# Foundations of Nuclear Power

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Cover: The first four decades of nuclear power recorded from the Navy's propulsion reactors to today's electricity-generating reactors.

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# No Real Alternative

It took over six centuries from the invention of gunpowder in China to the harnessing of explosives for useful purposes, such as construction or mining. Yet it took only six and a half years from the first nuclear explosion at Alamogordo on July 16, 1945, to the first generation of electricity by fission power on December 20, 1951, by the experimental breeder reactor. We should take pride in this swift forging of plowshares. But perhaps it is just because we succeeded so quickly that opponents of nuclear power are unable to separate the image and terror of the mushroom cloud from the peacetime use of atomic energy to generate electric power.

We certainly have a better perspective today than two decades ago when many were pushing atomic energy as a panacea. In the late 1950s, so favorable and glamorous was the public image of nuclear energy that a *Wall Street Journal* reporter observed, ''All that a company had to do if it wanted to move its stock up a point or two on the market was to issue a press release announcing that it had hired a nuclear physicist—the reaction was automatic.''

In the late 1970s we have departed so far from that point that we find some people embarked on an antinuclear crusade, disrupting the orderly buildup of a proven, needed technology that can generate electric power by the cheapest, cleanest means available today. They overlook the fact that in the brief 24 years since the start of a nonmilitary nuclear program, nuclear power has become an important contributor to this nation's total electricity generation, contributing more than all our hydropower dams. Further, during this period we have accumulated 275 plant-years of safe experience with central-station-type civilian reactors.

We should now ask, what are our energy needs and will curtailment of nuclear power development and use have disastrous effects on our country? Central to the question is our large and growing dependence on foreign oil. Last year we imported $45 billion in oil to satisfy about one-third of our total energy requirements. This resulted in a net imbalance of payments sufficiently high to seriously weaken the dollar in the international money markets and to diminish our foreign policy independence. In effect, jobs are flowing overseas in exchange for oil. At best this is a precarious balance, and one effort to stabilize the situation has been a call for utilities to convert to alternative fuels.

Should we delay, we aggravate the situation. Last year the Federal Power Commission warned of the ''distinct possibility'' of electricity shortages as early as 1979 and ''almost certainly'' by the mid-1980s; Mitre Corp. foresees shortfalls that could reach critical proportions in some regions by 1985. The demand for increased power generation is already built in. Even if we strive for zero population growth, children already born mean more households and increases in the labor force that in turn will require more power. Inadequate power will mean fewer jobs; reduced income and frustrated ambitions; curtailed and more costly transportation for people and for goods, thus built-in rising prices for almost every commodity on the market. Proponents of nuclear power believe that without nuclear power the nation will face massive and restrictive power shortages in coming decades.

To visualize this bleak projection, we need only remember the recent past. What would have happened during the last two unusually harsh eastern winters if nuclear power had not been available to help avert a crisis? When riverborne oil barges and utility plant coal piles were frozen and the fuel shortage was compounded by the four-month coal strike, it was the nuclear plants with their built-in year's fuel supply that helped to save one-third of the nation from unheated homes in subfreezing weather, electrified transport at a standstill, and hospitals without power.

Some ask why our increased energy needs can't be supplied by other new technologies. Just three years ago Robert Seamans answered this question at the EEI annual convention: "The public needs to know that there is not a viable alternative to nuclear power. Too often we hear from a segment of the public that we ought to forgo nuclear power and go directly to solar energy and fusion. The public must realize that significant quantities of any of the options are *at least* several decades off, and further, large additional funding of the programs now will not advance significantly the timetable. Even with accelerated production, coal alone cannot be expected to satisfy the nation's growing need for energy over the next several decades. The remainder of the need must be filled by nuclear."

In order for nuclear to make up the energy deficit, certain measures are urgently needed at this time. One is a demonstration of our ability to safely dispose of waste. While it is true that we cannot yet point to a waste-vitrification facility in the United States and say, "Look, here it is, it works, it's safe," we can say that about a facility that has been operating for four years at Marcoule in France (where a second, commercial-size plant went into operation last month). We too have the technology, but because of the low priority assigned by the government, we have not been able to demonstrate that technology.

Another problem is the delay in licensing. We must return to a rational lead-time in building nuclear power plants. As an example of the time we are losing, only three months ago an American reactor vendor started up a 1100-MW nuclear plant in Japan 6½ years after beginning the licensing process. A plant in the United States by the same vendor is currently scheduled to start up after 13½ years, 7½ years behind the original schedule.

Perhaps the most pressing need is an educational effort that recognizes the reasons some fear atomic energy, explains the difference between military hardware and the generation of electric power, and presents the evidence for our conviction that nuclear power is the cleanest, safest, and cheapest form of energy among today's technologies.

M Levenson

Milton Levenson, Director
Nuclear Power Division

# Authors and Articles

For those of us who mentally catalog nuclear reactors simply as PWRs or BWRs, the utility inventory of nuclear power plants is one of evident order. But these grow on a family tree that has many roots and has at times grown like a tangled vine. Dozens of other varieties have risen in scientific seedbeds, been grafted and hybridized—only to be pruned by technical or economic shears or to die back from policy malnutrition.

In "The Birth and Early History of Nuclear Power" (page 6), John Kenton traces the development of our familiar PWRs and BWRs, competitors since they first raised steam for power only two years apart. As the *Journal*'s nuclear editor, Kenton easily comes by his knowledge of this historical evolution. He was an editor of *Nucleonics* from 1955 to 1967, and also of *Nucleonics Week* from its beginning until 1967. He followed the nuclear power industry thereafter on the staffs of *Scientific Research* and *Nuclear Industry*, before coming to EPRI in 1976.

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One of the forces that nurtures the various energy technologies is national energy policy, conceived by the White House but shaped and given authority by Congress. That policy reflects, among other things, the collected U.S. political, economic, technical, and social data housed in national libraries.

The "Research Arms of Congress" (page 16) reach into these resources for facts and digests, precedents and opinions, and even for original research. Who they are and what distinguishes the strengths and skills of those congressional agencies is explained by Marie Newman of EPRI's Washington Office.

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Mauna Loa volcano on the island of Hawaii is speaking today in a quiet voice that demands our attention. There, on a slope 11,150 feet above the Pacific and 2200 miles southwest of the mainland United States, a meteorological station registers the rising atmospheric concentration of carbon dioxide.

The 20-year record is incontrovertible. And it also exhibits a seasonal pulse. Why? What mechanisms are at work? How fast? What do they mean for civilization? "$CO_2$ and Spaceship Earth" (page 22), by Stan Terra, surveys the scientific facts and opinions that are only now beginning to coalesce.

Before joining the *Journal* staff two years ago, Terra spent 18 years interviewing scientific, business, university, and government figures. He has reported for *Time* and *Business Week*, and at one time he covered government affairs from Washington, D.C., for a group of daily newspapers. In his research into $CO_2$, Terra found scientists who differ in their assessments. He also found uniform recognition that $CO_2$ is a pervasive byproduct of worldwide energy uses and agricultural practices. Mauna Loa's persistent voice clearly calls for a new research priority.

The oil barrel isn't empty, but other resources will take time to develop, and some of the new ones are going to be expensive to concentrate into useful form. Understanding these points influences one's view of national energy priorities and the technological avenues to follow. Chauncey Starr puts all of them into the context of "The Electricity Future: What Can You Believe?" (page 28), which asks—and answers—a question often put to utilities. Formerly president and now vice chairman of EPRI, Starr wrote the article as a speech before the Commonwealth Club of California in San Francisco last May.

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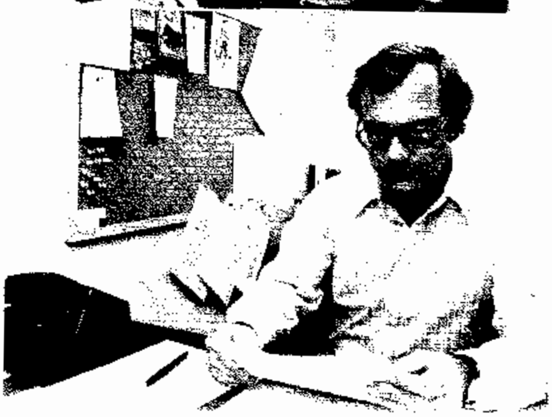
When EPRI's Board of Directors convenes, its agenda is filled with facts, policy options, and recommendations from EPRI management. When the Board adjourns, that agenda has been distilled into corporate resolutions that sustain the Institute's R&D programs.

Whatever the agenda during the last four years, it got the full attention of "Louis Austin: Down-Home Realist" (page 32). After leaving the Board last May, the chief executive of Texas Utilities talked at length with the *Journal*'s Stan Terra, stating opinions that sometimes register at a simmering temperature, sometimes at a boil, and occasionally at the level of a Texas barbecue.

Kenton

Starr



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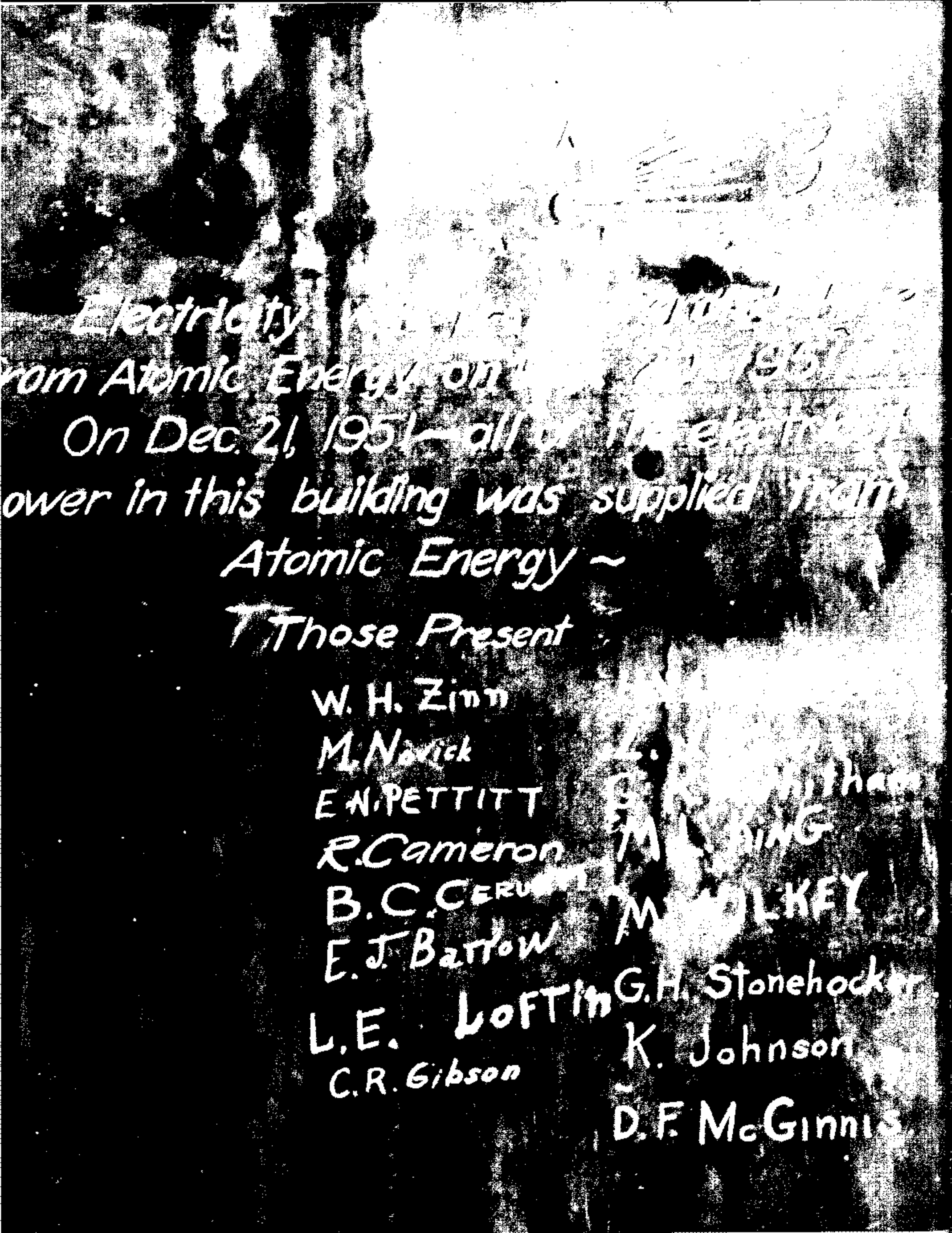

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D.F. McGINNIS

by John E. Kenton

# THE BIRTH & EARLY HISTORY OF NUCLEAR POWER

A decade of work on nonmilitary uses preceded the first token generation of electricity by a reactor in the Idaho desert in 1951. The technology has since come a long way.

Leicester, England, 1933. Sir Ernest Rutherford, one of the greatest contributors to our understanding of atomic structure, stood before the British Association for the Advancement of Science and declared: "The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine."

Only 25 years later, Lewis Strauss, second chairman of the U.S. Atomic Energy Commission, asserted that nuclear power would make electricity so cheap it would not be worthwhile to meter it.

It appears that nuclear power has been so fundamentally new to our experience that even experts are led into extremes of thought and comment. Yet in less than 50 years, nuclear generation of electric power has been transformed from "moonshine" into the source for 12% of the electricity used in the United States. Following Lord Rutherford's 1933 statement, a series of interesting and rapid technological and political developments took place that gave us the nuclear reactors in use today.

### Fertile imaginations

The majority of the world's electric power reactors are based on prototypes developed by the U.S. Navy, whose scientists were the first to grasp the potential of the controlled use of nuclear power. Ross Gunn, technical advisor to the director of the Naval Research Laboratory, saw the implications as far back as January 1939, when Niels Bohr and Enrico Fermi reported to the 5th Washington (D.C.) Conference on Theoretical Physics the startling news that Otto Hahn and Fritz Strassman in Berlin had split the uranium nucleus, releasing a significant amount of energy. Two months later Fermi briefed the Navy

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In the remote desert of southern Idaho, EBR-1 powered light bulbs to demonstrate the first production of nuclear power harnessed for peaceful purposes.

Department. While most of the naval staff present were thinking in terms of a weapon, Gunn was pondering the feasibility and potential of a nuclear propulsion engine that could power a submarine. Because a nuclear engine would require no oxygen, the ship would be liberated from the surface, except for reprovisioning.

On November 1, 1939, President Roosevelt's Advisory Committee on Uranium reported that a chain reaction was possible. "If it could be achieved and controlled," the report continued, "it might supply power for submarines. If the reaction should be explosive, it would provide a possible source of bombs with a destructiveness vastly greater than anything now known."

Gunn immediately contacted Merle Tuve of the Carnegie Institution, and a program to study the idea of nuclear-powered submarines was set up with $1500 in Navy funds. In 1940 Tuve reported that submarine propulsion appeared more practical at that moment than an atomic bomb.

The Navy maintained its interest in propulsion throughout World War II, even though early in the war the decision was made to go for the weapon first. The atomic bomb project was assigned to the Army. In the summer of 1942, with General Leslie R. Groves in charge, the A-bomb organization, code-named the Manhattan Engineering District (MED), was established.

The story of MED and its feverish race to fabricate an atomic bomb before the Nazis has often been told. While MED was concentrating the nation's best scientific talent on the awesome problems of mastering an unknown science, the concept of harnessing nuclear power for peaceful purposes continued to occupy farsighted minds. Fermi himself wrote that even as his team of physicists was shutting down the Stagg Field pile on December 2, 1942, the day the world's first controlled chain reaction was achieved, "We all hoped that with the end of the war emphasis would be shifted decidedly from the weapon to the peaceful aspects of atomic energy."

For about a decade following the Stagg Field experiment, all reactors were called piles. The original pile, built under the west stand of the Stagg Field stadium of the University of Chicago, was exactly that: a stack of graphite bricks piled in a large cube, with uranium buttons spaced at intervals in each layer. Later, as the configuration of chain-reacting devices diverged increasingly from the simple pile, the term *reactor* was borrowed from the chemical industry, where it denotes a vessel in which a reaction is made to take place.

### Earliest concepts

By 1944, a year before the war ended, at least five major reactor concepts were being considered.

Farrington Daniels, a University of Wisconsin chemist working in Chicago in MED's Metallurgical Laboratory (a screen, as its work was mostly in nuclear physics and chemistry), was planning a high-temperature power pile cooled by helium gas. On the recommendation of General Groves's Advisory Committee on R&D, Daniels and his team were later moved from the Met Lab (forerunner of Argonne National Laboratory) to Clinton Laboratories (forerunner of Oak Ridge National Laboratory).

Also at the Met Lab, Walter Zinn conceived a reactor that would breed more fissionable material than it consumed. This rabbits-from-a-hat trick would be accomplished by surrounding the chain-reacting core of a reactor with a blanket of natural uranium or thorium. Neither the uranium-238 isotope, which is the preponderant (99.3%) constituent of natural uranium, nor thorium-232 is fissionable; however, when exposed to a field of free neutrons, the nuclei of both uranium-238 and thorium-232 will absorb a neutron. As a result of this neutron capture, nonfissionable thorium-232 is naturally transmuted to uranium-233, which *is* fissionable; and nonfissionable uranium-238 is transmuted to plutonium-239, also fissionable. The hope was that during operation, more fissionable material would be created in the reactor blanket than was "burned" in the reactor core. Hence the term *breeder.*

By the end of 1945 Zinn was determined to try to build a fast-neutron, liquid-metal-cooled breeder pile, using highly enriched uranium (mostly fissionable uranium-235) in the core, with a natural uranium blanket to breed plutonium.

At Los Alamos Scientific Laboratory, Philip Morrison was working up a proposal to build a 10-kW fast-neutron pile using plutonium fuel.

A fast-neutron pile is one that does not use a moderator—the material placed in the reactor core to cushion and absorb some of the very high energy of neutrons at the moment of their release from a fissioned nucleus. With certain nuclear fuels, omitting the moderator increases the probability of further fissions to maintain the chain reaction. (Graphite was the moderator in the Stagg Field pile and in other early piles.)

At Clinton Laboratories, a radically different kind of pile was conceived—a pile in which the fuel would be in a homogeneous state, such as a solution of uranium-235 salts in water. Unlike the more common heterogeneous pile in which the fuel is in the form of discrete metal strips, rods, or cartridges, and a liquid or gaseous coolant is pumped past it to pick up its heat and carry it to a heat exchanger, the homogeneous pile circulates the fluid fuel itself. The fuel is allowed to become critical (i.e., chain-reacting) in a spherical tank whose geometry permits enough of the fuel solution to gather to form a critical mass. The reaction heats the solution, which is pumped out of the tank through narrow pipes in which it becomes subcritical, is passed through a heat exchanger (which boils water to steam), and is returned to the tank. The Clinton group proposed a 10-MW demonstration of this type of reactor, but it was to be 1950 before a smaller homogeneous reactor pilot plant was approved.

From the Naval Research Laboratory (NRL) came still another pile concept; this one used a novel metal coolant—a sodium-potassium (NaK) alloy that is liquid at room temperature.

The NRL concept was the subject of a March 1946 report by Philip Abelson, a civilian physicist with the Navy who had shared Gunn's early vision of nuclear propulsion. Abelson proposed building a nuclear-powered submarine in two years. Vague in many respects, his report is nevertheless the first concrete proposal in Navy archives for the construction of a nuclear submarine. The idea of using liquid metal as the heat transfer medium caught the attention of an engineering executive at General Electric Co. and led to a proposal from that company in May 1946 for a study of a nuclear-powered destroyer.

So by January 1947, there had been two years of work and activity on controlled nuclear power.

#### First project

The first formal power reactor project was the Daniels pile that was set up by MED at Clinton Laboratories. In March 1946, Charles A. Thomas of Monsanto Chemical Co., the operating contractor for Oak Ridge, proposed that the Navy participate in a joint government-industry project to build the Daniels pile.

Also early in 1946 General Groves, then still in charge of everything nuclear, suggested that the Navy assign a few engineering officers to Oak Ridge to learn the fundamentals of nuclear technology. This was to prove a key event.

In June 1946 a Navy team of five officers and three civilian physicists and engineers arrived in Oak Ridge to learn nuclear technology, work with the Daniels group, and lay the groundwork for a possible nuclear propulsion engine. The senior officer in the group was an electrical engineer, Captain Hyman G. Rickover.

Although the Navy had intentionally not named him officer-in-charge of the group because of differences of view among the leaders of the Navy's Bureau of Ships, Rickover soon took charge by sheer force of personality. The terms of the team's assignment specified that each of the five Navy officers would report to the Army command at Oak Ridge, but Rickover obtained authorization to write his fellow officers' periodic performance reports and thereby formalized his leadership of the team.

The Navy team soon learned that several of the scientists at Oak Ridge were unimpressed by the Daniels project, primarily because the Daniels group's technically ambitious plans included little systematic effort to define engineering problems. Rickover worked tirelessly to master the details of the arcane new science and insisted on relating nuclear physics and chemistry to the specific engineering problems of putting together a nuclear propulsion engine.

In 1946 Rickover's team heard Alvin M. Weinberg, leader of the Clinton physicists, suggest the possibility of using water under high pressure both as the heat transfer medium and as the moderator of a power reactor. The Navy men saw that for submarine application a liquid would be better than a gas coolant because it permits greater compactness in the coolant and it eliminates the bulk and weight of a graphite moderator stack.

After much competition among concepts and personalities and much project infighting in MED and in the Navy, the Daniels project was quietly abandoned (as Rickover had predicted would happen). The Navy—with Rickover now back in Washington, ceaselessly prodding—shortly took action.

The Navy planned to develop and build a land-based prototype and a seagoing version of each of the two most promising reactor concepts: the high-pressure water type and the liquid-metal-cooled type. A third type, helium-cooled with direct-cycle gas turbine, was also worked on under a contract with Rickover but was eliminated by 1949.

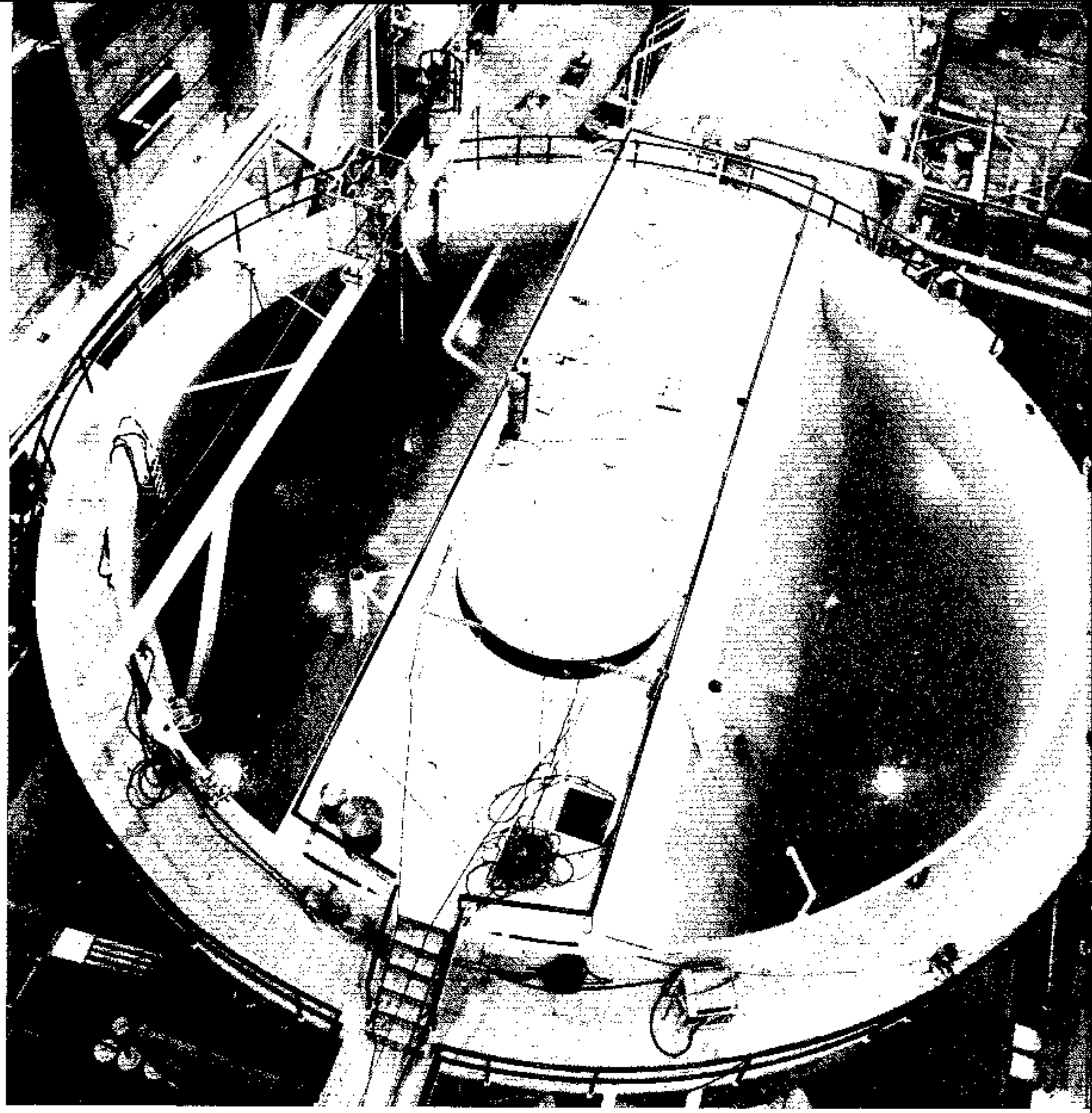
The first submarine reactor project was formally established in April 1948 at Argonne National Laboratory. This was the high-pressure water project; Westinghouse Electric Corp. was the prime industrial contractor.

Never one to leave his ace uncovered, Rickover continued working with General Electric Co. to develop the liquid-metal reactor as an alternative to the water reactor. However, the company was more interested in nonmilitary electric power than in a nuclear-powered submarine and wanted to build a liquid-metal-cooled power breeder as a nonmilitary power reactor prototype. As the company continued work on its power breeder, there was less and less certainty that the proposed design would indeed reach threshold conditions for breeding. After protracted negotiations, the Atomic Energy Commission (successor to MED) told General Electric in March 1950 that it would not authorize construction. The next month AEC and General Electric established the liquid-metal-cooled submarine project, which included a land-based prototype to be built at West Milton, New York, and an identical reactor to be installed in a submarine.

#### First civilian power experiments

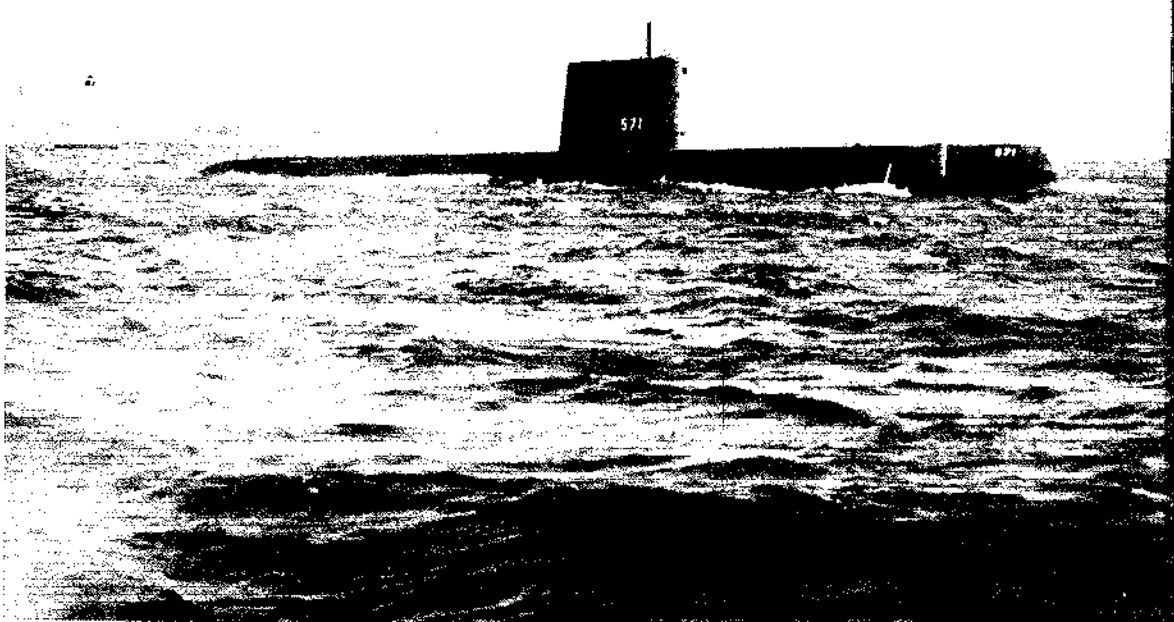
In 1949 AEC authorized construction of Zinn's experimental breeder reactor (EBR) at the National Reactor Testing Station (now the Idaho National Engineering Laboratory [INEL]), which it had established in the Idaho desert. Construction began late in 1949, and the small liquid-metal-cooled fast-neutron breeder reactor (LMFBR) was completed in 1951. A 100-kW turbine-generator was attached, and on December 20, 1951 —only 9 years, 18 days after Fermi's pioneering Stagg Field experiment—EBR became the world's first reactor to produce net electric power in kilowatt quantities.

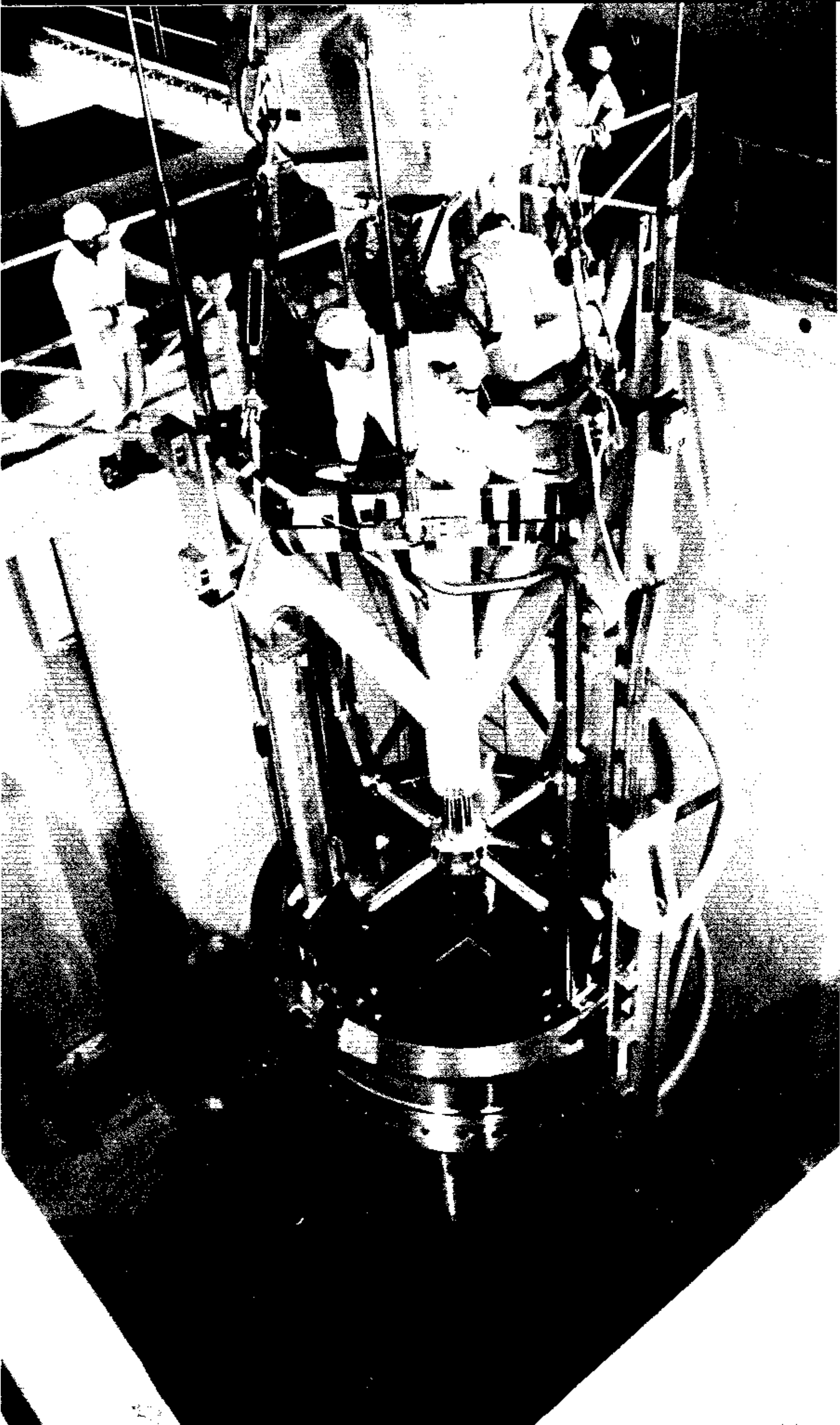
Meanwhile, a group at Los Alamos, working along the same lines as the Oak Ridge homogeneous reactor group, built a small demonstration reactor that was called the water boiler because an aqueous solution of uranium salt was brought to a boil (this should not be



At the Idaho reactor testing station, the prototype nuclear submarine reactor was built in a simulated submarine hull within a water tank, tested, debugged, and proved before its twin went to sea aboard the *Nautilus.*

*Nautilus*, after sending her famous message, "Under way on nuclear power," steamed out of the Groton, Connecticut, harbor on her first sea trial—only 17 days past the target date set 8 years earlier.





The first core of uranium fuel elements is lowered into the reactor vessel at Shippingport. A scale-up of the *Nautilus* reactor, this reactor was originally intended as an aircraft carrier propulsion plant but was redesigned and developed for utility use, becoming the first commercial-scale nuclear power plant in the United States.

confused with today's boiling water reactors). In early 1950 AEC authorized Oak Ridge to build a larger reactor of this type. The homogeneous reactor experiment (HRE) was completed and started up in 1952.

By March 1952 the first catalog of the world's nuclear reactors showed 33 having been operated, in operation, or under construction in Canada, England, France, Norway, the Soviet Union, and the United States. In addition, there were plans for construction of reactors in Argentina, Belgium, Brazil, Canada, France, Holland, India, Mexico, and Sweden. However, most of these were designed for plutonium production for weapons, scientific research, or civilian isotope production, and only a third or fewer for the development of reactors for central station power. A majority of the reactors were graphite (with air or gas coolant) or heavy water moderated.

One divergence in reactor design was based on the fact that most of the world's uranium-enriching capability was in the United States. Consequently, there was a great incentive in Europe and Canada to use natural (unenriched) uranium as fuel, which inherently favored larger reactor types. This led toward a graphite moderator with gas cooling (the choice of Britain and France) or a heavy water moderated and cooled unit (the choice of Canada). In the United States, the availability of enriched uranium made compact reactor types readily feasible, and the submarine application placed a premium on compactness.

Although EBR and HRE operated successfully, Rickover obtained top priority for the submarine projects, and they received most of the attention and available manpower during the early 1950s.

### Inventing on schedule

In 1948 Rickover dared to set a target date of January 1, 1955, for the first nuclear submarine to put to sea. The technological task that faced the engineers, physicists, and metallurgists at Argonne and at Bettis Atomic Power Laboratory (which Westinghouse set up for the Navy) to achieve Rickover's target was immense.

An ideal metal to contain the uranium fuel had to be found. The rare metal zirconium had good corrosion resistance and promised efficient use of uranium (then still in short supply) because of zirconium's low affinity for neutrons. But it cost almost half a million dollars a pound. Under Rickover's relentless driving, the Bureau of Mines developed a less expensive method for producing adequately pure zirconium, and Bettis developed the alloy Zircaloy.

The problem of shielding the reactor to protect the crew in the cramped confines of a submarine had to be solved. A reactor control material and a control rod drive system had to be developed. Special canned motor pumps to drive the high-pressure water coolant through the reactor had to be developed to meet the no-leak, limited-access, low-maintenance, no-lubrication requirements.

These are but a few of the many technological problems for which solutions had to be invented on schedule for the submarine program. Despite these hurdles, on January 17, 1955, only 17 days past the target date Rickover had set seven years earlier, the USS *Nautilus* sent her famous message, "Under way on nuclear power."

A year and a half before the *Nautilus* left the dock at Groton, Connecticut, at the reactor test station some 2200 miles away in the Idaho desert, the twin of her reactor was put through a simulated submerged transatlantic crossing and other rigorous shakedown tests. The submarine thermal reactor (STR) Mark I prototype first went critical (sustained a chain reaction) on March 30, 1953, and the following day generated several thousand kilowatts of thermal energy. In June the 100-hour simulated transatlantic run at full power was held. The Mark I thus became the world's first reactor capable of producing practical amounts of energy on a sustained and reliable basis. This event first demonstrated to naval strategists that a new era in ship capability was beginning, a fact corroborated a year and a half later by the *Nautilus.*

### Surface ship reactor

The tremendous momentum generated by Rickover's determination to get a nuclear-propelled submarine was shortly to carry over from the pressurized water reactor to central station power.

In July 1952 Rickover, acting in his two-hat role as head of AEC's naval reactors branch and as assistant chief for nuclear propulsion of the Navy's Bureau of Ships, expanded the contract with Westinghouse to include development of a nuclear power plant to drive large surface ships. At the close of FY53 the military requirement for the large ship reactor was eliminated. However, the pressurized water reactor (PWR) design that was to be scaled up from submarine size held enough promise for central station power that AEC decided to continue R&D.

### Five in five

In 1953 AEC adopted the first coordinated central-station nuclear power effort in the form of a five-year, five-reactor program to prepare the way for private industry to enter the field of nuclear power. In March 1954 Congress approved a budget of $199 million. The program was made possible by the Atomic Energy Act of 1954, which ended federal monopoly over the nonmilitary atom.

Included in this program were:

▫ PWR: the former large ship reactor now adapted for the utility industry's use, with an output of 60 MW. However, PWR development was still directed within AEC by Rickover's naval reactors branch, with little direct industry access. (The PWR facility, located west of Pittsburgh, is now known as Shippingport Atomic Power Station.)

▫ SRE: sodium reactor experiment, a graphite-moderated, liquid-sodium-cooled unit to be built in the Simi mountains northwest of Los Angeles, with an output of 5700 kW.

▫ HRE-2: a scale-up of Oak Ridge's HRE, with an output of 300 kW.

▫ EBR-2: a follow-up of Argonne's first EBR, complete with its integral fuel-reprocessing plant, with an output of 16.5 MW.

▫ EBWR: experimental boiling water reactor, a new entrant among reactor types, to be built at Argonne National Laboratory near Chicago with an output of 4 MW. This was, most simply, an unpressurized PWR. Not under high pressure, the water coolant was allowed to boil in the reactor vessel and was piped directly into the turbine without an intervening heat exchanger (steam generator).

It is startling today to recall that AEC, while billing the PWR as the first full-scale central-station nuclear power plant in the United States, regarded it as "clearly of conservative design with a poor long-term prospect for producing low-cost atomic power." So great was the value placed on high efficiency of heat transfer that sodium-cooled systems were thought to have intrinsically higher chances of yielding economic nuclear power.

The champions of homogeneous reactors relied on HRE's inherent simplicity: it was but "a pipe, a pot, and a pump" (as was said at the time) and avoided the heterogeneous reactors' need for a fuel fabricated like a Swiss watch.

Advocates of the breeder acclaimed its more efficient use of uranium.

The EBWR was an attempt to simplify the PWR by eliminating the heat exchanger. This had been suggested earlier, but there were fears that boiling in the core—entailing rising steam bubbles, which constitute voids in the water moderator—would cause continual changes in reactivity and consequently unstable operation. Another concern was that impurities in the water activated in the core might deposit in the turbine, making it too hot for contact maintenance.

An Argonne nuclear engineer, Samuel Untermyer II, proposed testing the first assumption. A small boiling reactor experiment called Borax was built at the Idaho testing station in 1953 and tested to destruction by imposing precipitously high rates of power increase. It was shown that the formation of steam in the reactor completely quenched the nuclear reaction before a dangerous temperature was reached. The stable operation of the BWR was proved, and a pilot plant in utility configuration was included in the five-year program. The EBWR went critical in December 1956, supplied part of Argonne's power for a decade, and showed that carryover of radioactivity to the turbine was not a major problem.

General Electric, whose power breeder had not made much progress, was still anxious to establish a position in the beckoning field of central station nuclear power. With Westinghouse entrenched in PWR technology, General Electric engaged Untermyer, built a slightly larger version of EBWR in California, and adopted the BWR concept.

By 1957 four of the five units in the five-year program had started up (EBR-2 was not to do so until 1963), and all operated successfully. However, HRE-2 had problems preventing uranium in the circulating fuel from settling out. The project was terminated after such a plate-out of uranium on the inside of the reactor vessel formed a hot spot and burned a hole in it.

The next step was to translate the results and successes of the five-year program to commercial practice. Impatient, AEC didn't await completion of all five reactors. As early as 1955, only one year after funding by Congress, it announced federal financial assistance for utilities willing to invest effort and capital in building a nuclear power plant. This was the first round of the Power Reactor Demonstration Program, and out of it came the Yankee Rowe uranium-cycle and Indian Point thorium-cycle PWRs, the Dresden-1 BWR, the Hallam sodium-graphite reactor, and the Fermi fast breeder.

### Sodium at sea

In 1955 General Electric's land-based prototype of the sodium-cooled submarine reactor started up; in 1956, propelled by its duplicate, USS *Seawolf* went to sea. Although the *Seawolf* had corrosion leaks in the superheater of the sodium-to-water heat exchangers and could operate at only 80% of design horsepower and 90% of maximum design speed, her reactor performed notably well. *Seawolf* steamed 71,600 miles in 18 months on the first core, and during that entire period no one entered the reactor compartment—there was no need to.

However, the Navy faced an embarrassment of riches. *Nautilus* had performed so well that a successful effort to solve *Seawolf*'s heat exchanger corrosion problem would have resulted in two nuclear propulsion modes requiring separate systems for backup and spare parts and separate training for the crew and engineers. Because this was clearly impractical and uneconomical, the Navy gave sodium-cooled reactors an honorable discharge.

### Other PWR challenges

By the middle of the 1950s, light-water reactors—pressurized or boiling—were the dominant type of reactors in use.

A few more reactor concepts appeared but lacked staying power. AEC built a pilot plant of an organic-moderated reactor—essentially a PWR flowchart using an organic (terphenyl) heat transfer agent as coolant and moderator. The municipal utility of Piqua, Ohio, built an 11.4 MW scale-up, but the terphenyl tended to decompose in use. In another venture, the molten salt reactor (MSR) experiment, AEC tried to recapture the basic simplicity of the homogeneous type while avoiding its pitfalls by using molten uranium fluoride salts as coolant. Although two MSR pilot plants performed well at Oak Ridge, an industry group has been unable to obtain support for a utility-scale demonstration of the molten salt concept.

Four small reactor experiments at Los Alamos tested novel variations of the homogeneous and gas-cooled types but went no further. Utilities tried out two other types: boiling water with integral superheat and pressure tube with heavy water moderator. These, too, operated a few years but without follow up.

The early lead of the PWR gave light water reactors a lead that proved insuperable, despite Rickover's attempts to protect military security by isolating naval PWR technology from industry and despite AEC's original low opinion of PWR's commercial prospects.

Only one other concept really challenged the light water reactor concept—the high-temperature gas-cooled reactor (HTGR). Shortly after the United States launched its five-year program, Britain started up dual-purpose full-scale plants for military plutonium and commercial power. It was a shock to the United States when Britain officially opened its Calder Hall nuclear station amid much fanfare on October 17, 1956, with Queen Elizabeth throwing the switch. Congressional leaders, afraid the United States might be missing a good bet, pushed hard for the gas-cooled concept and insisted that AEC build an experimental gas-cooled reactor (EGCR). EGCR was almost completed at Oak Ridge but was never started up.

A utility group meanwhile built an improved version that operated at a higher temperature and efficiency, the 40-MW Peach Bottom-1 plant, which ran successfully for eight years and was retired in 1974 only because it was too small to be economic. Peach Bottom-1 led to a 330-MW scale-up at Fort St. Vrain, Colorado, and to the design of 770- and 1200-MW units. Several of these units were ordered but were eventually canceled for a number of commercial reasons, including a nationwide utility financing crisis in 1974.

#### Economic nuclear power

Which reactor type would make nuclear power economic was the overriding question among those interested in nuclear power in the late 1950s. Cost projections were the rage, and endless papers analyzed the obstacles to reaching the competitive goal of 6 mills/kWh.

Suddenly, economic nuclear power was achieved. Yankee Rowe had been constructed within budget and schedule; Yankee Rowe, as well as Dresden-1 and Indian Point-1, had performed reliably for two to three years under the scrutiny of the nation's utility executives.

In 1963 Jersey Central Power & Light Co. published an economic analysis explaining its choice of nuclear over coal for its next large generating station. This analysis, which became widely known as the Oyster Creek Report, caused a sensation. Until that time, many utilities had justified nuclear projects on the grounds of preparing for the future, getting in on the ground floor, and patriotically supporting a national effort. Now for the first time a utility decision to go nuclear had been made on strictly commercial grounds, and the calculations leading to that decision had been published in detail.

The effect was like breaking a logjam. In 1963, 3 other nuclear plants were ordered; in 1965, 7; in 1966, 20; in 1967, 30; in 1968, 14. By the end of 1969, 91 units had been ordered. Also in 1969, the units bought in 1963 came on-line and utilities were able to begin judging performance. By the end of 1972, 160 units had been ordered.

What finally made nuclear power economic to the utilities was the scale factor. It had been recognized early that the chain-reacting device with power conversion capability would favor large units because of engineering design effects on capital cost. What perhaps had not been expected was the pace of scaling up. Yankee Rowe at 175 MW and Dresden-1 at 180 MW were the largest reactors built or planned in 1960 when two California utilities proposed building reactors that seemed huge by comparison—reactors of 300 and 360 MW. In 1962 the Yankee group announced plans for a second unit, Connecticut Yankee, at 575 MW. The next year came Oyster Creek at 650 MW. From there it was but a small step to the first 1000-MW reactors announced in 1966 by the Tennessee Valley Authority for the three-unit Browns Ferry station. Today there are 11 nuclear units of 1000 MW or slightly higher output in operation in the United States. The 1300-MW Biblis-B reactor in West Germany is operating, and Electricité de France has begun to build the first 2 of 18 PWRs of 1300 MW each, which it has on order.

#### The LMFBR

All but 1 of the 70 power reactors operating in the United States today are LWRs, and similar trends are emerging in Europe. France and the USSR have adopted the PWR; Britain may follow suit; and Germany is now building and exporting LWRs.

Aside from the HTGR, which is being reevaluated, the LMFBR is the only type still under serious consideration. The Fermi fast breeder is the only commercial LMFBR to have operated (intermittently from 1963 to 1973), but it was plagued by technical and institutional difficulties because it was years ahead of its time in design sophistication. Although enmeshed in controversy today, the breeder is felt by many to have a vital role because it could extend the energy content of uranium supplies by 60 times—making uranium a greater energy resource than all other fuels combined.

Much less has happened in nuclear technology in the last 15 years than in the previous 15. There have been marked advances, to be sure. Fuel performance and design have moved forward. Protection against design-basis accidents has become much more sophisticated. But fundamentally, the world's selection of the LWR as the predominant power reactor type was probably determined by the success of the USS *Nautilus* in 1955.

# Research Arms of Congress

In making decisions on such complex issues as energy, Congress draws on four of its own agencies to supply information and analyses.

Consider the decisions faced routinely by a U.S. senator or representative. In the course of a single workweek, he or she may deal with issues as diverse as natural gas pricing, drug regulation, tax increases, and labor reform. Often complex and technical, today's issues generate masses of information from a multitude of sources. How does a legislator assemble and digest the information, unravel the complexities, and analyze the policy options?

There is no single source of support. Legislators have traditionally drawn on agencies in the executive branch, universities, constituent groups, interest groups, and research institutes and have distilled much of their information through the congressional hearing process. They have also relied heavily on their committee staff who are expert in specific areas.

In recent years, however, Congress has recognized the need to strengthen its independent information-gathering and policy analysis capability. In part, this has been a result of limited staff resources and burgeoning information, and in part, it has stemmed from a desire by Congress to match in key areas the analytic capability of various sections within the federal government.

In the past decade, Congress has established two new organizations to act as information and research support arms, and it has expanded the roles of two other organizations that were formed in the early part of the century. In the studies they conduct, the reports they prepare, and the services they provide, the four research arms reflect the current priorities of Congress, and in some cases, indicate future trends and interests.

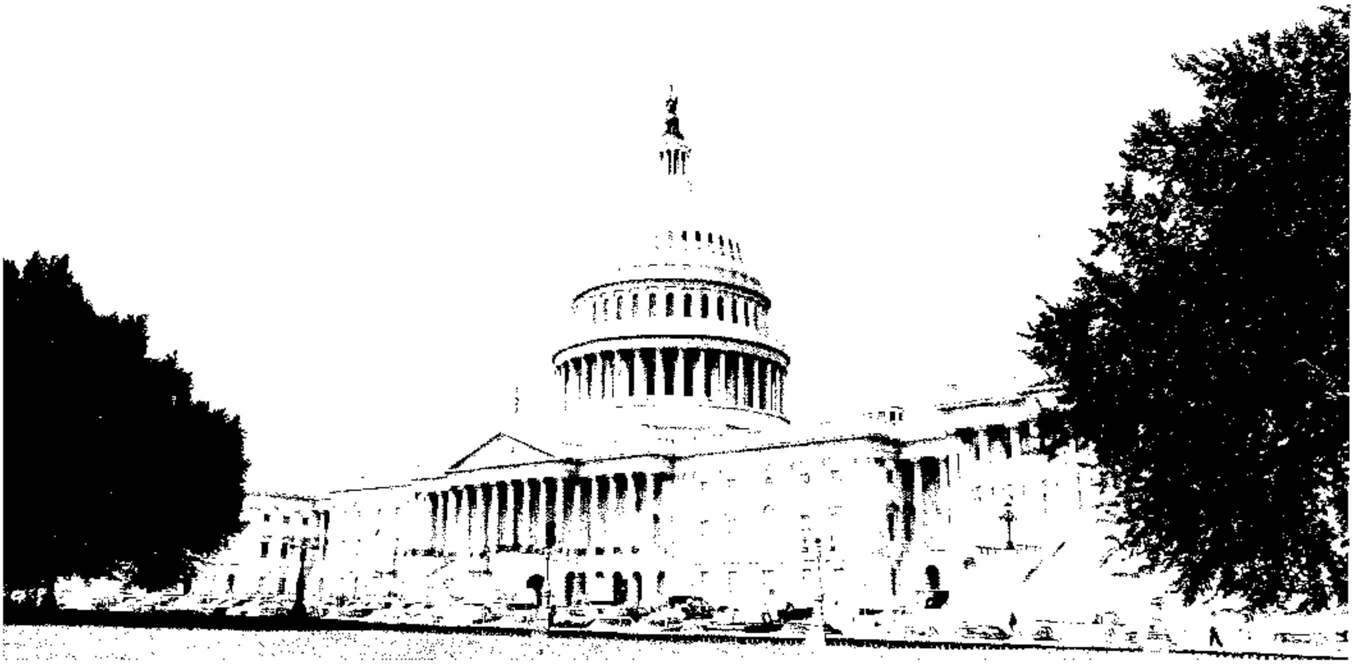
### Who they are

The Congressional Research Service (CRS) is the oldest of the support agencies and dates back to 1914, when it was formed as part of the Library of Congress. At that time, its basic orientation was toward library reference work. Subsequent legislation broadened that role, emphasizing the importance of subject specialists and in-depth policy analysis. As it is presently organized, CRS performs both quick-reference work for legislators and their staffs through the Congressional Reference Division and policy analysis through seven research divisions and a group of senior specialists. Issue briefs, legislation digests, and computer information support are also provided. CRS Director Gilbert Gude, a former congressman from Maryland, heads a staff of approximately 800 employees.

The General Accounting Office (GAO) is second in seniority. It was created by the Budget and Accounting Act of 1921, which also established the Bureau of the Budget (now the Office of Management and Budget). It is often called the investigatory arm of Congress. Initially that meant audits of government accounts. It has grown to include evaluation of government programs, both ongoing and proposed. GAO now employs more than 5000 and is divided into 10 functional divisions and several support offices. It is directed by the comptroller general, who serves by virtue of a 15-year presidential appointment. Elmer B. Staats is the comptroller at this time.

The Office of Technology Assessment (OTA) was mandated by the Technology Assessment Act of 1972. Its function is to help Congress anticipate and plan for the long-term consequences of technology applications.

OTA has a staff of 130 and is organized by subject area. It is governed by a bipartisan congressional board composed of six senators and six representatives, evenly divided by party. An advisory council composed of 10 citizens, the comptroller general, and the CRS director also assists the agency. OTA's current



director is Russell Peterson, former governor of Delaware (1969–1973) and former chairman of the White House Council on Environmental Quality (1973–1976).

The Congressional Budget Office (CBO), the newest of the support agencies, was formed by the Congressional Budget and Impoundment Act of 1974, the law that gave Congress the authority to set budget targets for spending, taxing, deficits, or surpluses. CBO was formed to support Congress with budgetary expertise and fiscal and program analysis. Among its functions are economic forecasting, scorekeeping (keeping track of how specific bills match ceiling targets), costing, annual reports, and special studies. Alice M. Rivlin, former senior fellow at the Brookings Institution, directs the CBO staff of 200 employees.

### The energy connection

Reflecting the growing emphasis on energy issues in Congress and in the executive branch, all four of the congressional support agencies have formed energy analysis groups.

The largest is GAO's Division of Energy and Minerals, under the direction of Monte Canfield, Jr., commanding approximately 6–8% of the agency's resources. "Energy," Canfield notes, "is now the largest substantive issue area in GAO."

It wasn't always that way. The group has expanded markedly since 1974 when Canfield arrived to spearhead a staff of only 8 or 9. But by 1977 the unit had grown to the point where it was elevated to division status, reporting directly to the comptroller general. Today it employs about 360.

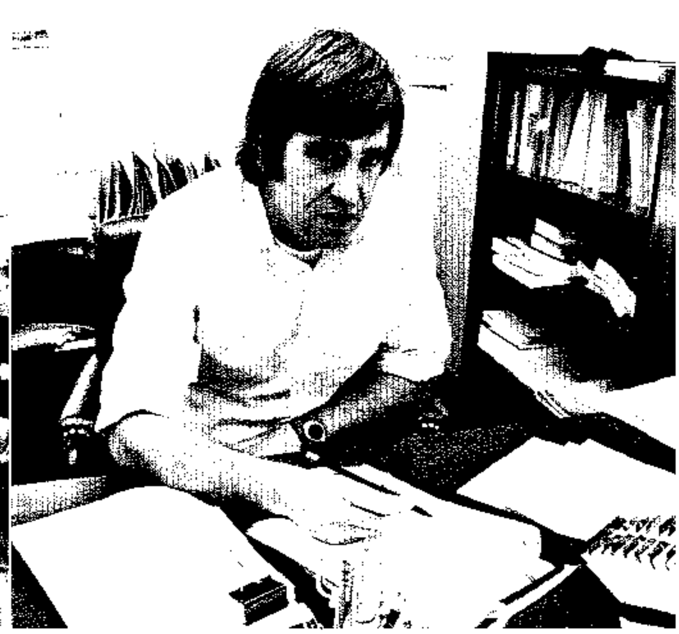
The group is now striving for greater professional diversity. Canfield estimates that at least 75% of his staff have "traditional backgrounds" for GAO—accounting, auditing, business. He hopes to eventually have a 50–50 mix of traditional and nontraditional disciplines represented, adding more chemists, environmentalists, economists, and social scientists.

The second largest energy analysis team is in CRS. Some 20 professionals are regularly involved, explains Elizabeth Yadlosky, associate director for research, and the number may be augmented by researchers from other disciplines when needed. Senior Specialist Alvin Kaufman labels this the "university" approach to research. "We have a deep well of talent that we tap for different studies," he says. "The bulk of our projects are cooperative."

Three CRS divisions deal directly with energy: Science Policy Research, Environment and Natural Resources Policy, and Economics. Kaufman is a member of yet another pool that contributes intermittently—the senior specialists who are nationally known experts. And finally, the quick-reference teams in the Congressional Reference Division answer questions from legislators and their staffs daily, often on a while-you-wait basis. If a congressman needs to know how much oil the United States imported in 1970, for example, these CRS researchers can provide the answer.

The Congressional Budget Office, with only 8 employees specializing in energy (mostly economists), plays a much smaller and more selective role. Raymond Scheppach, assistant director for the Natural Resources and Commerce Division, explains that many of CBO's resources are in the "quick and dirty budget-type things," such as scorekeeping and budget estimating. The deputy assistant director, Richard Morgenstern adds that "relative to CBO's total intellectual contribution to Congress, energy is a small proportion." CBO is primarily concerned with those items that have large budgetary impact, he explains. "The federal government's role in en-

Monte Canfield, Jr., General Accounting Office



Raymond Scheppach, Congressional Budget Office

ergy is not a major budgetary drain as compared to welfare or defense," he says. "So quite naturally, CBO's resources are more heavily placed in other areas."

The Office of Technology Assessment currently devotes about 10% of its resources to energy (13 employees and nearly $1 million). In fact, for FY79 more money was requested for energy than for any of OTA's other program areas. The Energy Program, managed by Richard Rowberg under the direction of Lionel Johns, OTA assistant director, is heavily staffed by individuals with technical backgrounds, including several physicists, a mechanical engineer, and a chemist. However, Rowberg also has on board a political scientist, an economist, and a systems analyst. The concept behind staffing, he says, is to have project teams with technically oriented leaders, with others responsible for specific impact areas (e.g., economic, social). The OTA energy staff, as in other programs, is augmented by contractors and consultants.

#### How they differ

At first glance, it might seem that these energy support groups, as well as their parent agencies, overlap in function. On closer examination, it is apparent they do not. The four agencies strive to avoid it.

"We don't start a job here that we haven't coordinated with the other agencies," GAO's Canfield says. Others make the same comment. All point out that their studies on similar issues are from different perspectives.

"We all did analyses of the National Energy Plan, but we all did them from different points of view," remarks Rowberg from OTA.

Yadlosky of CRS sees this as healthy. "Congress should get the benefit of analyses from different organizations. That helps eliminate tunnel vision."

The different orientations that underlie the studies are a function of the fundamental differences in the type of services the organizations provide to Congress. The focus of CRS, for example, is on short-term studies and quick answers regarding issues Congress may be dealing with at any particular moment.

"We're the kind of an organization tapped on a short-run basis," Kaufman explains. Quick-reference questions are generally answered the day received and longer studies seldom run beyond two months.

"Our mission is perceived by most—including the appropriations committees—as being an aid to Congress with its day-to-day work—expediting it, and keeping it rolling," Yadlosky adds. "We are response, service oriented. If you want to know what CRS is doing, all you have to do is look at the *Washington Post* or *The New York Times*. Our work closely parallels what's in the paper."

If the day-to-day, short-term work is the domain of CRS, just the opposite is true with OTA, whose studies average a year or longer. Rowberg explains that his organization seeks to give Congress "as good an understanding as possible of the long-term effects of what they do. We go beyond the immediate outlook."

CBO has a specific focus in terms of budgetary issues, even in the special studies area. "We are concentrating on issues that have budgetary impact as opposed to purely regulatory-type questions," Scheppach says. Average time for CBO's studies is about four months. However, the issued report is just the beginning, officials note. "A report may establish our credibility in a given area, but where we make our impact is often through subsequent briefings, memos, or conversations with committee staffs," Scheppach explains.

GAO's focus, according to Canfield, is on examining specific federal programs and assessing them to ascertain if they are in the national interest, efficient, ef-

Richard Morgenstern, Congressional Budget Office

Richard Rowberg, Office of Technology Assessment

fective, and economic. This includes traditional audits, as well as evaluating the pros and cons of ongoing, newly enacted, and proposed programs, and making conclusions and recommendations. "This role of interpretative analysis is increasingly important," he remarks. "Congress has been very receptive to it."

GAO's energy studies run about 6–12 months. "We gear them to our planning cycle and the legislative program year," Canfield states. "You know, it's no good issuing recommendations when you can see the train going down the track."

A clear distinction can be drawn between GAO and the other three agencies by noting the practice of making or avoiding explicit policy recommendations. GAO makes them as a matter of course. "We always show what the options are, but we will definitely choose one if it looks preferable to the others," says Canfield. OTA, CBO, and CRS present policy options but do not draw conclusions or make recommendations.

"We outline the options, the alternatives, the pros and cons, and some of the pitfalls of certain choices," explains Kaufman of CRS. "We don't make value judgments. Congress gets paid for making those kinds of decisions, so we don't tell them what they should do." OTA and CBO operate under similar philosophies.

Another key difference is the manner in which the organizations conduct research. For CRS, CBO, and GAO, it is basically an in-house process, with only selected use made of outside sources for advice and analysis.

"Our studies are almost 100% in-house," Scheppach says of CBO. However, he adds that information is drawn from outside sources and that papers are put out "for extensive review." Interviews with utility executives, for example, are being conducted as background for a study on nuclear power licensing. Similarly, Yadlosky of CRS explains, "We value our professional contacts outside CRS and we sometimes get a group of people together for guidance on a study."

Canfield of GAO says his energy division uses experts and consultants on a limited basis, sometimes as extended members of the staff and other times on an advisory basis. "At times groups of consultants may be brought in to review work in several stages of progress," he explains. "In such cases we don't ask them to reach collective judgments or show them our conclusions and recommendations. These are solely the responsibility of GAO."

It is with OTA that the most elaborate and extensive network of outside advice exists.

"We do call on the intellectual resources of the country," comments OTA's Public Affairs Officer Charles Wixom. He explains that such a small staff could not possibly cover all the aspects of a technology assessment. The office relies heavily on outside contractors and consultants to prepare individual segments of its analyses. An OTA project team monitors the work, synthesizes the material, identifies the major policies to be discussed, analyzes the impacts, and writes the final report.

Each OTA study is further guided by an advisory panel composed of persons representing various interests pertinent to the effort. For example, a current study on residential energy conservation includes a panel of representatives from the building industry, consumer groups, utilities, savings and loan institutions—"the whole range of interests," Rowberg notes.

This preference for an extended organization helps to draw a clear distinction between OTA's analyses and those of its counterpart agencies. Rowberg says OTA's analysis of the National Energy Plan was different in that "the principal input came from the 100-plus

Alvin Kaufman, Congressional Research Service

Elizabeth Yadlosky, Congressional Research Service

people brought in, formed into panels, and asked to write issue papers." The OTA staff edited and modified the work, adding their own perspectives. René Malès, director of EPRI's Energy Analysis and Environment Division, served on one of the panels for this study, and Ralph Perhac, manager of EPRI's Physical Factors Program, is serving on a panel for a coal-use study now in progress.

One other major difference among the organizations is the origin of the request for their studies. GAO is unique in that it can initiate its own work. "Most of our work is self-generated," Canfield says, emphasizing, however, that the agency works closely with congressional committee staffs to get a good feeling for where their interests lie.

OTA can conduct studies only at the request of a congressional committee (through the chairman or ranking minority member), a member of the OTA governing board, or its director. Committee request is most common. All assessment projects must be approved by OTA's board.

"The reason is to ensure that there is broad enough support for doing the study," Rowberg explains. "That's necessary because of the long-term nature of our studies and our limited resources."

In the CRS research divisions, the service to committees has increased because recent legislation has underscored that obligation. However, specific projects are prepared for members, and in addition, reports prepared for committees or in anticipation of interest by Congress as a whole are available to members and their legislative aides.

CBO also works at committee request, through the chairman or ranking minority member. "By statute, our first responsibility is to the House and Senate budget committees," Morgenstern explains, "and since much of the energy legislation lies outside the purview of those committees, we in the energy area have also been working closely with the authorizing committees."

### Congressional concerns

A glance at the kinds of energy studies being requested by Congress indicates where the major interests lie.

At CBO, energy staffers are working on an analysis of nuclear reactor planning and some of the policy questions in the Nuclear Siting and Licensing Act presently before Congress. The study will be delivered to its requestor—the House Interior Committee—sometime this summer. CBO is also preparing an assessment of federal R&D policy, including identification of the particular areas of scientific interest and the specific stages of the research process that are most suitable for federal involvement. In the past, CBO has issued reports on uranium enrichment, financing energy development, and nuclear reprocessing and proliferation.

At GAO, work is under way on a study of the role of cogeneration in the national conservation effort. A report on that topic will be published in September. Other studies under way are those reviewing the status and potential for new fission concepts (including EPRI's Civex proposal for reprocessing), analyzing future electricity demand requirements and capacity availability, and surveying DOE's solar heating and cooling demonstration programs.

OTA will release a major study this fall on the direct use of coal. In the past, the agency has issued assessments on coal slurry pipelines, on-site solar systems, nuclear proliferation and safeguards, and prospects for enhanced recovery of oil.

CRS officials are strictly prohibited from discussing studies in progress. And

Lionel Johns, Office of Technology Assessment

once a study is completed, it is the property of the committee or legislator who requested it. CRS does not publish its own studies. The requestor can (and usually does) publish the report in the form of a committee print or in the *Congressional Record.* Published prints include "Electric and Gas Utility Rate and Fuel Adjustment Clause Increases, 1976"; "Energy and the Economy"; "The Structure of the U.S. Petroleum Industry"; and "Alternative Energy Conservation Strategies: An Appraisal."

In general, energy officials in these agencies point to solar as the energy technology issue of prime interest to Congress right now. Other interests include the concept of a national electric grid; power plant siting and reliability; the back end of the nuclear fuel cycle and the breeder reactor; supply issues, including synthetic fuels; and renewable resources.

A surprising observation from these individuals is that energy, although definitely number one in congressional interest this session, might not remain so in the future. It will not decrease in importance, they stress, but it may in general interest.

"It used to be maybe seventh in interest, now it is first, but it may fall to third," Scheppach of CBO comments. "We will probably maintain that, but it is not going to be anywhere near as big as it is this session."

"There are some energy issues that conceivably could be decided once and for all, like natural gas deregulation, if that passes," adds Morgenstern. "I suspect that energy is going to be around to stay, but the crisis atmosphere that many perceive to be in existence may go away."

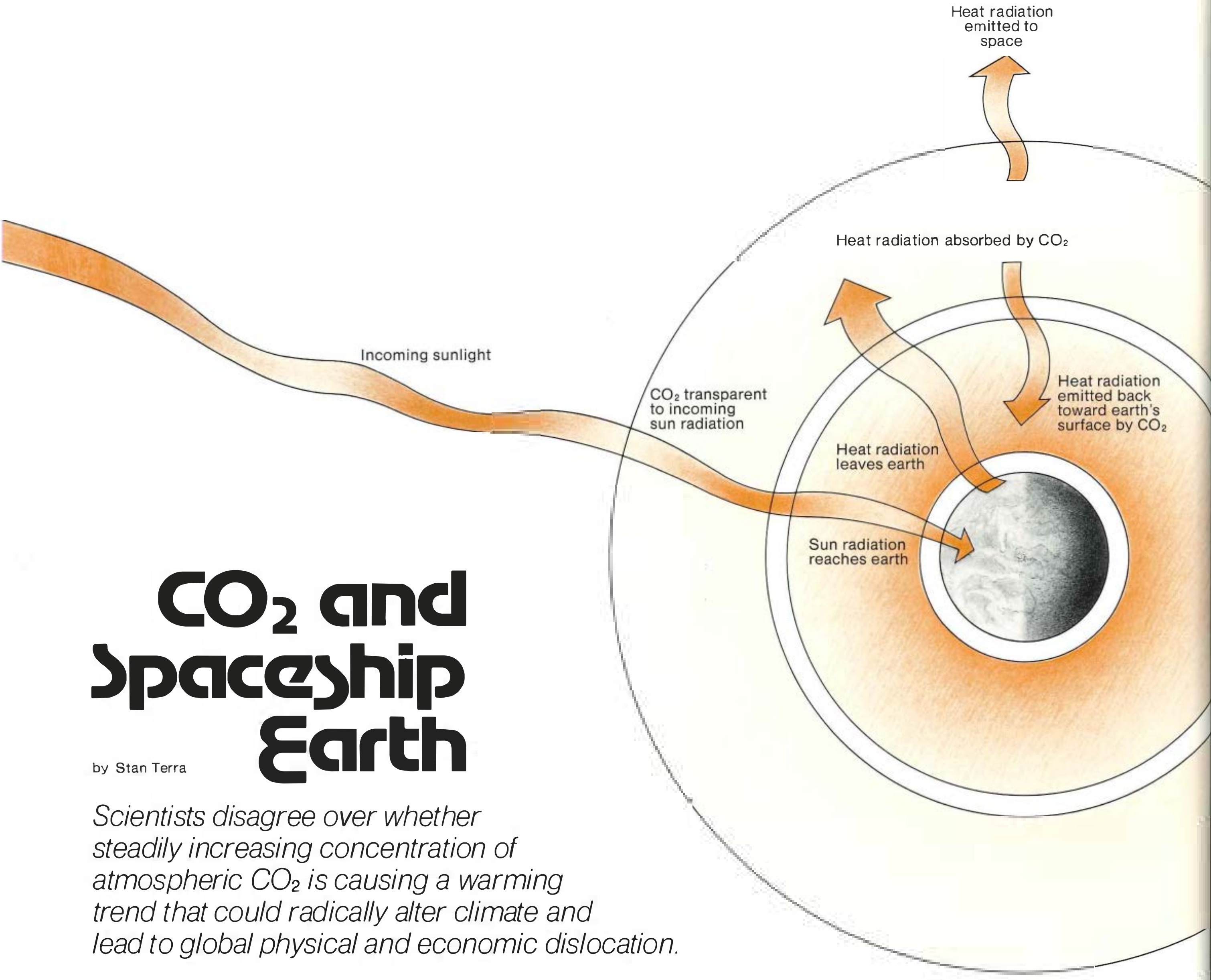
"It's at the top of the list right now, but this changes," says Kaufman of CRS.

"If something would happen to thrust recombinant DNA into the limelight, for example, energy would not be difficult to replace as the top issue," says OTA's Rowberg.

Canfield agrees. "After all the tremendous gnashing of teeth and wills, it's possible people are very tired of energy."

### Agencies to watch

The roles of CRS, GAO, OTA, and CBO are evolving. Cumulatively, they strengthen the capability of Congress to analyze the information, make decisions, and carry out its responsibility to the electorate. In energy issues as well as in other key areas, they are agencies to follow with interest.




# $CO_2$ and Spaceship Earth

by Stan Terra

*Scientists disagree over whether steadily increasing concentration of atmospheric $CO_2$ is causing a warming trend that could radically alter climate and lead to global physical and economic dislocation.*

Human beings are carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be repeated in the future," scientist Roger Revelle stated in 1957.

The eminent marine geologist and former director of Scripps Institution of Oceanography went on to explain, "Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in the sedimentary rocks over hundreds of millions of years. This experiment . . . may yield far-reaching insight into the processes determining weather and climate."

Central to this "geophysical experiment," in progress since the start of the industrial revolution, is the widespread burning of oil, natural gas, and coal—fossil fuels "stored in the sedimentary rocks over hundreds of millions of years," which have served as the major energy sources of the modern industrial world. Eighteen years after his statement, Revelle headed a panel of leading scientists in an investigation of the effects of energy use on climate. The report of the

Stan Terra is feature writer for the *EPRI Journal*.

two-year study, *Energy and Climate,* sponsored by the National Academy of Sciences (NAS), was published in 1977.

"The principal conclusion of this study," the report noted, "is that the primary limiting factor on energy production from fossil fuels over the next few centuries may turn out to be the climatic effects of the release of carbon dioxide." The panel urged the undertaking of a worldwide comprehensive research program that "should include studies of the carbon cycle, climate, future population changes and energy demand, and ways to mitigate the effects of climatic change on world food production."

Thomas Malone of Butler University, a cochairman of the NAS Geophysics Study Committee under which the *Energy and Climate* panel did its work, has said that conclusions in *Energy and Climate* should not be taken as a red light on coal use, but rather as "a flashing yellow light."

### Growing concern

Carbon dioxide ($CO_2$)—an atmospheric trace gas given off whenever matter containing carbon burns, decays, or otherwise oxidizes—is transparent to the sun's incoming shortwave radiation but absorbs the longwave radiation outgoing from the earth's surface. Consequently, an increase in atmospheric $CO_2$ concentration results in greater absorption of the longwave radiation and reradiation back to earth, leading to a rise in the earth's temperature. This is commonly called the greenhouse effect, the glass in a greenhouse being analogous to $CO_2$.

Scientists recognize that there are other atmospheric gases and particles that may also be important to the net balance of radiation heat in the earth's atmosphere. Among these is nitrous oxide ($N_2O$), released when the nitrogen in fertilizers combines with bacteria in the soil. As agricultural productivity intensifies to meet the food needs of the world's growing population, $N_2O$ concentration in the atmosphere may increase and thereby affect the earth's warming.

Also to be noted is the probable increase in cloud formation caused by greater evaporation as earth temperature rises. More cloud cover would tend to cool the earth and could counteract the warming.

The greenhouse effect may lead to a global warming trend; a change in climate and rainfall patterns, with consequent dislocation of established agricultural zones and attendant economic disruption; a melting of sea ice, or in the extreme, of the polar ice caps, which could flood coastal regions. These possible consequences have prompted concern and study in the scientific community and research support from the federal government.

According to George Woodwell, director of the Ecosystems Center at the Marine Biological Laboratory in Woods Hole, Massachusetts, "The carbon dioxide problem is one of the most important worldwide environmental issues." The U.S. government has shown a marked interest in the $CO_2$ issue since the 1972 Stockholm Conference on the Human Environment. The U.S. Office of Naval Research examined the problem in its Symposium Series in Oceanography in 1976. The Dahlen Conference in Biogeochemistry, held in West Berlin in 1976, also considered the matter and was followed last year by an ERDA (now DOE) conference in Miami on the world $CO_2$ problem and a meeting on the world carbon content in Ratzeburg, West Germany. A workshop on $CO_2$, climate, and society, cosponsored by the World Meteorological Organization, the United Nations Environment Program, and the Scientific Committee on Problems of the Environment, was held in Geneva in February of this year under the auspices of the International Institute for Applied Systems Analysis.

DOE has launched a long-range, multimillion dollar program designed to explore the uncertainties of $CO_2$ effects. The DOE effort, under the direction of Lester Machta, head of the National Oceanic and Atmospheric Administration's (NOAA) Air Resources Laboratory and a respected veteran meteorologist, will examine the carbon cycle, especially the storage and exchange mechanisms working in the world's forests, oceans, and humus (decomposed plant and animal matter forming the organic portion of the soil). Attention also will be given to the social and economic consequences of climatic changes resulting from an increase in atmospheric $CO_2$ and what might be done to lessen or prevent such changes.

A national climate bill, coauthored by California Congressman George Brown and Illinois Senator Adlai Stevenson, is being considered by Congress. (At this writing, the bill is expected to pass and be signed by President Carter.) The measure is intended to coordinate federal climate research efforts, with emphasis on supplying data to users of climate information (e.g., farmers, planners, scientists). Research on $CO_2$ effects is also included in the proposed legislation.

### Theories and uncertainties

Scientists who have studied the problem agree that the volume of $CO_2$ in the atmosphere has been steadily increasing. The level in preindustrial 1860 has been estimated at 293 parts per million (ppm). Since 1958, the atmospheric $CO_2$ concentration at the Mauna Loa volcano in Hawaii has been continuously recorded at a monitoring station set up by Charles Keeling, a Scripps oceanographer. Data collected at this station and at another station at the South Pole (both operated by NOAA) indicate a steady rise in $CO_2$ concentration from 315 ppm in 1958 to about 334 ppm in 1977. Over one-quarter of the 41 ppm increase since 1860 has come in the last 10 years. Some scientists believe that if the present 4% growth rate of fossil fuel use is continued, a doubling of atmospheric $CO_2$ could occur in the next 30–50 years. That, in turn, could result in a global temperature increase of 2–3°C, a 2% increase in average relative humidity, and 7% higher average rainfall. In theory, most of these changes would take place in the Northern Hemisphere, where industrial concentration and $CO_2$ emissions are the greatest.

Scientists disagree, however, on the long-range effects these changes would bring. Theories range from "a major disaster [owing to] a rapid 5-meter rise in sea level caused by deglaciation of West Antarctica" as seen by J. H. Mercer of the Institute of Polar Studies at Ohio State University, to the "wait and see" position of Helmut Landsberg, a well-known climatologist and emeritus professor at the University of Maryland. "I think the temperatures in the recent decade have been fairly level," says Landsberg, whose long-term observations indicate to him that no definitive changes—either toward warming or cooling—can be documented from the climatic record, and so are not "projectable."

"The critical question is not what will happen on a global scale," Landsberg says, "but rather what would happen in Iowa if world temperature rose one or two degrees. Would Iowans still be able to raise corn? What would happen to the rainfall in Louisiana and California? Would the Indian monsoon season be better or worse? We cannot answer these specific questions with the models we now have." Landsberg adds, "On top of that, we don't know what nature is doing independently. You see, nature has a cussed habit of crossing up predictions. As Fourier (19th century French mathematician and physicist) said, 'Nature doesn't give a damn how much trouble she gives mathematicians.' As a meteorologist, I'm quite sensitive to that. We just don't know all the feedback mechanisms."

The most widely accepted theory holds that man-induced influences on the atmosphere—mainly, the generation of $CO_2$ from fossil fuel combustion—will cause a significant rise in global temperatures over the next 25–200 years. William Kellogg of the National Center for Atmospheric Research, a leading proponent of this position, has been conducting an ambitious study of the cumulative impact on climate of society's environmental modifications.

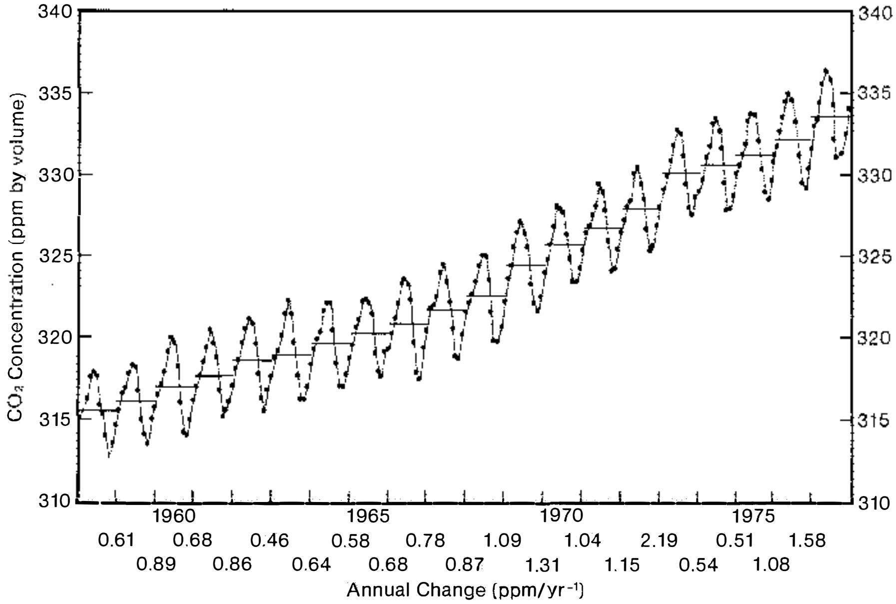
"It now appears," says Kellogg, "that we are becoming a significant factor in the climate balance." He estimates that the level of $CO_2$ in the atmosphere will increase to 400 ppm by the year 2000 and then double that by 2040. "This rate of warming will be appreciably larger than any change of mean surface temperature we have seen in the last 1000 years," Kellogg predicts, "and could roll the clock back to 4000–8000 years ago when the earth was warmer than now." He suggests that such a warmer earth might well be a more desirable place to live because rainfall patterns would be more favorable to the world's population than they are now. This could result in the increased fertility of wider regions in the Northern Hemisphere and population shifts from crowded areas to newly desirable, more spacious locations.

A position that tends to reconcile the extremes is that held by J. Murray Mitchell, senior research climatologist with NOAA. As Mitchell sees it, nearly 20 billion tons of $CO_2$ are released to the atmosphere annually through the burning of fossil fuels. This amounts yearly to about 0.7% of the total $CO_2$ already in the atmosphere, which is now some 13% greater than it was 100 years ago. A doubling of the current level of $CO_2$ would raise mean world temperatures by about 3°C. What would all this mean to future climate?

"If we rely for very long on fossil fuels to meet our energy needs, the consequences to climate are likely to become noticeable by the end of this century," Mitchell predicts. "On the longer, geologic time scale, consumption of the bulk of the world's known fossil fuel reserves would plunge our planet into what Wallace Broecker of the Lamont-Doherty Geological Observatory has described as a 'super-interglacial' era (warm period), the likes of which the world has not experienced in the last million years." Mitchell warns that if we wait until signs are clear that a warming trend has begun before we start phasing out our fossil fuel use, the damage will already have been done in the 50 or so years it would take for a fuel transition. And the consequences, he says, "would endure for thousands of years after the fossil fuels have been consumed!"

### Forests seen as source

Scientists engaged in projecting global climatic conditions rely on data generated by various mathematical models. In




This record by NOAA's Mauna Loa Observatory on the island of Hawaii indicates monthly average concentration of atmospheric $CO_2$. Seasonal oscillations result when $CO_2$ is removed from the atmosphere by photosynthesis during the growing season in the Northern Hemisphere and subsequently released in the fall and winter. The graph shows a rise in average atmospheric $CO_2$ of more than 5% since 1958. Current rate of increase is 1 ppm/yr ($2.3 \times 10^{15}$ grams of carbon).
*Source: Charles Keeling, Scripps Institution of Oceanography*

## EPRI LOOKS INTO $CO_2$ PROBLEM

So far, EPRI has funded two studies of the $CO_2$ problem: a state-of-knowledge study by John Laurmann of the mechanical engineering department at Stanford University and a more comprehensive investigation by Radian Corp.

Laurmann states in his report that projections of the extent of global climatic change from fossil-fuel-generated $CO_2$ "are uncertain and controversial, due in large measure to ignorance of the physical mechanisms involved." He notes, however, that the apparent evidence "suggests the need for the immediate introduction of remedial measures to bring about a smooth transition to noncarbon-based energy sources in the next 50 years." But he adds that because the uncertainties in climate change predictions are extremely large, actual climate change "may be negligible or, to the contrary, more critical than the most probable estimate indicates."

Laurmann goes on to say, "Since we can assign economic costs to the potential climate change impacts and to energy-use strategies designed to reduce them, a cost-benefit study based on decision analysis under risk can be carried out that would indicate an optimum energy-use strategy as well as the cost of delay in putting it into effect."

The Radian study assesses the implications of increased $CO_2$ emissions and their control for the country as a whole and for the utility industry specifically. Radian's report notes that the United States contributed 28% of the world's $CO_2$ from fossil fuel combustion in 1973 and that predictions point to a 19–28% U.S. contribution by 2025. Global $CO_2$ emissions by 2025 are projected at 3–6 times the 1973 level. "However, if the U.S. emissions were totally eliminated," the report states, "the world's $CO_2$ emissions from fossil fuels would still be 2–5 times that of 1973."

It is further noted, "The largest contributors to $CO_2$ emissions in the United States are the utility, transportation, and industrial sectors. In 1974 their contributions were 26, 27, and 38%, respectively." Projections to the year 2000 place the relative contribution at 30–40%, utilities; 26–30%, transportation; and 15–17%, industry. "To put the utility sector contribution in perspective," the report states, "at no time will the United States be the major global contributor of $CO_2$ to the atmosphere when compared to the other regions of the world. In fact, if emissions were entirely eliminated from the United States, global $CO_2$ emission levels would still be predicted to rise considerably. Depending on the energy mix of the future, annual global $CO_2$ emissions are predicted to increase by 105–362%, even if the entire United States burned no fossil fuels."

Among the Radian study's conclusions are:

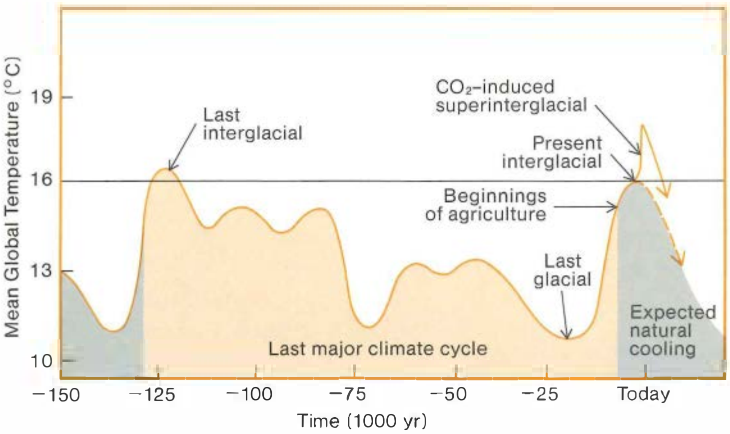
- The United States alone cannot solve the potential problem by unilaterally decreasing or eliminating $CO_2$ emissions. An international effort will be required.
- Reducing $CO_2$ emissions from the utility industry alone will not solve the U.S. or the worldwide $CO_2$ problem.
- Removal of $CO_2$ from flue gases does not appear feasible because of prohibitive costs and lack of disposal methods.
- Non-$CO_2$-generating energy sources are needed for worldwide use in underdeveloped as well as in industrialized nations.
- There is no effective control strategy that could be applied quickly on a global scale to reduce $CO_2$ emissions significantly.
- The only control measure immediately available is energy conservation.

Mitchell's view, since "no model is altogether realistic in its description of the real climatic system and because some of the physical processes that operate in the real climatic system cannot yet be simulated, it cannot be asserted that a doubling of carbon dioxide would have the same effects on real climate as a simulated doubling has on 'model climate.'" He adds, however, "Our experience with climate models suggests that their use leads to results that are likely to approximate reality fairly closely. Alternatives to our reliance on climate models do not really exist, unless we prefer the alternative of 'wait and see.'"

What is needed, Mitchell explains, are models that simulate "climatic change, including transients from one time to another as the carbon dioxide levels change. We don't have that yet. It's those transients that are going to influence the course of mankind and our decisions over the next 100–200 years."

A common assumption by $CO_2$ investigators that the steady increase of $CO_2$ in the atmosphere has been caused mainly by the combustion of fossil fuels is now thrown into question by new evidence reported by ecologist George Woodwell. There are strong indications, according to Woodwell, that the world's forests, commonly thought to be a sink for $CO_2$, are actually a source of atmospheric $CO_2$. Data from the monitoring stations not only have shown an increase in $CO_2$ but a variation in winter and summer, with a minimum in late summer and a maximum in late winter.

"Recently it has been recognized," reports Woodwell, "that the primary cause of the seasonal change is most probably the pulse of photosynthesis in forests of the middle latitudes." He explains that "the emphasis is on forests because they are extensive in area, conduct more photosynthesis worldwide than any other type of vegetation, and have the potential for storing carbon in quantities sufficiently large to affect the carbon dioxide content of the atmosphere."




A cooling trend leading to a new ice age might be expected in the next several thousand years if the pattern of the last interglacial is repeated—unless the warming effect of $CO_2$ induces a "superinterglacial." In that case, the next ice age would have to wait a thousand years or more—until this warming had run its course. *Source: J. Murray Mitchell, Environmental Data Service, NOAA, March 1977.*

The variation in the extent of the difference between the late winter and late summer $CO_2$ concentration is consistent with this hypothesis. Woodwell relates that the difference ranges from about 5 ppm at Mauna Loa to more than 15 ppm in central Long Island, New York. The difference decreases toward the tropics, where the seasonal pulse of metabolism is either less evident or absent, and there is less difference at higher elevations in all latitudes. Further, it is substantially less in the Southern Hemisphere, presumably because the smaller landmass limits the forest area. "The clear conclusion," says Woodwell, "is that the forests of the earth have a pronounced influence on the short-term carbon dioxide content of the atmosphere."

Woodwell further notes that new evidence shows there is probably a substantial release of $CO_2$ from the earth's biota (the totality of living matter). "The clear assumption that the increase in the carbon dioxide content of the atmosphere has been the consequence of burning fossil fuels, without regard to possible changes in the biota," he says, "has led to what now appears to be a serious miscalculation of the world carbon budget." As the forests of the world have gradually been cleared to make way for agriculture and other uses, Woodwell explains, this process of forest depletion has triggered a release of the carbon stored in the trees. This carbon, absorbed as $CO_2$ from the atmosphere by the trees in the photosynthetic process, is then returned to the atmosphere as $CO_2$.

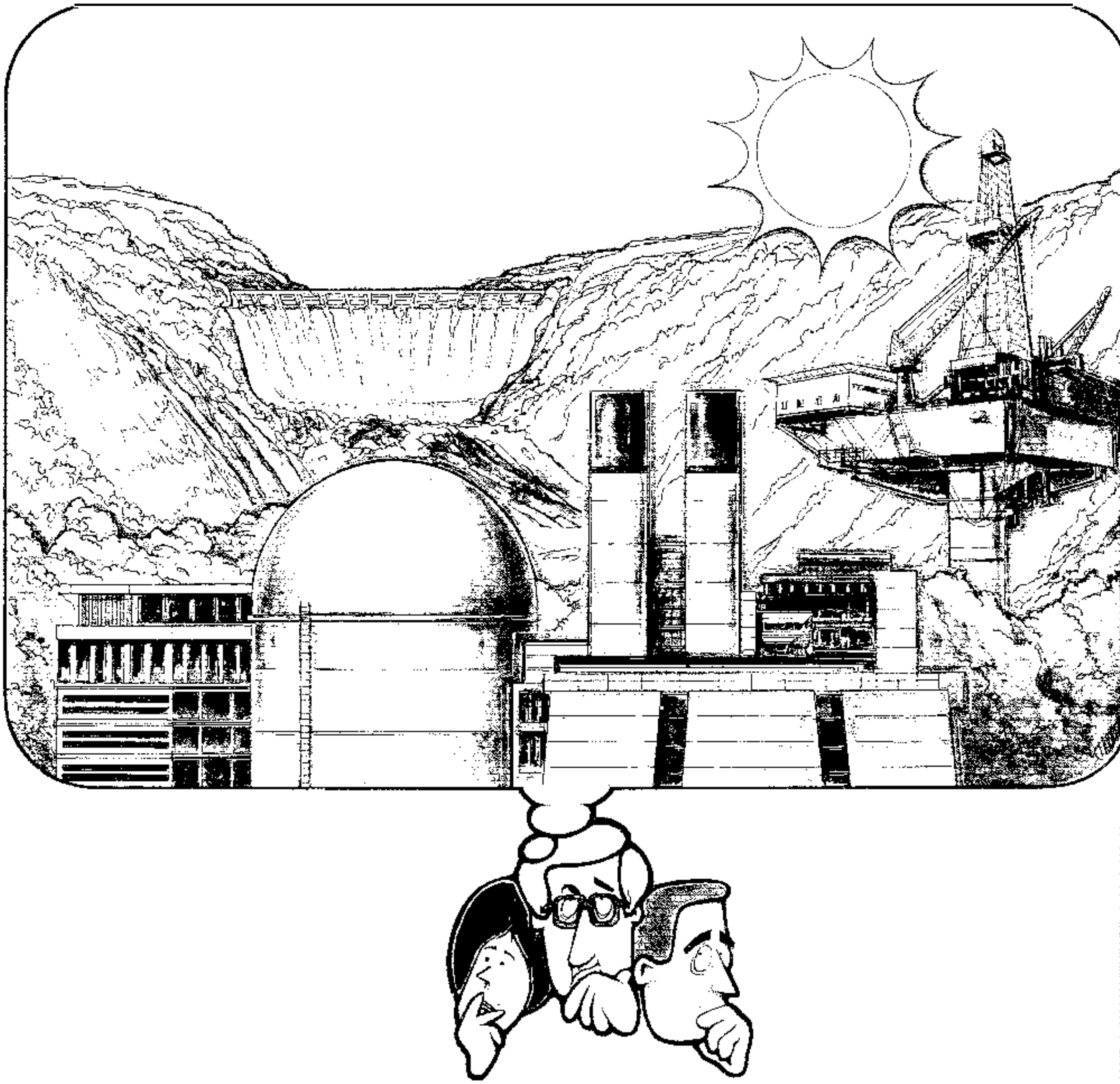
Another apparent miscalculation has been found in the oceans' ability to absorb atmospheric $CO_2$. Again, recent evidence indicates that the oceans are less of a sink for $CO_2$ than had been believed. Theoretically, the oceans have more than ample capacity to absorb the $CO_2$ that would result from combustion of all the known reserves of fossil fuels. But only a relatively shallow, well-mixed surface layer about 100 meters deep can react quickly enough to take up the $CO_2$. And as Wallace Broecker says, this surface layer "is already saturated with carbon dioxide." Broecker explains that $CO_2$ can combine with water molecules and with the carbonate ions that are part of the salt in the oceans. But there is a limited amount of these carbonate ions in any given volume of seawater.

"For every 10% of carbon dioxide taken up by the surface water, the carbonate concentration decreases 10%," Broecker points out. "So the effectiveness for reacting with more carbon dioxide is thereby diminished." The carbonate ions in the surface layer are replenished by a natural mixing process from the deeper ocean waters. This process of "ventilation" has been found to occur very slowly and is not well understood. Recent calculations suggest that the circulation is not fast enough to significantly increase the capacity of the world's oceans to absorb the steady increase in atmospheric $CO_2$.

Although Keeling and his colleague Robert Bacastow at Scripps disagree that the ocean's capacity to absorb $CO_2$ has diminished (Bacastow noting that the ocean covers three-fourths of the earth's surface), they emphasize that "the world's oceans cannot be expected to remove a major fraction of the industrial carbon dioxide from the air for a long time in comparison with the lifetime of human institutions." They add, "It is probably prudent to expect the concentration of atmospheric carbon dioxide to persist above twice the preindustrial level for at least several centuries."

**Will it be too late?**

NOAA's Mitchell feels strongly that "ours is the generation that must come to grips with the carbon dioxide problem and mount a vigorous research effort to allow us to understand all of its ramifications for the future." Woodwell says, "There is almost no aspect of national and international policy that can remain unaffected by the prospect of global climatic change. Carbon dioxide, until now an apparently innocuous trace gas in the atmosphere, may be moving rapidly toward a central role as a major threat to the present world order." And Kellogg warns, "If we wait to let the atmosphere perform the carbon dioxide experiment, we will finally learn how well our models have served in making the predictions of climate change—but then it will be too late to do much about it if a warmer earth should prove to be a sadder earth."



# The Electricity Future: What Can You Believe?

by Chauncey Starr

Distinguishing the elements and time dimensions of our energy problem highlights the need for many energy technologies.

With gasoline flowing from the pumps, newspapers writing of an oil glut, and a complacent public getting all the energy it wants (even though at a substantially higher price than in the past), it is reasonable to ask if there really is an energy problem.

The answer is not a simple yes or no. There are, in fact, two separate problems. The most urgent is our highly visible dependence on foreign oil. The other, a less visible problem, is our eventual exhaustion of mineral fuel resources. What meaning do these problems hold for energy technology in general—and for electricity in particular? When so much is uncertain, especially actual resource inventories and the predictions that flow from them, what can you believe?

### Oil politics today

Ever since the 1973 oil embargo made our dependence on overseas suppliers obvious, that dependence has risen markedly. We now import about 45% of our crude oil, and the problem today takes two forms. First, because the Arab cartel is using oil supply for policy purposes as well as for economic gain, we have undoubtedly lost a measure of foreign policy independence. Second, because of high prices for Arab oil and the associated increases for other fuels, we have suffered a substantial dislocation of our domestic economy, not to mention the adverse effect on our foreign trade balance.

For these near-term issues there is only one immediate solution—major reduction of oil imports, presumably by cutting overall oil consumption through intensive conservation across the board, substitution of other energy resources, or severe restraint of highly oil-dependent but deferrable end-use activities, such as recreational travel by auto and air.

Chauncey Starr, EPRI's founding president, was named to the new post of vice chairman in May of this year.

As a nation we have not been asked to make these kinds of adjustments. The administration is obviously gambling that the long-term self-interest of the Arabs will preclude another embargo or excessive price demands. Still, the risk of another embargo is recognized, and the federal government has initiated a national strategic oil reserve as a partial answer.

### How big is the oil barrel?

The visible near-term problem is often confused with a much less obvious long-term issue over which there is some professional doubt that a problem truly exists. Public concern has nevertheless been stimulated by the eventual depletion of worldwide mineral fuels and by a potential increase in the environmental impacts of growing worldwide energy use—two generalizations that are predictive truisms.

These issues are quantitatively very speculative because of our limited fact base, but the uncertainty itself has given rise to much emotional rhetoric about doomsdays to come. For example, our near-term problem of rising oil imports has been presented to the public as part of a worldwide acceleration of oil resource depletion. Yet, there is no indication that we are approaching the bottom of the world's oil barrel, if we are willing to pay higher prices. Oil cannot be found without looking for it, and this depends on the price incentives to do so.

### Oil policy for what?

Interestingly, many of those who are pessimistic about future oil findings are, in contrast, optimistic about finding uranium ore. Proven U.S. reserves of uranium are just adequate for the lifetime needs of the commercial nuclear power plants now built and under construction. For this reason the electric utility industry has urged the development of the breeder reactor, which uses uranium about 60 times more effectively than present nuclear plants. The administration has taken the position that ample uranium will be found and that the breeder may therefore be delayed, apparently on the premise that luck is an American heritage.

Unfortunately, most of the projected energy scenarios, whether doomsday or otherwise, are based on selective assumptions of what is likely to happen. Each scenario is shaped by the philosophic objectives, social values, and time perspective of the playwright involved. Does the playwright speak for the haves or for the have-nots? for continued growth in economic productivity or for the redistribution of incomes? for the day laborer or for the established professional? Is the playwright a believer in increased material benefits for people or is he more concerned with preservation of the natural ecology? Does he believe that resources should be used for the benefit of the present generation or should they be preserved for future ones? In short, depending on one's views, it is easy to select assumptions so that the picture of the future is optimistic or pessimistic.

The playwright may even use an energy scenario to support social doctrines such as the present administration's apparent preference for government regulation over individual market choice, centralized over dispersed responsibility, and a lifestyle of modest expectations. Therefore, we should not confuse dramatically publicized hypothetical scenarios (such as those surrounding the recent national gala Sun Day) with predictions reliable enough for sound policy making. As a student of the history of energy and resource development, I know that predictions made many decades ago concerning the future of these matters for the United States did not turn out to be valid.

### Fueling electricity growth

Let us now consider the role of electricity in our total energy structure. Electricity generation is an intermediate link that converts fossil fuel or uranium ore (or any other energy resource) into a versatile and available form of energy. Electricity use has grown at about twice the rate of total energy use in most industrial countries. It has always been more expensive on a pure energy basis than the primary fuels from which it is made, but the efficiency with which electricity is used and the unique convenience of its use has been its biggest contribution to the consumer, making it competitively desirable.

If electricity use continues to grow in the next 25 years as it has in the past, we will be producing almost four times as much electricity annually as we are today, and roughly half of our primary fuel energy will be going into the manufacture of electricity. With much more modest expectations, three times present production levels is a conservative planning target for 25 years hence.

To approach such high growth will require every electricity production option available to use. Consider what those options might be. Right now we have hydroelectric power, oil, gas, coal, nuclear, and some geothermal. Assuming that the oil and gas increments remain about constant, that hydroelectric grows somewhat, and that the alternative sources such as geothermal and solar develop, approximately 80% of all U.S. electricity produced 25 years from now will have to come from a combination of coal and nuclear resources. Arbitrarily splitting this equally so that 40% comes from coal and 40% from nuclear, coal production will have to be almost four times as much as it is today—an enormous though not impossible target. The number of nuclear plants needed can be built with the manufacturing facilities we have today, so nuclear capacity would not be plant-limited, but the uranium ore supply remains uncertain and the breeder would have to be part of such a system.

### New energy fuels

But what about the innovative electricity technologies that are based on renewable energy sources? Direct solar radiation, the temperature variations of ocean waters, winds, waves, biomass, and the earth's heat—all these are fantastically challenging because the total energy resources around the earth's surface are far beyond any foreseeable needs of the human race.

Unfortunately, they all have a similar difficulty: they are dilute and therefore involve large-area installations to collect their energy content for electricity generation. For example, there is an enormous amount of geologic heat stored in the earth's mantle, but the only fraction that is easily available to us is that from a few geothermal steam wells. Even these are geographically limited and not easy to exploit, although they have been an electricity source since 1904. The heat of the earth's rock may some day be tapped, but so far the engineering problems are large.

Solar electricity has similar problems. For example, solar-thermal electric plants collect and concentrate energy from the sun to operate a heat engine that is functionally similar to the equipment in a fossil- or nuclear-fueled power plant. But the capital cost of the solar collection surface area is an additional major component, analogous to the costs of fuel and the fuel delivery system of a conventional plant.

The difference between the costs for dilute and concentrated resources is basic. That is, the quantities of material required for dilute energy collection are large, and they are not likely to be much reduced, primarily because of the land surface area that must be covered. However, although solar electric plants will be more expensive than fossil- or nuclear-fueled plants, higher fossil fuel costs may eventually justify their entry into power networks to displace some intermediate-load plants.

The feasibility for most of the dilute energy resources has not yet been established. The challenge is not simply to demonstrate technical feasibility; workable systems must also be economically feasible. In the United States, we now apply about one-sixth of our annual business investment to the electric utility industry. Any multiple increase in utility investment would dramatically affect both the cost of electricity and the availability of capital for other U.S. industries. Neither prospect is likely to be acceptable.

### The role of time

There is general professional agreement on the basic building blocks that will structure our energy future during the next 25 years. These building blocks exist today, and it takes a long time to change any of them substantially, whether they are political, economic, social, or technical. Physical systems such as housing, transportation, and factories take decades to replace. And unless a new technical system or process is ready to go commercial now, it is likely to play only a minor role in the next quarter century.

It is on this subject of societal and technical lead time that we are most often misled by the glib urging of panaceas and miracle cures for our energy problems. Expectation of a technical miracle is an easy excuse to defer a difficult decision. But by confusing what might be available 25 years down the road with what is available today, some of our political figures often describe "pie in the sky" as though it is about to come out of the oven and be ready to eat at any moment —and, in effect, say there is no urgency for choosing from the current menu. Unfortunately, if the pie in the sky takes longer to bake, malnutrition will result.

### Today's ready fuels

The possibility of energy malnutrition motivates the electricity industry in its support of the nuclear power option. The industry believes that nuclear power is an available and economical electricity source, and the one with least environmental impact. This latter point startles many, but the fact is that in either its measured or its projected impacts on ecology, public safety, and health, nuclear power is without question the safest and cleanest of all our energy sources, including hydroelectricity.

The publicized nuclear power issues, such as reactor safety, radioactive waste disposal, and nuclear proliferation, are issues that have clear technical solutions with extremely low hypothetical risks. In 30 years there has never been an instance where nuclear power or any of its activities has adversely affected public health. In nuclear power the utility industry sees a system that meets all the requirements we seek today—namely, low-cost electricity and minimal environmental impact.

This is not to say that the other primarily available option—coal—is not acceptable also, but the combustion of coal produces effluents that are controlled only with difficulty. There are differences of professional opinion as to whether these effluents are now being sufficiently removed to be acceptable. However, compared with those from nuclear power plants, coal combustion effluents represent real environmental issues rather than hypothetical ones, and they are key factors in the design and construction of coal-burning power plants.

#### The basis for utility R&D

Where does all this leave us in judging what would be a wise national energy policy? Those of us who share the responsibility for delivering energy do not have a crystal ball that permits us to lay out a single, simple course. Perhaps we know too much. We recognize all the uncertainties, and for this reason most of us believe that the nation should invoke a multiplicity of energy supply options. First and foremost, of course, we must learn to use energy more efficiently. I think we are already well embarked on that course and we can probably save about 20% of our future needs by such technical conservation.

But the rest of our energy supply will have to come from the development of everything we have—finding more oil and gas, recovering oil from shale, developing coal resources and converting them to gas and liquid fuels, using nuclear power (including the breeder reactor), and commercializing any renewable resource that can be made credibly competitive.

Certainly we should try to prove out all the advanced technologies. Some of them may have to await a scientific discovery to bring them into the realm of either engineering or economic feasibility. Nuclear fusion is an example. Also, we must recognize that as energy from conventional sources increases in cost, we can justify the use of resources that previously were too expensive. The best example of this is shale oil, an indigenous resource with enormous rockbound reserves, but one where costs and environmental problems associated with recovery are so far a seriously inhibiting factor.

#### Cooperation to resolve uncertainty

In summary, we face a situation with so many uncertainties that nobody—and I underscore the term—*nobody* has the knowledge to choose a single course for the future, especially not an unproven one. It is easy to enthuse about pie in the sky if one does not have to be around to deliver it. However, it is socially irresponsible leadership that simultaneously worships the sun and exorcises the atom, that generally disapproves of the energy sources we can expand now, while praising those that have not been developed. We face important energy supply decisions now, and political diversions can only serve to delay meeting our real needs.

We cannot pursue the long-term approaches to energy issues without widespread cooperation, but false hopes prevent the formation of support, distort understanding, and destroy faith in any professional authority. The energy issue will be with us for a long time, and it is social and political as well as technical. Meanwhile, the energy industry needs to develop all available options because the alternative—restricted activity—means forfeiting the use of abundant energy to open new societal frontiers.

# Louis Austin: Down-Home Realist

The chief executive of Texas Utilities Company lets fly at some pet targets: overregulation, activist lawyers, interference with the free market, ivory tower research, and . . .

Louis Austin was born in Tennessee, educated in Alabama, and rose to prominence in Texas. He learned about coal underground as a summer laborer in a Pennsylvania coal mine while a student of mining engineering. And he got the hang of how to run a power plant as chief engineer aboard a Navy destroyer in World War II.

As chairman and chief executive of Texas Utilities Co. in Dallas, Austin's southern origins, hands-on experience, pragmatic values, and disarming down-home charm have served him well. As a member of EPRI's Board of Directors (his term expired in May), Austin was always well prepared—and usually heard from at Board meetings.

Austin joined Texas Utilities in 1953 to head its coal operation, became president of Texas Power & Light Co., and rose to his present post in 1975. Besides the three operating electric utility companies that form Texas Utilities, the system includes a service organization, a fuel company, a generating company, a coal and uranium mining operation in New Mexico, and a company engaged in the development of energy resources and technology.

The system serves about four million people, roughly one-third of the state's population, in an area that stretches from the sandhills of the far west to the piney woods of the east and from the Red River on the Texas-Oklahoma border to the center of the state. It's a region colorful in history and robust in growth—frontier drama, oil booms, and now throbbing centers of commerce and industry—that has come to depend on reliable, low-cost electric power.

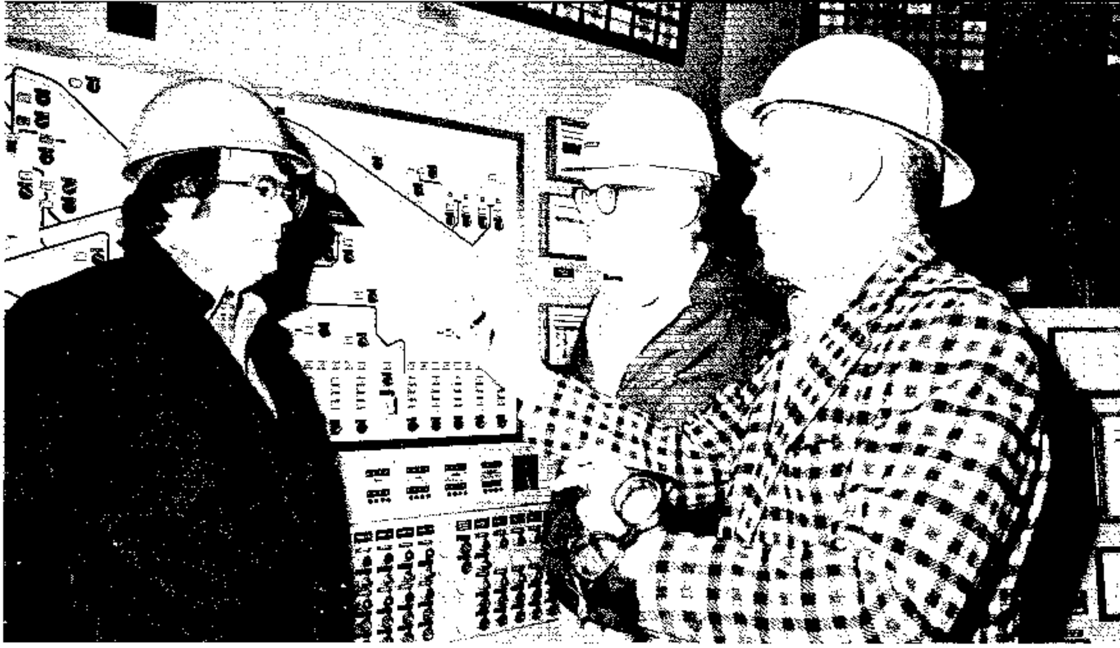
Symbolic of the area's economic vigor are such landmarks as the sprawling, ultramodern Dallas–Fort Worth Regional Airport; Dallas's 50-story Reunion Tower with its lighted geodesic dome housing a revolving restaurant and observation deck; and the sleek, gold-tinted glass-sheathed 2001 Bryan Tower building, where Texas Utilities has its offices. In his roomy, quietly decorated corner office on the nineteenth floor, Lou Austin sat comfortably in sport coat and slacks and shared some of his views with the *Journal.*

### Decries overregulation

One of those views (though not to be taken literally) is written, framed, and prominently displayed in Austin's office. It's a line from Shakespeare's *Henry IV,* Act 4, Scene 2: "The first thing we do, let's kill all the lawyers." Austin believes that "endless debate over such questions as 'How safe is safe?' and 'How clean is clean?' is stopping us from developing our best available energy sources." He quickly adds, "We have too many lawyers in our society. And lawyers have always gotten paid for debating."

Austin is convinced that "technologically, we have the brains and the creative minds in this country to design and build safe nuclear power plants and to mine and burn coal in an environmentally acceptable way." In his view, "Human law that inhibits strip mining, coal burning, nuclear construction, marketplace pricing, and slurry pipelines is counterproductive to keeping the price of energy down. It is a crime against the consumer." Austin makes the point that "geologic law dictates that coal and nuclear be our future energy sources."

Austin is on the board of a new California-based environmental group called Resolve, whose aim is to settle environmental disputes through mediation and thus avoid the traditional, time-consuming adversary proceedings. "Human law that creates formats where technical decisions are required to be made in adversary proceedings is wrong," he contends. "Courtroom adversary proceedings were created by society to preserve our freedoms and to see that justice is



Louis Austin (right) and Power Superintendent John Carlson (center) discuss the intricacies of the scrubber control room of Texas Utilities' Martin Lake (Unit 1) lignite-fueled power plant with Texas Congressman James Mattox.

done. But we must find a better way to make *technical* decisions," he says. "The very nature of adversary procedures is to create delay. And as lawyers maneuver (with their fee meters ticking away), the poor consumer catches the whole burden."

Austin recognizes that "a monopoly has to have some regulation." But his blood pressure rises from what he considers overregulation. For example, he sees the latest federal strip-mining act passed last August as "nothing but a relief and retirement program for activist lawyers." Says Austin, "We don't need this strip-mining law because everybody is reclaiming now. The country should look after its environment and we should be regulated to reclaim. But it's all the rules, procedures, *delays* that I object to." Texas Utilities Generating Co. has filed suit against the Secretary of the Interior, as have several others, challenging the new strip-mining regulations.

### Good reclamation record

Texas Utilities has a commendable record of restoring surface-mined land to productivity. Under way for more than six years, its reclamation program has transformed mined-out coal seams into wheat fields and grasslands. "We just go in there behind the draglines and fill in the holes and sow wheat or grass," Austin explains. He likes to compare strip mining and reclamation to human surgery. "Just as a skilled surgeon can make an incision, remove a tumor, and sew you up again like new," says Austin, "we take the skin of the earth, make a skilled incision, take out the coal, and then put the land back together so it can be farmed in a year or so." The company now leases the reclaimed land to farmers and eventually will sell these holdings. "The environmentalists are right in insisting we shouldn't 'rape' the land," Austin admits. "But they're wrong when they say we shouldn't mine it at all. We ought to mine the coal, but we ought to mine it *right.*"

Then there's the Clean Air Act. "Clean air standards should be set by the doctors in the National Health Service, not by laboratory technicians and lawyers in the Environmental Protection Agency," Austin believes. "And the standards ought to apply to ambient air levels," he adds. "Then it should be left to the individual company to decide how it's going to meet those standards, rather than the EPA or some other agency ordering companies to put in scrubbers and all that," he says heatedly, "which is just a ripoff of the public, because it's the customer that ends up paying for these controls."

Austin goes on to say, "Now we've even got something they call BACT—best available control technology. Every time somebody comes up with a better way to control flue gas, you've got to use it—so you're never meeting the standards." He offers an analogy: "It's like trying to meet standards for a clean shirt while better detergents are being developed. You've got to wash the shirt over and over again. Why, you end up wearing the damn thing out just washing it." He makes clear, "I'm for the environment. My grandkids and I have to live in the environment like everybody else. But I'm against this *overregulation.* The environment will be so clean it'll make you sick."

### Nuclear licensing delays

Regulatory changes, together with inflation, have substantially increased the estimated cost of constructing Texas Utilities' Comanche Peak Unit 1 nuclear power plant, which will be the first nuclear plant in Texas when completed in 1981 (a second 1150-MW unit is scheduled for completion in 1983). "Nuclear is one of the biggest areas of

Winter wheat is grown on land reclaimed from the Big Brown lignite strip mine operated by Texas Utilities. Dragline on an operating mine can be seen at upper right.

Louis Austin at a Texas Utilities briefing and Q&A session with selected employees, who will act as conference leaders in the company's series of information programs on such matters as employee benefits and alternative energy sources.

overregulation," Austin says, "and we don't intend to build another nuclear power plant, at least until I retire." He notes, "You can't blame all this on the Nuclear Regulatory Commission. They've been forced into some of their delaying action by intervenors. And all of this has come about because of the laws written by Congress. What it has done is to create so many uncertainties for the nuclear industry that there is no way to accurately estimate the cost of a plant."

Austin complains that the rules keep changing for licensing nuclear plants. He would like to see the NRC come up with a standard, approved design for nuclear plants that the industry could build to and thereby be assured of licensing "without having hearings on it."

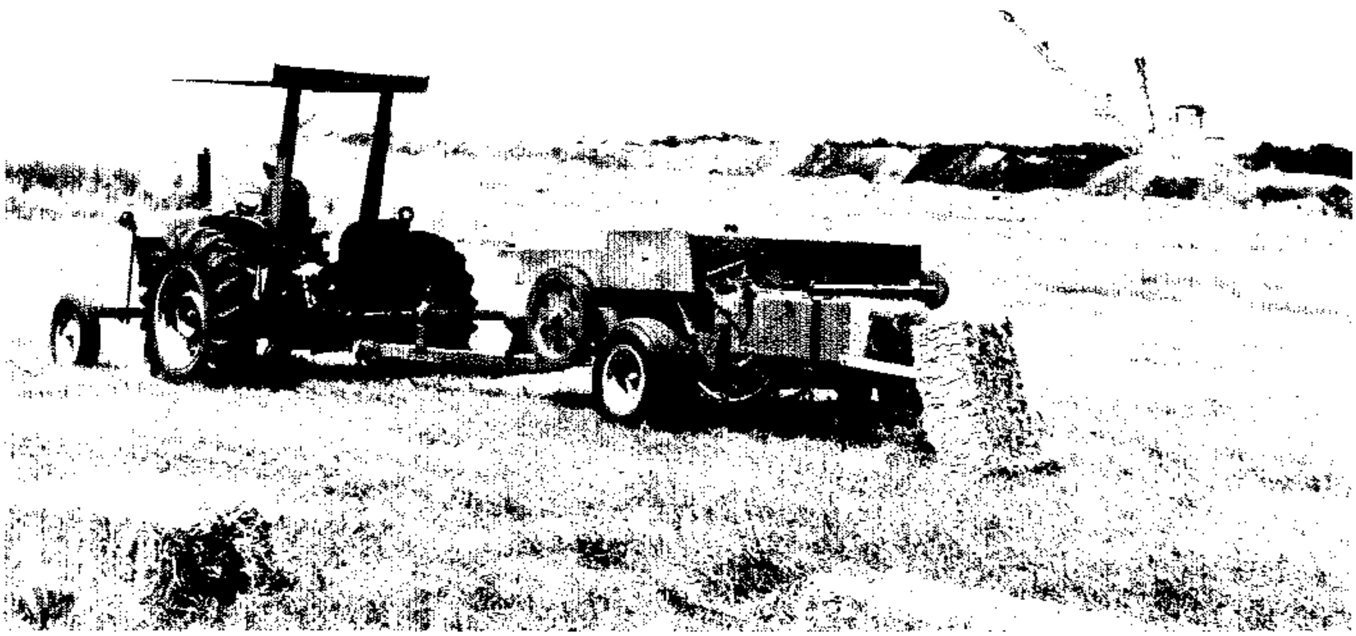
As for the revised procedures for licensing nuclear plants that the Carter administration has submitted to Congress, Austin has a set of project management flowcharts for construction of the Comanche Peak Unit 1 plant that show graphically how the proposed new procedures actually *complicate* and *prolong* the process. And what especially riles Austin about the proposed regulations is a provision for public funding of citizen intervenors. But he says hopefully, "We plan to work with those who are considering the new legislation in an effort to make changes so we can live with it."

**Ahead in fuel conversion**

Texas Utilities has been ahead of the regulators in converting its energy sources from oil and natural gas to coal. As recently as 1971, the system's entire kilowatthour generation was fueled by natural gas. Last year, natural gas accounted for about 66% of its kilowatthours, while lignite was used to produce 33% and oil, just under 1%. Lignite is expected to fuel 50% of the kilowatthours generated this year.

Texas Utilities was the first to use lignite as a fuel in a major power plant, firing a utility boiler with lignite in 1926. But lignite, a low-grade coal that abounds in eastern Texas, could not compete in price with natural gas that was being flared as a waste product in the 1930s and early 1940s. Although natural gas fueled the Texas industrial economy into the early 1970s, Texas Utilities held onto its lignite leases. And by the mid-1960s when the price of natural gas had risen to about 20¢/$10^6$ Btu, Texas Utilities found it could mine lignite at a competitive price. It began building power plants at the mine sites, producing lignite for about 14¢/$10^6$ Btu (now 40–50¢/$10^6$ Btu).

The company has since won national recognition for its construction of lignite plants to reduce dependence on natural gas. It was described as "having an eye to the future, a future that came sooner than expected" by the National Society of Professional Engineers in naming



Monticello Units 1 and 2 among the 10 top engineering projects of 1976. The first of four 750-MW units at the Martin Lake plant was completed last year. When the fourth unit goes on-line in 1983, Martin Lake will be the largest known lignite-fueled power plant in the world. Other lignite plants scheduled for construction through 1985 will add some 5400 MW to the system's capacity.

"Conversion to lignite has meant increased rates for our customers because we had to build more expensive plants," Austin notes, "but having now switched to coal and gotten over the crunch of investing in new plants, we are better off than if we were still using all that gas." And the conversion to lignite has since saved customers of the Texas Utilities system millions of dollars in fuel costs, he points out.

### Praise and caution

Austin was one of three EPRI Board members who directed a year-long study of the Institute's effectiveness (completed last November), an experience that sharpened his insights into EPRI. "To my knowledge, there has never been any operation that has come so far in so few years," Austin observes. "You just have to say that all those people out there are really top-notch. But, there are some things we need to guard against."

Austin is adamant about EPRI staying out of specific research that is already being done by manufacturers. "EPRI should leave the free market alone," he insists, "and do only the research that nobody else is doing or nobody else wants to. If a manufacturer is doing his own research, then EPRI shouldn't touch it with a 10-foot pole." Nor does Austin want to see all the industry manufacturers "dump their research on EPRI." He believes that vendors still should be doing their own major hardware research. "What I don't want to see happen in this country is a situation where, 20 years from now, the only turbine design available here will be an EPRI design."

Austin believes the approach that will most benefit the industry and its customers is for EPRI to continue to work closely with utility representatives through the Institute's advisory structure of committees and task forces. "There is a potential weakness out there at EPRI that the Institute will become an ivory tower, bureaucratic, university-type research outfit that would do 'interesting research' its staff would like to do, but wouldn't be worth a damn," he says. "Sure, it's slow and it's time-consuming and there are confrontations, but the only way the industry can keep its reins on EPRI so it does the practical, hardnosed research that is needed is to keep this industry advisory setup in force."

Austin adds, "EPRI's Board must have guts enough to maintain a strong hold on what research is done or not done, but still be sensitive enough to listen to what the Institute's Advisory Council has to say." (EPRI's Advisory Council is a panel of prominent scientists, educators, environmentalists, business executives, and regulatory commissioners that provides EPRI with viewpoints from outside the utility industry.)

### Homespun team worker

Just below the line from Shakespeare that hangs on Austin's office wall, is another graphic rendering of a view he holds. Its legend says, "None of us is as smart as all of us." Austin believes in teamwork, in collective wisdom, in people pulling together to achieve their common goals—the utilities, the regulators, Congress, the consumers, EPRI. And the lawyers, too.

# At the Institute

## Groundbreaking for Coal Liquefaction Plant

EPRI's largest individual research commitment, a $40 million contribution to the effort to produce liquid fuels from coal, entered a new phase in mid-May with groundbreaking ceremonies for a coal liquefaction pilot plant in Baytown, Texas. Other sponsors of the $240 million research program are DOE, The Carter Oil Co. (an Exxon affiliate), Phillips Petroleum Co., Atlantic Richfield Co., and the Japan Coal Liquefaction Development Co., Ltd., a group of 11 Japanese companies.

The project is scheduled to run until mid-1982 and is being managed by Exxon Research and Engineering Co. It involves the construction and operation of the pilot plant, which will be capable of liquefying 250 tons of coal a day, as well as bench-scale and engineering research.

The plant will use the Exxon Donor Solvent process, a product of work begun independently by Exxon in 1966. In this process coal is liquefied in a noncatalytic reactor at moderate temperature and pressure. The hydrogen required for the liquefaction reaction is supplied both in gaseous form and by transfer from a donor solvent, an internally generated coal stream liquid that is catalytically hydrogenated in a separate reactor before being mixed with the coal feed.

According to EPRI President Floyd Culler, Jr., who spoke at the groundbreaking ceremonies, the electric utility industry will continue to need clean, storable liquid fuels in the years ahead. "The utility industry recently advised the federal government that it will surely need liquids, preferably of domestic origin, synthetic or natural, to supply fuel for the 200,000 MW of electric generating capacity that will still require oil or gas in 1990," Culler pointed out.

He cited an estimate that the utility industry's need for liquid fuels in the next 10 years will reach about three million barrels of oil a day. "After 1985 there is a possibility that this will level off, but only if plans for generating capacity employing different fuels are initiated now, with the assurance that other fuels—coal and nuclear, in particular—will be approved by the various federal and state regulatory bodies."

Unfortunately, Culler noted, these alternative fuels are not now clearly acceptable. "Without substantial quantities of domestically produced coal liquids, we shall have to import ever-increasing quantities of oil," he said, adding that prudent planning urges a strong commitment to the coal liquids option.

## Projected Increase in Coal Demand Challenges Utilities

"A continued growth in electricity consumption and a projected decrease in the availability of oil and natural gas for electricity production mean that coal must remain the keystone of utility energy fuels," said EPRI's Richard Zeren at the Electro/78 Electronic Show and Convention in Boston in late May.

Zeren, manager of Program Integration and Evaluation in EPRI's Fossil Fuel and Advanced Systems Division, said the projected increase in coal use will challenge utilities to obtain approval for the design and construction of coal-fired power plants while complying with increasingly stringent environmental regulations and ensuring adequate coal supplies.

To help meet this challenge, Zeren said, EPRI has placed a major emphasis on improving coal-fired power plants. For example, EPRI is surveying utility experience with lime/limestone sulfur oxide scrubbers and has issued guidelines for the improved design and operation of scrubber components that most often fail. In another effort, EPRI is working on a coal combustor that will help reduce nitrogen oxide pollutants by controlling the combustion temperature and the air-fuel mixture.

Zeren also reported on a high-intensity ionizer developed under EPRI contract, calling it "a major advance in the control of ash particles in power plant stack gas." The ionizer puts a high electric charge on the ash particles so that conventional electrostatic filters can collect them efficiently.

In addition to improvements in conventional plants, new systems will be required as environmental restraints on burning coal become more severe. "Advanced coal-fueled power systems being developed by EPRI, such as fluidized-bed combustion and gasification–combined-cycle systems, may allow utilities to work within the restraints at costs competitive with or below those of conventional coal plants," Zeren said. EPRI is also developing a range of clean, storable coal-derived fuels, both solid and liquid, for use in peaking and intermediate-load generating plants.

"The projected role of coal for electricity generation justifies a multiple-path research and development strategy to provide utilities with options for using this resource," Zeren asserted. He added, however, that the great bulk of electricity consumed before the year 2000 will be from conventional nuclear and coal-fired power plants with improved emissions control technology. "Other power-generating options cannot make a substantial commercial impact before then."

## Compressed-Air Storage Symposium Held

During a recent symposium in Pacific Grove, California, Harro Lorenzen of KBB, Inc., Washington, D.C., described the construction work his firm is performing on the salt cavern for the Huntdorf, West Germany, compressed-air storage (CAS) project. Sponsored by EPRI, DOE, and Battelle, Pacific Northwest Laboratories, the meeting provided a forum for CAS specialists from industry, universities, and government to exchange information on the state of the art and on new development and research needs of CAS technology. The Huntdorf project is being funded and managed by the Nordwestdeutsche Kraftwerke Aktiengesellschaft of West Germany.

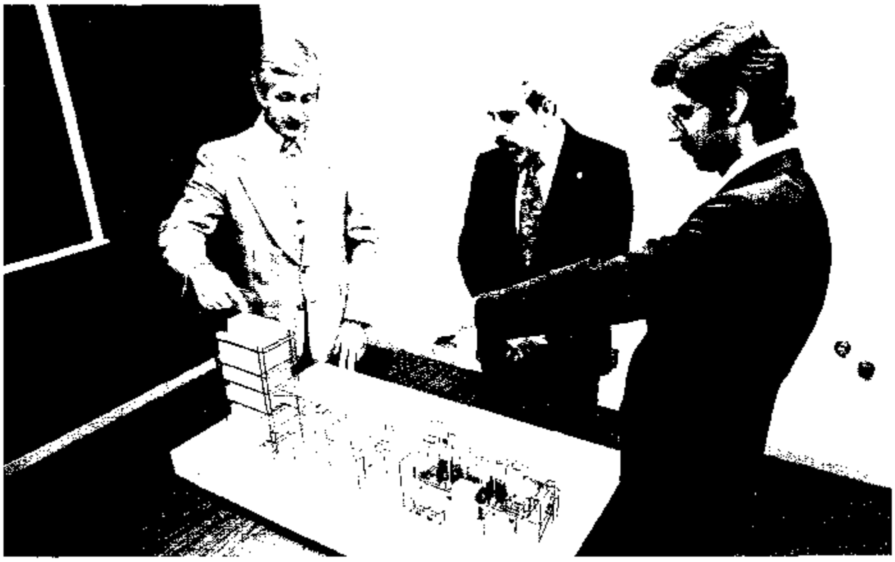
## Correction

The first German nuclear cargo ship, NS *Otto Hahn,* was designed and planned by the Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt (GKSS: Society for the Utilization of Nuclear Energy in Shipbuilding and Navigation), not the Institut für Werkstofftechnologie (Materials Technology Institute) as stated on page 28 in the June issue of the *Journal.*

## CEGB Director Visits EPRI

David Silverleaf, director of research planning for the Central Electricity Generating Board (CEGB), United Kingdom, met with EPRI division representatives recently to review various aspects of the EPRI–CEGB technical information exchange program. Through his visit, Dr. Silverleaf obtained a better understanding of EPRI's programs and objectives, while also exploring the possibility of new cooperative activities with EPRI. As part of the EPRI–CEGB program, technical information is exchanged, both formally and informally. In addition, a CEGB employee was on loan at EPRI, and at least two EPRI divisions are now funding projects at CEGB facilities. Pictured here with Dr. Silverleaf (center) are Robert Uhler (left), director of the Energy Analysis Department, and Walter Esselman (right), department manager of Program Plans and Technical Assessment.

## Test Facility Reviewed



Walter Piulle, EPRI project manager (left), and Donald Teixeira, manager of the EPRI Air Quality Control Program (right), use a model to explain the design of the Emissions Control and Test Facility to Joseph Palomba, Jr., technical secretary of the Colorado Air Pollution Control Commission and president of the Air Pollution Control Association. Palomba was at EPRI recently to get better acquainted with the EPRI staff and the EPRI research program.

The Emissions Control and Test Facility is a $4.5 million facility located at the Arapahoe Steam Electric Generating Station of Public Service Co. of Colorado. The purpose of the facility is to provide utilities and their suppliers with a major facility to support the development and demonstration of equipment for better collection and measurement of particulates from fossil-fuel-fired power plants.

# Project Highlights

## New Approach to Solar Conversion

A novel approach to the conversion of sunlight into electricity is being investigated for use in solar power plants.

This approach involves the use of thermophotovoltaic (TPV) converters, which are related to the conventional photovoltaic solar cells that have been used for 20 years to provide electric power to space satellites.

Solar cells convert sunlight directly into electricity by transforming energy from sunlight into electric charge motion, causing an electric current. In a solar TPV converter, however, a metallic heating element—a radiator—is heated by concentrated sunlight and serves as an intermediary between the sun and the cells. This heating element radiates primarily infrared light, to which the cells are most responsive.

Interest in TPV conversion dates back to the early 1960s, when the U.S. Army considered using it for silent, fossil-fired portable generators. Interest waned in the early 1970s, however, because system performance failed to reach expected levels.

The recent work of a Stanford University research group directed by Richard M. Swanson indicates that TPV devices have the potential to perform well enough to be used in solar power plants. The group, which is under contract to EPRI, has achieved efficiencies of 26% in converting incandescent light into electric energy—up from 12% a year ago—and has outlined a program with strong prospects for reaching 35% conversion efficiencies. Efficiencies that high will probably be required to make the use of the devices in large power plants economically feasible, explains EPRI Project Manager Edgar DeMeo.

Swanson has succeeded in recycling infrared energy unused by the TPV cells, which has led to the attainment of the high conversion efficiencies. Because of these encouraging results, EPRI plans to initiate projects addressing other key technical issues in TPV power plant development, including a conceptual design of the overall system. In addition, discussions between EPRI and DOE are expected to identify TPV program areas for joint research efforts.

R&D funding for EPRI's Solar Program is expected to total $25–$30 million over the next five years.

## Oil Shortage Unlikely

A global oil shortage may be avoided for the rest of the century, according to *Outlook for World Oil Into the 21st Century* (EA-745).

The most vulnerable period will be from the late 1980s to 2005, when an oil shortage could occur if there were rapid world economic growth, extended delays in the development of other energy resources, and little or no improvement in energy conservation. These developments, the report says, could lead to an energy shortage in the free world and substantially higher oil prices.

Such a scenario is unlikely, however, according to the report. Instead, during these years economic growth will probably slow down significantly from the post–World War II rate, and there will probably be substantial increases in the production of nonoil energy resources as well as more efficient energy use. Rather than an oil shortage, the free world can expect a gradual transition from oil to nonoil resources to meet energy needs.

According to EPRI Project Manager Thomas Browne, researchers at the Petroleum Industry Research Foundation, Inc., and the University of Arizona examined the free world oil situation for the periods 1976–1990 and 1990–2005 under different combinations of world economic growth and energy conservation. The analysis was based on economic, technical, and natural resource factors; it did not consider political factors.

The report forecasts that if there is moderate world economic growth and moderate improvement in energy conservation, the free world will need 32.8 million barrels of OPEC oil a day by 1985 and 35.8 million by 1990. It will need about 36.6 million barrels a day by 1985 and 43.1 million by 1990 if there is rapid economic growth and moderate improvement in energy conservation, and about 41.1 million barrels by 1985 and 51.7 million by 1990 if there is rapid economic growth and no significant improvement in energy conservation.

U.S. oil import requirements are forecast to increase from the present 8 million barrels a day to 9.4–12 million by 1985 and to 10–14.5 million by 1990.

Browne emphasizes that the study assumes the United States will continue to expand its efforts to produce domestic oil and gas and to develop synthetic fuels from shale and coal. He warns that failure to do so "could result in a poorer oil supply situation in the 1990s than the one foreseen in this study."

## EPRI Negotiates 43 Contracts

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| **Fossil Fuel and Advanced Systems Division** | | | | |
| RP267-2 | Mossbauer Effect Spectroscopic Study of Pyritic Sulfur in Coal | 15 months | 67.0 | General Electric Co. *W. Slaughter* |
| RP779-16 | Coal Structure and Coal Liquefaction | 6 months | 10.0 | Pennsylvania State University *W. Rovesti* |
| RP779-17 | Evaluation of Letdown Valve Materials for Coal Liquefaction Systems | 7 months | 45.0 | Battelle, Columbus Laboratories *J. Stringer* |
| RP835-2 | Effects of $NH_3$-Based $NO_x$ Control on Air Preheaters | 9 months | 10.0 | Air Preheater Co., Inc. *D. Giovanni* |
| RP979-2 | Fluidized Bed Combustion—Corrosion-Erosion Tests | 1 year | 219.0 | National Coal Board *J. Stringer* |
| RP1030-4 | Engineering and Economic Evaluations of Coal Preparation Concepts | 1 year | 30.0 | Kaiser Engineers, Inc. *K. Clifford* |
| RP1030-5 | Conceptual Design for Coal-Cleaning Test Facility | 3 months | 42.0 | Birtley Engineering, a division of Sverdrup & Parcel and Associates, Inc. *K. Clifford* |
| RP1083-1 | Analysis of Advanced Compressed-Air Storage Systems | 13 months | 95.5 | Central Electricity Generating Board *T. Schneider* |
| RP1131-1 | Particulate and Trace Element Emission Characteristics of Oil-Fired Utility Boilers | 4 months | 71.0 | Consolidated Edison Co. of New York, Inc. *M. McElroy* |
| RP1179-1 | Sorbent Requirements for a Gulf Coast Lignite-Fired Atmospheric Fluidized-Bed Combustion Power Plant | 4 months | 12.0 | Westinghouse Electric Corp. *C. McGowin* |
| RP1185-1 | Evaluation of Turbine Blade-Root Designs to Minimize Fatigue Failure | 1 year | 98.6 | Rochester Institute of Technology *J. Parkes* |
| RP1195-2 | Effects of Acid Addition for Scale Control on Geothermal Field and Plant Systems Operation | 3 months | 22.0 | Systems, Science & Software *V. Roberts* |
| RP1258-2 | Absorption/Steam Stripping—RESOX Engineering | 20 months | 333.5 | Stearns-Roger, Inc. *S. Dalton* |
| RP1265-1 | Failure Cause Analysis —Pulverizers | 1 year | 64.7 | KVB, Inc. *J. Dimmer* |
| RP1274-1 | Utilization of Heat Rejected From Major Transformer Substations | 16 months | 284.5 | City of Seattle, Department of Lighting *E. Ehlers* |
| **Nuclear Power Division** | | | | |
| RP494-3 | Evaluation of Feedback Between Coolant Heat Transfer and Cladding Swelling | 5 months | 25.0 | Rowe & Associates Inc. *R. Oehlberg* |
| RP620-27 | Liquid Metal Fast Breeder Reactor Plant Design | 5 months | 210.0 | Stone & Webster Engineering Corp. *G. Baston* |
| RP623-4 | Evaluation of Alternate Steam Generator Materials and Designs Under Varied Water Chemistry Conditions | 3 years | 354.5 | Combustion Engineering, Inc. *S. Laskowski* |
| RP695-2 | Review of Advanced Analytic Method Developments | 9 months | 12.0 | Banerjee & Associates Consultants, Inc. *L. Agee* |
| RP707-2 | Evaluation of Heavy Actinide Cross-Section Data for Evaluated Nuclear Data File | 6 months | 20.3 | Department of Energy *O. Ozer* |
| RP894-4 | Limiting-Factor Analysis of High-Availability Nuclear Plants | 1 year | 340.0 | Combustion Engineering, Inc. *R. Swanson* |

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP960-1 | Evaluation of Thermal-Hydraulic Effects on Power Distribution in BWRs | 5 months | 49.9 | Nuclear Associates International, Inc. *A. Long* |
| RP1066-1 | Steam Generator Code Development | 1 year | 196.0 | Cham of North America, Inc. *J. P. Sursock* |
| RP1066-2 | Steam Generator Code Development | 3 months | 11.4 | Combustion Engineering, Inc., Power Systems Group *J. P. Sursock* |
| RP1160-1 | Basic Investigation Qualification of Single-Channel Countercurrent Flooding Models | 1 year | 39.0 | University of California at Berkeley *B. Sun* |
| RP1166-2 | Evaluation of Ginna Steam Generator Tube | 4 months | 49.0 | Westinghouse Electric Corp. *J. Mundis* |
| RP1173-1 | Applications of Fiber-Optics Links Between Plant Multiplexed Instruments and Control Computer System | 1 year | 107.0 | E-Systems, Inc. *R. Swanson* |
| RP1230-1 | Effects of Steam Generator Performance on PWR System Safety | 9 months | 100.6 | Intermountain Technologies Inc. *R. Whitesel* |

**Electrical Systems Division**

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP281-4 | Prototype Fault Current Limiter | 2 years | 736.7 | Gould Inc. *R. Kennon* |
| RP993-2 | Vacuum Arc Commutating Switch | 13 months | 117.0 | Gould Inc. *R.Kennon* |
| RP1285-2 | Detection of High-Impedance Faults on Distribution Circuits | 15 months | 207.0 | Hughes Research Laboratories *H. Songster* |
| RP1287-1 | Development of Improved Boring Equipment for Installing Underground Distribution Cables and Conduits | 1 year | 724.1 | Flow Industries, Inc. *T. Kendrew* |
| RP1289-1 | Transformer Life Characteristics | 33 months | 607.0 | General Electric Co. *B. Bernstein* |
| RP1289-2 | Basic Research on Transformer Life Characteristics | 18 months | 458.5 | Westinghouse Electric Corp. *B. Bernstein* |
| RP7872-1 | Cable Oil Study | 25 months | 490.0 | General Electric Co. *S. Kozak* |

**Energy Analysis and Environment Division**

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP1105-1 | Integrated Supply Analysis System for the Uranium Mining and Milling Industry | 15 months | 342.9 | University of Denver *J. Searls* |
| RP1157-1 | Animal Toxicologic Studies on Inhaled Metal-Sulfite Aerosols | 3 years | 243.5 | New York University Medical Center *J. McCarroll* |
| RP1221-1 | New Coal-Using Techniques and Their Effects on Coal Markets | 1 year | 99.9 | ICF Incorporated *J. Karaganis* |
| RP1224-1 | Optimization of Aquatic Microcosm Designs for Pollution Impact Studies | 2 years | 203.5 | University of California at Berkeley *R. Kawaratani* |
| RP1298-1 | Analysis of Decision Methodology Relative to Adoption of New Technology | 1 year | 43.0 | Micro-Economic Associates *A. Halter* |
| RP1304-1 | Determining the Feasibility of Integrating Water Resource Constraints Into Energy Models | 7 months | 47.5 | Stanford University *R. Richels* |
| RP1306-1 | Modeling of Dry Deposition of $SO_2$ and Sulfate Aerosols | 8 months | 91.3 | Aeronautical Research Associates of Princeton, Inc. *G. Hilst* |
| RP1309-1 | Comparison of Indoor and Outdoor Concentrations of Atmospheric Pollutants | 20 months | 490.0 | GEOMET, Inc. *R. Perhac* |

# Washington Report

## Nuclear Waste Management: Looking for the Cure

"Sure, nuclear power sounds like a good idea. It's clean and has a good track record for safety. But what about the wastes? What are we doing to dispose of them?"

From high school students to U.S. congressmen, questions about nuclear waste management are being asked with increasing frequency and concern when conversations turn to the topic of nuclear power. The issue has high visibility and engenders intense public interest. Two states—California and Maine—have already placed laws on the books prohibiting the construction of nuclear plants until the waste disposal problem is solved. Other states are considering similar measures. The "Achilles' heel of nuclear power" is the way *Christian Science Monitor* writer Robert C. Cowan has described the waste management aspect, implying that if any one issue may render nuclear power unacceptable, waste management may be it.

The dimensions of the problem can't be denied. High-level nuclear wastes have accumulated from 35 years of military weapons and naval reactors. Although far less in volume, spent fuel from the nation's 69 licensed commercial reactors is building up and being stored temporarily at reactor sites across the country. With the administration's decision to defer reprocessing of spent fuel and with the National Energy Plan calling for increased use of light water reactor technology, many utilities face the prospect of running out of spent-fuel storage capacity.

What is the United States doing to solve the waste management problem? Formation of a national policy and plan for disposing of nuclear wastes is a responsibility of the federal government. At the present time, attention is focused on a group that represents 15 federal agencies that have varying degrees of responsibility for the problem. Called the Interagency Review Group (IRG), the team was established by President Carter on March 15 of this year as the successor to a task force composed primarily of DOE officials who reviewed waste management functions.

As described by John Deutch, Director of DOE's Office of Energy Research and a central figure in both study teams, the first group produced the "diagnosis" of the waste management problem and the IRG will "prescribe the cure." The IRG report is expected on October 1 of this year.

Deutch appeared recently before the House Subcommittee on Fossil and Nuclear Energy Research and affirmed the commitment by both the Carter administration and DOE to meet the waste management issue head-on.

"The formation of a credible and broadly accepted nuclear waste management policy is a matter of highest importance," Deutch stated. "There is legitimate public concern over our determination to deal with these wastes. An effective and responsible nuclear waste management program that meets these public concerns is an essential step toward ensuring that commercial nuclear power will continue to play an important role in meeting our energy needs."

The original DOE task force pointed out that in addition to DOE input a successful nuclear waste management policy should reflect the views of other government agencies, Congress, the states, industry, and the concerned public. In line with this recommendation, the president expanded membership in the IRG to include the Environmental Protection Agency, the Office of Management and Budget, the Council on Environmental Quality, the Office of Science and Technology Policy, the National Security Council, the Domestic Policy Staff, the National Aeronautics and Space Administration, the Arms Control and Disarmament Agency, and the departments of State, Interior, Transportation, and Commerce. The Nuclear Regulatory Commission was invited to participate as it deemed appropriate.

Six working groups were established within the IRG to define issues and examine options.

- Alternative technology strategies
- Federal involvement (licensing, standards, criteria)
- Defense waste
- Spent-fuel storage/charges
- Transportation issues
- International issues

To broaden opportunity for input from the public and key groups, the IRG is conducting meetings throughout the country for discussion of alternatives and issues. Small group discussions for in-depth consideration of specific viewpoints are being held in Washington, D.C., with utilities; industry; state and local governments; environmental, consumer, and other interest groups; the academic community; Indian tribes; and Congress. Larger, public meetings are being held in San Francisco, Boston, and Denver.

The end product of IRG's work will be a national radiation waste management work plan that (according to Deutch) "will establish procedures and specific milestones for both programs and legislative action." The work plan will determine how federal agencies will proceed to dispose of spent-fuel, high-level, and transuranic wastes; low-level wastes; uranium mill tailings; and decontamination and decommissioning wastes.

Once the policy is formed, DOE will implement it. Specifically, the job will fall to the newly formed Office of Nuclear Waste Management headed by Robert L. Morgan, who for the past five years has served as deputy manager of DOE's Savannah River Operations Office. As part of a recent reorganization of the Office of the Assistant Secretary for Energy Technology and in response to a specific recommendation of the original DOE task force, the waste management function was elevated to the status of a technical program office within Energy Technology. (Previously, the director of the Waste Management Program had reported to the director of Nuclear Programs. Now, the head of the office will report directly to the Assistant Secretary, a change that gives the function greater visibility and support.) The Office of Nuclear Waste Management is responsible for the planning, development, and implementation of defense and civilian nuclear waste processing and isolation; for spent-fuel storage and transfer; for the transportation of nuclear waste materials; and for decommissioning and decontamination.

One of the key projects managed by the office is the proposed waste isolation pilot plant (WIPP). The facility, which may be constructed in an underground salt formation 25 miles east of Carlsbad, New Mexico, is intended to provide for the permanent disposal of transuranic nuclear waste produced by the defense programs and for experimentation with other types of waste. Transuranic wastes are articles contaminated with transuranic elements, such as plutonium, which remain radioactive for thousands of years. The March DOE task force report noted that although only a small quantity of transuranic waste is being generated by the nuclear power industry, significant quantities have accumulated from DOE operations. Some 4 million cubic feet are expected to have been stockpiled by 1985, the report states, enough to cover 94 acres to a depth of 1 foot.

What else WIPP may be used for is a matter under consideration by DOE and the IRG. The DOE task force recommended that the WIPP mission be expanded to include the demonstration of disposal on a retrievable basis of up to 1000 spent-fuel assemblies. This recommendation is being reviewed and has been discussed at public meetings in New Mexico. It is possible that WIPP may also be used for the permanent disposal of high-level wastes from the defense program. This would require a formal licensing review, an environmental review, approval of an amendment to the operating license issued by NRC, and concurrence by the state.

DOE recently announced that a technical support contract would be negotiated with Westinghouse Electric Corp. to assist in developing the design of WIPP and to aid in preparing the required environmental and licensing documentation. If the decision is made to construct WIPP, DOE has the option to extend the contract to include technical support for managing the construction and planning the operation.

Although disposal of nuclear wastes in a geologic medium (primarily salt) has been the major focus of U.S. thinking for waste technology, DOE's Deutch has recommended that a broad-based R&D program be maintained "to determine the viability and practicality of other options." Among those alternatives, at the recent House subcommittee hearing he listed basalt, shale, and granite; seabed repositories; and space disposal.

# R&D Status Report
# FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

## GASIFICATION–COMBINED-CYCLE POWER PLANTS

*Integrated coal gasification–combined-cycle (GCC) power plants provide the electric utility industry with a technology option for generating electric power at high thermal efficiency and, at the same time, complying with stringent environmental control regulations. A recent engineering and economic evaluation of gasification–combined-cycle power systems conducted by Fluor Engineers and Constructors, Inc., has shown these systems to be economically competitive with coal-fired power plants that have stack gas scrubbers.*

Gasification of coal provides a convenient mechanism for the removal of sulfur prior to combustion of the resultant fuel gas. The gasification process converts most of the coal's sulfur to hydrogen sulfide, which can be readily scrubbed out of the fuel gas by a number of commercially available liquid absorption processes. In similar fashion, the nitrogen component of coal is converted into ammonia and elemental nitrogen during gasification. Ammonia can be removed from the gas, reducing the concentration of fuel-bound nitrogen compounds in the gas and thereby reducing the postcombustion $NO_x$ emission problem. Finally, limited data from small-scale pilot plants indicate that as crude fuel gas is subjected to many stages of liquid scrubbing—generally at elevated pressure—nearly all entrained particulates are removed from the gas prior to combustion. Therefore, coal gasification provides the electric utility industry with a technology option for the production of an extremely clean fuel gas that can be tailored to meet stringent environmental emission requirements.

A number of options exist for utilizing the clean fuel gas for electric power generation. Such options range from burning the gas in an existing boiler to constructing highly integrated GCC power plants. The purpose of this report is to emphasize the results of economic evaluations of GCC power plants. Work is under way to evaluate the potential incentives for burning the clean fuel gas in existing boiler and/or combined-cycle equipment.

A series of economic screening studies (AF-244, AF-416, and AF-531) indicate that the most economically attractive option for utilizing coal gasification in electric power generation is the integrated GCC power plant.

An integrated GCC plant is represented by three major subsections—a coal gasification section; a gas-cleaning module for the removal of particulates, sulfur compounds, and nitrogen; and a combined gas turbine–steam turbine power plant.

The general flow schematic of an integrated oxygen-blown GCC power plant shows the extent of integration between the gasification plant and the combined-cycle power system (Figure 1). Although essentially all the subsystem components shown in Figure 1 have been operated at commercial scale, they have never been operated in the integrated GCC mode. An extensive program is under way to demonstrate the operability and control characteristics of integrated GCC systems for electric power production. EPRI's progress in this area was summarized in the *EPRI Journal,* November 1977, p. 33.

Two key questions need to be addressed before the potential benefits associated with the development of integrated GCC systems for electric power production can be determined.

▫ How does the cost of electricity generated from GCC plants compare with that from alternative baseload fossil options (e.g., coal-fired boilers with stack gas scrubbers)?

▫ From an economic point of view, are certain specific gasifiers better suited to integrated GCC power production than others?

In an attempt to address these questions, EPRI sponsored an economic evaluation by Fluor (AF-642). The project has developed estimates of the capital and operating costs for a number of GCC plants based on a variety of gasification technologies. Air-blown Lurgi gasifiers were chosen to represent current commercial technology, whereas air- and oxygen-blown, two-stage entrained high-pressure devices, represented by the Foster Wheeler concept, were chosen to represent highly advanced third-generation options. Second-generation options, defined as those gasifiers that are well into the pilot plant stage, were represented by an oxygen-blown single-stage entrained Texaco system; the British Gas Corp. (BGC)–Lurgi moving-bed, slagging-bottom technology; and Combustion Engineering Inc.'s atmospheric pressure two-stage entrained gasifier.

Flowsheets for complete grass roots plants were designed for all six gasification options mentioned above, and major equipment items were sized. All plant capacities were in the range of 1000 MW, and site conditions were chosen to be representative of a Chicago location.

Plants of this capacity would be highly modular, containing approximately four to six gasification trains, three or four gas-cleaning trains, six to nine gas turbine–heat recovery steam generator sets, and a single steam turbine.

All cases studied were based on Illinois No. 6 coal, with the exception of the Lurgi case, in which a western subbituminous coal was used. The power blocks for all six systems were based on advanced combustion turbines having combustor outlet temperatures of 1316°C (2400°F) and pressure ratios of 17:1. Steam conditions of 10,100 kPa/482°C/538°C (1450 psig/900°F/1000°F) were employed for all cases. Performance and cost estimates for all six power blocks were provided by Westinghouse Electric Corp.

Performance and cost estimates for the GCC systems studied are summarized in

Figure 1 Flow schematic of an oxygen-blown gasification–combined-cycle power plant.

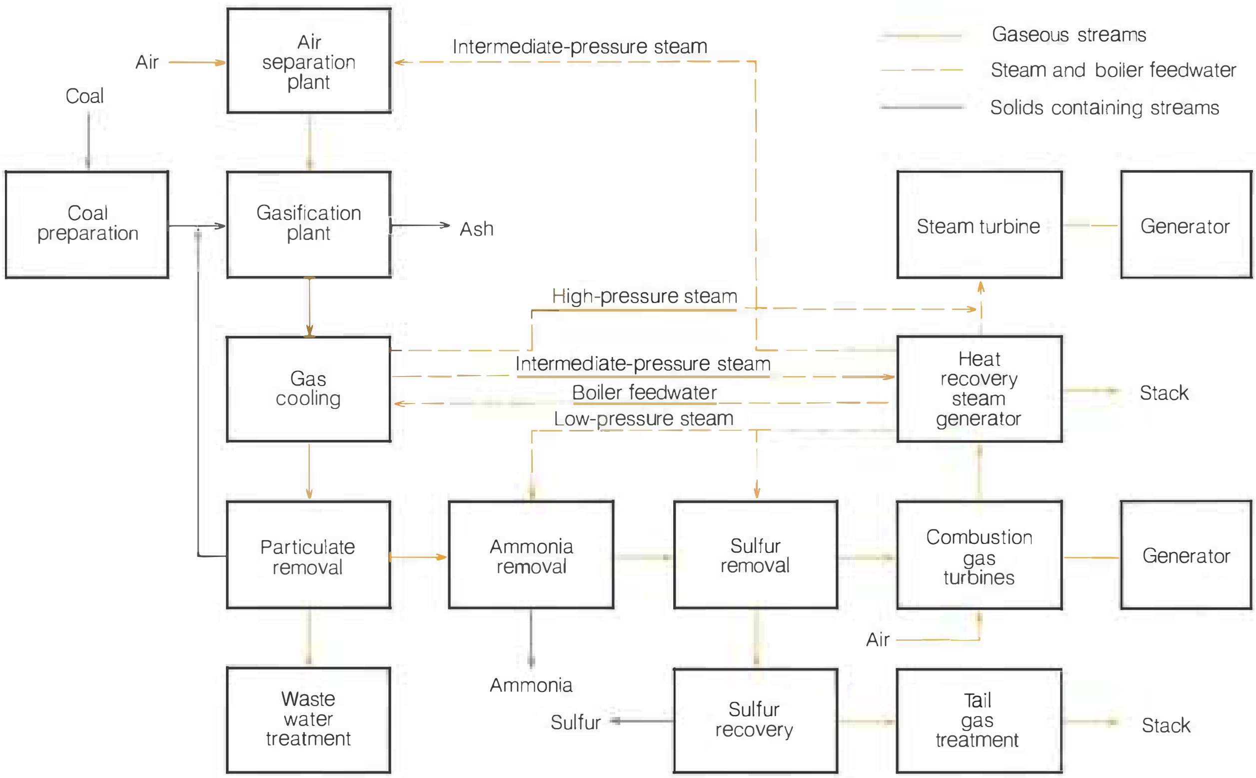



Table 1. Included for comparison are the costs for a new coal-fired power plant with stack gas scrubbers. Plant investment costs for the coal-fired power plant were taken from a Bechtel Corp. study (AF-342) and were adjusted to be consistent with the GCC cases evaluated by Fluor. Sulfur emissions for all systems investigated were limited to a maximum of 0.54 kg (1.2 lb) $SO_2$ per million Btu of coal fired. Costs of electricity reported in Table 1 are based on delivered coal costs of $1/$10^6$ Btu, a capital charge rate of 18%, and an operating load factor of 70%.

The results shown in Table 1 indicate that (in general) GCC-based power plants are expected to be cost-competitive with conventional coal-fired power systems. Key factors contributing to this conclusion are the improved heat rates and lower costs of sulfur removal associated with GCC-based plants. It is also to be expected that as environmental restrictions become more stringent and as the cost of coal increases, the economic advantages of GCC systems will be even greater than is shown in Table 1. It is also of interest to note that GCC power plants require substantially less water than their coal-fired counterparts. This feature of GCC-based systems could become an important factor in establishing future siting requirements for baseload power plants.

In comparing the different gasification technology options for GCC power plants, it is of interest to note that the available Lurgi option provides the most expensive electricity, whereas the highly speculative air-blown Foster Wheeler concept results in the lowest-cost system. The second-generation options, such as the Texaco system and the BGC slagger, are intermediate in cost. Lurgi costs tend to be high primarily because of low gasifier capacity and the production of such by-products as tars, oils, and phenols, which are costly to collect and handle in an environmentally acceptable manner.

The Combustion Engineering option appears to be expensive when operating in the combined-cycle mode primarily because of the high cost of fuel gas compression (the Combustion Engineering gasifier operates at atmospheric pressure). If lower-cost fuel gas compressors could be developed, the Combustion Engineering GCC option would improve considerably.

The BGC slagging-bottom gasification technology appears to be attractive for combined-cycle power generation, judging from the results of the Fluor study. However, it must be kept in mind that the performance data supplied by EPRI to Fluor for this study were based on an extrapolation of pilot plant data accumulated in Westfield, Scotland, on a 350-t/d device fired primarily with a Scottish coal. The results of the Fluor study presuppose that the slagger can be successfully scaled up, that it will operate as estimated on Illinois coal, and that coal fines and tar products can be recycled to the gasifier. The results of this study concerning the BGC slagger must be confirmed on a full-scale gasifier using eastern coking coal.

From the results of this study, the Texaco oxygen-blown coal gasification technology appears to be well suited to combined-cycle power generation. The gasifier is based on

**Table 1**
**PERFORMANCE AND COST COMPARISONS**

| | Coal Type | Oxidant | Net Heat Rate (Btu/kWh) | Water Requirement (gal/min)/GW | (m³/s)/GW | Total Capital Requirement ($/kW)* | Cost of Electricity (mills/kWh)† |
|---|---|---|---|---|---|---|---|
| Lurgi | Western | Air | 9,762 | 7,905 | 0.48 | 906 | 41.2 |
| Texaco | Illinois | Oxygen | 8,813 | 7,950 | 0.49 | 816 | 37.2 |
| BGC Slagger | Illinois | Oxygen | 8,410 | 6,716 | 0.41 | 711 | 32.8 |
| Foster Wheeler | Illinois | Air | 8,428 | 6,622 | 0.40 | 705 | 32.5 |
| Foster Wheeler | Illinois | Oxygen | 8,876 | 7,034 | 0.43 | 739 | 34.1 |
| Combustion Engineering | Illinois | Air | 8,959 | 7,596 | 0.46 | 931 | 41.4 |
| Coal-fired plant with stack gas scrubber | Illinois | Air | 9,928 | ~12,000 | ~0.74 | 838 | 40.9 |

*Mid-1976 dollars, including allowance for funds during construction, startup costs, working capital, contingencies, royalties, and initial catalyst and chemicals.
†First-year costs based on coal at $\$1/10^6$ Btu and a 70% operating load factor.

**Table 2**
**COST OF GCC PLANT SECTIONS**
(% of total plant cost)

| | Coal Handling | Oxidant Feed | Gasification and Ash Handling | Gas Cooling | Acid Gas Removal and Sulfur Recovery | Waste Water Treating | Fuel Gas Compression | Steam, Condensate, and Boiler Feedwater | Support Facilities | Combined Cycle |
|---|---|---|---|---|---|---|---|---|---|---|
| Lurgi | 4.36 | 3.25 | 17.00 | 3.25 | 5.09 | 10.03 | ... | 7.13 | 10.44 | 39.45 |
| Texaco | 3.56 | 18.95 | 3.92 | 10.81 | 4.61 | — | — | 0.14 | 8.91 | 49.10 |
| BGC Slagger | 2.63 | 10.23 | 8.76 | 1.58 | 4.15 | 5.50 | — | 0.36 | 10.25 | 56.54 |
| Foster Wheeler (air-blown) | 5.41 | 3.96 | 7.88 | 5.93 | 6.72 | 1.81 | ... | 0.30 | 11.42 | 56.57 |
| Foster Wheeler (oxygen-blown) | 5.39 | 12.30 | 6.55 | 3.57 | 5.01 | 1.41 | — | 0.51 | 10.58 | 54.68 |
| Combustion Engineering | 6.88 | 0.31 | 13.06 | 2.05 | 3.55 | — | 25.58 | 0.12 | 8.16 | 40.29 |

Texaco's 30 years of oil partial-oxidation experience for synthesis gas generation. A 15 t/d coal gasification pilot plant has been operated in Montebello, California, for the past four years. This pilot operation has demonstrated that the Texaco partial-oxidation technology can be successfully applied to coal. The gasifier appears to be extremely flexible and has been operated successfully on a large variety of coal feedstocks. A 150 t/d coal-fired Texaco gasifier has been constructed and started up in Germany for the commercial production of chemicals. This development is being followed closely by EPRI.

Because of the advanced stage of development of the Texaco gasification process and the economic incentives indicated by the Fluor study for Texaco-based GCC power plants, demonstration of an integrated Texaco GCC plant for utility power generation is now the primary goal of the Clean Gaseous Fuels Program. To further the achievement of this goal, the Advanced Fossil Power Systems Department is funding a $2 million experimental pilot plant program at Texaco's Montebello test facility, a number of system control and modeling studies (summarized in the November 1977 *EPRI Journal* p. 33), and ongoing system configuration and economic studies of the Texaco technology (RP239, RP986, and TPS78-773).

Another important result of the Fluor economic evaluation is shown in Table 2, which indicates the percentage contribution to total plant investment of each major section of the GCC plants evaluated. This table demonstrates that the gasification section of each plant rarely represents a major portion of total plant cost, indicating that it would be more cost-effective to develop advanced equipment for other sections of GCC plants (i.e., heat exchangers for hot, dirty gases; air separation plants; advanced power cycles; and so on) than to develop a variety of improved gasifiers for combined-cycle application. Concentration of Clean Gaseous Fuels Program funds on the Texaco gasifier development is consistent with this philosophy. *Program Manager: Michael J. Gluckman*

## CONDENSER BIOFOULING CONTROL

*Biofouling, or slime accumulation, in condenser tubes is a natural phenomenon that occurs in every power plant. Operators must take frequent action to control it, relying mainly on their ingenuity. Pending EPA limitations threaten to nearly eliminate the traditional means of control (chlorination) and hence cause significant reduction in plant performance. Several projects are under way and more are planned to provide solutions to biofouling—an elusive and complex biological-physical-chemical phenomenon. Efforts are proceeding along three avenues: understanding what causes biofouling and how different control measures work, developing instruments for quantifying the extent of slime-induced problems, and evaluating chemical/physical alternatives to chlorination.*

Any trout fisherman who wades in flowing streams knows what a problem slime films covering rocks can be. Slimes form naturally on any solid surface, whether in a pristine mountain stream or a polluted estuary. Elevated temperatures and constant flow over the surface seem to exacerbate the problem of microbial growth, which produces sticky molecules that hold particulate matter and microbial "groceries."

It's quite understandable that most power plant operators are familiar with the problems that slime causes. The insides of condenser tubes are an ideal environment for slime growth, except that algae don't grow here, as they would in a stream bed. The problem is that slime films reduce heat transfer between the condensing steam and cooling water and thus indirectly diminish the power extracted per unit of fuel consumed. The rate of biofouling, or slime accumulation, varies with season (accumulation is generally more rapid in summer), location (which determines water quality—mainly the supply of microbial nutrients and energy, as well as particulate matter), and control measures (either active or passive).

The preferred active control measure, which has evolved since the 1930s, is chlorination, in spite of the fact that it is unknown how this measure controls biofouling. Other oxidants, biocides, and—lately—dispersants have been actively promoted by chemical vendors. Sponge rubber balls (Amertap), brushes (M.A.N.N.), and thermal-hydraulic shocks are other active, on-line control measures available. A variety of mechanical-chemical off-line measures complete the list of active cleaning approaches.

Passive measures include control of condenser-related factors, such as water velocity, tube skin temperature, and alloy toxicity, which may influence biofouling rate. Biofouling can also be passively controlled by regulating the source water characteristics, such as the presence of toxins or solids that are of sufficient mass and density to scour the tubes.

The salient problem in biofouling is the difficulty of quantifying its characteristics and effects. The slime films are thin but cover a large area; they are inaccessible; they accumulate gradually; and they represent one of many factors that may affect condenser performance and steam backpressure. In order to apply active control measures on an as-needed basis, operators urgently need an on-line sensing device with adequate sensitivity and rapid response time.

### EPA limitations

It appears that chlorine is the major constituent in power plant cooling-water discharges that the EPA has targeted for control, if not outright elimination. Informally, EPA has indicated that the limit will be set at 0.02 mg/l of total residual chlorine at the point of discharge for all facilities, beginning in 1984 (the preliminary draft of the limitations is expected to be proposed in the *Federal Register* next January). EPA's tentative plan is to mitigate limitations on an individual-plant basis. If the utility believes that the limitation on chlorine discharge seriously threatens its control of biofouling, it must demonstrate to EPA that it has minimized the use of chlorine. Exactly what factor is to be minimized has not been defined—total mass of chlorine used per time period and unit (where mass/time = concentration × flow rate); mass of total residual chlorine discharged; or mass of free residual chlorine discharged. This situation poses a real dilemma: utilities are expected to fine-tune a control procedure, but no one actually understands how chlorine or its alternatives function as control measures. Additionally, there are no methods available for adequately quantifying the degree of condenser biofouling.

Several projects are under way, and more are contemplated, to attempt to meet industry needs in dealing with the problem of understanding and controlling biofouling in condensers (Table 3).

| Project No. | Title |
|---|---|
| RP902 | Biofouling Film Development and Destruction |
| RP1132 | Biofouling Control: Practice and Assessment, Phase I |
| | Biofouling Control: Practice and Assessment, Phase II |
| RP733 | Ozone Dosage and Contacti[illegible] for Biofouling Control |
| RP1372 | Alternatives to Chlorination |
| RP1261 | Treatment of Circulating Cooling Water |
| RP2808 | Biofouling Control Symposium |

**Table 3**
**CONDENSER BIOFOULING CONTROL PROJECTS**

| )bjectives | Focus | Sponsors | Contractors | Time |
|---|---|---|---|---|
| :valuate alternative film-sensing devices<br>)efine variables that affect ilm development<br>:valuate alternative nethods of film destruction | Laboratory study<br>Fresh water | EPRI | Rice University | September 1976–March 1978 |
| )ocument utility problem and control practice (basis and instrumentation)<br>)evelop model to relate cause and effect | Full-size condensers<br>Once-through cooling<br>All-quality waters | EPRI | NUS Corp. and Marine Research, Inc. | March 1978–April 1979 |
| :onduct biofouling control optimization program with seven utilities<br>'est model<br>'roduce guidelines | Full-size condensers<br>Once-through cooling<br>All-quality waters | Not yet determined | Not yet determined | Not yet determined |
| )etermine minimum $O_3$ for :ontrol<br>:valuate contactor design<br>:valuate cost | Pilot-scale condensers<br>Once-through cooling<br>Fresh and brackish water | EPRI, Public Service Electric and Gas Co., and Foster Wheeler Energy Corp. | Public Service Electric and Gas Co. and Rutgers University | May 1976 (continuing) |
| :valuate continuous ow-level $Cl_2$<br>:valuate dechlorination oxicity<br>)ptimize biofouling control<br>:valuate toxic coatings<br>:valuate ozonation | Pilot- and full-scale condensers<br>Once-through cooling<br>Brackish water | New England Power Co., Northeast Utilities, Boston Edison Co., The United Illuminating Co., Vermont Yankee Nuclear Power Corp., and EPRI | Marine Research, Inc. | June 1976–May 1977 |
| :ontrol biofouling, caling, and corrosion<br>)evelop system design rocedures<br>'roduce system operation oftware<br>)evelop operation uidelines | Pilot-scale condenser (portable test facility)<br>Closed-cycle cooling<br>All-quality waters | EPRI | Not yet determined | July 1978–September 1979 |
| ıform utilities of esearch, new control ptions, and instrumentation<br>ıform researchers of tility experience, roblems, and onstraints | Condenser biofouling control | EPRI | Marine Research, Inc. | March 1979 |

## Biofouling cause and control

There are several reasons why we know so little about biofouling and its control.

▫ Biofouling is a very complex biological-physical-chemical phenomenon that has not yet been systematically studied under controlled conditions.

▫ No one has yet attempted to collect, correlate, and analyze the information that utilities have from their vast experience in dealing with biofouling.

▫ The myths that have filled this gap in knowledge have greatly confused the issues. The first two projects listed in Table 3 are directed toward replacing myth with fact.

Laboratory studies were initiated at Rice University in 1976 (RP902) using three different highly instrumented loops that circulated water containing soluble organic matter and mixed bacterial seed. Bulk water temperatures (27–40°C; 82–104°F) and velocities (0.9–2.0 m/s; 3–7 ft/s) were controlled to simulate a condenser. Several conditions of this research should be noted because they may affect the applicability of these laboratory results to actual condensers; subsequent experiments may determine the importance of the conditions.

▫ Only glass and acrylic surfaces were used.

▫ The bacteria were not exposed to heat flux across the slime film and the associated temperature gradient.

▫ No particulate matter was added.

▫ Most of the experiments were done essentially as batch reactions.

▫ The organic carbon source was glucose, which is soluble and highly biodegradable, unlike the predominantly particulate, nonbiodegradable organics found in surface water.

Some attempts were made to compare the laboratory-developed slime films to real films, but since results were inconclusive, caution is suggested in using the results.

A generalized curve shows slime accumulation inside an initially clean tube in the absence of chlorination (Figure 2). Also shown are the effects of major condenser-related variables (temperature and waterside velocity) and water quality parameters that were investigated. In practical terms, growth rate is of greatest interest. Laboratory experience shows that control measures (short of brushing and chemically cleaning) probably remove only a portion of the slime film. The decision on how often treatment is needed—which is the operator's problem—depends on growth rate, treatment effectiveness, and film reduction. The data summarized in Figure 2 qualitatively support the seasonal variations in fouling that many operators experience (increased fouling in summer) but also suggest that the only way to control biofouling by passive measures is to design for it.

A series of experiments was conducted on the destruction of biofilm by chemical and physical means. Some interesting conclusions were reached, but their relevance to actual biofilm control depends on establishing comparability of the laboratory biofilms and actual biofilms by further study. It was found that chlorine controls the films mainly by oxidizing the slimelike structural fibers (presumably bacterial extracellular polysaccharides) and that shear stress from water flow induces erosion and sloughing of the weakened material. (This effect could open numerous avenues for control on both existing and new facilities.)

It is disconcerting to find that biofilms may regrow at an accelerated rate after chlorine treatment (Figure 3). This is consistent with the general finding that chlorine treatment removes only a portion of organic material and bacteria. Rapid regrowth could be expected on an inoculated surface that has a ready supply of "groceries" surrounding the surviving bacteria. The practical implication is that once a film has accumulated and chlorine has been applied, the frequency of treatment must be increased. The films were found to consume between 0.06 and 0.30 milligram of chlorine per milligram of film removed.

Limited laboratory experiments were done with other oxidants, but ozone was found to be far superior. It was the only oxidant that appeared to strip the surface clean. A test involving regrowth will need to be conducted to formulate a valid comparison, however.

For new facilities and some existing ones, physical treatments such as temperature excursions and flow reversal might be applied. Both treatments were tested and found to eliminate 30–90% of the film. Temperature excursions (to 50–60°C for more than 30 min) were the more effective means, and they appear to greatly retard regrowth. Some promising combined physical-chemical approaches are suggested.

Plans are to continue laboratory investigations, with emphasis on simulating real condenser conditions, incorporating particulate effects, and studying slime film destruction and control. This will be tied in with projects being conducted at power plants (RP1132) to ensure focus on realistic problems.

A project was initiated in March to deal directly with biofouling on a power plant scale (RP1132). Through the cooperation of many utilities and the EEI Power Station Chemistry Subcommittee, a valuable information base has been compiled that summarizes available information on facilities, biofouling problems, and control practices. EPRI and cooperating utilities will select seven cities where detailed work will be conducted on cause and control of biofouling. The goal is to produce industry guidelines by 1981 that will allow selection of a workable biofouling control program on a site-by-site basis while also minimizing adverse aquatic effects. It is anticipated that interim results will identify solutions to particular classes of fouling.

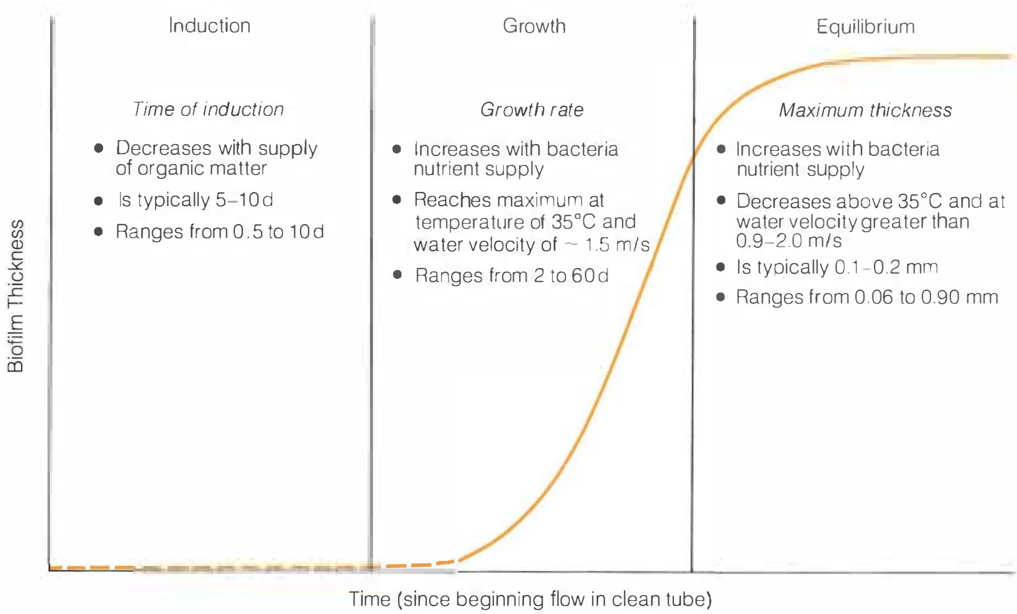



Figure 2 Biofilm development under laboratory conditions is divided into three distinct periods: induction, growth, and equilibrium. Within these periods are listed the major variables that determine the exact shape of the curve.

Several New England utilities initiated a project on control in the early 1970s, and EPRI became a participant in 1976. An interim finding is that ozone is a very effective biofouling control in fresh water but is not a good choice in brackish water because of residual toxicity.

### Instrumentation for biofouling measurement

Biofouling control would probably be routine if its effect on condenser and plant performance could be quantified rapidly and accurately. A second but less desirable approach is to develop instrumentation that will directly measure the extent of biofilm accumulation in a condenser tube. A third approach is to divert a slipstream through an instrumented device that facilitates measurement of biofouling, but with this approach there is a risk that the measurement will not accurately reflect fouling that would actually occur in the condenser.

All three of these avenues are being pursued in various combinations of the projects listed in Table 3, and additional work is being contemplated. The laboratory project (RP902) was directed at identifying approaches useful for research as well as for actual condenser applications. Nine measurement methods were investigated—four thickness-measurement approaches, two optical methods, two fluid frictional resistance methods, and one heat transfer method. The optical and frictional resistance methods seemed to offer the greatest promise.

Three identical model condensers are being used at Public Service Electric and Gas Co. (PSE&G), and the rate of fouling in the models will be compared with that in the condensers at the PSE&G Bergen Station, New Jersey, starting this summer (RP373). Several alternative slipstream approaches are to be tested at Brayton Point, Massachusetts (RP1372). Also, Wisconsin Electric Power Co. has developed an innovative method by making measurements on a few tubes extended through the outlet water box, but results of this research have not yet been published.

### Alternatives to chlorination

Results of ozonation and laboratory studies of physical means have been discussed. The testing of ozone on model condensers will begin shortly at two PSE&G stations to compare ozone effectiveness with that of chlorine. A cost analysis will also be performed. Other efforts are planned to evaluate physical and physical-chemical means of control.
*Project Manager: Roger Jorden*

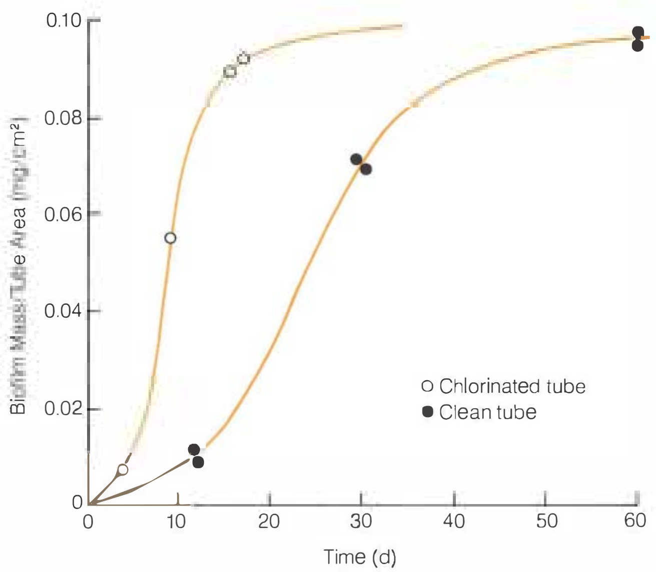



Figure 3 For biofilm samples collected at Houston Lighting & Power Co.'s Deepwater plant, tests indicated a much higher rate of biofilm buildup in a condenser tube that had been chlorinated (after a growth experiment) than in an originally clean tube.

# R&D Status Report
# NUCLEAR POWER DIVISION

Milton Levenson, Director

## WORKSHOP ON BWR PIPING INSPECTION METHODS

*Thirty specialists in the fast-moving field of nondestructive inspection met recently to exchange ideas. The occasion was a four-day workshop (January 16–19), which was sponsored by EPRI, hosted by Battelle, Columbus Laboratories, and attended by quality assurance engineers from utilities, in-service inspection companies, and NRC. Southwest Research Institute (SWRI) and General Electric Co. collaborated with Battelle-Columbus in organizing the workshop. The lecture demonstrations were supplemented by opportunities for every person attending to inspect real BWR pipe samples, using each procedure and item of equipment.*

The workshop centered on the use of recently developed equipment and procedures for early discovery of intergranular stress corrosion cracking (IGSCC) in stainless steel piping. Nine samples of pipe were provided, ranging from 10 to 65 cm (4–26 in) in diameter.

The main detection methods stressed in this workshop were new aspects of ultrasonic technique, including several new transducer types. Radiographic inspection and dye-penetrant procedures were also discussed and demonstrated.

Recent experience with the cracking of 10-cm (4-in) bypass with 25-cm (10-in) core spray lines in BWRs has heightened interest in improved methods of detecting and analyzing these flaws during maintenance inspections and in discovery of the cause and cure.

The problems associated with in-service inspection for such cracks were evaluated in a recent technical planning study (TPS75-609) and reported in the April 1976 and August 1977 issues of the *EPRI Journal.* As a result of this study, a three-year project (RP892) was initiated in 1977 to improve the overall process of ultrasonic inspection for detecting and analyzing IGSCC in stainless steel piping, using practical methods that are code-acceptable. The technical planning study indicated that some of the most effective equipment and procedures for detecting IGSCC were not generally available. Hence, one goal of the EPRI project is the rapid and efficient transfer of such technical information to practitioners in the field. This is the first of a series of workshops planned for that purpose.

The major objectives of the series of workshops are to:

- Replace the "art" and mystique of detecting IGSCC in stainless steel piping with a systematic approach to inspection
- Provide the industry with supplementary nondestructive inspection procedures, such as field radiography, to improve the overall capability of the inspector
- Transmit the combined knowledge of leading specialists to the utility industry in a rapid, efficient manner

New equipment and procedures were described and demonstrated each day. Then the participants, in groups of three, used the equipment on the samples provided, recorded the data, and analyzed and interpreted the results. Comparison of the results from the 10 groups was instructive. Participants were encouraged to use their own test equipment and procedures on the specimens provided and to compare the results with results from the equipment (primarily transducers) developed in RP892.

The workshop was intended for personnel working in nuclear in-service inspection who already had considerable experience with ultrasonic, dye-penetrant, and radiographic testing. The participants were:

- Quality assurance or inspection engineers from EPRI member utilities
- Inspectors from nuclear steam system suppliers or from in-service inspection groups that supply services to EPRI member utilities
- Code committee and government regulatory research representatives

Attendance at the workshop was restricted to 30 participants because of limitations on the number of specimens, instruments, and staff. Of the 30 participants, 21 were utility representatives, 8 were representatives from in-service inspection agencies, and 1 was an NRC representative.

The highlight of the workshop was the hands-on inspection of several 10-, 25-, and 65-cm (4-, 10-, and 26-in) diameter pipe specimens that contained many natural reflectors and internal flaws. The ultrasonic responses from these specimens were chosen as being typical of the detection problems faced in field inspections of nuclear piping systems. The reflectors contained in the pipe segments included IGSCC, weld defects, and geometric reflectors. Some nonflawed specimens were also used. This kept the participants from expecting cracks at each pipe station and emphasized the difficulty in reflector discrimination when a crack–no-crack decision had to be made.

The specimens at each station (laboratory bench) were mounted on wooden blocks, and the pipe ends were covered to discourage participants from looking at the inside of the pipe. The pipes were actual plant specimens and were mildly radioactive (less than 30 mrem at the surface). The 25-cm (10-in) pipe segments had been used previously in EPRI-sponsored round-robin inspections, and the extensive characterization of the defects in the segments is described in an EPRI special report (NP-436-SR). The 10-cm (4-in) pipe segments came from General Electric's environmental simulator. These had stress corrosion cracks that had been induced in the laboratory without radioactivity. A section of a 65-cm (26-in) diameter specimen also came from General Electric. The cracks in this specimen were produced by using a chemical method (Strauss solution) that roughly simulates environmental cracks.

Prior to the workshop, all pipe specimens were tested with fluorescent penetrant and radiographed using X-ray and gamma-ray techniques. Most of the specimens were radiographed by means of a double-wall field technique with and without water in the pipe. The double-wall radiographs were made as described in the ASME Boiler and Pressure Vessel Code, Section V.

The workshop activities consisted of a series of lectures, demonstrations, and hands-on activities. The lectures were designed to give background information on pipe welding, systems design, stress analysis of welds, nuclear code regulations and requirements, and state-of-the-art inspection techniques, as well as to present specially prepared procedures to be used in the workshop.

The lectures were given by representatives of in-service inspection agencies, laboratories conducting nuclear-related research, code and regulatory agencies, and vendors of nuclear systems and subsystems. The speakers were considered to be leaders in their fields. The workshop was coordinated and directed by Battelle-Columbus with assistance from General Electric, EPRI, and SWRI. All these laboratories are presently working as part of RP892.

The ultrasonic test procedure was demonstrated in the laboratory prior to the round-robin inspection by the participants (Figure 1). Other demonstrations were given of state-of-the-art fluorescent-penetrant tests and X-radiography. The improved sensitivity to IGSCC of the SWRI dual transducer (as compared with standard transducers) was demonstrated. The laboratory hands-on exercises were:

- Round-robin ultrasonic inspection of pipe segments and reading of available radiographs
- Detailed reexamination of pipe segments to complete data
- Reexamination of pipe segments after viewing penetrant indications and welds on the inside of the pipe
- Individual studies of hardware and procedures, including feedback from results obtained by others

The outsides of the pipes were covered except in areas of transducer placement.

Figure 1 Hands-on ultrasonic examination of a stainless steel pipe sample that is similar to a BWR bypass line.

Cotton and rubber gloves were worn during the examination of the pipe to protect the participants and to simulate field conditions.

After the ultrasonic round-robin exercise, radiographs of the pipes were read in a separate room with five viewing stations. The participants were asked to make evaluations based only on the radiographic examination. These evaluations could then be combined with the ultrasonic results for a final decision on the presence of a crack and its location in a pipe segment. The pipes were available for additional evaluations as requested.

The covered areas of the pipe were eventually revealed, and penetrant indications were given, along with detailed explanations of the history of each pipe segment. The pipe segments were made available for reexamination by ultrasonics so that each participant could examine regions of particular interest.

A critical evaluation of the workshop has been requested from each participant. In addition, the test data and results from each inspection team are being reviewed to determine the effectiveness of the workshop design and to define where additional work may be needed in technique development, data analysis methods, and inspection procedures.

As a direct result of the workshop, the dual transducers developed by SWRI were requested by a number of the utilities and inspection groups for trial use in the field. EPRI has agreed to supply these transducers and has requested that data obtained be made available to EPRI to aid in evaluating the transducers' effectiveness and limitations. An optimized transducer design with well-defined capability is expected to be available for the next series of plant inspections in fall 1978. *Project Manager: Eugene Reinhart*

## INTERPRETING THE CHARPY TEST FOR USE IN REACTOR SURVEILLANCE

*Of paramount importance in nuclear steam supply systems is the maintenance of the integrity of the primary pressure-retaining boundary, which contains the coolant for the nuclear reactor core. Although there are secondary containment systems designed to accommodate a rupture, integrity of the primary system is necessary for proper functioning of the plant and for public safety.*

*One key element in the structural integrity analysis of reactor pressure vessels is the fracture toughness of the construction materials throughout plant lifetime. The Charpy impact test is presently used in the surveillance programs of LWRs to assess the effects of fast-neutron bombardment on fracture toughness. The Charpy test is an extremely simple one to perform, and yet the results are very difficult to interpret in* *terms of quantitative fracture toughness. This research project develops a procedure for estimating fracture toughness from Charpy results for irradiated materials.*

To demonstrate integrity of the primary pressure boundary, requisite material properties must be known, and changes in properties due to operational factors (e.g., irradiation) must be accounted for during plant lifetime. The material surrounding the nuclear core is exposed to appreciable fast-neutron bombardment. Neutron bombardment embrittles the material to some degree. This embrittlement is manifested by a loss of ductility, a reduced resistance to fracture, and an increase in the brittle-ductile transition temperature. These manifestations may significantly affect the ability of some nuclear plants to meet technical specification limits, possibly encumbering future operation. It should be emphasized that such encumbrance can result from inadequate or inappropriate radiation data, even though the reactor vessel may actually be well within safety limits.

One of the principal design criteria needing revision in the current treatment of radiation damage is the use of an inappropriate materials test—the Charpy impact test—in radiation surveillance programs.

The Charpy test, developed in 1912, utilizes a three-point-bend steel specimen, 10 mm square and 40 mm long with a 2-mm-deep notch in the midsection that acts as a stress concentrator. The specimen is broken in a weighted-pendulum machine, and the principal test result is the amount of total kinetic energy absorbed during specimen separation. Charpy tests on reactor vessel materials are conducted at a number of different temperatures to capture the shape and position of the brittle-to-ductile transition characteristic of low-alloy ferritic materials. The maximum amount of energy, generally referred to as the Charpy upper-shelf energy, is absorbed in the temperature region where the specimen is fully ductile.

The Charpy test, when incorporated into the present reactor surveillance program, does not directly measure the property desired (fracture toughness) for fracture analyses. This test is qualitative and requires supplementary testing and service experience to differentiate between acceptable and unacceptable energy levels for safe operation. Fracture mechanics tests do measure fracture toughness, and the results are directly useful for design purposes and safety assessments. Presently, only tenuous correlations are available for predicting fracture toughness from Charpy impact energy.

In summary, the Charpy test has these assets: It requires only a very small specimen, is a simple test procedure, is amenable to hot cell testing, indicates fracture transition, and defines relative fracture resistance.

It has the following liabilities: It has limited design value; does not measure fracture toughness and therefore only indirectly supports inferences on allowable flaw sizes; can be very sensitive to test procedures and specimen preparation; can be oversensitive to grain size, orientation, and so on, when compared with the fracture mechanics test; and is sensitive to yield strength when compared with the fracture mechanics test.

Nevertheless, the conventional Charpy test is the standard technique for measuring radiation damage. Minimum levels of fracture toughness are being established from test results that do not directly measure fracture toughness.

An analytic correlation between Charpy energy and fracture toughness that takes into account the hardening effect of radiation would be useful in refining toughness estimates for vessel materials in operating reactors. The complexity of the test has been the primary deterrent to such an analysis in the past.

In summer 1976, it was decided that Lawrence Livermore Laboratories' work on RP603-1 should be redirected to address the Charpy interpretation problem. The project was initially structured to apply a ductile fracture model (developed with Department of Defense funding) to the analysis of the upper-shelf, intermediate-vessel fracture tests conducted under the auspices of the NRC-funded Heavy-Section Steel Technology Program at Oak Ridge National Laboratory. The fracture model was capable of predicting crack initiation and growth under fully ductile conditions—a difficult task. The model was to be calibrated for reactor vessel steel through the detailed simulation of actual laboratory tests of the material (Figure 2). Once the model was calibrated, essentially any structural test could be simulated on the computer. This required a large computing capacity, and Lawrence Livermore has one of the largest in the world.

Because of the importance of radiation embrittlement surveillance for operating nuclear plants, it was decided that the focus should be on analysis of the Charpy test by means of the calibrated damage model and on development of an analytic correlation between Charpy energy and fracture toughness.

Therefore, the new primary objective is to thoroughly analyze the standard Charpy test. The analysis permits the separation of total energy into initiation energy, energy associated with extraneous plastic deformations, propagation energy, and energy transmitted to the test machine. Only initiation energy is important to the correlation with fracture toughness. After the first analysis, it was possible to determine why the existing empirical correlations were unsuccessful. Only 10% of the total test energy is consumed at the point of crack initiation. The analysis of the test continued until a small but finite propagation existed. Results from

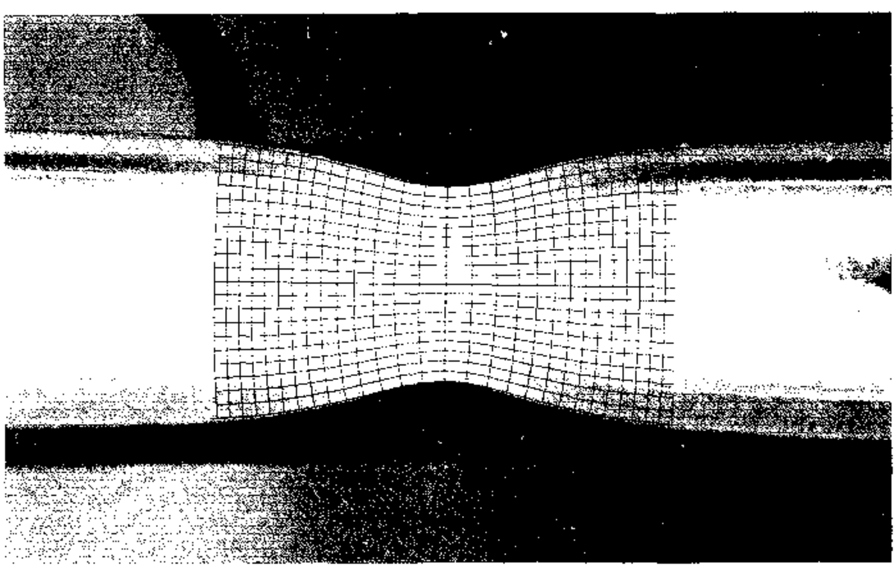
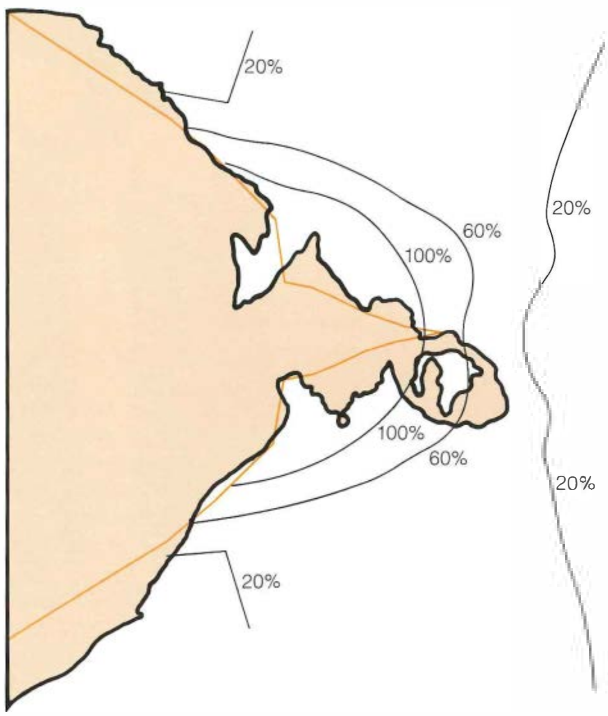


Figure 2 Computer simulation of a tensile test superimposed on a photograph of an actual test specimen, showing characteristic nonuniform deformation prior to failure.

Figure 3 Computer simulation of the Charpy impact test superimposed on a reproduction of the midsection of the actual test specimen. The predicted crack extension and contours indicating percent of damage are shown.



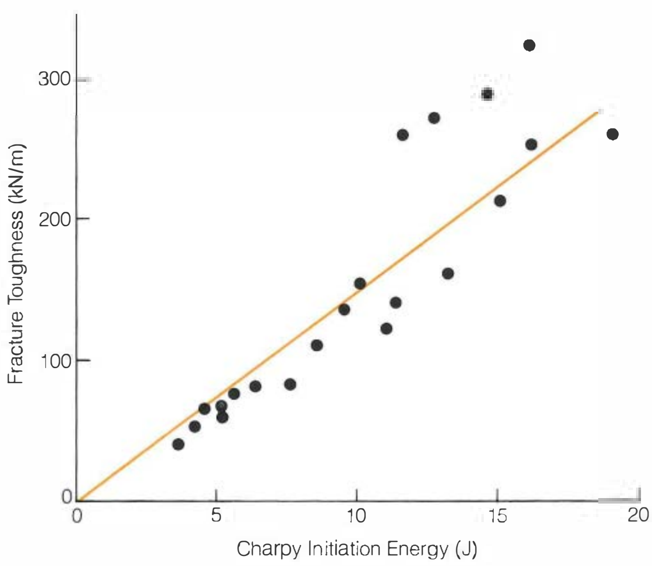




Figure 4 Analytically developed correlation (solid line) for relating fracture toughness to Charpy upper-shelf energy. The data points are experimental determinations.

interrupted Charpy tests confirmed the accuracy of the analysis (Figure 3).

A second phase of this correlation is to take the developed computer model and simulate a fracture toughness specimen. Thus the model will provide a direct analytic correlation between the Charpy energy (the available information) and the fracture toughness (the desired information). The fracture specimen simulation will also be confirmed by interrupted fracture toughness experiments.

As mentioned before, fast-neutron irradiation alters the flow properties of the material as well as altering the fracture toughness. Both of these manifestations affect the Charpy test results. One objective in the research is to sort out the two effects and correct for the altered flow-property effect.

Though desirable, it was impractical to work with irradiated material to test the correlation developed on the unirradiated material. Therefore, the flow properties and fracture toughness were altered by different heat treatments. This did not simulate radiation damage but provided additional material states with which to evaluate the correlation and the model.

Analysis of the materials with increased yield strength clearly demonstrated that the fraction of the total Charpy energy associated with crack initiation increased with yield strength. This observation has great significance for the interpretation of Charpy properties of irradiated material in terms of fracture toughness. If a minimum level of fracture toughness is specific for unaffected operation of a nuclear plant, the corresponding level of Charpy energy would be less in the radiation-hardened condition than in the unirradiated condition.

In order to establish the credibility of this analytically developed correlation, most of the existing data on fracture toughness and Charpy energy were evaluated. The range of yield strengths extended below and above the range of interest for reactor surveillance purposes. The correlation is much more effective in relating Charpy energy to fracture toughness than were the previous empirical correlations (Figure 4).

The next phase in the research will be to finish the Charpy test simulation by completing failure of the specimen. This will entail developing a capability for analyzing shear-dominated failure. With this capability, the entire test can be simulated and the total test energy estimated.

In addition, samples of the test material will be irradiated in a test reactor to evaluate the correlation for irradiated materials. *Project Manager: Theodore Marston*

# R&D Status Report
# ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

## UNDERGROUND TRANSMISSION

### Comparing pipe-type and self-contained cables

Nearly all underground transmission cables in this country are of the high-pressure oil-filled pipe type. A few major installations of self-contained cables exist, but pipe-type cable is the overwhelming choice for general-purpose transmission. The situation is equally unbalanced elsewhere in the world, except that it is the self-contained type that is dominant. In both instances, the total cost of installation and operation is given as the prime reason for choosing one cable type over the other. Thus the U.S. electric utility industry is faced with the question, "Is self-contained cable an economic alternative for underground transmission in this country?"

To attempt to answer this question, Power Technologies, Inc., made a comparison of installed costs for self-contained and pipe-type cables (RP7849). The project results produced generalizations as guidance for the industry, while showing that individual site specifics tended to negate many generalized assumptions. This limitation should be recognized when the study is used in decision making. The study points in a general direction, and precise answers can be found only when site-specific assumptions are integrated.

The following tentative conclusions are drawn from the draft final report on the study:

- Material costs for pipe-type cables and self-contained cables of equal conductor area are about equal.
- Installation costs for pipe-type cables and self-contained cables are nearly equal under certain assumptions about installation practices.
- The self-contained cable has a higher ampacity than a pipe-type cable of equal conductor area, and the differential increases as circuit voltage increases.
- Some factors not evaluated in the study (such as open-market conditions and long-term familiarity of a utility with a cable type) may override all other known variables in a choice between cable types.

This last conclusion is important: while the facts seem to support self-contained cable as an economic choice, only an individual evaluation for each transmission circuit will clearly answer the question of economics. *Project Manager: John Shimshock*

### Losses in pipe-type cables

Accurate information on losses in pipe-type cables is of considerable importance in cable design and operation. The most widely used methods for calculating these losses are based on the 1957 AIEE Transactions Paper *The Calculation of the Temperature Rise and Load Capabilities of Cable Systems* by J. H. Neher and M. H. McGrath.

The empirical factors introduced in the Neher-McGrath equations were based on copper-conductor cables rated as high as 138 kV. Over the past 20 years, manufacturing techniques have been refined, and voltage ratings have increased to the 765-kV level. Because of the many changes in cable design, it became necessary to verify the applicability of the Neher-McGrath equations to modern cables. An EPRI project, jointly funded with DOE and General Cable Corp., was initiated to verify these equations (RP7832).

Measurements of ac/dc resistance ratio were made on cable systems rated 115–765 kV. Most measurements were made on cables with 1015-mm² conductors of aluminum or copper. The copper conductors were made up of wires with various metal and dielectric coatings. Measurements were also made on cables with 1776-mm² tin-coated copper conductors and with 2385-mm² and 2690-mm² aluminum conductors. All were conventional three-phase systems in carbon-steel pipes, and measurements were made over a temperature range of 20–115°C. One interesting result from these tests is that thermal cycling increases the ac/dc resistance ratio of cables that have copper conductors made of bare or metal-coated strands. The increase occurs almost entirely during the first thermal cycle. This effect is attributed to a decrease in electrical contact resistance between strands due to displacement of oil from the interstrand space.

Preliminary work has also been carried out by the University of Windsor, Ontario, Canada, under subcontract to General Cable, on the development of a computer program based on the fundamental electromagnetic equations. The results of this project indicate that the Neher-McGrath equations are applicable to today's pipe-type cable systems; however, certain empirical factors have been corrected to permit accurate calculations. A follow-on project will be initiated in the near future to establish the ac/dc resistance ratios of very-high-capacity pipe-type cable systems that employ low-loss pipes in single-phase and three-phase configurations. *Project Manager: Felipe Garcia*

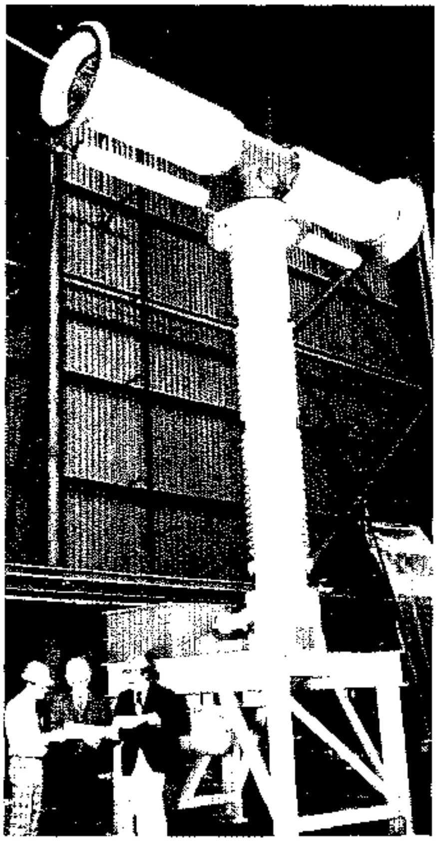
## SUBSTATIONS

### EHV reactor/capacitor switch

Through a recently concluded development project, a line of switches has been developed for EHV reactor and capacitor switching functions (RP655). These switches employ puffer-type, $SF_6$ interrupters and incorporate resistors to reduce in-rush currents that result from back-to-back switching of capacitor banks. Also, these resistors curb high-frequency transients that arise from deenergization of shunt reactors.

Phase 1 of this project resulted in the development and testing of a prototype interrupter, establishing a satisfactory 600-A

Figure 1 EHV reactor/capacitor switch to be field-tested at 550 kV on Bonneville Power Administration's system.



switching performance. During the project's second phase, a three-phase switch was built and laboratory-tested for 550-kV applications. This switch requires two interrupters in series to perform the switching function satisfactorily (Figure 1).

Transient network analyses were conducted to study a specific application on the Bonneville Power Administration (BPA) system. They showed that a resistor of 75 Ω will effectively limit the in-rush currents for back-to-back switching of capacitor banks rated 325–500 MVAR. However, the high-frequency transients generated while de-energizing shunt reactors require large limiting resistors (300–400 Ω). A compromise value of 150 Ω was selected for the design of a single switch that would perform both switching functions. This switch is capable of limiting the in-rush currents to approximately 20% for capacitor switching and can limit the overvoltages to approximately 1.5 per unit for reactor switching. The projected performance relates to this specific application with a chosen resistor value. However, for general application, the resistance value can be chosen to suit any specific requirement.

This switch is expected to be installed on BPA's system in July for a full field evaluation, and a report will be issued covering the field test program. *Project Manager: Vasu Tahiliani*

### Arc interruption in gas flow

Phase 1 of General Electric Co.'s fundamental investigation of arc interruption in gas flow is now complete (RP246). This work attacks the greatest problem in gas interrupters—thermal reignition of the arc immediately following current zero that results from short-line faults. This problem increases in severity as fault duties become larger.

The results of Phase 1 (EL-284) provided a better understanding of the basic design parameters for the nozzle and electrode geometry and for the interrupter gas. The results will be applicable to the design of more efficient gas interrupters.

The second phase of the project continues the basic investigation of the thermal interruption region close to current zero. More information is needed on arc properties, such as size, temperature, and form, in the near-zero period. This information will lead to better analysis of the arc-cooling process required for interruption. Improved diagnostic techniques have been developed and used that will provide more accurate arc data. High-speed framing pictures, taken at rates as high as two pictures per microsecond, are providing better information on arc size and form. These pictures cover the interruption and reignition process, where it occurs.

Improved techniques have been developed for precisely measuring the very small postarc current. Such data will facilitate a better understanding of arc power loss and arc cooling during this period. Studies of the characteristics of segments of the arc along its axis will show the effectiveness of the gas flow on the interruption process in various sections of the nozzle.

Other topics being studied are double-flow interrupters, thermal interruption model calculations, the transition period between thermal recovery and dielectric recovery, and correlation of model interrupter test data with performance data from full-size interrupters. *Project Manager: Glenn Bates*

### Transient recording systems

The industry is taking a growing interest in the nature of switching surges, particularly as they affect equipment design. For instance, insulation requirements are often determined by switching-surge stresses; ultrahigh-speed relays of the future will have to discriminate between nonfault and fault surges; control devices for current limiters will have to respond quickly to faults in the limiting zone; new arresters of the highly nonlinear type may be subjected to surges at their operating levels more frequently than conventional arresters are. All of these problems require a better understanding of the nature and frequency of switching surges. EPRI is therefore conducting a project with Westinghouse Electric Corp. that will develop an instrumentation system capable of recording transients of the switching-surge type (RP751). The system is presently being tested and debugged at Westinghouse's High Voltage Laboratory.

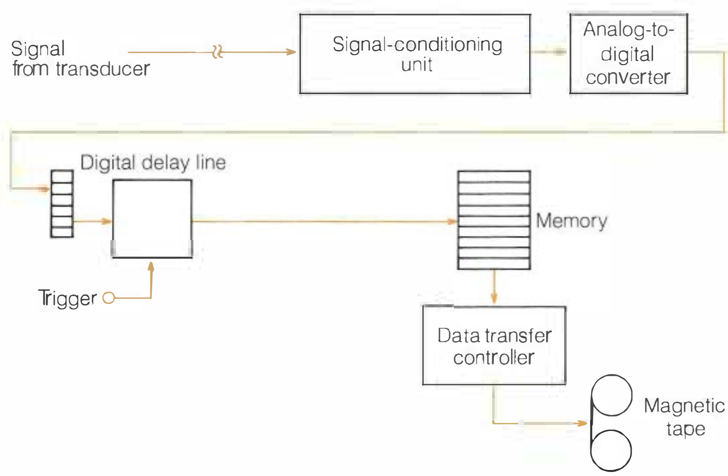
Two instrumentation systems will be built. They are expected to be shipped for installation in Florida Power & Light Co. substations in August. One system will be installed in a 500-kV substation, and the other system will be installed in a 138-kV substation, both located in the Fort Lauderdale area. Each instrumentation system comprises the following major components:

- Three 500-kV high-frequency current transducers
- Six 500-kV capacitive voltage dividers
- Three 5-A high-frequency current transducers for measurement of current in current transformer secondaries
- Three 115-V high-frequency transducers for measurement of voltage in potential transformer secondaries or coupling-capacitor voltage transformer secondaries
- One 15-channel digital recording system for the transducers mentioned above

The instrumentation system, which is built for unattended operation, is capable of recording transients with a frequency content of 2–100 kHz. A surge automatically triggers the recorder, which stores 8192 samples per channel during each recording interval. Hence, at the fastest sampling rate, it can record about one full cycle (60 Hz) each time it is triggered. However, in order to conserve memory space, the recorder will automatically switch between two selectable sampling rates, which could extend the recording interval to 1 s or more if little high-frequency content is present in the transient. The signal path within the recording system is shown in Figure 2.

We expect that this instrumentation system should collect the information needed to better understand surges. It is possible that a worst-case surge that is needed for

Figure 2 Digital recording system for high-frequency transients that occur during switching surges. A surge will trigger the recorder, which will store 8192 samples per channel during each recording interval. Its maximum sampling rate is 1 sample every 2 μs.




design of equipment may not be recorded during the entire monitoring period, but this does not mean that such a surge can never occur. The value of the system lies in its ability to incorporate empirical results that will augment theoretical development work. This could lead to improved fault models that are necessary for the successful development of ultrahigh-speed relays. The simple models that have been used in the past may no longer be adequate, and the dynamic behavior of the fault may have to be included in the model. The transient errors of current and voltage transformers may have adverse effects on both control devices for fault current limiters and ultrahigh-speed relays. However, it should be possible to estimate these errors using recorded data.

The resultant data base of power system transients can also be used for testing or verifying digital, protective-relay algorithms and may, in addition, provide statistical information of importance to substation equipment designers. *Project Manager: Stig Nilsson*

## DISTRIBUTION

### Load forecasting

Load forecasting for small areas is a necessity for the distribution planner, since his plans deal with specific feeders and substations, both of which serve limited areas. The need for a small-area forecasting capability is further reinforced when growth rates vary within the service area. Two methods for forecasting distribution load have been developed during Phase 1 of this project (RP570). Both methods forecast load for small areas, typically by quarter sections (160 acres).

All forecasts require appropriate data. The two forecasting methods, time series trend analysis and multivariate spatial analysis, require different amounts of data. There is also a striking contrast between the types of data required by each model. Consequently, the trend model produces a load extrapolation or projection, and the multivariate model produces a true load forecast.

The time series trend analysis model is a tool familiar to load forecasters. However, the conventional "log-of-load versus time" plot rarely matches actual growth when applied to small areas. In order to overcome this deficiency, three curve shapes have been made available to the planner—the "load versus time" curve, the "log-of-load versus time" curve, and the "S" curve. Tests using Salt River Project data from the Phoenix area and Pacific Gas and Electric Co. (PG&E) data from the Fresno area indicate that the "S" curve follows closely the growth observed in many areas. However, other options are provided that permit the planner to select from a total of 12 possible curve fits.

The major advantage of the trend model is that data requirements are minimal. It has been determined that from 7 to 10 years of historical growth data for each small area are sufficient to produce valid load projections. The accuracy of these projections is sensitive to the area size. Typically, the trend model generates accurate load projections by quarter-section areas for the following 3 years. In order to gain similar accuracy for load projections for 5 years and beyond, the area size must be increased to about 38.8 $km^2$ (15 $mi^2$).

Two constraints may be applied to the trend model to improve the accuracy of medium- and long-range load projections: (1) the load projection for the individual small area may be set at a load level that corresponds with a definite point in time, such as the horizon point, and (2) the sum of the forecast small-area loads in a large area may be set at a specified yearly value.

The trend model should be attractive to utilities that have limited distribution data and limited computer hardware and software facilities.

The multivariate spatial analysis model is a true load-forecasting model. For input, this model requires factors that are responsible for load growth rather than a load history. Fewer years of data are required than for the trend model. However, the amount of data needed to derive the correlated variables is greatly increased. The correlative data (control variables) are largely demographic, covering land use, census information, job classifications, and so on. The input to the model starts with the historical load data and control data for the urban area. Typically, these historical data are required for two points in time, such as 1970 and 1975. The forecasting algorithm then predicts the control variables for the years to be forecast, such as 1980, 1985, and 1990. The data needed to derive the control variables may not be readily available to the distribution planner but can usually be obtained from urban planning agencies. Otherwise, data must be obtained from studies performed by the utility, which may have to develop and implement an urban model.

The multivariate model is obviously more data-intensive. It rewards the distribution planner with small-area forecasts in which he can have great confidence. Again, tests using Salt River Project data and PG&E data indicate that the multivariate model is accurate. Historical load data and control variables for 1970 and 1975 were used to produce a 1976 load forecast for the Fresno, California, area. This year was selected for forecast because 1976 was the last year of accurately known load. The forecast for the Fresno area produced by the multivariate model was within 2% of actual load. The average error for the small areas was less than 100 kW per area, with more than 1000 small areas considered.

It should be emphasized that the above test only established the accuracy of the model. However, it shows that accurate forecasts are possible, but they depend on the accuracy of the input data.

This project has resulted in load forecasting models that can be used with a range of computer hardware. The trend model should be attractive to the small utility that has limited computer capability. For the utility with a large computer capability that can handle factors responsible for load growth, the multivariate model is available. This choice between developed forecasting models is available to the distribution planner for the first time.

The multivariate model is flexible and will accept as many control variables as the user wishes. Each user utility must establish which variables contribute to the forecast accuracy and must limit the variables to those that have substantial impact on the forecast. Both forecasting programs (the time series trend analysis and the multivariate spatial analysis) and their respective user manuals will be available to the industry after the completion of this project in October 1978. *Project Manager: William Shula*

## SYSTEM PLANNING AND OPERATION

### Synchronous machine models

For over half a century, the parameter values of synchronous machine models have been based on calculations performed by machine designers. Various conventional models, with their calculated parameters, have been used in computer analyses to simulate the behavior of the synchronous machine under dynamic operating conditions. In recent years, a number of investigators have shown that the computer results do not correlate well with test results. Accordingly, four EPRI contractors will determine the value of model parameters through test methods and will use these parameters with both conventional and new models in computer studies simulating dynamic machine behavior (RP997-1, -2, -3, and -4).

C. A. Parsons & Co., Ltd., will determine model parameters by shop and field tests, develop model structure, and validate model performance. Ontario Hydro will determine model parameters by field tests of system behavior, validate model performance, and evaluate model adequacy. Power Technologies, Inc., will determine model parameters by the deMello method (based on the abrupt opening of breakers), validate model performance, and evaluate model adequacy. Westinghouse Electric Corp. will determine model parameters by shop and field tests and by field tests of system behavior and will validate model performance. The Parsons, Ontario Hydro, and Westinghouse efforts all involve frequency response testing procedures.

Tests have been performed by each contractor on one or more large synchronous machines (over 450 MVA) to determine the values of many of the parameters required in conventional models. Studies are progressing to determine the various models that will be used in the computer simulations. The next six months of the project should produce meaningful data for evaluation.

The project commenced in April 1977 and is scheduled for completion in the fall of 1979. *Project Manager: Don Bewley*

# R&D Status Report
# ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

## RESIDENTIAL HVAC SYSTEMS

*Accurate assessment of the performance and energy requirements of various heating, ventilating, and air conditioning (HVAC) systems is important to electric utilities, regulators, builders, and the public. Analysis of HVAC system choice has been hampered in the past by inadequate analytic tools and incomplete and inappropriate data, particularly field test data.*

*Ohio State University conducted a major study that resulted in a mathematical model and a computer program for calculating the energy required to heat residential housing units on hourly, daily, monthly, and seasonal bases* (RP137). *Further work is being undertaken to validate the model for different U.S. climatic conditions, to simplify it for ease of application, and to calculate thermal efficiencies of different modes of residential space heating* (RP1364).

*Uncertainty about the load and use characteristics of residential heat pumps and about the impact of their use on electric utility system loads motivated a large-scale data collection and analysis effort by Westinghouse Electric Corp., Advanced Systems Technology (RP432). A follow-on study by Gordian Associates Inc. is using the data developed by Westinghouse to assess the impact of residential heat pumps on electric utility system loads (RP1100).*

### Field testing residential HVAC systems

The choice and sizing of HVAC systems is of importance to utilities' kWh sales, load profiles, and capacity requirements. Analysis of HVAC system choice has been hampered in the past by inadequate analytic tools and by incomplete and inappropriate data. In particular, there has been a lack of field test data comprehensive enough to use for engineering analysis. The distinction between bench test data and field test data is important, since the real world corresponds to field tests but decisions currently being made are normally based on bench tests—hence, the importance of developing accurate field test data. EPRI's Demand and Conservation Program, through its technical performance and measurement subprogram, is attempting to improve the quality and quantity of data and the quality and usefulness of analytic approaches.

The Demand and Conservation Program stops short of designing and testing new end-use technology. This type of activity is undertaken by the Energy Utilization and Conservation Technology Program and the Solar Program (Fossil Fuel and Advanced Systems Division). It is clear that analyzing the use characteristics of HVAC systems and testing the effects on utilities are closely related to these programs' research interests. The Demand and Conservation Program staff coordinates its research in this area with the FFAS Division. (The relationships between these programs are described in the *EPRI Journal*, October 1976, p. 25.)

### Residential heating

EPRI contracted with Ohio State University to conduct a major study that resulted in the development of a mathematical model and a computer program for accurately calculating the energy required by residential housing units on hourly, daily, monthly, and seasonal bases (RP137). The model is general enough to be applied to any type of residential structure in any climate, given the appropriate input data. A detailed version of this model has been tested in Columbus, Ohio. The general mathematical model is designed for application to various types of single- and multifamily dwelling units, (i.e., units constructed and insulated with different materials, units located in different climatic zones of the continental United States, and units with all-electric or fossil-fuel heating systems).

The computer program developed in the study was produced by consolidating two widely accepted building heating and cooling load programs (not heretofore applied to residential structures) and several new programs.

The energy requirements model was verified by extensive calculations and field measurements made on four identical two-story frame houses (one of which was unoccupied throughout the project), a ranch-style house, a split-level house, and three townhouse apartments. In order to study variations in energy consumption of different systems, researchers changed heating and cooling equipment in two of the frame residences during the project. In addition to the monitoring of the houses themselves, researchers collected data on dry-bulb temperatures and on direct and indirect solar radiation. Other weather information was obtained from the National Oceanic and Atmospheric Administration.

In the course of validating the energy requirements model, calculations were made of the end-use distribution of energy necessary to satisfy the thermal loads for gas furnaces, electric furnaces, electric baseboard heating, and air-to-air heat pumps. While the samples were quite small in a statistical sense, the instrumentation of the houses was complete enough to suggest how energy is used in various systems in different climatic zones. Results from Columbus, Ohio, are shown in Table 1.

In addition to collection and analysis of energy consumption characteristics of the Columbus sites studied by Ohio State, data were gathered from 48 homes in six utility service areas, which represent a wide range in the annual number of heating degree-days.* These data will be analyzed in an-

*A degree-day is a unit measuring the extent to which the outdoor mean (average of maximum and minimum) daily dry-bulb temperature falls below (in the case of heating) or rises above (in the case of cooling) an assumed base. The base is normally taken as 65°F unless otherwise designated. One degree-day is counted for each degree of deficiency below (for heating) or excess over (for cooling) the assumed base, for each calendar day on which such deficiency or excess occurs.

**Table 1**
**ENERGY USED IN HEATING SYSTEMS**
(% end use)

| | Central Gas Furnace (2 houses) | Central Electric Furnace (2 houses) | Electric Baseboard Heating (1 house) |
|---|---|---|---|
| Stack losses (estimated) | 25 | — | — |
| Furnace cycling and jacket losses | 2–4 | 0–1 | — |
| Air distribution losses | 21–35 | 22–32 | — |
| Pilot light losses | 2–3 | — | — |
| Energy to satisfy heating load | 35–47 | 66–78 | 100 |

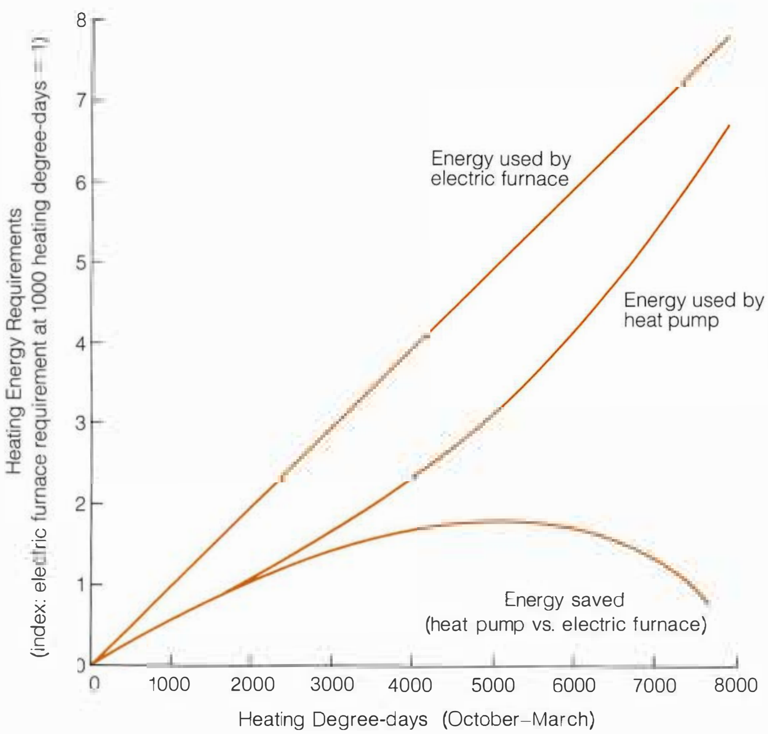



Figure 1 Residential heating energy requirements (in index form) are plotted against the number of heating degree-days between October and March. Heat pumps use much less energy than electric furnaces in climates that average approximately 5000 degree-days over a six-month period (examples of cities in this heating degree-day range are Philadelphia and Albuquerque). In climates where the six-month seasonal load exceeds 5000 degree-days, electric resistance heating is needed with increasing frequency as a backup to heat pump systems, and the energy savings decline.

other study (RP1364), which has as its objectives the validation of the Columbus results for a wide variety of climatic zones, a simplification of the present general model, and further assessment of the comparative performance of various heating systems.

### Heat pump data collection and analysis

Although manufacturers have provided a great deal of test data on the performance of residential heat pumps, little has been known about actual performance of heat pumps installed in residences. EPRI and the Association of Edison Illuminating Companies (AEIC) sponsored a study of the load and use characteristics of electric heat pumps in single-family residential housing units.

The primary objective of this study performed by Westinghouse, Advanced Systems Technology was the compilation of a data file on 120 residences in 12 widely varying degree-day zones (RP432). Data on heat pumps, direct and indirect solar radiation, and dry-bulb temperatures were recorded at 15-min intervals for two heating seasons and one cooling season. In addition, 43 of the heat pump installations had automatic timers that bypassed the heat pump on alternate days, thus effectively making them electric resistance furnaces. By comparing the energy used in resistance-heat-only operation with the energy used by the heat pump during normal operation, estimates of seasonal performance factors were made for each of the two heating seasons.

In addition to the seasonal performance factor calculations, load profiles were developed for the alternate-day systems. The calculations resulting from this study tended to confirm a number of widely held views about heat pumps and illustrated several other points, which while less obvious, are consistent with conventional ideas about heat pumps. As expected, the seasonal performance factor declined as the number of heating degree-days increased for a given six-month period. That is, in colder climates the heat pump compressor alone could not handle the entire heating load, and backup resistance heating was necessary. In terms of total energy savings, however, the maximum savings compared with resistance heating occurred at approximately 5000 degree-days for a six-month season, with savings tapering off as the number of heating degree-days increased (Figure 1). It should be pointed out that the selection of a six-month season does not show that additional savings could be realized in colder climates because of longer heating seasons. Also not shown is the likelihood that heat pumps could handle the parts of the heating season before October and after March more effectively than they could the midwinter portion of the heating season shown in Figure 1. Hourly load profiles tended to peak in the midmorning for daily average temperatures up to 16°C (60°F). For warmer temperatures, the heating load shifted to a cooling load with normal afternoon peaking.

This study has provided important data and analysis on individual residences and on group data. It is not known, however, how the load and use characteristics of heat pumps will affect utility system load profiles. In an investigation of this topic, Gordian Associates will endeavor to simulate the effect of various levels of heat pump saturation on system loads for different types of utilities, as characterized by climate and the level of sales accounted for by residential, commercial, industrial, and other customer classes (RP1100). Through the development of simulation models that can be used by individual utilities, it will be possible for companies to assess the effects that residential heat pump saturation would be likely to have on their system loads.

The following types of information were collected in RP137 and RP432: energy used by the heating system, total electrical load for the house, and indoor temperatures. In the energy requirements study (RP137), flow meters were used to measure natural gas consumption, and several major appliances were monitored. In the heat pump study (RP432), compressor load for heating and cooling, energy used by the indoor fan, and the backup resistance heating mode were monitored separately. Both studies collected data on direct and indirect solar radiation and dry-bulb temperatures in the vicinity of the homes that were being monitored. All the data were recorded on magnetic tape at 15-min intervals and translated to be computer-readable.

In addition to the magnetic tape data, extensive surveys were made to develop data on building and household characteristics for each residence monitored, and AEIC conducted a survey of customers' attitudes and their experiences with heat pumps. *Program Manager: Robert Crow*

## MODEL VERIFICATION AND ASSESSMENT

*Recently developed energy system models are an important resource for energy studies and policy evaluations. Model verification and assessment are required, however, before EPRI and the industry can have confidence in the application of these models. For a model to be fully understood and evaluated, it must be run by someone other than the modeler. Such a verification can reveal the deficiencies as well as the strengths of the model and ensure that the modeler's description is complete and adequate for the needs of the user. The purpose of RP1015 is to develop a trial model verification and assessment facility for evaluation of selected energy system models.*

The electric power industry has been building and using models for a long time in planning for capacity expansion and in scheduling existing generation capacity to satisfy customers' energy demand at minimum cost. The industry, through such organizations as the Edison Electric Institute, the American Public Power Association, and EPRI, has recently provided support for developing large-scale models that encompass the interactions between the electricity sector of the economy and the rest of the energy-economy system. In addition, there are a number of important models not used directly by the electric power industry that play a role in determining public policies of interest to the industry. Sponsors of these more general models include the National Science Foundation, private foundations, and government agencies.

Models that are of value to the electric utility industry include the Baughman-Joskow Regionalized Electricity Model (REM), the Wharton Macroeconomic Energy Model, the Hudson-Jorgenson Macroeconomic Energy Model, the Manne ETA and ETA–MACRO models, the Pilot Energy-Economic Model, the Gulf-SRI Energy System Model, the Brookhaven Energy System Optimization Model, and the FEA Project Independence Evaluation System. Each of these models includes an explicit representation of the electric power sector, and (to varying degrees) each model is being used in technology assessment and/or policy analysis relevant to the electric power industry. It is important for electric utilities to be certain that such models accurately represent the real world. This is the basic rationale for sponsoring the model verification and assessment project being conducted at the MIT Energy Laboratory (RP1015).

The model assessment laboratory set up in this project provides two types of evaluation. One type is an overview assessment of selected models whose strengths and weaknesses EPRI needs to determine before using them in connection with new technologies or for making policy analyses. Such overview assessments are also used to identify models for which a more detailed assessment is required. The other type is a critical assessment of models that EPRI intends to use extensively. Critical assessments provide an in-depth analysis of model formulation, data development and integrity, and appropriateness of statistical estimation techniques. These evaluations also include replications of statistical estimation and simulation results and sensitivity studies of critical points. A key distinction between an overview assessment and an in-depth assessment is that the latter includes the complete assimilation of the model on the model assessment laboratory's computer system.

The project is a major step toward developing effective procedures for the independent evaluation of energy models. Independent model assessment is a critical element in making models more accessible and useful in technology assessment and policy analysis. Such third-party assessments identify the weak points of a model's theoretical structure, empirical techniques, and implementation procedures. This information can be used to improve the effectiveness of the existing model and to help direct the development of future models.

Independent assessment is most effective when undertaken as a cooperative venture, not as an adversary proceeding, with support from and dialogue with the modeler. Independent assessment can increase confidence not only in a particular model but also in the credibility of the model developer, who has an expert role to play in technology assessment and policy analysis.

During its first year, MIT's model assessment laboratory undertook overview assessments of the Baughman-Joskow REM and the Wharton Macroeconomic Energy Model. It is now completing an in-depth assessment of the REM. The results of these studies will be available in an EPRI report this fall. The research thus far has been successful and has played an important role in shaping EPRI's use of the REM and the Wharton model. Third-party verification and assessment have enabled EPRI to better understand the strengths and deficiencies of the models and to improve model utilization in planning the research and in making studies.

Efforts are under way to arrange cofunding with DOE for the second year of the model assessment laboratory. An in-depth assessment will be made of a model of mutual interest to EPRI and DOE—a model that would be used to analyze significant electric utility industry issues. *Project Manager: Richard Richels*

# 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) 855-2000.

Requests for copies of specific reports should be directed to Research Reports Center, P.O. Box 10090, Palo Alto, California 94303; (415) 961-9043. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others pay a small charge. Research Reports Center will send a catalog and price list on request.

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

## ELECTRICAL SYSTEMS

### Electrochemical Treeing in Cable

EL-647 Final Report (RP133)

The purpose of this work by Phelps Dodge Cable & Wire Co. was to establish the influence of various electrical, thermal, and chemical parameters on the rate of growth of electrochemical trees in polyethylene (PE), cross-linked polyethylene (XLPE), and ethylene-propylene rubber (EPR).

The main conclusions from this work are that: the rate of electrochemical tree growth is strongly influenced by voltage stress and frequency; both XLPE and EPR exhibit substantially lower tree-growth rates than PE; the lower tree-growth rate in XLPE is attributable primarily to the presence of catalyst by-products of the cross-linking reaction, principally acetophenone; and electrochemical trees decrease the dielectric strength of PE, XLPE, and EPR. *EPRI Project Manager: Felipe Garcia*

### A Prototype Field Calibration System for Coupling Capacitor Voltage Transformers (CCVTs)

EL-690 Final Report (RP134-1)

In recent years, the CCVT has come into wide use for 0.3%-accuracy EHV revenue metering in interties between utilities; this metering has been performed for many years by the inductive potential transformer (PT). Whereas the PT has been thoroughly proven in this application, the CCVT has not. Considerable user experience has raised doubts about its adequacy and has suggested the need for periodic calibration. Since the CCVT is permanently installed in the substation, this calibration must be done on-site.

A prototype field calibration system for CCVTs has been developed by the National Bureau of Standards in the form of a compact mobile unit that is comparatively easy to use. Only a two-man crew and minimal support from the local utility are required to assemble and operate the modular system at the test site. *EPRI Project Manager: Stig Nilsson*

### Surge Behavior of UD Cable Systems

EL-720 Final Report (RP795-1)

In this project, McGraw-Edison Co. investigated the behavior of surges that enter an underground distribution system. The industry has accepted, for the most part, that the margin of protection provided by a typical distribution arrester installed at the overhead-underground junction of a 15-kV underground system will be adequate to protect the distribution equipment. However, this margin of protection is diminished as the distribution voltage is increased to 25 and 35 kV.

Two principal conclusions were drawn from the results of this project. First, underground distribution cables shorter than 910 m (3000 ft) do not attenuate surges enough to significantly influence the margin for insulation coordination. Second, multiple arresters are necessary to achieve acceptable margins of protection for 25-kV and 35-kV underground cables.

The report provides models and techniques needed by the distribution engineer to design the appropriate surge protection system. *EPRI Project Manager: William Shula*

### Extremely High Strength Porcelain

EL-722 Final Report (RP427-1)

McGraw-Edison Co. has developed a high-strength electrical porcelain with inexpensive raw materials and standard porcelain manufacturing methods. The porcelain is reinforced at the glassy phase with strong needle-shaped crystals of mullite, which are grown during the firing cycle. Additional strength is gained by decreasing the closed porosity of the fired material to nearly zero.

The electrical properties of this material are approximately equivalent to those of standard porcelain. The cost is approximately 5% higher than standard porcelain because of increased costs of raw materials and a small additional labor cost. The use of high-strength porcelain can lead to smaller and lighter insulators, less chance of breakage, increased safety, and a subsequent savings in total cost to the utility. *EPRI Project Manager: E. R. Perry*

### Frequency-Domain Analysis of Low-Frequency Oscillations in Large Electric Power Systems

EL-726 Interim Report (RP744-1)

When major electric power systems are interconnected through ties of relatively small capacity, low-frequency intersystem oscillations are likely to be troublesome under some operating conditions. The potential for unstable oscillations must be considered in planning bulk generation and transmission systems, in designing control systems for turbine generators and dc line terminals, and in planning system operations.

Present practice depends almost entirely on time-domain simulation for large-system analysis, with computing costs that are relatively high and information in a form that is often unsuitable for study purposes. The objective of this research by Westinghouse Electric Corp. is to develop an alternative to time-domain simulation for damping studies. This alternative involves the use of a linearized system model and the calculation of only those natural frequencies of oscillation and damping factors in the system that are most intimately related to generator rotor motions. *EPRI Project Manager: Paul Anderson*

### Far-infrared Inspection of Cable Insulation

EL-738 Interim Report (RP794-1)

United Technologies Research Center studied the feasibility of real-time, in-process detection of voids and contaminants in the polyethylene insulation of power cables. The detection technique involved far-infrared laser scattering from defects embedded in the insulation. The project included demonstration of noncontacting, nondestructive, real-time detection of voids and contaminants in thin slabs of polyethylene and cross-linked polyethylene materials, in a stationary 25-kV power cable, and in the same cable in motion. *EPRI Project Manager: Joseph Piscioneri*

### $SF_6$-Dielectric Fill-Gas Gage

EL-747 Final Report (RP656-1)

The use of $SF_6$-gas-insulated equipment in substations is gaining wide acceptance. For reliable operation, however, a gage for continuous monitoring is necessary to ensure that gas density is maintained within design limits and that the gas is not contaminated. The gage should be able to detect leaks of more than 1–2% per year and gas contaminants of significant levels.

Conventional gages measure only total gas pressure, so gas density measurements are derived indirectly from pressure and temperature measurements. In this project by Nucleonic Data Systems, Inc., a prototype gage demonstrated that it is feasible to directly measure both the density of $SF_6$ gas and the gas humidity. *EPRI Project Manager: Stig Nilsson*

## ENERGY ANALYSIS AND ENVIRONMENT

### Environmental Effects of Right-of-Way Management on Forested Ecosystems

EA-491 Final Report (RP103-3)

West Virginia University made studies of ecological parameters in electric transmission corridors to determine the impact of vegetation management practices. Repeated broadcast herbicide sprayings produced a low plant cover dominated by sedges, grasses, ferns, or herbicide-resistant woody species. Selective herbicide treatment, in which shrubs and small trees were avoided in the spraying, caused a gradual increase in communities of woody plants.

The studies showed that infrared photography offers promise as an aid in routing new transmission lines, mapping right-of-way vegetation, zoning transmission corridors into management units, determining the amount of bare and eroding soil, appraising the completeness of herbicide coverage after broadcast and selective spraying, and identifying dead and dying edge trees. *EPRI Project Manager: Robert Goldstein*

## FOSSIL FUEL AND ADVANCED SYSTEMS

### The Dynamic Behavior of a Mirror Fusion Reactor

ER-521 Interim Report (RP547-1)

This report by the University of Michigan describes one of the plasma physics models being used as part of a project to investigate the interface of fusion power systems with future electric utility systems. The scope of the project covers issues related to plasma physics, the fusion reactor, balance of plant, and the utility grid. Interactions between these issues are being defined and analyzed in order to identify useful directions in fusion R&D.

In particular, this report describes a simplified but accurate representation of a burning deuterium-tritium plasma contained in a magnetic mirror fusion reactor. Parametric relationships between the plasma characteristics and engineering design elements are described, including, for example, the impact made on fusion power density by changes in neutral-beam injection energy and angle, magnetic mirror ratio, value of magnetic field, and other variables *EPRI Project Manager: Noel Amherd*

### Solar-Thermal Conversion to Electricity, Utilizing a Central Receiver, Open-Cycle Gas Turbine Design

ER-652 Final Report (RP475-1)

Black & Veatch prepared a conceptual design for a commercial-scale solar-electric power plant that uses an open-cycle gas turbine as the prime mover. The design employs an elevated central receiver surrounded by a field of 7000 heliostats. There are four receiver cavities at the top of the tower, one facing each quadrant of the heliostat field. Energy storage, both buffer and long-term, is provided by fossil fuels. The fuel, either oil or gas, is burned in combustors that are in a parallel arrangement with the solar receivers.

The turbine inlet gas temperature is 982–1066°C. Because these temperatures preclude the use of currently available metals for the heat transfer surface, ceramics are employed. Each of the four receiver cavities contains about 70 U-tubes made of silicon carbide. Although many of the properties of silicon carbide are well documented, the material has never been used in an application of this type. The next activity in this program is the design, fabrication, and testing of a bench-model solar receiver with silicon carbide tubes. *EPRI Project Manager: John Cummings*

### H-Coal Integrated Pilot Plant

AF-681 Final Report, Vols. 1 and 2 (RP238-1)

The H-Coal process catalytically converts coal to oil in an ebullated-bed reactor. In addition to flexibility of operation, this process offers the advantage of constant catalyst activity through on-line addition and withdrawal of catalyst and reactor backmixing, which allows low temperatures for the reactor feed streams.

Hydrocarbon Research, Inc., designed a 200–600-t/d coal liquefaction pilot plant. In a laboratory program to support this design, a 3-t/d process development unit was operated to demonstrate operation with heavy boiler fuel oil, operation at commercial reactor gas velocities, and operation with high residuum concentration in the reactor. Solid-liquid separation by antisolvent precipitation, high-vacuum distillation, and hydrocloning was demonstrated. *EPRI Project Manager: Jerry Fox*

### Development of Sodium-Sulfur Batteries for Utility Application

EM-683 Interim Report (RP128-4)

In a project conducted by General Electric Co. between May 1976 and September 1977, materials, components, and designs anticipated for commercial hardware were specified and demonstrated on small (30-Wh) laboratory cells. These small cells demonstrated a life of over 1000 cycles (nearly half the goal for utility application) and sustained capacities exceeding 80% of theoretical capacity for over 250 cycles. Degradation of internal glass seals was the major failure mechanism. Because of the success of these small cells, scale-up to the full-scale, 300-Wh cell will be initiated. Manufacturing and cost studies project that this battery system will have a selling price below the goal of $40/kWh for electric utility application. *EPRI Project Manager: James Birk*

### Development of High-Efficiency, Cost-Effective Zinc-Chlorine Batteries for Utility Peak-Shaving

EM-711 Interim Report
(RP226-2 and RP226-1-2)

During 1976, Energy Development Associates tested two full-scale cells (about 1.5-kWh capacity) and initiated testing of a 10-cell (20-V) 20-kWh battery. Instrumentation and control difficulties limited testing of these systems. Design, manufacturing, and cost studies suggest an estimated selling price below the goal of $40/kWh for utility application. *EPRI Project Manager: James Birk*

### Assessment of the Tokamak Confinement Data Base

ER-714 Final Report (RP920-1)

In a 1977 survey of the tokamak physics data base, Science Applications, Inc., identified the important tokamak physics characteristics necessary for developing a fusion reactor. An aggressive survey was then carried out to establish the range of relevant parameters that has been achieved in tokamak experiments, the diagnostic techniques and their reliability in determining these parameters, and the state of understanding of the basic physical laws that cause performance limitations. The findings are detailed in this report, along with an overview of the tokamak fusion reactor program and suggestions that will help expand the data base. A brief status report of the mirror fusion reactor research is included. *EPRI Project Manager: Robert Scott*

### Noncatalytic $NO_x$ Removal With Ammonia

FP-735 Final Report (RP835-1)

A potential approach to the control of nitric oxide (NO) in utility boilers and to the modification of the combustion process is the selective homogeneous gas-phase reduction of NO with ammonia. A laboratory study was conducted by KVB, Inc., at a scale of $3 \times 10^6$ Btu/h to evaluate the applicability of ammonia injection for the reduction of NO in coal-fired power plants. Four coals were tested to determine achievable levels of $NO_x$ reduction and by-product emission. *EPRI Project Manager: Donald Teixeira*

### Sodium–Antimony Trichloride Battery Development Program for Load Leveling

EM-751 Interim Report (RP109-3)

Research conducted from January 1976 to July 1977 by ESB Inc. demonstrated a lifetime of 500 cycles for 20-Wh laboratory cells. Failure of the electrolyte, seals, and current collector has typically resulted in short cycle life for these laboratory cells. Manufacturing and cost studies show that there is a low probability the sodium–antimony trichloride battery will achieve the cost targets for electric utility application. *EPRI Project Manager: James Birk*

### Economics of Texaco Gasification–Combined-Cycle Systems

AF-753 Final Report (RP239)

This report presents the results of an economic screening study for air-blown Texaco coal gasification coupled with combined-cycle power generation. The objective of this study by Fluor Engineers and Constructors, Inc., was to determine whether the economic advantages of an air-blown Texaco gasifier are greater than those of an oxygen-blown Texaco gasifier. *EPRI Project Manager: Michael Gluckman*

### Survey of Feed Pump Outages

FP-754 Final Report (RP641)

The emergence of power plant availability as a critical parameter for electric utilities motivated an investigation by Energy Research & Consultants Corp. into the reliability and failure mechanisms of feedwater pumps. An industrywide survey was made to provide data that would help identify reasons for loss of availability. The report summarizes specific design, operation, and maintenance deficiencies and system-related problems responsible for most outages that result from feed pump failures.

It is concluded that feed pump problems require more of the high-technology engineering that is now being applied to many other types of rotating machinery. Also, it is concluded that less emphasis is needed on maximizing pump efficiency at full load and more is needed on operating performance over the entire load range. Recommendations are made for improving feed pump reliability. *EPRI Project Manager: John Dimmer*

## NUCLEAR POWER

### Engineering Aspects of the Pool-Type LMFBR, 1000 MW (e)

NP-645-SY Final Report,
Vols. 1, 2, and 3 (RP620-21 and RP620-22)

LMFBR development in national programs here and abroad has established that both loop-type and pool-type primary coolant systems should be considered as viable options for an LMFBR power plant of practical size. Since the technological base in the United States for the pool-type plant is significantly smaller than that for the loop type, this study by Rockwell International Corp. and Bechtel Corp. of a 1000-MW (e) pool-type plant concentrated on those areas of the plant unique to the pool concept in order to establish a wider basis for reassessment of this concept. The work indicates that the pool concept is feasible with respect to design, construction, and licensing practice in the United States. *EPRI Project Manager: Joseph Matte*

**A Study of Zircaloy-4—Steam Oxidation Reaction Kinetics, Part 2**

NP-734 Final Report (RP249-2)

Experimental studies have been performed at Worcester Polytechnic Institute to evaluate the oxidation of reactor-grade Zircaloy-4 tubing in steam throughout the 649–982°C temperature range. Oxidation behavior in this temperature range was found to be substantially different from that predicted by either the Baker-Just equation or extrapolation of oxidation data from temperatures above 982°C. *EPRI Project Manager: Howard Ocken*

**Planning Support Document for the EPRI LWR Fuel Performance Program**

NP-737-SR Special Report

The progress made in 1977 by EPRI's LWR fuel performance projects is reported. The basic goal of these projects is to develop a comprehensive fuel performance data base with verified predictive models and codes to improve fuel rod reliability and hence increase plant availability. *EPRI Project Manager: Adrian Roberts*

**UCB Reflood Program: Experimental Data Report**

NP-743 Interim Report (RP248-1)

In this report by the University of California at Berkeley, experimental results are presented for the quenching of a vertical 3.66-m tube by the bottom injection of water at temperatures of about 21°C and 66°C and at rates that gave water velocities at the tube inlet of 25–180 mm/s. Thirty-two combinations of initial tube temperature, water velocity, and water temperature were examined, and the results include the variation of tube wall temperature, the equivalent height of the water in the tube, the flow rates of the exiting liquid and steam, and the temperature of the exiting fluid. Local heat fluxes and apparent heat transfer coefficients in the region above the quench front are also presented. *EPRI Project Manager: K. H. Sun*

**Nondestructive Evaluation of Steam Turbine Rotors**

NP-744 Interim Report (RP502-2)

The discontinuities present in large steam turbine rotor forgings and their growth during service are of major concern, since failure of these rotors is extremely expensive in terms of potential loss both of lives and of revenues. In-service inspection of rotors is thus a significant part of electric utilities' quality control programs to assure the safe and continued operation of power generating stations. This report by Battelle, Columbus Laboratories reviews nondestructive evaluation processes used for rotor inspection, describes the types of internal indications that are considered technically relevant from a stress distribution viewpoint, and recommends ways of improving rotor examination. *EPRI Project Manager: Floyd Gelhaus*

**Probabilistic Safety Analysis III**

NP-749 Interim Report (RP767-1)

In continuing work on probabilistic methods development and application, Science Applications, Inc., studied anticipated transients without scram and analyzed external fuel-cycle risk. The codes developed have application both in fault tree assessment and in accident consequence estimations. A study of earthquake frequency was also made. *EPRI Project Manager: Gerald Lellouche*

**Major Outage Trends in LWRs**

NP-755 Interim Report (RP705)

This report by Science Applications, Inc., is a summary of major outages that occurred in LWRs from January 1971 through June 1977. Only outages of greater than 100 hours' duration (exclusive of refueling outages) are included. The outage trends related to various reactor systems and components are presented as functions of plant age and calendar year. The principal contributors to major outages are ranked by their effect on the overall outage time for PWRs and BWRs. In addition, the outage history of each operating nuclear plant greater than 150 MW (e) is presented, along with a brief summary of those outages lasting more than two months. *EPRI Project Manager: William Lavallee*

**SUNYAB–EPRI Combined Injection ECC Program**

NP-757 Interim Report (RP341)

After the test facility and test runs are described, preliminary analyses of results of experiments undertaken by the State University of New York at Buffalo are given both for reflooding and for combined reflooding and top injection. Characteristic flow oscillations observed during the experiments are also described. *EPRI Project Manager: Romney Duffey*

**Proceedings: Workshop on EPRI Availability Engineering**

NP-759-WS

EPRI held a workshop on availability engineering methods in Albuquerque, New Mexico, October 17–19, 1977. The workshop evolved from an eight-month study by Holmes & Narver, Inc., on assessment of methods for implementing availability engineering in electric power plants. The 101 workshop participants represented 32 utilities, 14 architect-engineers/consultants, 5 equipment manufacturers, and 6 other organizations. Participants divided into small working groups to address various issues and concerns pertaining to increased application of availability engineering methods in utilities and related industries. Summaries of the working groups' recommendations and conclusions are included in the report. *EPRI Project Manager: William Lavallee*

**Pipe Stress Intensity Factors and Coupled Depressurization and Dynamic Crack Propagation**

NP-763 Annual Report (RP231-1)

This report describes predictive models developed by the University of Washington for the initiation and propagation of cracks in pipes and presents the numerical results obtained during the second year of the study. Crack initiation was studied by evaluating stress intensity factors under static conditions for a series of representative flaws. *EPRI Project Manager: John Carey*

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