The rate of production and buildup of various fission product nuclides during the operation of a power reactor must be known accurately in order to optimize the use of nuclear fuel. Information about the heat generated during the radioactive decay of such nuclides is also required for loss-of-coolant and safety analyses. In view of this need, the Fission Product Subcommittee of the Cross Section Evaluation Working Group (responsible for the development of the national reference nuclear data base, ENDF/B) has recently prepared (primarily under ERDA funding) a massive data file containing information for over 800 fission product nuclides. The principal investigators for the present project have been major contributors to the development of this file, which has been released as part of the fourth version of ENDF/B.

The objective of the project, conducted by the University of California at Los Alamos, has been the reduction of this major data base to a form more appropriate for use in thermal reactor core analysis and burnup calculations. This has been accomplished by grouping the fission product nuclides into 84 linearized decay chains and by calculating the effective fission yields and four energy group cross sections for the most important, longer-lived nuclides in each chain.

As a further simplification, a second set of 11 major decay chains, plus a "fictitious" chain accounting for the remaining nuclides, has also been prepared. The resulting libraries are given in a form that can be used directly in the computer code CINDER. This code is widely used for LWR burnup calculations, and it constitutes an integral part of the EPRI–CELL module of EPRI's fuel cycle analysis code system, ARMP. An upgraded version of the ARMP (EPRI–CINDER) has also been produced as part of this project. At present the libraries can be used in EPRI–CINDER or earlier versions of the code in a stand-alone mode. Incorporation into ARMP is being considered as a topic for a future report.

The description of the work is given in two parts. Part I gives a description of the procedures followed in reducing, processing, and testing the basic data. Part II is a user's manual for EPRI–CINDER. *EPRI Project Manager: O. Ozer*

Full-scale tornado-missile impact test

NP-440 Final Report (RP399)

The design of walls and roofs of nuclear plant auxiliary buildings to resist impact from tornado-generated missiles has most recently been based on subscale data and empirical formulas derived from military tests of limited applicability. The testing described in this report by Sandia Laboratories provides data from full-scale, simulated tornado-missile impacts on reinforced concrete walls. These data can be used directly for design and for the development of improved design and analysis techniques.

A 16-mm color-sound documentary of the tests is available for loan or purchase on written request. *EPRI Project Manager: G. Sliter*

SUNYAB–EPRI combined-injection ECCS program

NP-446 Key Phase Report (RP341)

One of the primary objectives of the SUNYAB–EPRI combined injection ECCS project is to experimentally investigate the combined top and bottom injection ECC and reflood phenomena that could occur in a simulated PWR configuration after a hypothetical LOCA.

In this report by the State University of New York at Buffalo, the system design requirements based on the above objective are established, and the results of detailed facility design are presented. Test parameters and their ranges are then defined, and the test plan for the first phase of the investigation is tabulated. Detailed drawings of facility components and computer programs, developed in conjunction with the operation of the facility, are given in the appendixes. *EPRI Project Manager: R. B. Duffey*

Assessment of methods for implementing availability engineering in electric power plants

NP-493 Final Report (TP576-662)

This report is the result of an eight-month study and evaluation by Holmes & Narver, Inc., of the applications of availability engineering methods to improve the reliability and productivity of electric power plants. Availability engineering is defined as the systematic engineering approach used to set and achieve a numeric availability goal at minimum cost. It can be applied to major components, to plant systems, to modifications of operating plants, and to new plants. It relies on the use of past experience, expressed as outage frequency and duration, to identify availability-related deficiencies in hardware, software, and personnel actions. It identifies corrective actions that must be taken to achieve the goal, considering both potential savings and costs. It identifies controls that must be imposed to prevent degradations during installation, operation, and maintenance.

The methodology of availability engineering can be applied by engineers charged with improving power plant performance. It is an extension of ongoing engineering activities that introduces the specification and assessment of outage frequency and duration as a way of controlling availability.

The study concludes that availability engineering can be a worthwhile supplement to the traditional engineering process and should be used by the industry. The study also notes that the groundwork identified above must be completed before the discipline will gain widespread use. *EPRI Project Managers: R. L. Long and D. Anson*

Plasticity theories and structural analysis of anisotropic metals—Zircaloys

NP-500 Final Report (RP456-2)

Structural elements of the modern LWR core are composed primarily of zirconium alloys, Zircaloy-2 and Zircaloy-4. In the course of diagnosing faults in the core region and in designing improved core components, it often becomes desirable to predict the mechanical response of these components to the duty cycle imposed in service. Continuing developments in the field of computer-oriented structural analysis methods are making it increasingly possible to accurately predict core component behavior under the complex loading conditions encountered in service. The results of this project represent a very significant improvement on previously available methods for describing the material behavior in the form of mathematical equations and for solving the equations in a structural analysis computer program.

The work at General Electric Co. has been part of a coordinated effort with the Massachusetts Institute of Technology and Stanford University. General Electric's responsibilities were to produce a mathematical description of the directional dependency (anisotropy) of the mechanical behavior of zirconium and to reduce the analysis method of the coordinated project to practical use. Stanford's task was to mathematically describe the non-direction-dependent behavior of the metal. All three organizations performed materials testing and contributed to the theoretical understanding of the material behavior; the MIT and Stanford work will be related in subsequent reports.

Results of this project will be of immediate use to a current EPRI fuel rod modeling project, RP971. Use by others is presently limited by two circumstances: lack of concrete recommendation on which of the several theories presented in the report best fits the combination of material and loading history; and the existence of numerical (stability) problems, which appear in some equations under certain conditions because of the mathematically inconvenient behavior of the material.

Efforts are currently under way to resolve these problems, and more general application of the methodology should become possible within the year. *EPRI Project Manager: T. Oldberg*

PWR secondary water chemistry study

NP-516 Interim Report (RP404-1)

This report by Nuclear Water and Waste Technology Corp. describes work that was initiated to help resolve problems occurring in recirculating-type steam generators in PWRs at commercial nuclear-powered utilities. The water chemistry in the secondary systems of these plants, particularly when air and cooling water inleakage occurs, is believed to be an important contributory factor to corrosion damage in steam generators.

The purpose of this study is to characterize and better understand secondary system water chemistry under all phases of plant operation and to attempt to relate the information obtained to the occurrence of steam generator corrosion damage. This will provide a better technical basis for corrective measures. Five nuclear plants are included in the study in order to encompass important system design and site-related variables and thereby extend the scope of applicability of program results: Calvert Cliffs-1, Prairie Island-1 and -2, Surry-2, and Turkey Point-4. *EPRI Project Manager: L. J. Martel*

Evaluation of electromagnetic-acoustic concepts of inspection of steam generator tubing

NP-519 Final Report (RP698-1)

Inspection of steam generator tubes is required for all PWRs. The specific in-service inspection requirements are governed by Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," of the ASME Boiler and Pressure Vessel Code. At the present time, these requirements are met with an eddy-current inspection method. Under some circumstances it would be desirable to have complementary information obtained through a different inspection method.

Recent progress in the development of noncontacting ultrasonic transducer technology shows it to be a promising method for tube inspection. Thus the primary objective of this project was to evaluate the feasibility of the noncontacting electromagnetic-acoustic concept for generating ultrasonic waves to inspect steam generator tubing. A secondary objective was the evaluation of this concept for inspecting carbon steel boiler tubes similar to those used in fossil-fueled power plants.

The results from this project indicate that it is feasible to efficiently excite ultrasonic waves in Inconel and ferritic tubes with noncontacting electromagnetic transducers and that these signals can be used to sense a wide variety of defects. Included in the demonstration was the development of a new probe that excites torsional modes in the tube wall and the formulation of design models to describe its performance. *EPRI Program Manager: G.J. Dau*

High-temperature properties of Zircaloy-oxygen alloys

NP-524 Final Report (RP251-1)

The objective of this project was to systematically investigate the behavior of Zircaloy cladding in relation to the requirements of LOCA evaluation codes. Jointly sponsored by EPRI and the Metal Properties Council (MPC), the research was conducted by Battelle, Pacific Northwest Laboratories. Five nuclear fuel suppliers (Babcock & Wilcox Co., Combustion Engineering, Inc., Exxon Nuclear Co., Inc. General Electric Co., and Westinghouse Electric Corp.) provided MPC with additional funding.

The project consisted of four research tasks that should lead to reduction in uncertainties associated with analyses of postulated LOCAs and other accidents. The ID/OD oxidation task provides the reference experimental data to characterize the relative ID/OD oxidation that could realistically occur near the rupture area during a LOCA.

The transient deformation and rupture task, combined with the mechanical deformation analysis task, provides the data base and a more general mechanical deformation analysis for assessing the biaxial time-dependent deformation and rupture behavior of Zircaloy cladding. Results from these two tasks should lead to reduction in the uncertainties associated with calculating uniform dilation (swelling) and time to rupture. These tasks also provide methodology and data needed for calculation of ID/OD oxidation, flow blockage, and gap conductance.

The task on high-temperature properties is the subject of this report and provides data on several physical properties critical to the LOCA analysis for Zircaloy cladding. Property measurements were made to temperatures as high as 1538°C (2800°F) at various oxygen levels and thus provide a data base for LOCA heat-up analyses as well as cool-down and quench analyses. Properties measured include thermal expansivity, thermal emittance, elastic moduli, and thermal diffusivity. *EPRI Project Manager: J. T. A. Roberts*

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