Energy From Refuse

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Cover: As municipal solid waste piles up and petroleum supplies grow short, some view the old dump as a new mine from which to extract fuels, metals, and glass.

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Resource Recovery

In recent years we have begun to recognize that our resources of energy, land, water, and air have finite bounds. Each year, about 150 million tons of municipal solid waste (MSW) is generated in the United States. About 70% of it consists of combustible paper, wood, plastic, and other material—the fuel equivalent of more than 200 million barrels of oil per year. The remainder contains magnetic metals, aluminum, and glass, much of which can be recovered and recycled. Thus, as part of our developing conservation efforts, it makes sense to develop an integrated system involving municipalities and private industry to recover and recycle energy and raw materials from MSW.

In this month's lead article, we explore the complex issues involved in implementing a resource recovery system and assess the potential role that electric utilities will play in energy recovery from MSW.

Significant issues, primarily institutional in nature, must be resolved before a resource recovery operation can become a reality. These include economics, financing, ownership and operation of resource recovery facilities, commitment of MSW sources, and the search for customers to buy the recovered energy and materials.

The emerging role of electric utilities in resource recovery projects appears to be that of a customer for the recovered fuel or energy. Depending on economics and on the needs of the utility, energy is recovered either in the form of steam or as a solid, liquid, or gaseous fuel called refuse-derived fuel (RDF). In most cases RDF will be used to augment conventional fossil fuels in existing power generation equipment. Electric utilities will generally be receptive to cooperating with their communities on solid waste projects as long as RDF utilization does not interfere with environmental and other regulations, reduce the reliability or availability of generating units, or increase the cost of electricity to their customers.

In whatever direction resource recovery goes, electric utilities will serve a necessary and important function in our resource recovery systems.

Kurt E Yeager

Kurt E. Yeager, Director
Fossil Fuel Power Plants Department
Fossil Fuel and Advanced Systems Division

■ One hundred-fifty million tons is a heap of garbage. That's how much municipal solid waste (MSW) Americans produce each year, four pounds by each of us every day. Getting rid of it has come to rank third in all costs incurred by local government. What is being done with this refuse of our throwaway society? In **"Municipal Solid Waste—Problem or Opportunity?"** (page 6), we take a look at the realities of what appears to be "a very appealing idea" for using such waste—convert it to fuel.

Consider the prospect: By processing MSW we can reclaim some of the basic materials of industry for reuse, such as ferrous metals, aluminum, glass; we reduce the volume and weight of the refuse, easing the disposal problem for local government; we conserve land otherwise used for garbage dumps; we have a readily available source of fuel. And in the process, we virtually dispose of the waste.

But, alas, there are drawbacks as well, especially economic and institutional barriers. With present technology, the cost of converting MSW into solid, liquid, or gaseous fuels is usually greater than the price of competing fuels. No one is going to pay more for refuse-derived fuels (RDF) than for equivalent fuels already in use. Only by transferring existing disposal revenues to the new RDF operation can the latter be justified—a move requiring institutional cooperation and complex contracts. MSW is a problem not given to easy solution (or burial).

Serving as EPRI technical sources for the MSW article were Charles McGowin, manager of technical analysis and of solid waste projects in the Fossil Fuel Power Plants Department, and Shelton Ehrlich, a program manager in the same department, who is responsible for research in coal cleaning and coal combustion, including fluidized-bed technology.

■ The system operator is what his title implies, the controlling hand on a utility's generation and transmission system. His moment-to-moment task is simpler to state than to do: match generation with load. He must hold frequency within tight limits, cutting a mix of generating units on- and off-line as load fluctuates. Improving his bases for choice is the aim of EPRI research to correlate system security factors and their costs. The need and the beginning program are discussed in **"System Operation at Optimal Cost"** (page 14) by **Charles Frank,** project manager of EPRI's research in power system operations.

Frank joined EPRI last year after some 20 years of experience in computer sciences. While he was at Westinghouse Electric Corp.'s Central Laboratories in Pittsburgh, Pennsylvania (1956–1966), his study of optimization methods employed in electric power economic dispatch resulted in an algorithm still used by Westinghouse. For five years before joining EPRI's Electrical Systems Division, Frank served as a staff consultant with Landis & Gyr in Sunnyvale, California, and was responsible for electric power system software development. He designed system software for automatic real-time, closed-loop control of power generation and distribution.

Frank

Frank holds a doctorate in electrical engineering from the University of Pittsburgh and has written a number of scientific papers.

■ In **"The Published Product"** (page 19), a sampling of users of EPRI technical reports tell how they put the reports to use and how useful they are. Journal staff writer Stan Terra talked to a dozen people at utilities, in government, and with manufacturers, who offered their candid comments.

■ Charles Coutant, an aquatic biologist with Oak Ridge National Laboratory and a member of EPRI's Advisory Council, believes the time has come to distinguish between the ethical concerns for the environment and the scientific considerations of ecology. In the natural environment of Aspen, Colorado, at the Advisory Council's summer meeting, Coutant shared views and insights with JOURNAL Editor Brent Barker, **"Charles Coutant: Ecology and the Scientific Method"** (page 22). Coutant hopes that environmentalists and ecologists alike will broaden their vision and achieve what he calls a "holistic perspective."

Municipal Solid Waste—Problem or Opportunity?

A very appealing idea: Take all the municipal solid waste (MSW)—150 million tons or so a year—turn it into a fuel, and extract such usable materials as metals and glass. In one stroke, you've solved the waste disposal problem, saved valuable materials, and helped to alleviate the energy problem.

Dr. Rocco Petrone, director of the National Center for Resource Recovery, summarized the appeal when he said, "Resource recovery might be considered an idea whose time has come. It is an appealing concept. It satisfies our awareness of the need for conservation. It goes hand in hand with our desire for environmental improvement. It is a domestic source of supply of ultimately depletable raw materials for industry. For the cities plagued with waste disposal problems, it greatly reduces the volume and weight of the discard that ultimately must be disposed of in some manner."

Solid waste in perspective

Unlike air and water pollution, the solid-waste problem seems to have a good side—the potential for recovering energy and usable materials. But in many ways, that potential only obscures the issue, making it more difficult to see solid-waste utilization in its proper perspective.

There's no doubt that MSW is a problem. It is estimated that we produce between 1.3 and 1.8 kilograms (3–4 pounds) of MSW per person per day—between 110 million and 150 million tons per year. This includes household, commercial, and institutional waste but excludes industrial waste and sewage.

There is no ideal way to dispose of MSW. Some of it is incinerated, which

Ideally, extracting energy from refuse could alleviate two critical, contemporary problems simultaneously. But roadblocks remain that are less technological than economic and institutional in nature.

☐ An EPRI state-of-the-art feature

can cause air pollution. Some is simply piled in unsightly, insanitary open dumps. Most of it is buried in sanitary landfills, where at least it is out of sight but where it can still cause problems. Moisture in the ground can leach chemicals out of the waste, and the chemicals can find their way into groundwater and then into the local water supply. Landfills also produce methane-rich gas through a process called anaerobic digestion, which amounts to decomposition of the material in the absence of oxygen. While methods have been devised for tapping this source of usable gas, most of it simply escapes into the air, causing air pollution and odor.

But the biggest problem with landfill disposal is that many cities are running out of places to bury their waste. The Environmental Protection Agency (EPA) estimates that large urban areas will run out of convenient or accessible landfill sites within the next 10 years.

Collecting and disposing of MSW is also expensive—the third largest expenditure of local government, according to an official of the National League of Cities. The total bill for all MSW-related expenses in the country came to $6.5 billion in 1975, and because of inflation and more remote landfill sites, it is expected to reach $10 billion by 1980.

There's also no question that MSW contains some potentially valuable ingredients. About 75% (wet weight) of MSW consists of such burnable materials as paper, plastic, garbage, yard waste, textiles, and wood. Roughly 8% is metal (ferrous and nonferrous) and about 10% is glass. The rest is miscellaneous debris.

Unprocessed MSW contains potential heat energy, usually estimated at around

There are four major ways to recover energy from MSW:

- Burn the MSW in a water-wall incinerator to produce steam
- Process the MSW into solid RDF
- Process the MSW by pyrolysis to produce gas or oil
- Extract the methane-rich gas produced by the natural decomposition (anaerobic digestion) of MSW either in landfills or in digestors (chemical process plants)

Of these alternatives, water-wall incineration is a well-established technique, with a half-dozen plants operating in the United States. Conversion to solid fuel is a newer process, but there are 12 plants in the country in various stages of development from planning to operation. Pyrolytic gas and oil processes are still in the development stage, as are techniques to directly process MSW by anaerobic digestion—one such plant is under construction in Florida and another is planned in Delaware.

Water-wall incineration—so called because the incinerator walls are lined with tubes carrying water that collects heat from MSW combustion—has been used in Europe for more than 20 years but only recently in the United States.

Waste is not normally processed before firing except for removal of such large items as mattresses. The MSW is loaded into the incinerator, where it is burned on traveling grates. The ash produced is usually water-quenched, and such materials as metals may be separated from the ash. The ash remaining after incineration (about 20% by weight of the original MSW) is used for landfill. The processor sells the steam, usually for district heating or industrial process heat. The steam is at low pressure and temperature (4.14 MPa, 260°C; 600 psig, 500°F) and is therefore unsuitable for use in large power plant turbines.

The advantage of water-wall incineration is that it requires little or no prior processing of MSW. Disadvantages include difficulty in maintaining uniform steam production because of uneven burning rates, corrosion on boiler tubes and grates, and high capital and maintenance costs.

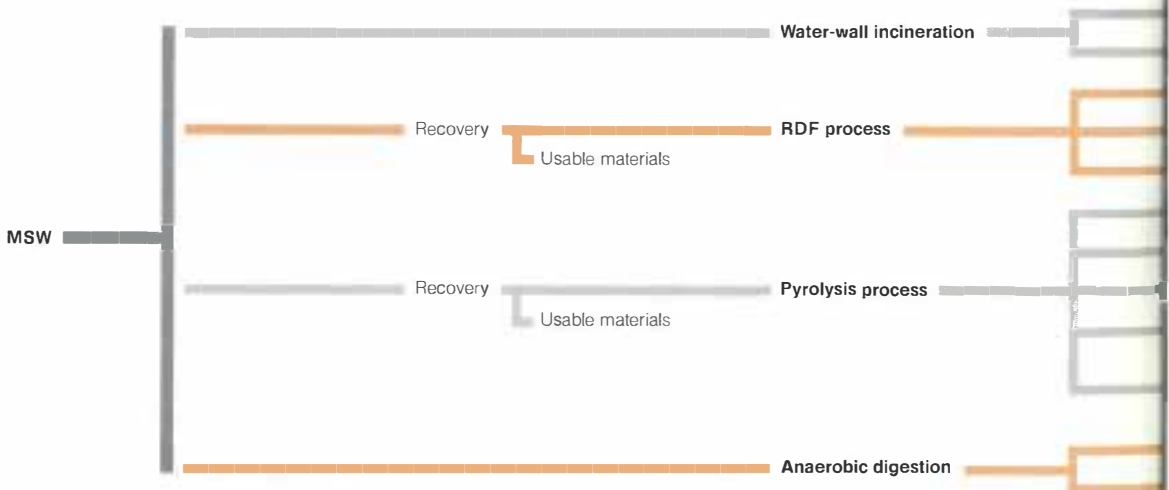
Solid RDF requires much more processing than does incineration. Waste received at the plant is sent first to a shredder, where it is reduced to 8–13-cm (3–5-in) particles. The shredded waste is then sent to an air separator. Lightweight materials, such as paper and plastic (60–80% of the MSW), rise with the airstream and are removed from the top of the separator. Heavier materials, such as metals, glass, and sand, fall through the airstream and are removed from the bottom of the separator.

The light fraction is sent to a second shredder, which reduces the material to the size required for the fuel—usually 2.5–5 cm (1–2 in). This finely shredded fuel, containing from 4000 to 7000 Btu a pound, is sold for burning in grate-fired boilers or in suspension boilers designed for burning coal. The fuel may also be burned in a boiler at the processing plant to produce steam for sale.

The heavy fraction of the MSW goes through another series of processing steps to recover usable materials. Magnets separate ferrous metals; aluminum magnets (using eddy currents) separate aluminum; and screens separate glass and other materials. The remaining refuse, 10–20% of the original MSW, is disposed of in a sanitary landfill.

RDF plants have lower capital and operating costs than water-wall incineration or pyrolytic techniques.

Due to high-temperature chloride



corrosion, it is not practical to use RDF as a primary fuel in electric utility boilers. However, when used as a supplemental fuel in combination with coal or oil, it can be burned in boilers designed for coal firing. Data on the long-term effects of supplemental firing of RDF are incomplete, but no significant corrosion has been found to date. EPRI is cofunding a corrosion study with Wisconsin Electric Power Co. and Combustion Engineering, Inc., to assess the long-term corrosion effects of supplemental firing of RDF at Wisconsin Electric's Oak Creek station.

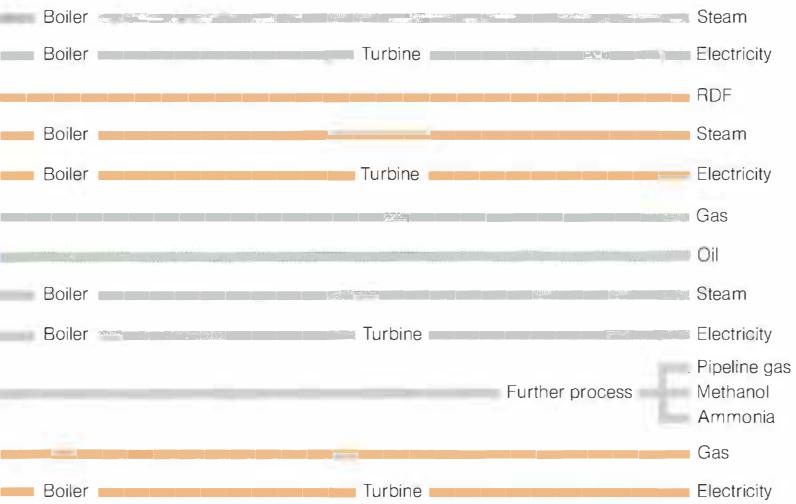
In the pyrolytic process, organic materials are heated in an oxygen-deficient atmosphere to produce a gaseous and/or liquid product, char, and slag. This process is still in the development stage, but a small development plant has been set up in San Diego, California, to process 200 tons of MSW a day. Pyrolytic liquids produced will be burned in a utility boiler.

Pyrolytic operations may or may not include recovery of usable materials, but most are similar to RDF processes in the "front end." MSW is shredded and air-classified, and the heavy fraction is removed for further separation of usable materials. The light fraction, instead of going through a secondary shredder, is fed into a pyrolytic reactor.

As the shredded MSW enters the reactor, it is dried by hot pyrolytic gases. It then moves to the middle of the reactor, where pyrolysis takes place. As the carbon char residue from the pyrolysis settles in the reactor, it burns in the presence of air or oxygen injected into the reactor to produce the heat needed for the process.

Finally, the molten slag from noncombustible material flows into a water quench tank and is removed for disposal. The material for landfill is equal to approximately 20% of the original MSW.

Pyrolytic processes have high capital and operating costs. Their advantage is that there are many potential uses for the products. Pyrolysis gas (120–300 Btu per 28 cubic meters [1000 standard cubic feet]) can be sold as a fuel or used as a synthesis gas and converted to ammonia, methane, or methanol at additional cost. Pyrolysis oil has low sulfur content and 70–80% of the heating value of No. 6 fuel oil. It requires special handling because of higher viscosity, corrosive activity on mild steel, and a tendency to degrade at moderate temperature.



9 to 9.4 million Btu a ton. By comparison, a ton of coal contains potential heat energy of about 23 million Btu; a barrel of fuel oil, 6.2 million Btu; and 28 cubic meters (1000 cubic feet) of natural gas, 1 million Btu. If all the MSW produced annually in the United States could be collected and processed, it would generate the equivalent heat energy of about 225 million barrels of oil—about one-half the volume that the Alaska pipeline will carry in its first year of operation.

Does that mean that MSW is a valuable energy resource? Unfortunately, no. At present, the cost of producing energy from MSW is greater than the value of the energy in the marketplace. Furthermore, although the amount of energy in MSW is significant, it could only contribute about 5–6% of the total energy requirements of U.S. electric utilities (contributions to local requirements could be greater).

Congressman Fred Rooney put it this way in his opening remarks to the Symposium on Resource Conservation and Recovery* in April 1976, "Energy and materials recovery, beneficial as they may be, are only the by-products of the real concern, which is to get the garbage off the streets and to dispose of it in a manner that does not harm the environment or impair the enforcement of other environmental acts."

Cost and credits

There are many systems for processing MSW, but almost all are designed to convert the organic fraction into a solid, liquid, or gaseous fuel and extract such salable materials as ferrous and nonferrous metals. These fuels are then usually sold to a single customer at competitive prices.

Unfortunately, competitive prices mean that MSW processing is seldom self-supporting. Presently, the conversion of MSW to a solid refuse-derived fuel (RDF) costs between $10 and $20 a ton. Further processing of this solid into liquid or gaseous form raises the total cost to around $20–$30 for each ton of MSW. For RDF, which is cofired

*The two-day symposium was sponsored by the Subcommittee on Transportation and Commerce of the U.S. House of Representatives.

with coal, these production costs translate into $1.50–$3 a million Btu of energy output. However, the coal it is intended to displace costs only $1 a million Btu.

Similarly, the production costs for liquid and gaseous fuels exceed the price of competing fuels. Whereas pyrolytic techniques for producing such liquids and gases (of uncertain quality) from MSW run in the neighborhood of $2.50–$5 a million Btu—and perhaps higher—fuel oils (high-quality, low-sulfur) presently command only $2–$3 a million Btu in the marketplace.

Fuel customers, in all but a few cases, are unwilling to pay more for RDF than they do for competitive fuels. Moreover, they usually insist that the costs they incur for plant modifications and increased maintenance on boilers as a result of using RDF be deducted from the price of the fuel.

As a result, the sale of RDF is usually uneconomic, and other revenues must be accrued if the processing business is to break even. Certainly the sale of RDF and recovered by-products contributes to the cash flow, but a tipping fee will almost always be necessary to make up the difference between processing cost and these resource credits.

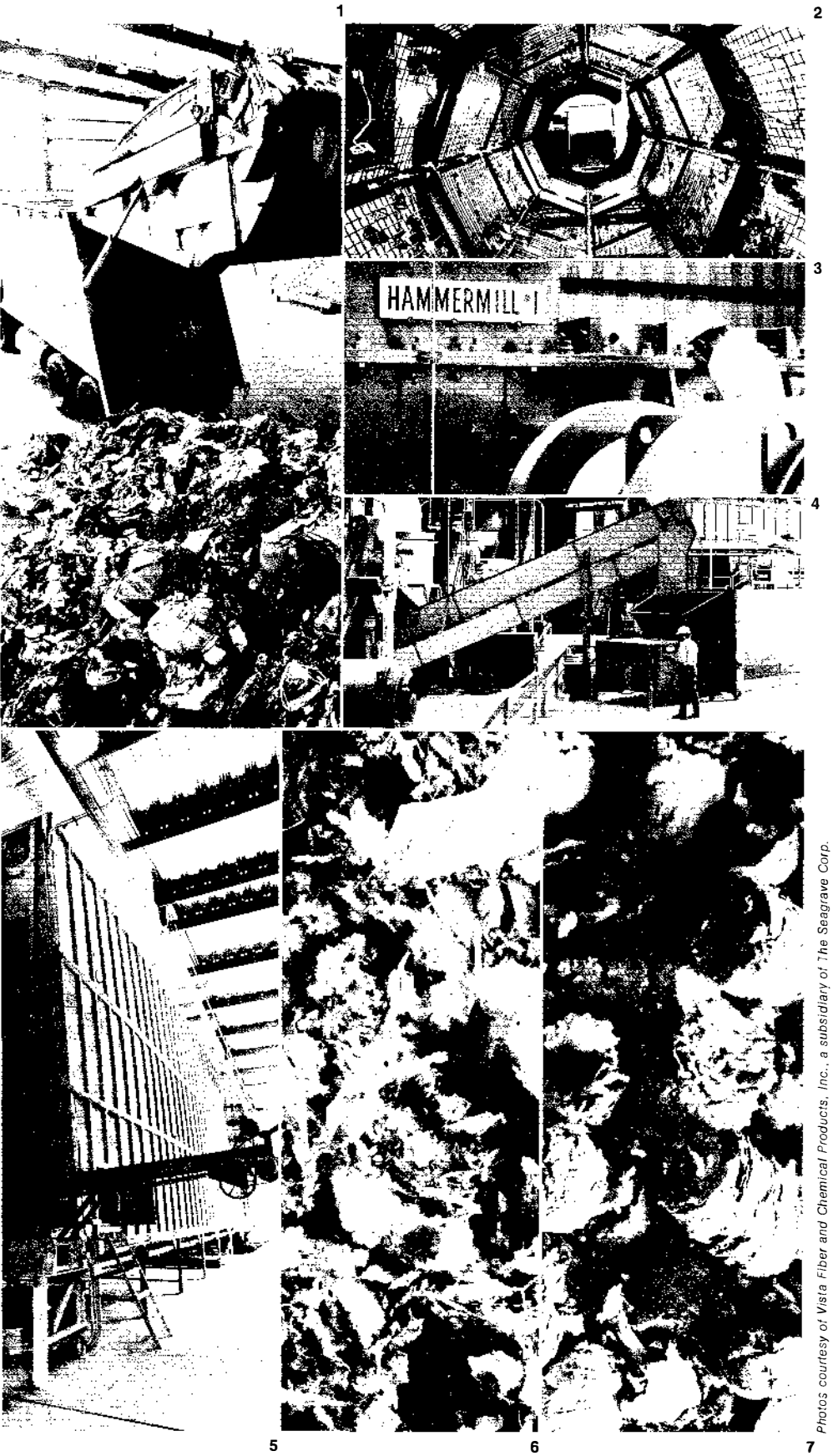
The tipping fee charged at the MSW processing facility is a function not only of the deficit described above, but also of

- The cost of alternative means of disposal, such as a local landfill operation
- The difference in the transportation cost to the landfill and to the processing facility
- Such institutional factors as who owns and operates the processing facility, whether MSW collection is privately or municipally operated, and the future availability of landfill

For example, consider the case of a privately owned and operated processing facility. If a tipping fee of $10 a ton is charged by the processing facility, then the facility could compete with a landfill operation having a disposal charge of $5 a ton and a transportation

Table 1
SELECTED MSW PROJECTS IN THE UNITED STATES

MSW Process	Location	Key Participants	Utility Participant	MSW Capacity (ton/d)	Status
Water-wall incineration	Hempstead, N.Y.	Town of Hempstead; Hempstead Resources Recovery Corp.	Long Island Lighting Co.	2000	Construction (operation 1978)
	Saugus, Mass.	12 communities including Saugus, N. Boston; Wheelabrator-Frye, Inc.	General Electric Co.	1200	Operational
Solid fuel (RDF)	Ames, Iowa	City of Ames	Ames Municipal Electric System	200	Operational
	Bridgeport, Conn.	Connecticut Resources Recovery Authority; Occidental Research Corp.; Combustion Equipment Assoc.	The United Illuminating Co.	1800	Construction (operation 1978)
	Chicago, Ill.	City of Chicago	Commonwealth Edison Co.	1000	Startup in progress
	Milwaukee, Wisc.	City of Milwaukee; American Can Co.	Wisconsin Electric Power Co.	1600	Operational
	Newark, N.J.	City of Newark; Combustion Equipment Assoc.	Public Service Electric and Gas Co.	700	Planning (operation 1979)
	Norfolk, Va.	Southeastern Virginia Public Service Authority	Norfolk Naval Ship Yard	2000	Planning
	Rochester, N.Y.	Monroe County; Raytheon Service Co.	Rochester Gas and Electric Corp.	2000	Construction (operation 1979)
	St. Petersburg—Clearwater, Fla.	Pinellas County	Florida Power Corp.	2000	Planning
Pyrolysis (oil)	El Cajon, Calif.	San Diego County; Occidental Research Corp.	San Diego Gas & Electric Co.	200	Startup in progress



1 2 3 4 5 6 7

Photos courtesy of Vista Fiber and Chemical Products, Inc., a subsidiary of The Seagrave Corp.

1 Residential solid waste arrives by compactor truck at the MSW processing plant, where it is expelled by hydraulic ram onto the floor of the receiving area.

2 To reduce the silicon content and produce a cleaner, higher-Btu product, the refuse is tumbled through an inclined, rotating trammel. Bottles and bags are broken by the lifting and falling action, and glass, dirt, and plant clippings fall through the screen to the floor below.

3 Conveyed to a hammer mill, the waste is homogenized by being shredded into smaller pieces. Rotating hammers, weighing hundreds of pounds and resembling extended fingers, smash the waste against a large steel plate at high speeds, breaking the material down and forcing it through the bottom grate (4–8-in.—10–20-cm—openings).

4 The ferrous metals (about 7% by weight of received MSW) are magnetically removed and loaded into shipping containers for transport to detinners and steelmakers. The remaining waste can then be conveyed to a second hammer mill for further size reduction (i.e., 2 in.—5 cm—or less), depending on the end use of the product.

5 Fed into the air classifier, the shredded waste is drawn by air currents through a hazardous path of impact plates that stop the forward motion of heavy materials. A vertical jet of air lifts the light, combustible materials, which are then pneumatically conveyed to the storage bin, while the heavy materials fall to the bottom. The heavy fraction tends to be very rich in aluminum and is itself a marketable product.

6 The fuel fraction, consisting of light paper, fiber, plastics, and other combustible materials, has an energy value of 5000–8000 Btu/lb. Resembling fluff, the fuel can be compacted in a truck and shipped to a power plant or cement plant for cofiring with coal, or mixed with sewage sludge and pyrolyzed to produce a gas.

7 For ease of handling, transport, and storage, the fluff can be compressed and extruded into pellets at the MSW processing plant. The pellets can be used directly in a stoker or grate-type furnace but may have to be reshredded before firing in a suspension-type furnace.

cost at least $5 a ton greater than the cost of taking the MSW to the processing facility.

The disposal charge for landfill varies widely—from as little as $2 a ton to as much as $18 a ton for landfills around congested metropolitan areas. Overall, MSW processing is likely to be given serious consideration only in areas where the disposal charge for landfill is large, where landfills are destined to be shut down by state or local mandate, or, conceivably, where municipalities are motivated to subsidize RDF operations. As one EPA official put it, "As long as there are cheap options, such as the inexpensive dump, there is really no way that material can be diverted to a resource recovery plant. It is an economic kind of thing."

Utilities' role

Every MSW-processing project has several stages: collection and supply of MSW, processing, burning the fuel product, sale of recovered materials, and disposal of residues. The supplier may be the city itself or private contractors who collect refuse in the city. The processor may also be the city, but the emerging pattern is that a separate company builds and operates the processing plant.

Potential customers for the fuel product include an industrial plant, district heating system, electric utility generating plant, or any other facility that uses a large amount of energy.

Since utilities need large, constant supplies of fuel, they appear to be excellent candidates for RDF use. But utilities are reluctant to get involved with RDF because, as they see it, the risks are high and the return, in terms of an inexpensive, reliable fuel supply in large quantities, is small or nonexistent.

Utilities set for themselves extremely high standards of providing reliable service to their customers. Utility management believes that technical uncertainties of RDF could jeopardize their ability to meet those requirements.

Burning RDF could also make the utilities' operation less efficient. A boiler that is firing RDF must be used continually, or the RDF will start to pile up in the receiving and storage areas. By continuing to use the boiler when it would otherwise be more efficient to shut it down, the utility suffers an economic dispatch penalty.

Thus far, the New York Public Service Commission is the only state regulatory agency to have taken a formal position on utilities' participation in MSW projects. While the New York commission encouraged utilities to help communities find ways to dispose of refuse, it also said that utility funds should not be used for MSW-processing facilities and that the utility's cost for burning RDF should not exceed the cost of other kinds of fuel. A survey of other regulatory agencies by the New York consulting firm Gordian Associates Inc. found that they would also oppose any participation that resulted in higher costs.

In general, utilities have been willing to use RDF as long as rather stringent conditions are met and they are able to minimize or eliminate risk to themselves and their customers. They typically require a guaranteed quantity of fuel, as well as a guarantee of quality in terms of heating value, ash content, and other factors. They may also stipulate contracts with other risk-limiting provisions, including one or more of the following.

- Deducting costs that result from the use of RDF, including more frequent corrosion inspection, more frequent replacement of conveyor parts, and even increased bookkeeping charges
- The right to refuse fuel at any time
- Agreement from the processor to pay for boiler modifications and to buy back storage facilities and other equipment if the utility decides to stop using the fuel
- Test periods of up to a year before the utility signs a long-term contract for RDF, with the utility having the exclusive right to decide whether the fuel passes the test

Community service

H. J. Young, senior vice president of Edison Electric Institute (EEI), the principal national association of investor-owned electric utilities, summed up the utilities' view of MSW processing by saying, "The electric utility industry realizes that there is a critical solid waste disposal problem and that the utility industry has a potential part to play in the solution of that problem. It also realizes that solid waste cannot be viewed as a major source of fuel for generating electricity but that wastes can be a partial help to the utility industry in future years."

While utilities may be less than aggressive in initiating MSW processing programs, they are staying abreast of developments in the field. Young reported that an EEI survey of its members in 1976 showed that 49 out of 93 companies were involved in studies of various kinds of MSW projects. Most were studying the purchase of shredded RDF.

Utilities will continue to fill the key role of customers for MSW energy. Occasionally, they will participate because of an opportunity to cut costs or because they need a supplementary source of energy. For the most part, though, the utilities' motive for participating in MSW projects will be to help communities in their service areas solve their refuse disposal problems.

"Utilities," Young said, "tend to place a high value on efforts at civic improvement and will go unusually far to help improve their service areas." He added that over half the companies involved in MSW studies said that their primary motive was public service.

Utilities can also play an important role as sources of technical information in their communities. With the knowledge they have gained through experience and research, utilities are in a unique position to assist local officials in evaluating processes and processors.

A TALE OF TWO PROJECTS

One that didn't make it . . .

Union Electric Co. of St. Louis was one of the first utilities to burn RDF. In 1969, it joined with the City of St. Louis in a demonstration project in which the city classified the waste, separated metals, and shredded the rest for fuel. Union Electric burned the fuel in coal-fired boilers.

After its experience with the demonstration project, Union Electric took an unprecedented step for a utility: It announced plans to build and operate its own MSW processing plant through a wholly owned and unregulated subsidiary, Union Colliery. The solid waste utilization system (SWUS), as the project was called, would process up to 8000 tons of MSW a day collected from St. Louis and surrounding communities. Waste would be brought by truck to four transfer stations, where it would be loaded into railroad cars for shipment to the processing plant at Union Electric's 2400-MW Labadie power plant.

In April 1977, four months before the originally planned start of operations, Union Electric announced that the project would be abandoned. The problems were political and economic. Last November, the voters of Missouri adopted a proposition that prevented electric companies from including the carrying costs for construction funds in their electric rates. That restriction, plus rising costs, made the economics of the project questionable.

Another factor in Union Electric's decision was the company's inability to obtain permission to build the fourth transfer station in a suburban St. Louis community. The community refused to issue a permit for the station, saying that it involved dumping of waste, which was prohibited by ordinance. A similar situation in the city of St. Louis was resolved when the city attorney ruled that the transfer station there involved the movement of waste from one form of transportation to another, not dumping. The suburban community's attorney refused to make a similar ruling.

A bi-state commission of Illinois and Missouri officials is now considering taking over the project from Union Electric.

and one that did.

In 1971, the City of Milwaukee and Wisconsin Electric Power Co., which serves Milwaukee and much of southeastern Wisconsin, studied the feasibility of recycling solid waste to produce energy. While they concluded that conventional incineration with heat recovery was technically feasible, they also found that it would cost more than the landfill disposal that was then being used. However, they took note of the experiments in St. Louis with the burning of solid RDF.

In 1973, Milwaukee requested proposals for disposing of solid waste by any method that would "not cause degradation of the environment." The proposal by the Americology Division of American Can Co. was chosen from the seven submitted.

Americology proposed to receive solid waste at a downtown-Milwaukee processing plant and at three transfer stations. The plant, with a rated capacity of 1600 tons of MSW a day, would separate bundled paper, metals, glass, and other products from the MSW and shred the rest for solid RDF.

The key to the project was the decision by Americology to underwrite the project's risk, coupled with the participation of Wisconsin Electric. The City of Milwaukee required that Americology secure Wisconsin Electric's agreement to burn the fuel before it would enter a contract with Americology for processing. Agreements on both sides were reached in January 1975.

Under its agreement with Americology, Wisconsin Electric will burn solid RDF as a supplementary fuel at its Oak Creek station and will pay for the heat value of the fuel at the same rate as the equivalent heat value of coal, less amortization of capital investment and expenses that result from burning the RDF. Wisconsin Electric will evaluate the use of RDF in a one-year test program. It has the option of cancelling its agreement with Americology at the end of the test program.

The Americology plant is not yet in full-scale operation due to plant modifications. Problems have been encountered in shredding the waste to a sufficiently small size and in removing noncombustibles from the fuel. To date, 7000 tons of MSW have been processed. The fuel is now being fired on a routine basis but at a very limited burning rate.

System Operation at Optimal Cost

by Charles J. Frank

Rising fuel prices are putting new importance on the economic impact of a system operator's dispatch decisions. EPRI research is exploring new techniques for fine tuning the generation mix to gain a better balance between performance and cost criteria.

Harry Truman's famous desk motto, "The Buck Stops Here," applies most appropriately to one individual in an electric utility, the power system operator, or dispatcher. Regardless of how well the system planners and designers have done their job, the operator must take what they give him and make it work—match the generation to the ever-changing load.

Planners accommodate many expectations, such as daily and seasonal cycling and projected service growth, when they design new facilities. They also consider many contingencies, such as loss of transmission lines, loss of generators, and other equipment failures. But the operator is faced daily with using whatever is actually available to do his job.

A system operator may be likened to a flight controller at a big airport. At any moment the availability of runways (perhaps of different length and pavement thickness) depends on such variables as wind speed and direction, visibility, electronic aids. As flights seek to take off or land, the controller must accommodate them. If the field is socked in, he holds all departures and diverts fuel-starved arrivals to an open field elsewhere.

The power system operator also faces a fluctuating traffic pattern—system load—and he also faces the eventuality of being "socked" by equipment failure, forcing him to buy power from a neighboring utility or, in an extreme case, to shed customer loads so as not to exceed his remaining generation capacity.

Unique in the power system operator's work is the requirement to generate power only as it is needed. For the most part, electric energy cannot be stored. The operator must monitor all possible information about routinely changing load patterns, as well as the sudden changes that occur. He can then arrange to have sufficient generation and sufficient reserve capacity—ready at all times for use at moment's notice—to meet the anticipated load variations.

Priorities of responsibility

Given the variety and magnitude of load fluctuations that confront him, what are the operator's criteria for deciding his course of action? These criteria—and their all-important priority order—suggest the context in which refinements and improvements are sought. From most to least critical, an operator's responsibilities are stability, reliability, security, and economy.

The operator's first concern is the stable operation of his generation and transmission system. Stability is directly affected by the location and amount of generation for a given load pattern. The operator must not allow uncontrolled oscillations in power flow, cascading

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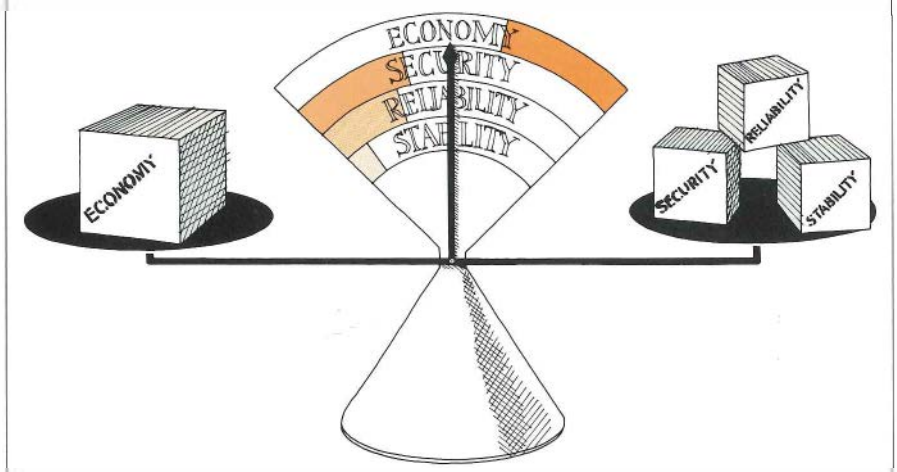
Constant, urgent communication is the task of power dispatch. It takes a system operator and three district dispatchers to monitor and control the five oil-fired base stations and numerous peaking units that make up Long Island Lighting Co.'s 3400-MW system capacity. Tough decisions are made here—such as to break the tie with Consolidated Edison Co. when New York City's blackout threatened Long Island last July. *Photo courtesy Long Island Lighting Co.*

System security, reliability, and stability must strike a balance with economy. How delicate is that balance? Where does insecurity begin? How much of an imbalance—and for how long—will compromise reliability? EPRI-sponsored research and analysis seek techniques that utilities can apply to evaluate and sharpen their own system performance.



NAPSIC GUIDELINES

Number	*Area of Interest*
1	Automatic generation control
2	Frequency bias setting
3	Scheduled interchange
4	Time error standard and correction
5	Inadvertent interchange accumulations
6	Calibration of frequency meters and time error devices
7	Monthly summary of inadvertent interchange accumulations
8	Regulating surveys
9	Action in emergency
10	Reserve capacity
11	Load shedding, sectionalizing, and restoration
12	Communications
13	Generator security
14	Relaying
15	Transmission
16	Maintenance coordination
17	Training of dispatchers and operators
18	Notification of system disturbances
19	Exchange of information
20	Analysis of system disturbances
21	Monitoring for system security
22	Action for an energy emergency

outages, or uncontrolled separations from neighbors. Furthermore, he must ensure that these undesirable conditions are not even likely in the event of equipment outages or sudden power excursions. Unless the operator maintains stable operation, it is futile to consider reliability, security, or economics. On the other hand, he must not operate in so conservative a manner that he incurs enormous costs and maintains excessively high equipment reliability.

Reliability is the operator's next concern. The reliability level he achieves is determined by the ability of generators and transmission lines to supply the system load, while maintaining adequate reserve generation and transmission capability. Closely related to reliability is system security. The operator must use the generation and transmission equipment at his disposal within normal operating ranges. For example, if a transmission line approaches its loading limit, the operator must consider routing additional power over alternative lines or take the risk of losing that line because of overload. Operating a transmission line near its operating limit reduces both system security and system reliability.

Only when each of the above requirements is satisfied can the operator consider operating his system in the least costly manner possible. Stability, reliability, and security are interrelated. All follow the same pattern; that is, an increase in stability causes higher reliability and higher security.

But economy acts in the opposite direction. The operator's job is achieving the proper balance among these four requirements.

Today's technical criteria for stability, reliability, and security have evolved from system interconnection practices. Most utilities in North America are linked with their neighbors. Interconnections were added over the past 50 years to bring a measure of additional security in operations, while offering economic advantages. Thus, with the help of its neighbors, a sudden disturbance on one power system can be met with the combined resources of all the interconnected members. But to get this help in time of need means each utility must be prepared to help its neighbors when they have disturbances. Through interconnected operation, a power system responds not only to its own disturbances but also to any

that the interconnected group experiences. This is a small burden to absorb in exchange for the advantage of pooled operation that affords lower-cost power when one or another system has excess capacity to sell.

Voluntary guidelines

With the growth of interconnected operations, the cooperating utilities realized that a common set of rules was needed. The North American Power System Interconnection Committee (NAPSIC) was therefore organized in 1962. Using all that had been learned in the previous 35 years of interconnected operation, NAPSIC developed a set of guidelines for its members. These guidelines are periodically modified to meet changing system conditions.

For example, the first guideline (on automatic generation control) was incorporated into the operating manual in 1967. Revised in 1973 and again in 1975, this four-page guideline identifies four basic principles of generation control with either analog or digital equipment. It also designates the minimum required facilities, such as monitoring equipment, recording devices, and backup power supply. Finally, it delineates the practices an operator must follow to achieve acceptable control performance.

In addition to the guidelines in the NAPSIC operating manual, a set of minimum performance criteria was issued in 1973. These criteria deal mainly with the primary control error an operator uses to measure his own system's performance. They identify maximum excursions that are tolerable and the speed with which the control error must be returned to zero. Still another part of the NAPSIC manual deals with operating reliability criteria.

Although NAPSIC has prepared extensive guidelines and criteria, it is a voluntary organization—decisions to follow these guidelines rest with the individual operators in each of the interconnected utilities. When problems requiring research arise, NAPSIC can count only on voluntary help from its members. Because their research resources and capabilities vary considerably, this is where EPRI can be of assistance.

NAPSIC MINIMUM OPERATING RELIABILITY CRITERIA

Number	Area of Interest
	Normal Conditions
1	System contingency robustness
2	Highest reliability goal
3	Operating reserve
4	Automatic generation control
5	Interchange scheduling
6	System monitoring
7	Reactive supply and voltage control
8	Frequency and time error control
9	Communications
10	Relaying
11	Maintenance
12	Training operating personnel
13	Equipment ratings
	Emergency Conditions
1	Emergency power transfer limits
2	Disturbance rebalance limit (10 minutes)
3	Defensive strategies for abnormal loading and voltage
4	AGC frequency cutoff
5	Emergency and backup power supply
6	Load shedding and sectionalizing
7	System restoration
8	Major disturbances
9	Long-term emergencies

Research in operations

Economic aspects of system generation, in particular, seem to be a subject area for research on a nationwide scale. Two examples illustrate the distinctly different viewpoints that have evolved among power system operators over the years.

The first has to do with generation cost, especially as it relates to regulation. One group contends that there is a cost variable associated with generators that are used to track the consistently fluctuating system load. As a result, this group commits generation sparingly in contributing to the regulatory response. A second group feels there is no difference in cost whether a unit is generating at constant level or is responding to small fluctuations in load, but with an average value equal to the constant level.

Which opinion is right? Is there a cost associated with providing generator regulatory response?

Another difference of opinion among operating groups concerns time, that is, the accuracy of electric clocks. Is it the responsibility of a utility to sell both energy and a time standard? One group of operators contends they do have this responsibility. They feel they must operate as close to 60 Hz as possible so that all their customers' electric clocks are accurate. Other utility operators have steadfastly maintained that providing accurate time is not one of their obligations. They have changed their operating principles in this regard only when they have become members of larger interconnected groups.

So the question is, should utilities sell a time standard? If so, what is the added cost to provide this service?

Such questions have one area of commonality—economics. And today, because of rapid escalation in fuel prices and uncertainties in fuel availabilities, operators must reevaluate the impact of these questions on their own control techniques. The delicate balance between economy and stability, reliability, and security has been altered. To help answer the questions and to assist in developing techniques to evaluate operating practices, research in the economic operation of power systems has been initiated at EPRI.

Altogether, the research touches on the system operator's functions in automatic generation control, economic dispatch, and generating unit commitment. Continual changes in electric utility operating conditions require a reevaluation of the methods the operator uses to ensure security and provide adequate control. A major motivation, for example, is that methods of operation that were eco-

nomical at lower fuel costs no longer remain so. The result is much more emphasis on ways to improve daily procedures in the utility dispatching office.

Five projects have been selected for funding. The first concerns system control performance. EPRI's goal is to identify the factors needed to analyze the performance of each member of an interconnected power system. The contractor, Autocon Industries, Inc. (a division of Control Data Corp.), together with Northern States Power Co., will develop criteria, guidelines, and working tools for analyzing the performance of any control area of an interconnected power system. Of principal interest are factors affecting operating economy and control.

The second project, on an area control simulator, will provide a digital computer simulation program for studying multiarea interconnected operation. The contractor, Philadelphia Electric Co., will develop the simulator for Autocon and Northern States' use in their studies and for use later by other utilities. In addition, Philadelphia Electric will hold a workshop on the use of this simulator in the fall of 1978.

A third project in this group concerns improved dispatch methods. The objectives are to assess improved methods of representing turbine generator incremental costs and to evaluate the effects of turbine generator operating constraints. The contractor, Philadelphia Electric Co., will evaluate the methods now used to determine and update turbine generator input-output representations. It will examine standard test procedures and conditions used to measure input-output curves and will determine the instrumentation and analytic requirements needed to frequently update the input-output curves. In addition, Philadelphia Electric will identify the various turbine generator operating constraints that must be considered by the power system operator and will include the constraints imposed by boiler and fuel types used.

Two final projects particularly address the effective utilization of fuel resources. For the project on pool daily fuel dispatching, Power Technologies, Inc., and the New York Power Pool are developing a computer program to efficiently allocate the fuel for a group of interconnected utilities on a daily basis. The daily fuel-dispatching procedure will satisfy most, if not all, operating requirements, while optimizing a cost equation. The requirements to be considered include constraints on thermal units, such as unit minimum down- and uptimes; operating limits; response rate limits; limitations of fuel supply; reserve requirements; operation of conventional hydro generation; operation of pumped-storaged hydro generation; and transfer limitations for multiarea operations.

A second contract on fuel dispatching has been awarded to Boeing Computer Services, Inc., which will study the problem of coordinated monthly, daily, and instantaneous fuel dispatching and develop practical computer application programs for use by power system operators. The overlap of this work with the pool daily fuel dispatching is intentional. Because of the large amounts of money involved in the production cost of generation, two parallel efforts on the fuel dispatch problem seem justified.

Follow-on efforts

Most of the work on these projects will be completed in two years. However, because of the changing conditions and requirements of interconnected power systems, research in system control performance and modeling control performance will undoubtedly be continuing efforts.

From the research on improved dispatch methods, techniques for more rapid updating of economic dispatch data will be developed. In addition, the impact of equipment limitations, constraints, or outages will be pursued. Finally, the fuel-dispatching effort will result in techniques for influencing on-line economic dispatch programs to account for fuel utilization requirements. Thus, EPRI foresees potentially significant effects. Not only is more up-to-date information the goal of current research but computer programming changes to account for equipment limitations and fuel usage constraints will also be considered. The result of this future work on economic dispatch will be coordinated with generation control research being pursued by the Department of Energy.

But other research will be needed to balance the program. To this end, the following topics have been identified by EPRI's advisory task force for power system planning and operations:

- *Real-time data equivalents* Here the concern is the on-line power flow analysis needed for a power pool environment. This work will be closely related to current work in hierarchical control—that is, data management at different levels of computer networks. The goal will be to develop the network simplification and equivalencing techniques and to specify the equivalencing power system data requirements.

- *Security analysis* The goal will be the development of steady-state and dynamic security assessment methods for use in daily power system operations. The key phase will be utility demonstrations of the developed techniques.

- *Load management for operations* Because of the amount of work being done in load management techniques, research and development must consider the needs of power system operators. The research effort will identify these needs and seek to reflect them in load management development.

- *Plant availability* Work is needed to determine optimal generation and plant availability needs. Study will likely include determination of the cost benefit of higher generator availability (allowing deferral of secondary generation sources) and other scenarios.

EPRI research in power system operation today is thus directed at the highest-priority problems that have been identified, and orderly progress is being made to define related investigations that will optimize the performance and cost considerations of electric power dispatch.

The Published Product

Since its inception, EPRI has undertaken more than 1000 research projects and published over 400 technical reports on completed research. A survey reveals how they are being used and how useful they are.

What does an engineer at Yankee Atomic Electric Co. in Westborough, Massachusetts, have in common with a program planner at ERDA in Washington and an environmentalist at Otter Tail Power Co. in Fergus Falls, Minnesota? All receive, read, and put to beneficial use EPRI technical reports.

Robert Smith, an engineer who deals with metallurgy problems in nuclear reactors at Yankee Atomic, has used data from an EPRI study of radiation dosage effects on structural components in nuclear reactors. Smith extrapolated the reactor geometry in the study report and applied it to the similar geometry of the Vermont Yankee Mark I reactor in his attempt to determine what materials would best inhibit radiation damage. He says that "the flux data in the report were directly applicable" to the problem he was working on. And he adds that information from the EPRI study has also been used by Yankee Atomic in updating reactor operating data that the company is required to report to the Nuclear Regulatory Commission. Smith went on to say that EPRI research in fracture mechanics has not only been useful but also "will probably lead to a change in Section 3 of the ASME Boiler Code."

According to Erik Svenson, assistant director for federal program plans for ERDA, information from several EPRI environmental reports, among other sources, was used in drafting a recent White House—ERDA analysis of various environmental issues. The reports were supplied by Mike Tinkleman of EPRI's Washington office to a Svenson staff member on special loan to the White House.

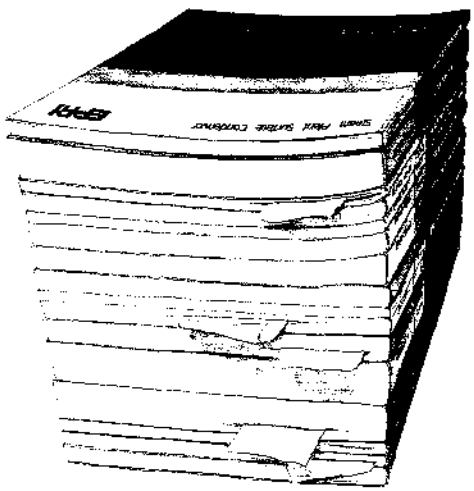
Svenson says he has found EPRI technical reports "a very useful information source" in his task of preparing a compendium of current R&D programs at 18 federal agencies. This national plan for energy R&D and demonstration includes a volume on policy and is produced annually, sent to Congress, and made available to the public. Generally, he says, he reviews EPRI reports to keep abreast of research developments in the electric utility field. They also help him evaluate ERDA research budgets and set priorities. And they aid in his role as an information liaison between ERDA and the energy R&D community outside the agency.

Svenson spoke of the "staggering" volume and diversity of EPRI reports and admitted to reading in depth only about half those that cross his desk. But he volunteered that he reads the JOURNAL "from cover to cover" and finds the information not only technically sound but also understandable and "not available in any other publication."

Environmentalist Verlin Menze of the Otter Tail Power Co., which serves some 120,000 customers in portions of Minnesota and North and South Dakota, is keeping a close watch on the controversy raging over the proposal of a group of neighboring power companies to construct 400 miles of ±500-kV dc lines from central North Dakota to the Minneapolis–St. Paul area. Some Minnesota farmers have threatened violence if these high-voltage lines are permitted over their fields and livestock. Court and regulatory hearings have dragged on, Menze notes, delaying construction approval. All this has created a special interest, he says, in the reports of EPRI research into the ecological and biological effects of high-voltage electric fields.

As the company's environmentalist, 18-year veteran Menze says he is generally interested in EPRI's reports on the environmental effects of electric power generation and transmission, and he has reviewed reports on such matters as SO_2 dry removal systems; SO_x, NO_x, and particulates; and ozone, noise, and corona discharges.

David Jopling, research coordinator for Florida Power & Light Co., views the energy field as "a swirling morass of confusion that makes it difficult to fit the pieces together." Jopling believes that some EPRI reports "are helping to settle the uncertainties" in a business that is "high risk with many unknowable cost considerations." For example, he points



out, "Nobody knows how much it will cost to deal with the sludge created by precipitators."

Jopling notes that FP&L has been an EPRI member for only two years and "is just beginning to appreciate how new technical developments can affect decisions." He adds, "Utilities are learning what R&D really is, how it can help, and how it can't."

Typifying how manufacturers use the technical reports are Donald Lane and George Silvestri of Westinghouse Electric Corp. Lane, who is the liaison between EPRI and Westinghouse Advanced Power Systems and heads a field office near EPRI's Palo Alto headquarters, says that EPRI reports "get distribution and exposure to a large cross section of people at Westinghouse." He listed the corporate R&D center near Pittsburgh, heat transfer division in south Philadelphia, and the nuclear facility in Monroeville, Pennsylvania, among locations receiving them. Lane's office issues a monthly newsletter, which lists the most recent EPRI report titles (among other EPRI-related information) and is circulated in several Westinghouse divisions. Lane points out that Roland Coit, a well-known condenser design expert and a Westinghouse consultant, had written a letter to William Lavallee, EPRI project manager for a study of steam plant surface condenser leakage. Coit complimented Lavallee on a "valuable report," whose data were "carefully collected and analyzed."

Silvestri, an engineer at Westinghouse's steam turbine division near Philadelphia, says he looks to EPRI technical reports for the latest data on state of the art and for "independent, authoritative information" on technical points over which he and his colleagues may have a difference of opinion. He's been following with special interest EPRI work on the relative costs of coal gasification and stack gas cleanup.

An EPRI report on the evaluation of dry alkalis for removing sulfur dioxide from boiler flue gas has led to a parallel research effort at Pacific Power & Light Co. in Portland, Oregon, according to

Verlin Menze

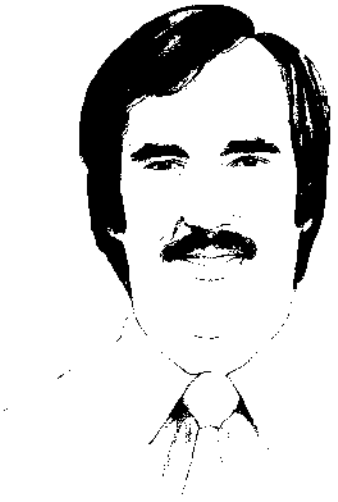
Peet Soot, PP&L research coordinator. "There's no doubt that EPRI technical reports are of use here," says Soot. PP&L also serves portions of Wyoming, whose air quality standards are more restrictive than the federal criteria. The alkali process detailed in the EPRI report, Soot explains, "is more efficient than wet scrubbers." And if PP&L's effort to develop a process whereby alkali can be used to remove SO_2 from its flue gases proves effective, Soot says, "We foresee substantial cost savings."

Some 400 copies of EPRI's evaluation of EPA's Community Health Evaluation Surveillance System (CHESS) report on asthma data (1970–1971) for New York City were distributed by Richard Laska of EPA's R&D office in Washington to key decision makers in several federal agencies. EPRI's analysis of these particular CHESS data questioned the contention that there is a link between the incidence of asthma attacks and the sulfate and particulate levels in the air.

Anthony Colucci of Greenfield, Attaway & Tyler, Inc., a principal investigator in EPRI's analysis of the CHESS data and in an earlier report on the current state of knowledge regarding sulfur oxides, has been testifying almost nonstop over the past year before regulatory commissions on behalf of utilities in the U.S. and Canada. Colucci reckons he's spent the equivalent of 100 days in actual testimony, presenting facts from the two reports.

"The data developed in these reports," says Colucci, "have been very useful to utilities in regulatory hearings related to emissions and air quality standards." He says that the studies "have advanced the state of knowledge regarding sulfur oxides and have given government agencies more scientifically based data." Colucci, a public health specialist with a doctorate from Johns Hopkins University, believes that "the sulfur oxides study will probably have a significant influence on EPA when it comes to drafting new criteria for SO_2 emissions standards." He notes that similar studies on nitrogen oxides and particulates are being done for EPRI by his consulting firm.

Not everyone sings praises for EPRI's technical reports. William Johnson, chief electrical engineer for Pacific Gas & Elec-



Robert Smith

Erik Svenson

tric Co. in San Francisco, finds the reports "too voluminous" and says, "It's too difficult to get the technical meat out of them, when it's there." Johnson, a member of EPRI's Research Advisory Committee, thinks the main problem with the reports is that "they seldom have a good summary. Most summaries are self-serving—they tell what was done but not what was found." He would like to see "the first couple of pages of a summary give a knowledgeable reader enough information to enable him to decide whether or not to go further into the report."

Johnson noted that the reports he sees, mostly from EPRI's Electrical Systems Division, have been improving in this area. He added that the EPRI publication he has found most useful is the *Technical Assessment Guide,* produced by the technical assessment group on EPRI's Planning Staff.

On the other hand, Howard Philipp, research planning director for Niagara Mohawk Power Corp. in Syracuse, New York, says that he's seen "a lot of research reports in 25 years in the utility business, and EPRI's are the best."

EPRI's technical reports on research projects are prepared by the contractors. The EPRI project manager responsible for the research closely monitors the efforts of the contractors during the course of the work up to the preparation and publication of the final report.

Philipp comments, "EPRI does an exceptionally good job in preparing reports. The research is carefully monitored as it progresses and the results are presented in a report format that facilitates its use."

As this article was being prepared, a new service was being readied by EPRI for those who prefer to receive a shorter version of the reports—technical summaries. The summaries, which include the title page, abstract, and executive summary from the full reports, cover all EPRI technical reports published during the previous month.

"This new service is designed to save the reader time—and shelf space," explains Carol Poole, EPRI's publications distribution administrator. Each packet of summaries contains information for ordering those reports the reader may want. Poole points out that the new procedure "eventually will enable us to cut the cost of printing reports, since our inventory will more closely reflect demand."

George Silvestri

Thus far, EPRI has published some 400 technical reports on completed research projects that cover a broad range of concerns in the electric utility industry. These reports—in effect, EPRI's published product—are distributed widely in the United States and abroad and are put to a variety of uses.

Some 4500 reports are mailed gratis each month to EPRI member utilities, affiliates, contributing nonmembers, advisory committee members, U.S. utility industry associations, federal, state, and local government agencies, and foreign organizations with which EPRI has information exchange agreements. Among the overseas groups receiving the reports are the Central Electricity Generating Board in England, Swedish State Power Board, Electricité de France, Australian Coal Industry Research Laboratories, and the Central Research Institute of Electric Power Industry in Japan. Members of EPRI's various advisory committees also receive them.

As the reports and requests for them grew in number, EPRI was forced by cost considerations to begin charging nonmember and nongovernment organizations for reports. Beginning in March of this year, EPRI set up an arrangement whereby these groups could obtain reports at a moderate cost from Research Reports Center in Palo Alto. Microfiche reproductions of the reports are available from the National Technical Information Service (NTIS) in Springfield, Virginia.

Guy Farthing, EPRI's manager of member services, says that among his concerns in calling on member utilities is to find out how EPRI's technical reports are being used and to encourage members to get the maximum benefit from them. "Adequately understood and properly used," says Farthing, "these reports become a major asset to the electric utility industry."

Charles Coutant: Ecology and the Scientific Method

Experimental science is an emerging force in the ecological movement, allowing the separation of fact from intuition and promising more soundly based environmental standards and energy systems design.

▫ An EPRI interview

Ecology is difficult to separate from the other sciences," says Charles Coutant, "because it is by definition a combination of all of them."

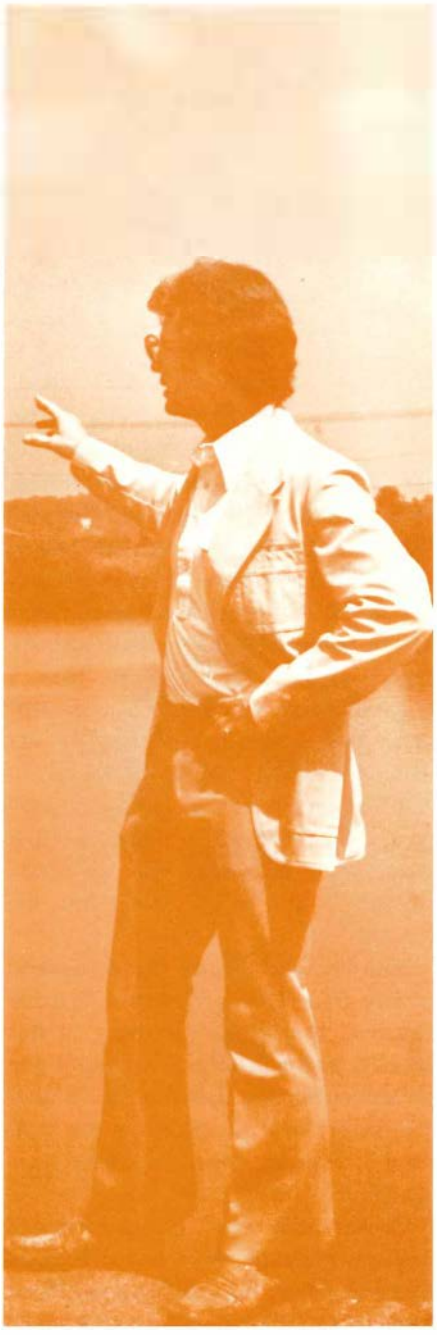
Definitions aside, Coutant, an aquatic ecologist and long-standing member of EPRI's Advisory Council, points out that this "holistic perspective" is somewhat at odds with the latest developments in his field, namely the increasing tendency to use experimental techniques that are normally associated with scientific specialization.

"The ecologist is always torn in two directions. We want to put the whole picture together, but if we want to do a detailed experiment to find out why or what the causal relationship is between this and that, we have to narrow down, drop the big picture, and look at the smaller pieces. As a result," says Coutant, "depending on which group I'm talking to, I'll sound like a fishery biologist or I'll sound like a fish behaviorist, even though the real aim of what we are up to is to look at the system in its entirety."

The system to which Coutant refers and to which he has devoted much of his career is the power plant cooling cycle and the water bodies to which it is linked. At Oak Ridge National Laboratory, he is manager of an R&D program that is investigating the ecological changes associated with power plant cooling systems. The intention is to predict the nature and extent of aquatic disturbances in order to "allow for proper design and siting of power plants."

The ecology movement, from Coutant's perspective as a scientist, is too often confused in industry's mind as a single homogeneous body given to moral polemics and confrontation politics. During an interview at a recent EPRI Advisory Council meeting in Aspen, Colorado, Coutant was emphatic in differentiating the ethical or quasi-religious aspects of the movement from its scientific counterpart—but in fact pointed to their common origins. He explained, "The science of ecology sprang from the environmental ethic that was preached by the old-time conservationists, and the two have gone parallel since. As a holistic science, it really has had to develop from natural-history observations, a phase we've gone through and are still going through, and it's only recently that we have been getting into the more experimental and quantitative phases. However, today I think we have reached the point where we need to make a social distinction between those who speak from an ethical concern for ecology and scientific ecologists, who really try to do a rigorous analysis based on what we know or at least on what is a clearly logical extension of what we know."

"We need to make a social distinction between those who speak from an ethical concern for ecology and scientific ecologists."



Uninformed intuitivism is a phrase used by Coutant to describe preconceived positions (whether taken by well-intentioned extremists or legislators) that are devoid of a sound factual basis. When pressed for examples, he ignored the obvious one of the radical fringe of the environmental movement and addressed his concerns to the regulatory framework.

"Do we really have a good, factual basis for stating that sulfur dioxide emissions are damaging to human health?" he asked. "We really don't. A lot of people feel intuitively that sulfur dioxide is bad. In itself, it is. It will kill plants and it will kill people. But we're making a lot of regulations when we really don't have good, scientific facts as a basis. On the water side, there are several problems. Many of our thermal standards around the country were set up more on intuitive feel for what things should be rather than on good data. We have been learning a lot from power plant studies and experimental work, which shows in many cases that these standards are really not well founded—that organisms, for example, are more tolerant to temperature change than we thought they were and that the systems are more tolerant overall. As a result, the real problem now is to make sure that the legal standards and the decisions that are made through analysis truly reflect the increase in knowledge that we have."

Coutant's penchant for good experimental data, as well as for the mental flexibility to adapt to new scientific evidence as it arises, stems in part from his own experience. He is fond of pointing out the evolution in the thinking of his own profession, notably the movement from an initially narrow focus on thermal discharge to a continually broadening perspective that now incorporates all mechanical, chemical, and thermal stresses of cooling systems upon the aquatic environment.

Coutant's career in power plant cooling stretches back nearly 20 years to his undergraduate days at Lehigh University, and his interest in marine life goes back to his childhood. Having "grown up on water and boats" in upstate New York, he had become at an early age "really fascinated with the whole aquatic business." At Lehigh he became the protégé of Francis Trembley, one of the first to do consulting work in aquatic systems, pollution problems, and lake and stream surveys. Coutant describes him as "the old-time naturalist, the kind that could take a hike and tell you the name of every blessed flower and tree and the integration of all the natural things." His work with Trembley was instrumental in his gaining a National Science Foundation fellowship to study effects of power plant thermal effluents on microinvertebrates—stream-dwelling insects, clams, snails, and so forth.

"The modelers have done something the ecologists have tried to do for years, and that is to put it all together."

Coutant stayed on at Lehigh for his graduate training and received "increasingly greater exposure to systems analysis and the more formal ecological concepts." He continued his power plant studies through to his master's degree and then, to broaden his perspective, turned his research toward reservoir effects—"what happens to a stream ecosystem when you suddenly plop a reservoir with a deep discharge in the middle of it."

He found that in summer the reservoir temperature stratified and then the reservoir itself chemically stratified, "so that all the active biological life was up on top; below there was a huge decay zone that was completely anoxic—it lost oxygen and developed high concentrations of iron, manganese, and reduced iron that were then released downstream. As a result, bottom organisms were completely different downstream from upstream, fish populations were completely different, and similarly, attached algae. The reservoir completely changed the ecosystem. So with hindsight, although I thought I was changing my perspective greatly by moving from a thermal problem to a reservoir problem, many of the differences imposed by the reservoir, aside from chemical ones, were really temperature differences. For my master's,

I was working on a power plant study where we had an abnormal increase in temperature, and then I turned around and looked at the reservoir study where we were abnormally decreasing the temperature."

After receiving his PhD in 1965, Coutant was asked to join AEC's Hanford plant to research the effects of the reactor cooling water on invertebrates in the Columbia River. A few years of frustrating work followed "because the invertebrates are down at the bottom of a very deep and fast-flowing river and because the real religion out there is fish." Gradually, with migrating salmon as a focal point, he was given "an open door to study not only radionuclides (corrosion-inhibiting chemicals activated by neutrons) but also various questions of temperature on the Columbia River system."

During his tenure at Hanford, Coutant was also asked to participate in the first U.S. regional power plant siting study. Bonneville Power Administration contracted for the equivalent of today's impact assessment for each of a dozen potential sites in the Pacific Northwest. Research on the biology, fisheries, meteorology, hydrology, and hydraulics were integrated into mini–impact statements for each location. Notably, a number of these have been used directly or indirectly over the past decade in plant siting (e.g., for the Trojan nuclear facility).

In 1970, AEC decided to expand its national program on thermal effects and invited Coutant to initiate a second program at Oak Ridge National Laboratory. He accepted and over the next few years found his own perspective broadening: "We went in with one idea—that thermal was the thing—and soon realized that other things were happening. It's not just the fact that we heat water. We're moving the water around, we're pumping it, we're squeezing it through tubes and running it through screens, and all these impact organisms in some way. We realized that the mechanical and physical stresses of entrainment and impingement were just as important as thermal. . . . With hindsight, we didn't do a very complete job on the Columbia River because at that time we were thinking strictly thermal."

"The real problem now is to make sure that the legal standards . . . truly reflect the increase in knowledge that we have."

At Oak Ridge, Coutant and his staff are now attempting to predict quantitatively how and when changes occur in an aquatic ecosystem as a result of the combined stresses imposed on it by a power plant cooling system. Coutant explained, "Ecosystems have characteristics that are not reflected in the sum of the various organisms. Diversity, redundancy, and inertia are all characteristics of the system as a whole. Diversity, which can be described mathematically as a distribution of the kinds and numbers of various species, will change with stress. Pollution tends to reduce diversity and increase the number of the dominant species. We can see systems in parks, for example, that are dominated by carp, systems that are unbalanced from the standpoint of species diversity. Redundancy is a characteristic of an ecosystem in which the same species are to be found under a wide range of environmental conditions and are able to take over important ecosystem functions (i.e., photosynthesis) as environmental conditions change. Inertia is used in the same sense as in physics. If you take an ecosystem with a whole web of interactions—with many species, things eating things, and a lot of interplay going on—and you perturb that system with some kind of stress, you will find it takes a lot to make that system change. The response of the system is not directly proportional to the amount of pressure put on it. The system will absorb the stress, be it a pollutant or whatever, and then suddenly it will start to move. The threshold is reached, and suddenly you'll be seeing changes in species diversity and so forth."

Ecosystems analysis, Coutant points out, is a field that has drawn heavily from the engineering and mathematical sciences. As he said, "The modelers have done something the ecologists have tried to do for years, and that is to put it all together." One of their more ambitious tasks is to trace the cycling of materials

"There is no such thing as a zero-impact facility. There can't be. So we balance, we trade off. If you look at all the sources, you can come up with the best solution."

and energy throughout the biosphere. Carbon dynamics, for example, are being "perturbed in a long-term way by the clearing of forests and the transfer of carbon from fossil fuels to the atmosphere, with the hope that the ocean will serve as a sink. From a systems standpoint, we need to recycle more carbon through agricultural and forest products or somehow provide more opportunity for the CO_2 to come back out of the atmosphere."

Similar efforts have been made by ecosystem analysts to trace the flow of energy through the biosphere. It has been found that although the initial conversion of sunlight by microorganisms is very inefficient (about 1%), it is thereafter efficiently transferred from organism to organism. This has led Coutant to comment, "I think there is an analogy—which like any analogy breaks down if you take it too far—that ecosystems are really designed to get a bit of energy and hold it in productive fashion as long as possible. The well-functioning ecosystem will have a long food chain, so that the energy goes through a long series of uses before it is dissipated. In the poorly functioning system, energy is brought in, used, and dissipated by one organism. So I like to draw this analogy: Let's do the same thing with our own energy systems.

"It doesn't make much sense to take a batch of energy, whatever the fuel, convert a third of it to electricity, and then simply dissipate the rest. There are a lot of uses for that low-grade heat before it is released to the environment; many things that could be done by stepping that energy down in phases and putting it to productive use."

Extending this thinking, Coutant foresees the time when power plants could be designed to optimize energy production rather than electricity production. "In other words, think of your power system as a system designed to maximize the energy you put in, even if you have to reduce the efficiency in the electricity production. The utility that views itself

"The utility that views itself as an energy supplier and not just an electricity supplier can provide process steam and hot water."

as an energy supplier and not just an electricity supplier can provide process steam and hot water. Hot water can be transferred considerable distances without loss. There are a lot of opportunities we're not using."

Coutant discussed a few of these opportunities for low-grade heat use that are now under development in his field, notably in fish culture and various aspects of agriculture. Fish growth rates, he pointed out, have an optimum temperature, as do those of most plants, and up to that point, even small increases in temperature can provide considerable growth stimulation. He referred to a multipurpose system operating in France that is based on a concept developed at Oak Ridge several years ago. The system takes water from the cooling tower, runs it over a greenhouse, collects it, runs it through pipes underground in open agricultural fields to stimulate crops, and eventually dumps it into fish-culture ponds. Coutant refers to such efforts as examples of productive energy conservation in contrast to reductive energy conservation.

It is perhaps the nature of ecologists to seek an ever more comprehensive framework of knowledge with which to make specific decisions. At least this is certainly true of Coutant, who emphatically states his preference for the breadth and flexibility inherent in the National Environmental Policy Act (NEPA) to the more recent and rigid philosophy of the 1972 Water Pollution Control Act.

Coutant describes NEPA as "probably the most important piece of legislation that this country has passed so far as environmental issues are concerned, because it said officially, for the first time, that agencies had to look at everything. It isn't sufficient to look at the impacts that you think you are going to have with your system. You have to look at alternative systems. The upshot is that you have the flexibility to conclude which is the best way to go for that system, for that site, under those circumstances—acknowledging the fact that you are in Newburg, New York, and not Palo Alto, California."

In contrast, Coutant characterizes the philosophy of the Water Pollution Control Act, "'Thou shalt not pollute,' regardless of your circumstances, your site, your engineering system, or the ecological system to which these materials will be added. The law implies that we can have nationwide standards, restrictions, and permits. It is authoritative in that it purposely disallows analysis of site-specific conditions and the consideration of social and economic factors."

It is this philosophy, Coutant explains, that has led to the notion of closed-cycle cooling as a panacea. Such systems, he points out, require corrosion-inhibiting chemicals, which when flushed out during a periodic blowdown can actually aggravate other pollution problems, notably eutrophication. As a holistic scientist, he views this as merely shifting the pollution to another part of the system.

Coutant displays a certain restlessness about pedantic solutions to pollution control and about the narrow focus inherent in the search for panaceas. "There is no such thing as a zero-impact facility. There can't be. So we balance, we trade off. . . . If you really look at all the sources of potential damage and all the sources of potential benefit from all the alternatives, you can come up with the best solution."

Coutant feels the best solution to power plant siting, from an ecological and legal point of view, is to move away from the estuaries, which are the traditional areas of population density. He explained, "Estuaries are the nurseries and spawning grounds from which most of our fish products are derived. We have seen the decline in oysters, striped bass, blue crabs—all these have had disastrous experiences with man's influence. Now the tendency is to stay out of estuaries, to find open coastal sites, freshwater sites, sites on the Great Lakes, or to go to the rivers and use cooling towers. And it's a good trend. The whole question of power plant siting is in a maturing phase now, both in the power companies and in the regional planning groups. The State of Maryland, for example, has accepted responsibility for finding sites that will be the least damaging to the environment. And we're seeing it in other places too. Of course, it makes me rather proud because that's the kind of thing we were doing back in the Pacific Northwest in 1966."

Over the past two decades, Coutant's career has paralleled the emergence of the scientific method in the field of ecology. He has proved to be an innovator and is proud of having joined the EPRI Advisory Council at its inception. Assessing the influence of the Council, he says, "I'm convinced it's had an important impact, not only on EPRI's programs in the sense of its ongoing work but also on how EPRI was formed to begin with. It was one of the first things set up." Overall, Coutant expressed satisfaction with EPRI's program balance, as well as the current status of its environmental research. "However", he added, "I would like to see more emphasis on waste heat utilization."

Looking back over his years of professional experience, Coutant commented, with a note of amusement, "I'd say one of the best things that ever happened in my career was the fact that we got into some very good, long, knock-down-drag-out fights with some very good engineering people. NEPA was a catalyst that forced us to work together, and the differences were usually language and communication more than anything else. We were working on power plant siting problems, on discharge problems, and on systems that simply could not be considered in the strict realm of animals and plants in which ecologists are used to thinking, or in the realm of nuts and bolts or thermal hydraulics in which the engineers are used to thinking. Conflicts were inevitable, but we learned to communicate. It's a perspective you develop. It's a broadening that I wish many more environmentalists had."

At the Institute

Former Council Members Assume Top Positions in Nation's Capital

Three former EPRI Advisory Council members have assumed government and legal positions in Washington, D.C. All three were state utility commissioners and resigned from the Council when they left their state regulatory positions.

Alfred Kahn, former chairman of New York's Public Service Commission and acknowledged dean of utility regulators, left the Advisory Council in May after he was appointed chairman of the federal Civil Aeronautics Board. Kahn had been an Advisory Council member since 1974.

Peter Bradford, who served as one of Maine's three regulatory utility commissioners and had been a Council member since May 1975, resigned in August after U.S. Senate confirmation of his nomination as a commissioner on the Nuclear Regulatory Commission.

Marvin S. Lieberman, former chairman of the Illinois Commerce Commission, left in September when he joined the law firm of Zuckert, Scoutt, and Rasenberger in Washington, D.C. He had served on the Council since May 1976.

"These three officials provided a great service to EPRI, the electric utility industry, and the general public by representing the regulatory community on the Advisory Council," stated Dr. Robert L. Loftness, Council secretary and director of EPRI's Washington, D.C., office. "By giving us insight into their area of expertise, they have helped to foster electric utility research and development in the best interests of society."

Kahn, Bradford, and Lieberman served on the Advisory Council by virtue of their state regulatory positions. There are seven state regulators on the Council who are nominated by the National Association of Regulatory Utility Commissioners (NARUC) and approved by EPRI's Board of Directors. Current NARUC nominations to replace Kahn, Bradford, and Lieberman are now awaiting Board action.

The EPRI Advisory Council is composed of leaders from all segments of society. It serves as a link between the public and EPRI's Board of Directors, officers, and staff.

Energy Modeling Group Meets

The second EPRI-sponsored Energy Modeling Forum working group met recently at Stanford Institute for Energy Studies to examine the use of computer models for studying the possible rates and limits of U.S. coal utilization to the year 2000. Participants in the working group, "Coal in Transition: 1980–2000," designed questions and scenarios that will be addressed to a set of selected computer models.

Consisting of both energy decision makers and modelers, the working group intends to provide, through example, a clear explanation of the common features or important differences embedded in the models. The ultimate objective of the group is to build communication bridges between energy decision makers and energy modelers.

The group's efforts will help decision makers and modelers better understand the complex interactions between industry and consumers, different regions, time frames, technologies, environmental constraints, and pricing regulations, according to Bill Hogan, executive director of the project.

The first Energy Modeling Forum working group recently completed a computer modeling study of the relationship between energy and economic growth. The Forum project is sponsored by EPRI and administered through the Stanford Institute for Energy Studies.

Soviet Delegation Visits EPRI

John Maulbetsch, manager, EPRI Water Quality Control and Heat Rejection Program, describes his program and EPRI organization and operation to a visiting delegation of Soviet experts on September 21. Standing behind him is Ross Lavroff, an interpreter.

A delegation of Soviet energy experts recently visited EPRI as part of a two-week U.S. tour to exchange information on dry and wet/dry cooling and reject heat utilization. The tour was organized by the U.S.–USSR Joint Coordinating Committee on Scientific and Technical Cooperation in the Field of Thermal Power Plant Heat Rejection Systems.

John Maulbetsch, manager of EPRI's Water Quality Control and Heat Rejection Program and member of the U.S. Steering Committee of the sponsoring organization, said the visit was reciprocal. In February, a group of U.S. scientists toured Soviet power plants and research organizations.

According to Maulbetsch, the Soviet visitors expressed interest in cooperating in research ventures, in exchanging data, and in reciprocal attendance at workshops and symposiums. "They were particularly interested in cooperative research involving the EPRI ammonia phase-change, dry-cooling tower project now under way with Union Carbide Corporation," said Maulbetsch.

During the daylong session on September 21, Ben Johnson of Battelle, Pacific Northwest Laboratories presented a paper on current U.S. research on advanced concepts of dry cooling. Leigh Stamets of the California Energy Resources Conservation and Development Commission described his agency's role in the energy research field in California, particularly as it relates to the electric utility industry.

In addition to Maulbetsch's description of his program and EPRI organization and operation, Robert Kawaratani of EPRI's Environmental Assessment Department gave a presentation.

Pressure Vessel Study Group Meets

Participants in the Pressure Vessel Study Group semiannual meeting are (from left) R. L. Noel, Electricité de France; A. D. Rossin, Commonwealth Edison Co.; R. O'Neil, United Kingdom Atomic Energy Authority (UKAEA); B. J. L. Darlaston, Central Electricity Generating Board (CEGB), Britain; R. Nichols, UKAEA; P. Shewmon, U.S. Advisory Committee on Reactor Safeguards (ACRS); Yoshio Ando, University of Tokyo; and Ed Zebroski, EPRI. Also present at the meeting were Guido Possa, Centro Informazioni Studi Esperienze (CISE), Italy; Marcello Galliani, Ente Nazionale per l'Energia Elettrica (ENEL), Italy; Hermann Kreppel, Gutehoffnungshuette Sterkrade AG, West Germany; D. G. H. Latzko, Delft University, Holland; Michael Wenk, Technischer Überwachungs Vereinigung (TUV), W. Germany; Alf Gerscha, Kernkraftwerk Union (KWU), W. Germany; Dr. -Ing. L. Issler, Materialprüfungsanstalt (MPA), W. Germany; Dr. Walter Marshall, UKAEA.

Members and guests of the Pressure Vessel (PV) Study Group, an EPRI international technical advisory committee, recently held their semiannual meeting to review EPRI programs on PV reliability, inspection, fabrication, and fracture mechanics. The EPRI meeting immediately followed the Fourth International Conference on Structural Mechanics in Reactor Technology (SMIRT) in San Francisco.

Ed Zebroski, director of the EPRI Nuclear Systems and Materials Department, reported that participants reviewed EPRI programs on PV reliability and compared current results of related programs throughout the western world. Participants also reviewed plans and progress on related development programs in Europe and Japan and discussed current regulatory concerns about beltline irradiation of some older PVs with sig-

nificant copper content in the welds. "The most fruitful areas for further effort were discussed and a consensus reached on nondestructive examination and control of fabrication processes," noted Zebroski.

One highlight of the SMIRT conference was a panel, chaired by EPRI Program Manager Karl Stahlkopf, on probabilistic safety assessment. "Panelists agreed that a PV reliability better than one significant release event every million years of vessel operation is a measure of the current reliability level and that work is under way that could move this to one event for every 10 million years of vessel operation," Zebroski stated. Papers by EPRI authors were presented, including those by Terry Oldberg, Karl Stahlkopf, Ted Marston, Richard E. Smith, Adrian Roberts, and Norbert Hoppe, who is on assignment to EPRI from Belgium.

WEST Associates Updated on EPRI

Members of the Western Energy Supply and Transmission (WEST) Associates Engineering and Planning Committee recently met with EPRI staff for an update on EPRI activities. WEST Associates is a planning and research organization composed of 21 privately and publicly owned electric utilities that operate or serve customers in all or part of 11 western states.

Although the committee expressed a wide interest in EPRI's work in general, their particular interests on this visit related to power system stability, air and water quality equipment, and various forms of energy resources.

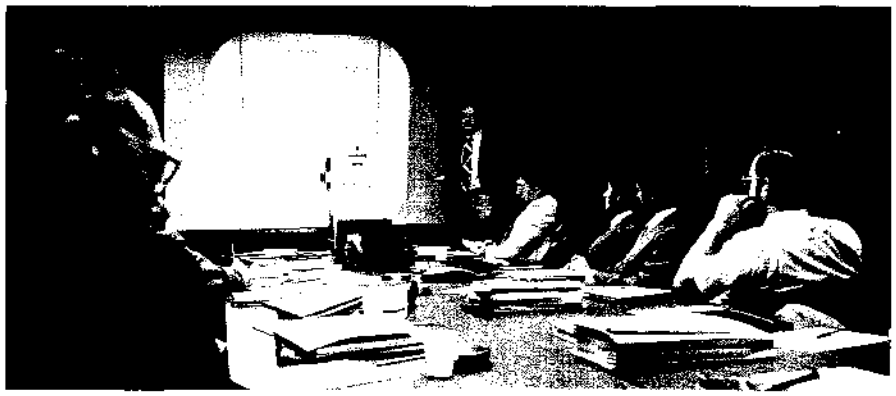
During the all-day session, EPRI staff gave presentations on technical division activities. Richard Zeren, assistant to the division director, Fossil Fuel and Advanced Systems Division, described his division's R&D program. He was assisted by Paul Zygielbaum, project manager, Advanced Fossil Power Systems Department, and Donald Teixeira, manager, Air Quality Control Program. Frank Arrotta, assistant to the division director, Nuclear Power Division, and Larry Minnick, director, Engineering and Operations Department, Nuclear Power Division, gave an overview of the nuclear power activities at EPRI.

Charles Rudasill, manager, Technical Assessment, described his group's work, Charles Frank, project manager, Electrical Systems Division, and Julius Dalzell, assistant to division director, Electrical Systems Division, discussed power system stability.

Members of the Energy Analysis and Environment Division, including James McCarroll, Robert Goldstein, Martin Greenberger, Jerry Karaganis, and Ron Wyzga, discussed the Ecological Effects and Health Effects programs under way in the Environmental Assessment Department.

WEST representatives were Dave Bedford, Public Service Co. of New Mexico; Jack Taylor, Arizona Public Service Co.; Merwin Brown, Arizona Public Service Co.; Harry Bishop, San Diego Gas and Electric Co.; Wayne Schmus, Southern California Edison Co.; and Bob Hugo, Public Service Co. of Colorado. Other representatives included H. Lydick, Tucson Gas and Electric Co.; H. I. Zimmer, El Paso Electric Co.; Steve Chalmers, Salt River Project Agricultural Improvement & Power District; Bill Kersting, New Mexico State University; and Max Jones, Sierra Pacific Power Co.

Richard Zeren, assistant to the division director, Fossil Fuel and Advanced Systems Division, EPRI, describes the division's R&D program to members of the WEST Associates Engineering and Planning Committee during an EPRI visit on September 22.



Project Highlights

EPRI Negotiates 33 Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP365-2	Magnetic Separation of Ash in Coal Liquefaction Processes by MIT	6 months	95.0	Massachusetts Institute of Technology *H. Lebowitz*
RP549-3	Individual Load Center—Solar Heating and Cooling (ILC—SHAC) Residential Project	36 months	1409.0	Arthur D. Little, Inc. *J. Cummings*
RP906-1	Cooling-Tower Plume Model Studies	24 months	241.8	Argonne National Laboratory *J. Maulbetsch*
RP989-1	Gas Turbine Combustor Performance on Coal-Derived Liquids With High Fuel-Bound Nitrogen	9 months	251.6	Westinghouse Electric Corp. *A. Cohn*
RP1040-1	Low-Emission Combustor for 300-Btu Gas From Coal	8 months	199.6	United Technologies Corp. *R. Duncan*
RP1045-2.	Low-Activation Structural Materials for Fusion Reactors	33 months	182.8	Rockwell International *R. Richman N. Amherd*
RP1045-3	Low-Activation Structural Materials for Fusion Reactors	24 months	80.0	Battelie, Pacific Northwest Laboratories *R. Richman N. Amherd*
RP1085-2	Sulfur-Tolerant Components for Molten-Carbonate Fuel Cells	13 months	142.7	Institute of Gas Technology *A. Fickett*
Nuclear Power Division				
RP443-2	Separated Flow Model of Two-Phase Flow	17 months	113.0	Dartmouth College *K. Sun*
RP519-6	Documentation of Operating Data From Light Water Power Reactors for Methods Verification	6 months	20.1	Carnegie-Mellon University *W. Eich*
RP613-4	Benchmark Analysis for Transuranics at 10 Nanocuries Per Gram	4 months	2.1	Laboratory for Electronics *M. Lapides*
RP620-21	Liquid Metal Fast Breeder Reactor Plant Design	7 months	650.0	Bechtel Corp. *L. Minnick*
RP620-24	Proliferation Assessment Methodology Development	12 months	15.0	Stanford University *R. Williams*
RP892-3	Ultrasonic System Optimization Study, Project III, UT Systems Evaluation	29 months	240.0	Battelle-Columbus Laboratories *E. Reinhart*
RP895-3-1	Power Shape Monitoring System	22 months	230.4	Nuclear Associates International Corp. *F. Gelhaus*
RP900-2	HTGR Steam-Cycle Technology	3 months	18.1	NUS Corp. *M. Lapides*
RP961-1	Validation of Real-Time Software Used in Nuclear Plant Safety Systems	15 months	169.1	Babcock & Wilcox Co. *A. Long*
RP962-1	Measurement of Iodine Partition Coefficients in Nuclear Power Plants	12 months	79.9	Science Applications, Inc. *H. Till*
RP964-3	Vibration Tests at Indian Point 1	24 months	120.0	Applied Nucleonics Co., Inc. *C. Chan*
RP965-2	Analysis of LOCA-Induced Fluid Structure Interaction	12 months	30.0	Northwestern University *J. Carey*
RP968-1	Qualification and Implementation of Alternative Piping Alloy for BWR Applications	48 months	2385.6	General Electric Co. *R. Smith*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP971-1	Fuel Rod Mechanical Performance Modeling, Task 1	36 months	709.9	Science Applications Inc. *T. Oldberg*
RP1067-2	Analysis and Testing of Steam-Chugging Pressure Suppression Systems	18 months	298.4	SRI International *J. P. Sursock*
Electrical Systems Division				
RP764-4	Low-Order Dynamic Models for Pressurized Water Reactors	12 months	55.0	University of Tennessee *P. Anderson*
RP997-4	Determination of Synchronous Machine Stability Study Models	13 months	125.2	Westinghouse Electric Corp. *D. Bewley*
RP1046-1	DC Field Strength Instrumentation	18 months	287.7	Westinghouse Electric Corp. *L. Svensson*
RP1047-1	Power System Data Management Requirements	42 months	534.1	Computer Science Corp. *C. Frank*
RP1048-5	Pool Daily Fuel Dispatching	24 months	158.0	Power Technologies Inc. *C. Frank*
RP7859-1	Maximum Design Voltage of Oil/ Cellulose Paper	27 months	568.9	BICC Power Cables Ltd. *F. Garcia*
RP7863-1	Investigation of Particle Trapping and Voltage Breakdown in Compressed-Gas-Insulated Systems With Impulses Superimposed on 60-Hz Voltages (6M620)	12 months	42.0	Westinghouse Electric Corp. *R. Samm*
Energy Analysis and Environment Division				
RP950-1	Electricity Supply Models	15 months	499.9	Gordian Associates Inc. *J. Chamberlin*
RP1108-1	Application of Integrated Systems Planning to Studies	10 months	90.7	Decision Focus, Inc. *S. Peck*
RP1109-1	Effect of Acid Precipitation on Microorganisms and Biochemical Activities of the Soil	24 months	118.8	Cornell University *R. Kawaratani*

Agreement Signed for Coal Liquefaction Project

An agreement has been signed by EPRI and Exxon Research and Engineering Co. to continue research aimed at producing liquid fuels from coal by the Exxon Donor Solvent (EDS) process. Total cost of the research program will be $240 million, one-half of which is to be paid by ERDA and $40 million has been budgeted by EPRI.

"This level of funding should ensure that electric utility requirements for gas turbine and boiler fuels are a major objective of the program and that special assistance will be provided by Exxon to the electric utility industry in commercialization of the procedure," said Dwain Spencer, director of the EPRI Advanced Fossil Power Systems Department.

The research program, managed by Exxon, involves both small-scale research and development work and the design, construction, and operation of a pilot plant capable of processing 250 tons of coal a day. The pilot plant, scheduled to be in operation by 1980, will be built adjacent to an Exxon refinery in Baytown, Texas.

Successful completion of the program will help bring coal liquefaction to commercial readiness by demonstrating the process with equipment that can be scaled up to commercial size, EPRI officials believe. Appreciable amounts of coal-derived liquid fuels, however, will not be on the market until the 1990s, with the first commercial-size plants in operation by the late 1980s.

The EDS process produces low-sulfur fuel that can be used by utilities in both boilers and turbines. An advantage of coal-derived liquid fuels is that they can meet current and future environmental requirements. Liquid fuels are compatible with present utility equipment and refining and transport systems. They can be stored for use during peak and intermittent electricity-generating periods, which saves expensive installation of stack gas pollution control equipment.

The new EPRI–Exxon agreement extends through December 1982. EPRI officials believe that the EDS process has excellent potential for successful development because many of its features are based on technology that has been proved in the petroleum refineries.

Fluidized-Bed Development Facility Dedicated

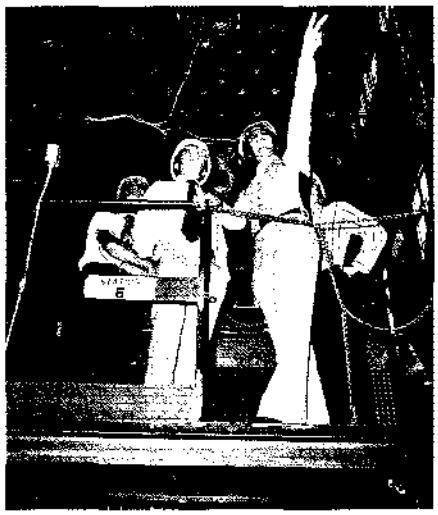
Fifty research engineers and electric utility executives from the EPRI Fossil Fuel Power Plant Task Force convened at the Babcock & Wilcox research center on August 30 for the dedication of a coal-fired, fluidized-bed combustion (FBC) development facility. The facility is designed to burn coal in an environmentally acceptable manner.

Development of FBC is one of EPRI's major efforts toward reducing dependence on natural gas and oil for electric power generation. The new unit that was dedicated, which is 1.8 m × 1.8 m (6 ft × 6 ft), will be used to develop the necessary data for designing the much larger commercial demonstration units now being planned.

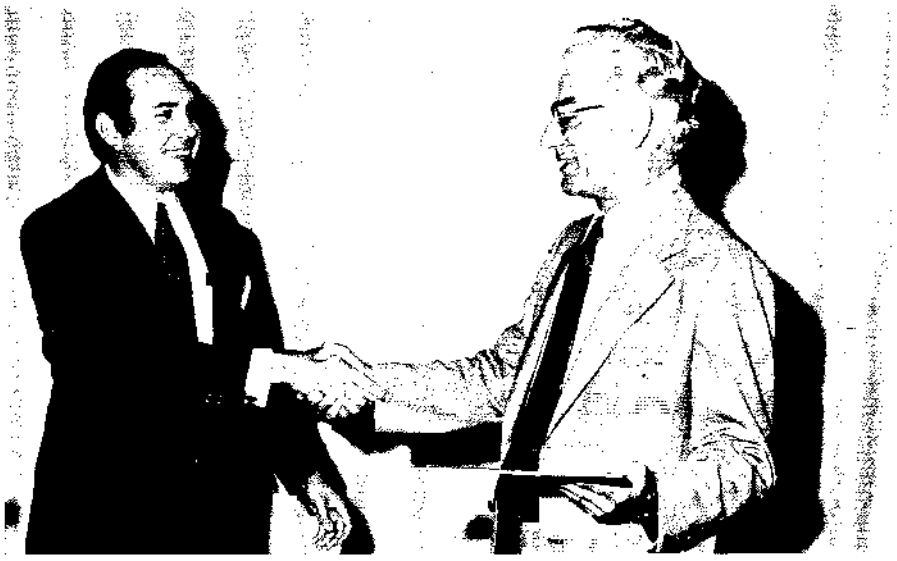
The initial research efforts will be geared to answering questions on combustion efficiency, heat transfer, and air pollution control. Control of NO_x and SO_x is inherent in the FBC process. Crushed coal is burned in a bed of fluidized limestone that contains the boiler tubes. Limestone reacts directly with sulfur oxides to form a dry, granular residue or bottom ash. The boiler tubes in the fluidized bed prevent the combustion temperature from exceeding 826°C (1550°F), thus greatly reducing the formation of NO_x.

According to EPRI officials, the FBC development unit was needed to confirm data obtained in much smaller units being operated worldwide. Heat transfer data are obtained by using boiling water, pressurized water, and steam-cooled tubes in the fluidized bed. Babcock & Wilcox plans to heat its Alliance, Ohio, research center with steam generated from the developmental FBC unit. According to Kurt Yeager, director of the EPRI Fossil Fuel Power Plants Department, this will not only save the State of Ohio some natural gas but will also save EPRI the expense of adding a cooling tower.

"By burning high-sulfur Appalachian coals, a fluidized-bed boiler could provide an alternative to existing pollution control systems," said Yeager. "It may also eliminate the need to import low-sulfur coals into Ohio and other regions that have plentiful reserves of high-sulfur coal."



Using an elevator for closer inspection, members of EPRI's Fossil Fuel Power Plants Task Force listen to a description of the coal and limestone feed systems for EPRI's fluidized-bed development facility. The elevator will be used for gas and solid sampling in the unit's 5.5-m (18-ft) freeboard when the five-story test facility becomes operational later this year.



George Musat, director, Babcock & Wilcox research center, Alliance, Ohio, accepts the dedication plaque for the fluidized-bed development facility from Kurt Yeager, director, EPRI Fossil Fuel Power Plants Department.

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

CLEAN GASEOUS FUELS

GCC system control

Gasification–combined-cycle (GCC) power systems have been identified as an attractive option for converting coal to electricity in an environmentally acceptable manner. Generically, GCC plants must include three major subsystems: the gasification section, the gas-cleaning module, and the combined-cycle power system. Each of these subsystems (e.g., Lurgi gasifiers for syngas production, liquid absorption systems for H_2S and CO_2 removal from natural gas, and combined cycles for utility power generation) has been operated at commercial scale for many years. However, there is no experience to indicate that these components can be integrated into a system for producing electric power in a reliable, controllable, and economical manner. All the commercial experience on the fuel-processing elements of the GCC plant (gasification and gas-cleaning subsystems) has been obtained under steady-state operating conditions.

If GCC plants are to become a major source of utility generation in the near future, their ability to meet the requirements for power maneuvering on electric utility systems must be investigated (Figure 1). Until recently, little attention was given to developing control strategies for GCC plants so that the response capabilities required in a power system could be achieved within the equipment operating constraints for each subsystem of the GCC plant. As the commercial viability of this form of generation depends to a large extent on system control capabilities, EPRI has launched a program to investigate the response and control characteristics of GCC power plants. The elements of this program are shown in Figure 2.

A two-pronged approach is being taken. Experimental facilities will be constructed and operated to acquire data on the dynamic response characteristics of the various subsystems of an integrated GCC plant. These experimental efforts will be backed up by a number of study projects that will be used to direct the experimental program and analyze the data obtained from the test facilities.

The largest of the experimental projects currently planned is the gasification–combined-cycle test facility (GCCTF) proposed for construction at Commonwealth Edison Co.'s Powerton Station in Illinois (RP138). This 25-MW test facility represents a first-of-a-kind effort to integrate a fixed-bed gasifier with a hot potassium carbonate H_2S removal system and General Electric Co.'s Frame-5 gas turbine with waste heat boiler. One of the major objectives of the GCCTF is to determine the response and

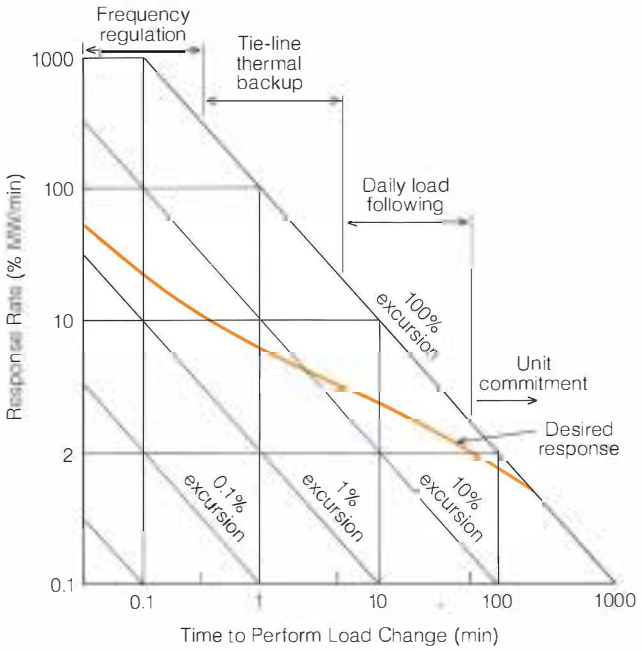
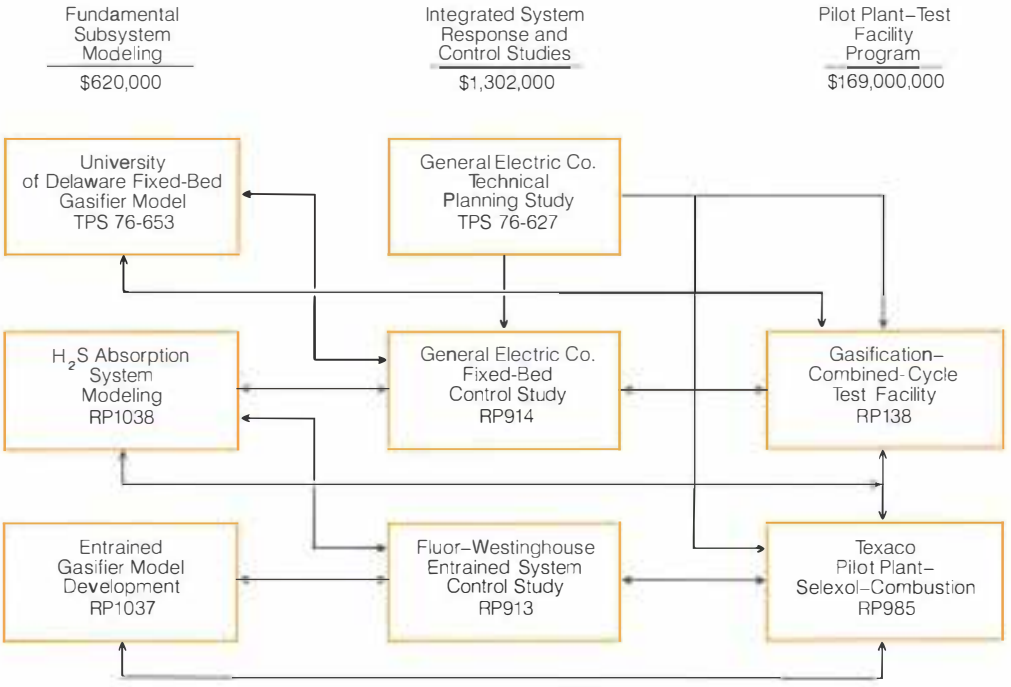


Figure 1 Different power system maneuvers pose different requirements for generator response on this representative large interconnected system. EPRI studies of GCC unit designs will determine in which region of the overall desired response curve they will be able to operate.

Figure 2 Evaluation of power-maneuvering capabilities of GCC plants entails many research studies and projects organized in three concurrent phases under EPRI sponsorship. Administrative coordination and information exchange link many of the activities.



control capabilities of integrated GCC plants. The three-year test program is planned to commence in 1980.

Early in 1976, EPRI funded a technical planning study with General Electric in an attempt to identify the most promising control strategies for GCC plants in general and the GCCTF in particular (TPS 76-627). The results of the study (which was based on a simplified model of the fuel processing facilities) indicated that control strategies could be devised for GCC plants so that they could respond rapidly in a utility environment. This conclusion is extremely encouraging but must be treated with caution. The simplified model of the fuel processing plant did not include any equipment operating limitations; that is, it was assumed that both the gasification and the gas-cleaning subsystems could tolerate any rate of flow or pressure change required to satisfy the fuel demand of the gas turbine under dynamic load conditions.

Therefore, General Electric's fixed-bed GCC control study was extended to include the detailed response characteristics and operating limitations of the fuel processing plant (RP914). This detailed control study was initiated in January 1977 and will be concluded in December 1978. Its scope includes not only the dry-ash, fixed-bed, Lurgi gasifier but also the slagging-bottom, fixed-bed, BGC-type gasifier. The simulation model generated for this control study will be used initially for suggesting control strategies and response characteristics that could be investigated at Powerton. The model also will be used to analyze and interpret data from the test facility.

The weakest link in the ability to represent the transient operating characteristics of a GCC plant has been the lack of steady-state and dynamic gasifier simulation models. A project was therefore initiated in October 1976 with the University of Delaware to develop a steady-state model of a Lurgi gasifier that could be extended to include major dynamic effects (TPS 76-653). Such a model will provide a major input to General Electric's fixed-bed system control study and could also provide a tool for evaluating gasifier operating data from the GCCTF.

All the above studies and the GCCTF are based on the only commercial pressurized-coal gasifier, the fixed-bed, Lurgi type. Recent economic studies conducted for EPRI by Fluor Engineers and Constructors, Inc., and Stone & Webster Engineering Corp. have shown that the cost of electricity from a GCC based on advanced gasifiers may be substantially below that projected for GCC systems with fixed-bed gasifiers.

Entrained-bed GCC systems

A thorough investigation of the state of development of advanced gasification devices has indicated that the single-stage, entrained Texaco coal gasifier will probably be among the first advanced gasifiers to be operated at commercial scale. More than 140 Texaco gasifiers are currently fired with either natural gas or liquid fuels. Coal-firing capability has been developed by Texaco, Inc., at its Montebello, California, research facility on a scale of 15 t/d over the past three years. A Texaco unit capable of gasifying 160 t/d of coal is under construction in West Germany and will be operating in 1978. This advanced state of development, coupled with mechanical simplicity and extreme fuel flexibility, renders the Texaco gasifier a leading candidate for utility power generation. Therefore, a program to investigate the response and control character-

istics of entrained-bed GCC power plants is also being developed (RP913).

Starting in late 1977, an experimental program utilizing the existing 15-t/d coal gasifier will be conducted at the Texaco Montebello pilot facility (RP985). Plans are under way to convert the gas-cleaning modules at Montebello to Allied Chemical Corp.'s Selexol system, identified by our engineering studies as a preferred gas-cleaning technology.

One of the major objectives of the Montebello test program will be to determine the dynamic response of both the Texaco gasifier and the Selexol H_2S absorption system. Other objectives include testing the combustion characteristics of the fuel gas in a full-scale gas turbine combustor modified for low NO_x emissions and investigating the particulate removal capabilities of the gas-cleaning equipment.

The experimental program at Montebello will be paralleled by an entrained GCC plant control study conducted by a team composed of Fluor Engineers and Constructors, Inc., and Westinghouse Electric Corp. (RP-913). On the surface, it might appear that the entrained GCC plant control study duplicates the fixed-bed GCC plant control study, but they are both required because of the different characteristics of fixed-bed and entrained gasification devices. The Texaco gasification scheme generates large quantities of high-pressure, saturated steam in the gas-cooling section, which must be exported to the steam section of the combined cycle. A Lurgi gasifier consumes steam, requiring a different integration and control strategy than would be employed in a Texaco GCC plant. Further, an entrained gasifier is more sensitive to changes in the oxidant feed rate than a fixed-bed gasifier due to the lower inventory of carbon in the vessel. Therefore, control strategies found satisfactory for fixed-bed gasification systems might be inadequate for entrained GCC power plants.

The entrained system control study, to have been initiated in October 1977, will be supported by the development of a detailed dynamic simulation model of an entrained gasifier (RP1037). A contractor for this model development project will be selected shortly.

All previous consideration of the integration and control aspects of GCC power plants has concentrated primarily on the characteristics of either the gasifier or the combined-cycle equipment. Very little attention has been given to the operability of the ammonia or H_2S absorption systems under dynamic operating conditions. This lack of concern probably is based on the fact that large-scale absorption systems have been operated for many years in oil refineries and chemical plants. However, these commercial absorption systems operate under steady-state conditions; the operability of such systems under dynamic conditions is a subject that even the process developers are not able to discuss.

An understanding of the mechanisms by which mass transfer is achieved in gas-liquid absorption systems indicates that there should be well-defined operational limitations beyond which the equipment ceases to perform the required duty. Control schemes must be devised to prevent hydraulic problems, such as tower flooding, unirrigated packing, gas and liquid channeling, and liquid carryover by entrainment. Any one of these undesirable conditions will result in a serious degradation of system performance that could ultimately lead to a total system shutdown. A second area of concern—particularly for a physical absorption system such as Selexol—is the effect of changing pressure on the absorber. A pressure reduction in the absorber would result in a rapid desorption of gases from the liquid in the tower. This would not only impair the ability of the system to continue absorbing H_2S from the incoming fuel gas but would also allow H_2S-rich gas to reach the turbine combustor, resulting in the formation of SO_2.

For these and other reasons, an understanding of the operating limitations of liquid absorption systems is critically important in order to develop intelligent control strategies for GCC plants. To this end, a separate project is to be initiated in November 1977 to develop detailed dynamic models of both the Selexol and the Benfield hot potassium carbonate absorption systems and of an ammonia absorber (RP1038). Information from these detailed models will be used to verify the response characteristics predicted by the simpler models developed by General Electric and Fluor-Westinghouse for the control system studies. Also, data generated at Texaco's Montebello pilot plant on the response characteristics of the Selexol system will be fed back to modify the detailed simulation models.

The simultaneous development of analytic simulation models and pilot plant data represents an efficient and cost-effective approach to system development. Model development is an inexpensive technique for learning how a given system will respond to a wide variety of conditions. Changes that can be made to a system computer model in a matter of days could take months to effect in a pilot plant. A poorly planned test facility trial could result not only in the failure of a particular experiment but also in damage to an expensive piece of hardware. In many instances, such disasters can be averted by first checking an anticipated trial on the simulation model. Finally, a good simulation model is invaluable at the conclusion of a test facility or pilot plant project for scale-up to larger plants and for operator-training purposes.

It is important to realize, however, that both the modeling and the experimental parts of this program are strongly linked—each part being essential to successful development of the other. Test facility data are necessary to validate and improve the predictive capabilities of simulation models that, in turn, are invaluable for planning, understanding, and extrapolating the data. *Project Manager: Michael J. Gluckman*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

TRANSURANIC CONTENT OF LIQUID REACTOR WASTE

About two years ago EPRI began a study with Scientific Applications, Inc., to determine the transuranic element content of the liquid and solid wastes from operating power reactors (RP613). At that time virtually no data were available on the subject, but it was anticipated that the levels of transuranic elements would become the focus of regulatory attention as part of the continuing deliberations on disposal of radioactive waste.

At the present time, a reasonably comprehensive data base has been acquired for both PWR and BWR units, including some with fuel defects in their operating histories. These data, together with the results of round-robin verification testing, are to be published shortly as an interim project report.

Data accumulated to date suggest that operating reactors do not have a substantial transuranic content. If the regulatory specification is set at a level of hundreds of nanocuries, it is possible that the results of this project may serve as adequate evidence of generic acceptability. However, if the specification is set at a lower level, some form of certifying measurement may be required.

Alpha monitoring of waste streams is extremely difficult and expensive. Therefore a present objective is to correlate the observed transuranic behavior with that of other isotopes that can be detected more readily by normally available plant instrumentation. It is believed that this indirect measurement will serve for all but the lowest levels of possible specifications.

Work in progress includes further refinement of indirect measurement, extension of plant measurements, and further examination of the transport of transuranics within operating units. The transport studies aim at refining our understanding of the relationships between observed measurements, measurement locations (i.e., type of waste), and operating history. Factors such as water chemistry, in-plant holdup, and radwaste processing system configuration have some bearing on experimental observations.

Several organizations are currently undertaking evaluations of appropriate levels of transuranic content acceptability.

The only published report containing current data on this subject is that by the Utilities Waste Management Group (*1*). This report, published earlier this year, concluded that values of 400 nCi/g for any transuranic element should be acceptable. This view is in marked contrast to the historically held perception favoring a value of no more than 10 nCi/g. It is to be expected that a regulatory assessment of the acceptable values will be established within a year.

A project review meeting was held in June this year by EPRI personnel and representatives of six reactor-operating utilities. At the meeting, data acquired to date were reviewed, analyses of data discussed, and future direction of the project considered. *Project Manager: Melvin Lapides*

Reference

1. *Suggested Quantity and Concentration Limits to be Applied to Key Isotopes in Shallow Land Burial.* Rockville, Maryland: Utilities Waste Management Group, Working Group No. 2, 1977.

IODINE BEHAVIOR IN POWER PLANTS AND THE ENVIRONMENT

Iodine-131 is considered one of the important radionuclides that contribute to radiological exposure from gaseous effluents released in operating nuclear power plants. Its reduction to the guideline levels established in 10CFR50, Appendix I, is a significant design objective in the licensing and operation of such plants. This appendix sets a requirement that radioactive material in effluents released to unrestricted areas from nuclear power plants must be kept "as low as reasonably achievable." The foundation on which this guideline rests assumes that the most realistic models based on the best available data will be applied.

To provide the detailed information to support this approach, EPRI has undertaken studies to determine the most prominent locations in plants where radioactive iodine is likely to emanate; the behavior of the radioiodine in plant effluent streams; the long-term effectiveness of large charcoal filters for adsorbing the radioiodine; and the persistence in the environment of the chemical forms of radioiodine following release.

To address these concerns, the following studies are currently being conducted by EPRI: partitioning of the iodine from the aqueous to the gaseous phase from fuel storage pools under actual operating conditions; evaluation of a radiological dose model based on measurements; cost-effective control of iodine; stability of the inorganic chemical forms of iodine; and atmospheric diffusion as it applies to radiological doses under normal operating conditions and to the control room doses under accident conditions.

Radioactive iodine in gaseous effluents is directly related to its concentration in the reactor coolant water. It enters the coolant as a result of microscopic defects in the fuel cladding and from trace quantities of "tramp" uranium on the outer cladding surfaces. Most of the iodine is removed continuously by passing the coolant through cleanup systems.

There are two types of releases: the unplanned and those that (although undesirable) are to be expected in present plants. The latter sources of gaseous releases from BWRs are:

- Off-gases from the condensing steam in the turbine condenser. This gaseous waste is treated principally by a delay technique that permits radioactive decay. New plants will have augmented waste gas treatment systems that will virtually eliminate this

source; operating plants will be back-fitted to incorporate these systems.

- In some older plants, steam extracted from the main steam line to the turbine is used for the turbine gland sealing system. Fission and activation gases that are not condensed are held up for a time to permit decay of the shorter-lived products, then discharged. In newer plants, auxiliary steam that does not contain radioactive materials is used.

- To maintain the vacuum on the main condenser during plant shutdown (and in some cases during startup), a mechanical vacuum pump is used, the exhaust from which is usually not treated. This usually becomes the principal source of radioactive discharge during shutdown.

In PWRs, radioactive gases removed from the primary coolant are normally collected in pressurized storage tanks to allow for decay of radioactivity prior to recycle or release to the environment. Alternative methods include charcoal filters and cryogenic distillation.

The unplanned radioactive iodine that appears in the building ventilation usually comes from leakage of primary coolant from valves and pumps. In some cases these leaks can be reduced by special design features, use of auxiliary steam, or increased maintenance. As the leaked water evaporates, the contained radioactive iodine becomes airborne. Its quantity usually depends on the location of the leak.

Table 1
NORMALIZED ANNUAL RELEASE FROM MAJOR RELEASE POINTS AND ASSOCIATED CHEMICAL FORM OF IODINE-131 IN BWRs

	Release (Ci)	*Iodine Chemical Form (%)*			
		I_2	*Particulate*	*Inorganic*	*Organic*
Reactor building					
Power operation	0.04	25	20	15	40
Shutdown	0.008	20	5	25	50
Turbine building					
Power operation	0.15	50	20	15	15
Shutdown	0.05	27	7	41	25
Radwaste building					
Power operation	0.03	15	5	10	70
Shutdown	0.004	1	5	9	85
Gland seal exhaust					
Power operation	0.03	5	10	10	75
Mechanical vacuum pump					
Shutdown	0.03	3	1	8	88
Total	0.34				

Note: Releases were adjusted to a coolant concentration of 0.005 μCi/g reactor coolant. Corresponding data for PWRs will be available shortly.

In-plant studies

The in-plant studies consisted of continuous measurements over about one year at locations representing major release pathways in each of six operating nuclear power plants and measurements on specific components contributing to these pathways for periods ranging from weeks to months. The measurements were performed both during plant operation and during refueling outages.

The in-plant studies for BWRs indicated that radioactive iodine is released principally from the turbine and reactor buildings. Reactor water cleanup pumps, inadequately ventilated sample sinks, and valves on steam extraction lines in the condenser area were the major components where leaks occurred within these buildings. During refueling and maintenance outages, the mechanical vacuum pump maintaining the vacuum on the main condenser and the fuel transfer and storage pools became the major sources.

The components in PWRs that caused major releases were charging pumps and purification demineralizer cells.

During transport of the iodine with the plant ventilation air, an aging of the iodine was observed in terms of its chemical form and isotopic ratios; this was in proportion to the distance traveled from the reactor core. The chemical forms change from the more reactive elemental form prevalent in the vicinity of leaks to the less reactive organic form, which is more prevalent in releases from systems and in locations remote from physical leaks.

Two models were developed: one to help generalize the data for predictive purposes, another for describing the behavior of the radioactive iodine within the plant buildings. In the first case, ratios of release rates at specific sources were developed for the iodine concentrations in the reactor coolant to establish a normalization factor. In the second case, iodine concentrations at building release points were related to leaks from internal components. Developing normalized release rates removes the influence of the fuel on iodine concentration, thus generalizing the results.

Release rates for BWRs are shown in Table 1. These rates are based on the normalized approach and adjusted to the coolant concentration applied by NRC in the licensing process and to the chemical forms of iodine as a function of major release points. The second model is intended to predict the release rate from a building and is based on factors operating within the building, such as leak rates, air change rates, and deposition and resuspension from local surfaces.

Sampling durations were usually for periods of one or two weeks. In addition, short-

term samples of one day or less were taken during special field trips in which a motor van equipped with analysis equipment was used. These samples were taken to collect such information as iodine emission on shutdown in PWRs, high-resolution analysis of individual leaks, and line loss tests. Figure 1 is an illustration of the time rate of iodine emission in the coolant concentration.

The majority of measurements were made with the iodine species sampler that segregates both chemical and physical forms of iodine. The form of the iodine is an important factor in a realistic radiological dose assessment. For ingestion dose evaluation, which involves the critical pathway, elemental iodine (I_2) is the important form; the others are relatively insignificant. Organic forms of iodine contribute mostly to the inhalation dose.

The form of the iodine is important for the degree of deposition on grass. The affinity of grass for the elemental form is much greater than for organic forms and particulate forms. There is as yet insufficient information on the deposition of the inorganic.

Efficiency of filters

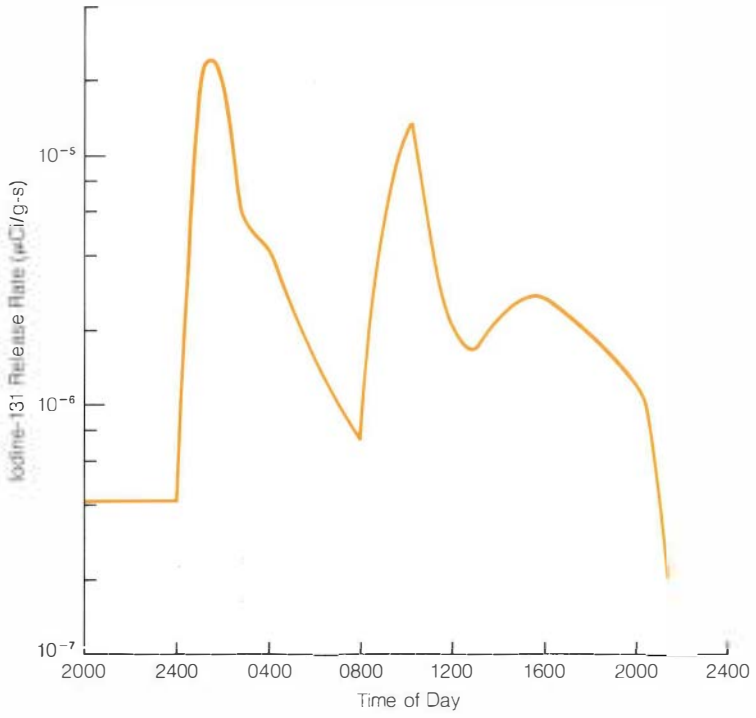
One method of reducing releases of radioactive iodine to the atmosphere from operating nuclear power plants is to filter ventilation exhaust through charcoal. The study conducted by EPRI measured the effectiveness of large charcoal filter installations in continuous use over long periods of time. This study provides information useful for estimating the aging of charcoal filters, which is necessary for predicting the approximate frequency for filter changes and operating costs. Figure 2 shows the combined performance of two charcoal filters for organic iodine collection. The results for I_2 and hypoiodous acid indicated much larger collection effectiveness, with decontamination factors ranging from 100 for new filters to about 20 for filters three years old.

Environmental study

An environmental study was conducted to determine the persistence of the chemical form of radioactive iodine subsequent to release from nuclear power plants. The chemical form in discharge streams was monitored continuously at two plants and simultaneously monitored at up to eight surrounding locations at distances of 1–10 km.

The chemical form of the naturally stable iodine was measured simultaneously. Table 2 shows fractions of the chemical form compared for the source and field sites. The environmental study indicated that the or-

Figure 1 Curve shows the time rate of iodine emission in the reactor coolant concentration, reflecting releases of iodine-131 into the primary coolant.



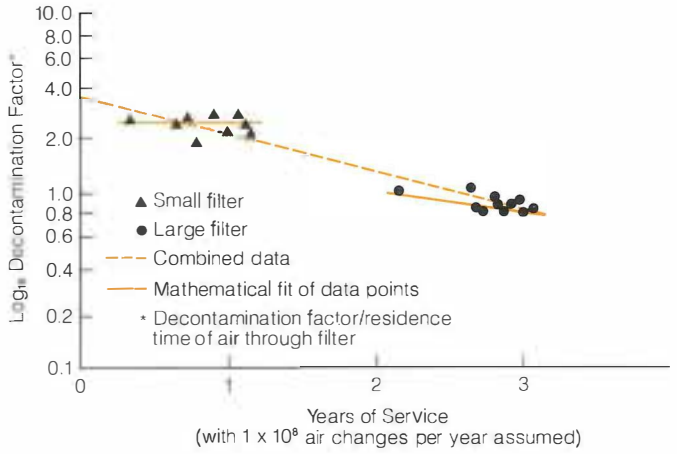


Figure 2 The performance of two charcoal filters, one large and one small, in operation at the same plant.

Table 2
IODINE-131 CHEMICAL FORM
(% measured)

Chemical Form	*Discharge Point*	*Field Locations*
Particulate	5	13
Elemental (I_2)	24	35
Inorganic (HOI)	26	
Organic (CH_3I)	45	52

ganic form tends to have the greatest persistence in the environment, and I_2 tends to have the least. A comparison indicated that the predicted results grossly overestimated the measured values.

Future directions

As a result of these EPRI studies, much more is known about the behavior of iodine in power plants and in the environment. Improved methods of generalizing and modeling the data for application to estimates of future releases were developed. The studies discussed above have provided the following conclusions on the behavior of radioactive iodine in and around nuclear power plants:

- The majority of the iodine emanating from the plants is from one or two major locations and appears locally treatable in a cost-effective manner without requiring large banks of charcoal filters.
- The interaction of iodine with surfaces is an important phenomenon in determining the fate of iodine. It appears to contribute to the shift in chemical forms from the more reactive to the less reactive.
- The organic forms tend to persist in the environment and the elemental forms do not.
- The shutdown transient in PWRs produces nominal iodine emission in the reactor coolant.
- Normalized release rates provide a more realistic method for predicting future releases.

Related projects under contract or under consideration at EPRI are to develop cost-effective ways of controlling iodine; to study the partition coefficient for iodine from fuel storage pools as a function of pool water conditions; to verify radiological dose models for radioactive iodine; to study the atmospheric dispersion of effluents from power plants; and to develop information similar to that developed in the work described above for important radioactive nuclides other than iodine. *Project Manager: Henry Till*

FAULT GROWTH AND CRACK ARREST ANALYSIS

All man-made structures contain defects of one sort or another. The defects may be cracks, lack of fusion in welds, embrittled regions, missing fasteners, and so on. Every practical effort should be made to remove those defects that may affect the design performance of the structure, which may be based on reliability, safety, efficiency, maintainability, and the like, depending on its use. In the case of nuclear pressure vessels, safety is of primary concern.

During fabrication, every effort is made to remove all injurious defects before the component is placed in service. Occasionally, a small defect may escape detection during the fabrication inspections. There is also a possibility that a small crack may develop during service. For these reasons, periodic in-service inspections of the safety-related components are required for nuclear installations. If a flaw is detected during one of these inspections, its effect on the safety of the component must be assessed.

The flaw evaluation procedure for nuclear pressure vessels is presented in Section XI of the ASME code, "Rules for Inservice Inspection of Nuclear Power Plant Components." For the flaw to be deemed innocuous to the performance and integrity of the pressure vessel, it must meet two sets of stringent criteria, one for normal operating conditions and one for faulted conditions.

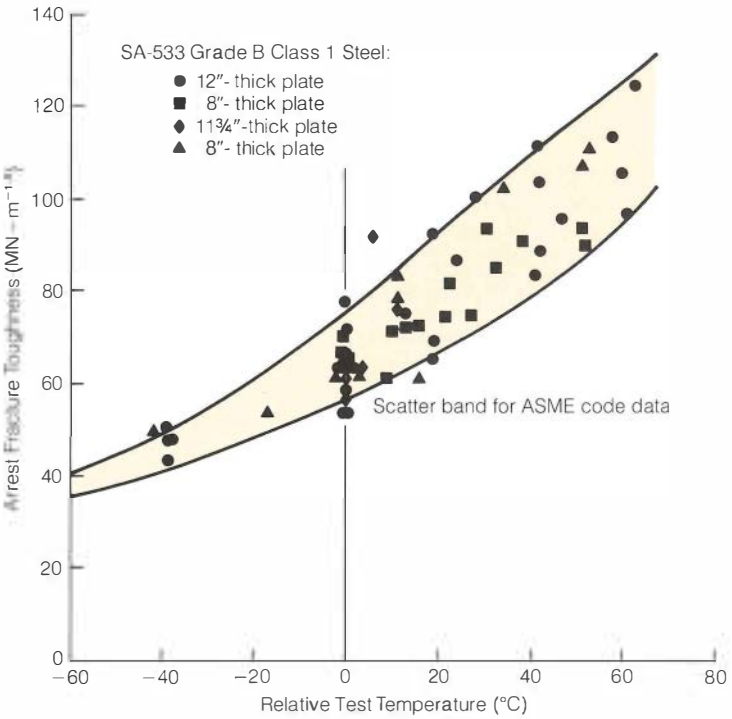


Figure 3 Crack arrest data based on extensive testing by Materials Research Laboratory in support of the prior code corroborates the reference curve in the code.

The criterion for normal operating conditions requires that potential flaw growth due to design transients be accounted for, as well as any irradiation damage. To be acceptable, the maximum size of the discovered flaw, including growth, must be less than one-tenth the size of the critical flaw. The critical flaw is the smallest flaw predicted to cause failure of the component during the design transients. This ensures that the discovered flaw cannot grow during normal operation.

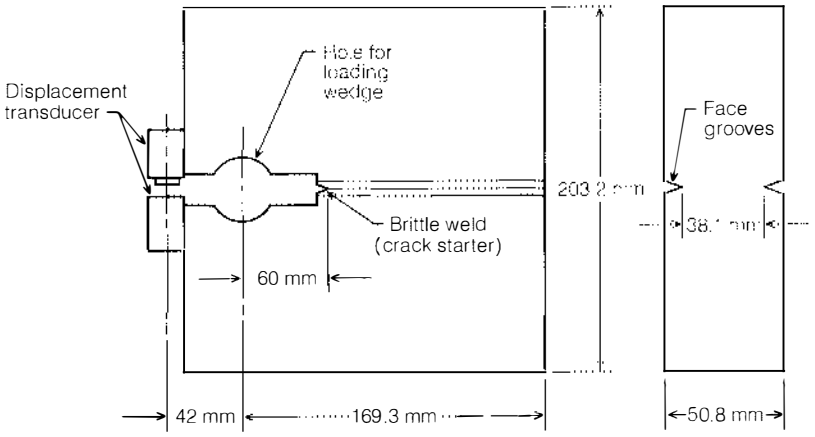
The criterion for faulted conditions is based on the requirement that the core must be in a coolable condition after the most severe postulated accident. For this to be accomplished, the vessel cannot be breached by the flaw as a result of the accident loadings. To be acceptable, the discovered flaw (with growth) must be less than one-half the critical flaw size. In the faulted case, the critical flaw is one that can initiate but can propagate through only 75% of the reactor wall. A verified criterion for the arrest of a propagating crack is necessary for this to be demonstrated.

The criterion for crack arrest is the central theme of the research being conducted by the Materials Research Laboratory (MRL) under contract with EPRI (RP303). In 1974, the conservatism and even the meaningfulness of the arrest criterion incorporated in the ASME code was questioned by the technical community. The arrest concept in the code is based on the premise that crack arrest is analogous to crack initiation in that both are governed by material properties. In the case of arrest, it is crack arrest toughness, K_{Ia}. Therefore crack arrest occurs whenever the stress intensity of a propagating crack falls below K_{Ia}. This crack arrest methodology is very attractive from an applications point of view because only a static linear elastic fracture mechanics analysis is required. Other arrest theories are based on balance-of-energy criteria and require sophisticated dynamic analyses of the structure. Because of the great importance of crack arrest and its safety ramifications, NRC joined with EPRI in a program to resolve the crack arrest issue, develop a significant data base of crack arrest information, and produce test methods for future ASTM standardization.

Significant achievements to date as a result of the program include:

▫ Resolution of the crack arrest issue has been achieved. Formal concurrence on the applicability of the material property crack

Figure 4 Schematic of a compact specimen used for crack arrest toughness determinations.



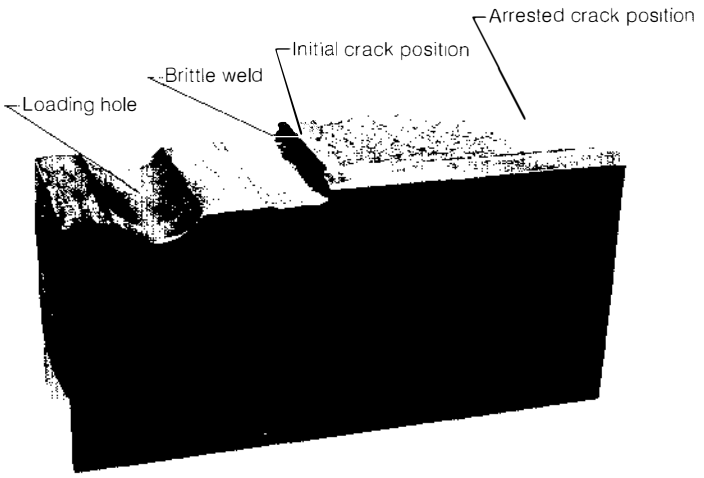


Figure 5 Photograph of a tested compact specimen shows the initial and the arrested crack position (indicated by color changes).

arrest toughness, $K_{ID_{min}}$, to the analysis of propagating cracks in engineering structures was reached at the International Symposium on Fast Fracture and Crack Arrest (Chicago, June 1976) and subsequently in London (July 1976) at a similar meeting.

- Extensive crack arrest testing by MRL on several heats of steel removed from actual reactor vessels corroborates the base data vessel for the reference crack arrest curve contained in the ASME code. These data are shown in Figure 3 with the scatter band for the code data. Similar K_{Ia} data have been generated with four different specimen geometries inferring the existence of a material property that controls the arrest of propagating cracks.

- Tentative crack arrest test procedures have been submitted to ASTM for standardization. This is a necessary step for inclusion in the federal regulations on nuclear plant licensing and operation.

- MRL has recently developed a test procedure for measuring crack arrest toughness with a considerable saving of material and manpower over previous methods. This specimen procedure is of particular interest for assessing arrest toughness of irradiated materials that must be tested in hot cells. The specimen is shown schematically in Figure 4 and a tested specimen is shown in Figure 5. The run-arrest sequence of the fracture surface has been oxidized and appears as the dark portion of the fracture surface.

- A cooperative test program is being organized to evaluate the proposed test methods in terms of reproducibility, variability, and facility. Fifteen laboratories in the United States, Germany, Japan, England, France, and Sweden will provide the testing and analysis gratis; the specimens and test fixtures are to be furnished by EPRI and NRC.

Future efforts

The present code procedures for evaluating flaws under accident conditions where crack arrest must be demonstrated appear to be adequate and conservative. The effects of irradiation on crack arrest toughness need to be evaluated, as do baseline and irradiated data on some of the older (pre-1970) plant materials. The development work scheduled for the fourth quarter of 1977 should establish a test specimen size and procedure suitable for irradiation testing. *Project Manager: Theodore Marston*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

URANIUM SOLUTION MINING

Conventional uranium production requires the mining, hauling, crushing, and milling of 500–1000 t of ore for every ton of uranium. Many subeconomic deposits are known but for economic reasons will probably never be tapped by conventional techniques. Some deposits may require moving 3000–4000 t of ore for every ton of uranium produced. Other deposits are too small to justify a large, fixed investment in mine shaft and surface processing (milling) facilities. Still other small, isolated deposits are uneconomic because their development would require hauling many tons of ore long distances to mills.

A new uranium mining technique, solution mining, is gaining prominence because of its advantages in making available some of these otherwise subeconomic deposits. Disarmingly simple in concept, the technique involves drilling into the deposit, injecting and circulating a solution that dissolves the uranium in place, and extracting the uranium from this solution in a surface plant. It thus avoids direct physical movement of the ore body and the resulting costs and environmental effects. Other advantages of this method are lower initial capital requirements, reduced lead times, lower labor requirements, safer operations, and improved possibility of extracting deep, low-grade deposits and small and/or isolated ore deposits.

In practice, many geologic, hydraulic, and chemical factors can combine to make solution mining more difficult than it appears from this description. Nevertheless, the technique is being used more frequently, mostly in development operations but to an increasing degree in actual production operations.

EPRI's Supply Program is concerned with forecasting uranium availability and price. With this in mind, it is currently funding two projects to develop cost models for uranium solution mining. The models will relate production costs to various physical, financial, and environmental factors. They will be capable of integrating whatever information is available about these factors now or that may be developed in the future. The contractors are S. M. Stoller Corp. (RP803-3) and NUS Corp. (RP803-2). This review draws mainly on the latter project because it is at a more advanced stage of research.

Solution mining of uranium, first proposed in 1957, was studied only in research and pilot projects until 1975, the date of the first commercial production. Since then, its use has been expanding rapidly. Currently there are 15 companies conducting operations, although many of these are developmental. Commercial production is now confined to Texas and Wyoming; however, Utah, Colorado, and New Mexico also have deposits that are amenable to this method. Solution mining has established a strong foothold in southern Texas, where four plants currently have a combined production of 400 t of U_3O_8 annually. (Total U.S. uranium production is about 15,000 t/yr.) The largest plants built so far have a capacity of 125 t/yr. Wyoming Mineral Corp. is operating one such plant in Wyoming and U.S. Steel Corp. operates another in Texas. Both have announced plans for expansion during the next two years; the Texas plant is to be expanded fourfold to 500 t/yr. In addition to its 125-t/yr plant in Bruni, Texas, the Wyoming Mineral Corp. is bringing a 250-t/yr plant on stream at Ray Point, Texas. Additional expansions are planned in 1977 and 1978 by Intercontinental Energy Corp. and Mobil Research and Development Corp. Some observers predict that uranium solution mining could contribute 10–15% to overall domestic production capability in 10 years (5000–8000 t/yr).

As in conventional uranium milling, no two uranium solution operations are identical. Furthermore, there are almost no publicly available data on operations because of the sensitive and proprietary nature of the work. Therefore, the researchers on the two projects have used a survey of contacts in both the public and private sectors to augment information readily available. In addition to this public and proprietary information, the project team has drawn data and judgments from personal experience on other applicable projects. The proprietary problems have been mitigated somewhat by the fact that the EPRI models do not attempt to present a cost analysis for a specific mining situation. The models are designed to accommodate variations in a number of key parameters that influence cost results. This will allow the models to be applied in a general, overview way to a wide variety of mining, financial, taxation, and other assumptions.

The cost model nearing completion by NUS Corp. is a process-oriented analysis technique that computes the capital investment, operating costs, and selling prices required to provide a desired return on investment. The costing methodology involves four submodels corresponding to four major cost categories: exploration and development drilling costs; initial well-field costs; plant and equipment costs; and operating costs. A fifth submodel deals with financial analysis and computes the required selling price, using discounted cash flow methodology and constant 1977 dollars.

Costs for the first submodel (exploration and development) are related to average figures from actual industry experience. In this submodel, acquisition costs can be included or excluded. The initial well-field cost submodel computes solution flow rates required and the corresponding number of required wells. The well-field pattern assumed is the commonly used five-spot pattern (four injection wells surrounding a single production, or recovery, well at the center of the pattern). The plant and equipment submodel basically computes the surface plant costs. These costs are based on a standard 0.09 m^3/s (1500 gal/min)

plant with appropriate scale-correction factors applicable to the size of plant required. Costs of environmental monitoring wells and equipment are included in the preceding two submodels. The operating submodel computes costs for chemicals, labor, pumping energy, annual well-field development costs, and aquifer restoration costs. Information for this submodel is based on data from service suppliers and historical data from ongoing solution operations. The financial submodel computes total project costs as opposed to forward cost presentations, which do not include such items as exploration cost and profit margin.

The model will compute required selling price for any variety of solution mining situations dictated by the user. Currently, the user must specify values for the following 11 input variables: annual production level, concentration of production solution, solution injection rate, uranium extraction efficiency, depth of deposit, ore thickness, well-pattern spacing, ore grade, reserve tonnage, required return on investment, and type of solution (acid or alkaline).

The relationships among these input parameters are complex. They are now under study in an attempt to reduce the number of input parameters required for the use of this model.

At this stage of the research, results are preliminary and unverified and should be treated cautiously. To show the magnitudes involved, for instance, for a 183-m-deep (600-ft) deposit, an ore thickness of 6 m (20 ft), a deposit grade of 0.05%, an extraction of 70%, a return on investment of 15%, and using typical industry values for the other is $68/kg ($31/lb) in 1977 dollars. It should be noted that this figure is higher than estimates recently reported in the literature. This difference stems, at least partially, from a more comprehensive treatment of cost categories, as previously noted. *Project Manager: Richard Urbanek*

PLUME MONITORING BY LASER RADAR

As a result of EPRI funding, the use of differential absorption laser radar for field measurement of atmospheric pollutants is nearing the demonstration phase. SRI International, under contract to EPRI, is developing a truck-mounted laser unit capable of remote measurement of atmospheric concentrations of SO_2, NO_2, and O_3 (RP1060). Not only will the unit be able to measure the upper atmosphere from the ground but it will also be able to do so at any time of day or night and under all weather conditions.

The rising concern about air quality has prompted the electric power industry to give careful consideration to plant siting, to air quality monitoring, and to pollution control. The measurement (or monitoring) of stack emissions is a key factor in judging air quality, in designing control devices, and especially in understanding the chemical reactions that occur in the atmosphere, particularly in plumes. Present measuring techniques depend on ground stations (which can, at best, give only an indirect indication of atmospheric constituents at higher levels) and aircraft (which are limited by cost, weather, and a variety of flight restrictions). What is needed is a way to measure atmospheric constituents from the ground, under all weather conditions. A laser device has such capability. The device being designed by SRI will be mobile and able to analyze the atmosphere at any discrete interval (e.g., any area between 305 m and 457 m [1000–1500 ft]) from ground level to about 2134 m (7000 ft). The basic laser unit has already been developed by SRI. The present EPRI contract calls for the unit and computer equipment to be truck-mounted for full mobility.

Differential absorption laser radar operates on a simple principle. A pulse of light at a particular wavelength is emitted into the atmosphere. A portion of this pulse is reflected by dust or other particles toward the laser unit. Light reflected by particles closer to the source arrives sooner than light reflected by those farther away, hence the presence of particles from any given region of a plume can be identified. Current equipment allows distance resolution of about 100 m (330 ft), that is, the system can distinguish pollution at 300 m from that at 400 m. Lasers can be used for more than simply identifying the presence of particles. If, for example, the wavelength of emitted light is one that is absorbed by a gas in the atmosphere (e.g., SO_2), less light energy will be returned than was emitted. The amount of light absorbed by the gas is directly proportional to the concentration of the absorbing species; thus the instrument can be used for remote, quantitative analysis. In practice, factors other than absorption of energy by pollutants of interest could cause the return signal to be less than expected. To correct for these other factors, a second energy pulse can be emitted along the same path as the first pulse but at a slightly different wavelength. The different wavelength can be chosen so that it will not be absorbed by the pollutant of interest, but will suffer all other losses as did the original pulse. The difference in return intensity of the two energy pulses would indicate how much energy absorption was due to the pollutant's being measured. Equipment is now available to analyze the atmosphere for SO_2, NO_2, and O_3.

EPRI's interest in remote sensing with lasers is not new. Through its Environmental Assessment Department, EPRI is supporting a project at Stanford University to develop a new type of laser that operates in the infrared range (RP486). Such an instrument would yield greater sensitivity than the ultraviolet laser being used by SRI. Both Stanford University and SRI are working closely together so that if the new unit proves successful, it can be incorporated into the mobile system being built by SRI.

Present plans call for the first field demonstration of the mobile unit in late 1977. That demonstration will be followed by about six weeks of field testing in the northeastern U.S. where the large-scale EPRI sulfate regional experiment (SURE) is under way. When fully operational, the mobile unit will be available for a number of studies at utility sites and for use in the SURE program. *Project Manager: Ralph Perhac*

RESIDENTIAL ENERGY DEMAND

EPRI research in the area of residential energy demand and conservation has been advancing in a number of directions to improve the quality and detail of energy demand models. The aggregate residential kilowatthour forecasting model used in *Demand 1977* (national energy consumption forecasts by EPRI's Demand and Conservation Program staff) produced aggregate demand forecasts at the national level (RP431). Refinements of this modeling structure are underway and are expected to be completed in early 1978 (RP1098). This work is aimed at improving the data and modeling treatment of fuel oil, electricity, natural gas, and household appliances. It will also involve tests of the ex-ante forecasting properties of the kilowatthour and appliance stock forecasting models. Many current energy problems, however, call for more residential sector detail than can reasonably be expected from this type of aggregate modeling structure.

The increasingly detailed nature of energy policy questions facing the electric utility industry requires more detailed energy demand forecasting models than have been needed. This is a natural consequence of the energy-related experience since the Arab oil embargo in 1973. Before then, energy questions tended to focus upon such highly aggregate variables as world

petroleum prices, the nation's level of economic activity, and state and national demand for electricity. These questions are still with us, but today's energy consumption policies are considerably more detailed and require models that are correspondingly more elaborate.

Residential consumption issues requiring models with more microlevel behavioral detail include household heating fuel choice and fuel switching, increased household insulation, the implications of various energy conservation measures, the responsiveness of special load management devices, and the time-of-day and seasonal pricing of electricity. Such questions are best investigated through models that focus directly on the energy-consuming unit, which in the residential sector is the household.

The Demand and Conservation Program is moving toward increasing the household-level detail of its aggregate models in four principal directions:

- Developing load forecasting models and integrating them with aggregate kilowatthour structures. (These projects were discussed by Anthony Lawrence in his modeling article in the August 1977 issue of the JOURNAL, p. 12.)

- Forecasting the residential appliance stock and the demand for new goods. These projects cover the development of methodology for predicting the demand for new goods with an illustrative application to residential heat pumps (RP488), the implications of electric automobiles for utility system loads (RP758), and the analysis of household appliance choice (RP1005).

- Generally improved detail concerning such energy-related household characteristics as regional household formation, the nature and characteristics of new and existing housing, population migration, regional employment and labor force participation, fuel consumption, and energy price detail. It is expected that a major effort will be started in this area early in 1978.

- Basic data-development projects to effect progress in each of the above areas. This work has generally been undertaken in cooperation with federal agencies because of the immense cost involved in collecting household-level energy consumption data. Projects in this area cover patterns of residential energy use by electrical appliance (RP576), analysis of load management experimental data (RP1006), and development of household energy consumption survey data (RP1099). The remainder of this report will elaborate on these three projects.

The Federal Energy Administration (FEA) is cosponsoring the project to collect survey data on residential energy consumption (RP576). The chief objective is to collect monthly appliance usage data from a nationally representative sample of 150 households. Metered electric appliances include heaters, stoves, refrigerators, air conditioners, washers, dryers, freezers, and swimming pool pumps. Electric appliances in each house were metered in 16 cities across the country. These households were sampled from a primary survey of 2000 during late 1976. In addition to providing the necessary sampling for the selection of the 150 homes to be metered, the primary survey provides a great deal of useful cross-section information on household characteristics and their relationship to energy consumption. The survey contains background data on housing characteristics, insulation, the economic status of the household, and meteorological and demographic detail. These survey data are of considerably better detail, quality, and breadth than previous sources and have now been used by FEA as a principal input for establishing federal appliance efficiency standards. This project is scheduled for completion by early 1978.

The analysis of load management experimental data was initiated to examine 13 load management demonstration, time-of-day, and seasonal pricing experiments being conducted throughout the U.S. (RP1006). The main objective is to examine the experimental design and sampling characteristics to determine the potential usefulness of the underlying data sets for the original objectives of each experiment and for EPRI's energy analysis objectives. In addition to assessing the potential usefulness of the panel data, this project will suggest the objectives the experiment may or may not be expected to achieve. It is hoped that some of the household data from the experiments may ultimately be integrated into the EPRI energy consumption and load forecasting models to provide additional disaggregate detail. The Institute for Social Research, University of Michigan, is the contractor for this project, which is scheduled to be completed in early 1978.

One of the principal limitations of existing cross-section data bases in the energy field has been the absence of a continuously updated household survey. The residential survey data project will remedy this deficiency by producing a national representative sample of about 8000 households to be resurveyed every other year (RP1099-1). The project, scheduled for completion in early 1979, is being cofunded by FEA and ERDA. EPRI is participating in the design phase of this project, which will not only help EPRI meet its needs for detailed microlevel household data but also will ultimately constitute the best available household energy consumption survey data base.

Project Manager: James Boyd

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

TRANSFORMERS

Improvement in the performance of major electrical equipment is a major research goal of the AC Substations Program. The projects described below specifically address the development of new insulation/cooling oils and gas detectors.

Oil

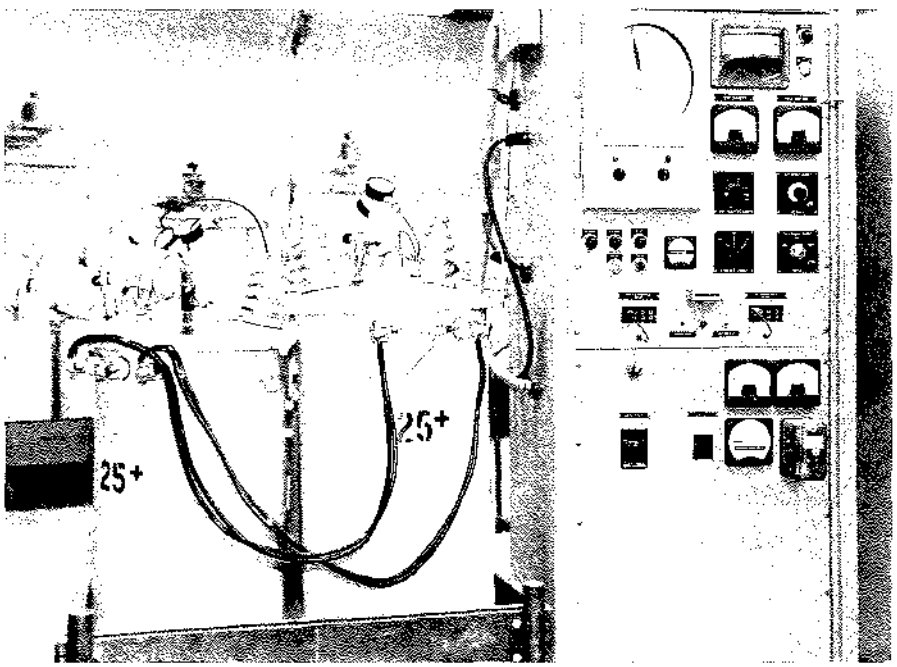
It is likely that the supply of naphthenic-base insulating oil will become critical by 1985. As a result, a contract between EPRI and Westinghouse Electric Corp. has been initiated to study paraffinic-base oils that could replace naphthenic oil in distribution transformers, circuit breakers, tap changers, and large oil gaps (RP577).

Four experimental and one naphthenic-base oils were selected as a result of work performed by General Electric Co. (RP562-1). The selection was based on the screening of many possible substitute oils furnished by oil refiners. This phase of the analysis was an examination of such general characteristics as lubricity, gasing tendencies, arc-formed gases, oxidation stability, and the compatibility of the oils with transformer construction materials. These tests showed that paraffinic-base oils compared favorably with the naphthenic standard.

The substitute oils so closely approximated the currently used transformer oils that it was possible to proceed to the second phase of the project, which is a life test in distribution transformers at an elevated temperature (Figure 1). All oils successfully completed the first temperature cycle, the initial electrical end-point tests, and those tests following the first aging cycle. As many as 40 cycles will be necessary to determine whether the oils will satisfy long-term stability requirements.

Westinghouse Research and Development Center is studying the effects of corona and high-current arcing in the experimental oils to determine their suitability for electrical application. Likewise, Westinghouse's Medium Power Transformer Division at Sharon, Pennsylvania, has manufactured two types of production tap changers that will be used to study mechanical operations at low temperature. These studies will be followed by life tests at 100°C and 1000 A, which is the current rating of the units. The oils will be tested for rate of carbon formation and rate of carbon settling, as well as mechanical wear on the contacts and tap changers themselves.

Figure 1 Group of transformers on life test with control equipment to keep the hot spot temperature of the coils at 180°C and the top oil temperature at 140°C (RP577).



To complete the program, production tests will be made on the oil in a power circuit breaker at the Westinghouse High Voltage Laboratory in Pittsburgh. Special parallel-plane electrode studies will be made at Westinghouse's Muncie, Indiana, plant. The latter will use practical electrode geometries and large oil volumes to ensure that the experimental oils are suitable for high-voltage insulation systems.

From the work to date, it is reasonable to expect that paraffinic-base insulating oil can become a replacement for naphthenic oil in major electrical apparatus.

The second part of the project is being carried out by McGraw-Edison Co. The objective is to age selected oils in 600 miniature capacitor cans containing transformer materials, thereby simulating large transformer performance.

One-half of the capacitors are nitrogen-blanketed and use uninhibited oil. The remaining half are free breathers and use oil inhibited with 0.3% ditertiary butyl paracresol. One-half of the nitrogen-blanketed

units went on test at 140°C and 29.5 kV/cm stress on May 2, 1977. Tests on the remaining half will begin on February 6, 1978, at 150°C and 29.5 kV/cm.

One-half of the free-breathing units went on test on May 2, 1977, at 120°C and 29.5 kV/cm stress. Tests on the remaining half will begin on February 6, 1978, at 135°C and 29.5 kV/cm stress. The last samples will be removed from testing on July 24, 1978.

Thirty special minicapacitor samples with high-voltage bushings have been made and are being tested at the same temperature and stress levels as those above. Corona inception voltage and corona extinction voltage are determined at periodic intervals by acoustic emission techniques. The frequency used is in the 100–300-kHz range.

Up to now, 5 of the 30 minicapacitors have failed. Of these, 4 had been filled with the same oil. No oxidation inhibitor remains in any of the 5 oils after 12 weeks of testing at 120°C and 29.5 kV/cm stress. The interfacial tension of all these oils has dropped below 20×10^{-7} N•m. Dissolved copper and iron vary greatly with oil and temperature. At 120°C, dissolved copper varies from 60 to 320 ng/ml, and dissolved iron varies from 4 to 170 ng/ml. At 140°C, dissolved copper varies from 23 to 680 ng/ml and dissolved iron varies from 48 to 400 ng/ml.

The treated paper has shown little sign of deterioration at this time. However, nitrogen depletion was found. After six weeks, the nitrogen content of the paper was analyzed in both the active area (in direct contact with copper) and in the inactive area (not in direct contact with copper). The nitrogen content in the active area was found to be 1.8–1.9%, while in the inactive area the nitrogen content was zero. In contrast, the original nitrogen content of the treated paper was 2.0–2.3%.

A related but more fundamental project concerning the search for new insulating oils is being conducted by General Electric Co. (RP562). Its objective is to survey the supply of electrical insulating fluids applicable to electrical equipment for the next decade. After the survey, the requirements for insulating fluids can be formulated.

General Electric reports that the results from its work on paraffinic-base oils continue to be encouraging. It appears likely that paraffinic oils will compare favorably with naphthenic oils in chemical and electrical stability and heat transfer properties at typical ambient and operating temperatures. Nearly completed accelerated-life testing of transformers containing paraffinic oils supports this hypothesis.

Unresolved questions remain, however. Paraffinic oils can form wax at temperatures below 0°C. Dewaxing can be done but becomes progressively more expensive as the temperature of wax formation is decreased. Deep dewaxing by processes not yet commercial in the U.S. results in oils that appear comparable to naphthenic oils down to the pour-point standard of −40°C. Conventional dewaxing together with flow modifiers (pour-point depressants) results in pour points of −30 to −38°C. Work is continuing in order to determine if these pour points can be lowered by other flow modifiers and, if not, to determine the effect of these higher pour points on electrical apparatus.

Transformers and other electrical equipment are normally in service for decades. For research, a means of highly accelerated aging is required to adequately demonstrate that a new and potentially useful oil will function over these long lifetimes. Improved testing and analytic methods are being developed and applied to paraffinic oils. *Project Manager: Ed Norton*

Bushings

One Westinghouse project (RP565) is intended to develop a 242-kV, 4000-A apparatus bushing that is small in diameter, low in cost, simple in construction, and easy to maintain (Figure 2).

Two strategies are involved. First, a heat pipe cooling system is incorporated within the central tubular conductor to permit operation at high current density. Second, cast-epoxy solid insulation is used to replace the oil-impregnated paper and porcelain.

Six prototypes will be produced as test specimens that will be used to verify performance at standard and overload conditions. This process demonstrated the feasibility of manufacturing outsized and complex epoxy insulating parts with a vacuum casting technique.

Casting of the capacitively graded core insulation involved pouring masses of epoxy formulation as large as 181 kg (400 lb) under vacuum into an 18-piece mold, while carefully controlling the temperature. Also, a nest of 13 concentric, tubular capacitive foil inserts was positioned in the mold prior to pouring. Nevertheless, excellent density was experienced with these complex subassemblies. This was largely attributable to the low viscosity of the special, highly filled epoxy formulation.

The upper half of the bushing core insulation, which protrudes above the flange, is encapsulated within a weathercase made of a second epoxy formulation. This is a flexible cycloaliphatic material developed specifically for weathercase applications. It is mechanically resilient and resistant to damage by impact. Also, under electric stress it is highly resistant to wet tracking. Similar formulations have been under surveillance on outdoor test racks in the field for up to seven years with creditable results. Completion of the verification test program is expected by late 1977. EPRI is interested in arranging for a test of this bushing at a suitable location on a utility system. *Project Manager: Ed Norton*

Figure 2 Prototype of a 230-kV, heat-pipe cooled-epoxy bushing with 4000-A rating. Since it is oilless, this new design will reduce the cost of processing, at the same time eliminating the need for oil expansion domes, oil level gages, springs, and gaskets. Ed Norton (left) is EPRI's project manager, and Don Covaleski is Pennsylvania Power & Light Co.'s project adviser.

Insulating gases

For many years, a large percentage of transformers have been built with a space over the oil that contains nitrogen gas to provide an inert atmosphere. The inert gas levels improved insulating and cooling characteristics of the transformer. It is possible, however, that other gases may be superior to nitrogen in this regard, but very little development has been done either to improve these properties or to reduce costs.

A project at Westinghouse is designed to evaluate the possibility of substituting sulfur

hexafluoride (SF_6) or hexafluorethylene (C_2F_6) for nitrogen (RP808). Although SF_6 is currently used as the insulating material for gas-insulated substations, it has not been used in the U.S. as an insulating gas in oil-filled transformers. Indeed much effort has been expended in the design of bushings that would serve to completely separate the SF_6 in the substation from the transformer. If SF_6 were found, for example, to be inert with regard to its effect on the oil in the system, considerable design savings could result.

The work on this project, which is approximately half completed, has been limited to work on conventional naphthenic oils to date. Nevertheless, some evaluation of paraffinic oils will be included in future work. The parameters being investigated include: gas/oil solubility, dielectric performance, gas evolution and/or absorption behavior under stress, compatibility, arcing, and stability. Some of the interesting developments to date are noted below:

- The solubility of both SF_6 and C_2F_6 decreases with temperature, while that of nitrogen is essentially unchanged. In contrast, the solubility of all three gases increases with pressure. Nitrogen and SF_6 follow Henry's Law, which states that solubility and pressure increase in an essentially linear fashion. Interestingly enough, both experimental gases are more soluble in oil than is nitrogen: C_2F_6 by a factor of about nine and SF_6 by a factor of about six.

- Regardless of the observed differences in solubility, the data on breakdown strength as a function of temperature and pressure reveal essentially no change relative to the nitrogen system.

- Under discharge conditions, the data show that oil absorbs C_2F_6 slowly, while N_2 and SF_6 are evolved (released) from the oil. The oil evolves SF_6 at a considerably higher rate than nitrogen. The significance of these points is under investigation.

Tests in progress also include compatibility and stability studies and arcing tests. *Project Manager: Bruce Bernstein*

Gas detector

A project with Westinghouse is concerned with the development of an on-line device to detect the presence of combustible gases dissolved in the oil of a transformer (RP748). Other devices have been available for detecting combustible gases in the gas space, but the proposed device provides continuous monitoring of gases that are dissolved in the oil. The results of the laboratory tests show that the concept and the components perform satisfactorily.

Two prototype units are presently being prepared and assembled for attachment to operating transformers. Arrangements are being made with two utility companies to put these units on their transformers for field evaluation. Structural modifications are required, however, to improve the economics of the units. *Project Manager: Ed Norton*

SWITCHGEAR

The successful interruption of an arc in a vacuum was demonstrated over 50 years ago. But only recently have the desirable features of vacuum interrupters been applied to power circuit breakers. Many problems had to be resolved before vacuum interrupters were available that could meet the requirements of electric utilities for current interruption, voltage ratings, and reliability. It has only been 15 years since the technology became available for manufacturing vacuum interrupting devices that would meet these requirements and so extend their application to power circuit breakers for distribution systems and to metal-clad switchgear.

EPRI has a 39-month project with the General Electric Co. to develop a vacuum interrupter with an interrupting rating of 63 kA at 72 kV on the low side, and 80 kA and 80 kV on the high side; it would have a 3000-A continuous current rating (RP754). Emphasis is now on increasing the voltage rating as high as possible while maintaining the interrupting rating at 63 kA or greater. These goals, if achieved, would provide units with ratings that are twice those in current use.

Existing vacuum interrupters may develop an anode spot during the arcing half-cycle. The probability of this happening increases with increasing current and contact separation. The anode spot may produce massive electrode erosion and can limit or prevent arc interruption. One of the objectives of this project is to develop an interrupter with an electrode design that will keep the arc in a diffuse mode during the arcing half-cycle. This will provide improved current-interrupting performance. Our evaluation shows that we should make a significant advance in vacuum interrupter technology. *Project Manager: Glenn Bates*

DISTRIBUTION

A sizable item in the annual maintenance budget for distribution systems is the cost of trimming trees to keep them clear of overhead distribution lines. The cycle for retrimming trees, usually annual or biennial, is governed by their rate of regrowth, which varies among species of trees. The severity of trimming must also be consistent with good public relations.

Utilities need valid answers to the following questions before they can make sound new policy decisions:

- Can control chemicals reduce tree growth and thus extend the tree-trimming cycle?

- Do control chemicals reduce the number of sucker sprouts and thus reduce the cost of retrimming?

- Is the additional cost of chemically treating trees justified by the results obtained?

- Can the control chemicals be readily applied and yet avoid objectionable appearance of the treated trees?

- Would alternative methods of chemical application be more effective and economical?

The unresolved questions led EPRI to sponsor two projects: one with the Agricultural Research Service of the U.S. Department of Agriculture (RP214), and one with the Department of Horticultural Sciences of the University of California at Davis (RP380). Each seeks answers to the above questions through different preselected methods of chemical application. The first, which concerns new methods and chemicals to control tree regrowth, has resulted in lightweight, portable equipment that injects chemicals directly into the trunk of the tree. The second, which concerns bark banding of chemicals to inhibit tree growth, relies on direct application of a band of chemicals to the outer bark of the tree trunk.

Chemical injection

Aqueous solutions of seven chemicals that were formerly associated with foliar spray were mixed in varying concentrations and injected into seedlings and into trees in the field. The purpose was to establish suitable dosages that will control regrowth for a variety of species without distorting foliar appearance. Table 1 shows good growth-retarding results, indicating that control is effective over three years.

Evaluation of such data, using mean sprout length as a base, indicates that a three-year trimming cycle with this treatment is as good or better than an annual trimming cycle without treatment. Based on mean longest sprout, more than a one-year advantage is gained. Also, a reduction in the number

Table 1
AMERICAN ELM SPROUT GROWTH DATA
(trees topped and injected in June 1974 with Slo-Gro [maleic hydrazide])

	1974	*1975*	*1976*
Untreated control group			
Mean sprout length (cm)	76	127	132
Mean longest sprout (cm)	129	216	287
Mean number of sprouts	9.3	5.9	7.8
Treated group			
Mean sprout length (cm)	30	41	56
Mean longest sprout (cm)	48	61	168
Mean number of sprouts	7.8	5.7	5.1

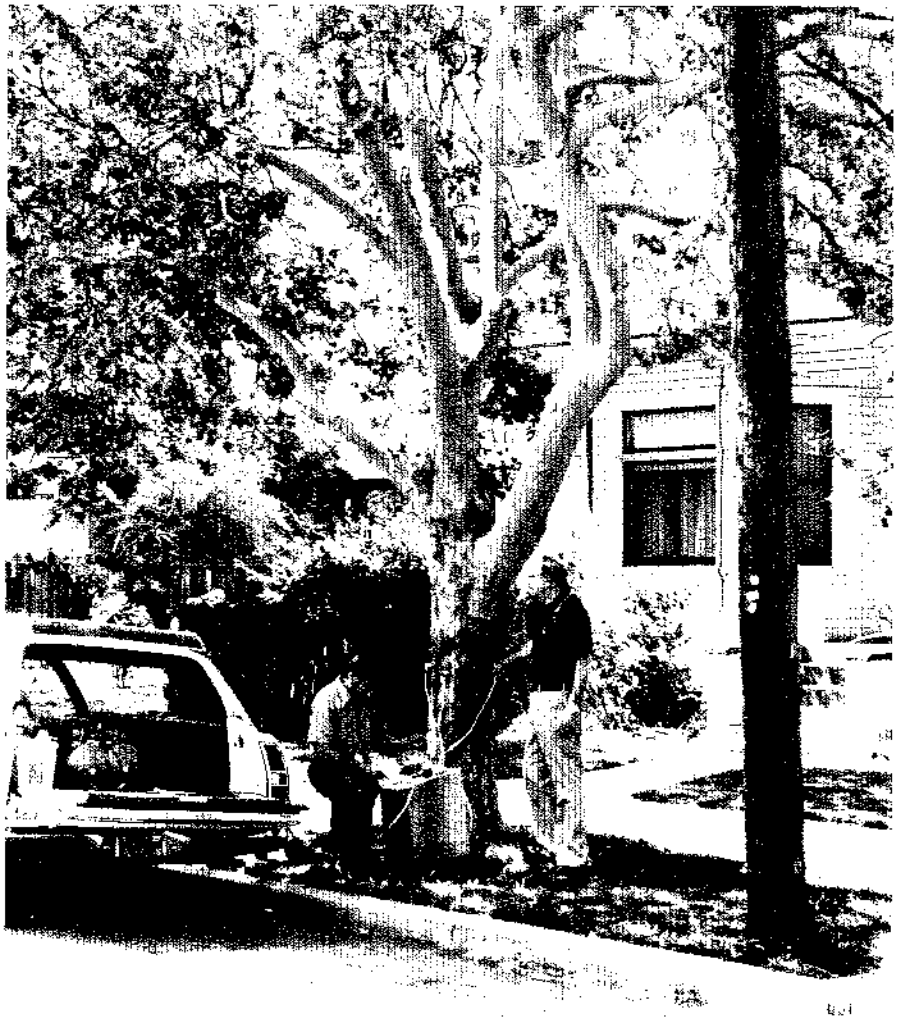


Figure 3 Portable chemical injection equipment with air supply developed to control tree regrowth after trimming. EPRI Project Manager Robert Tackaberry is shown at right.

of sprouts reduces the next trimming job. With field injections continuing yearly in a wide range of species, it is anticipated that one or two chemicals can be used for the widest possible variety of tree species and sizes.

A portable injection system has been developed and is now being used in regional trials. It consists of injection equipment housing, battery-operated drill, and portable air tank (Figure 3).

The equipment has performed satisfactorily during 1976 and 1977 operations. Injection time varies with species, amount to be injected, and time of year. It ranges from a few seconds to two minutes.

Based on results obtained in the first two years, a selection of two of the original seven chemicals was made for the third-year activity: Slo-Gro and Atrinol. Three concentrations were selected for each, based on earlier results, so that effective control without objectionable appearance could be demonstrated in trial applications over wide regions of the country.

The tree species treated locally in the past three years include American elm, silver maple, ash, sycamore, red oak, water oak, and Siberian elm. Recent injections made on a regional basis include sycamore, shamel oak, eucalyptus, red oak, Siberian elm, silver maple, and water oak. The regional applications will allow comparison with results obtained locally.

Bark banding

At the University of California at Davis, growth-retardant chemicals, primarily chlorfluorenol methyl ester (CFME), have been applied in a band directly to the bark of trees in the field and to seedlings in the greenhouse. It has been necessary to determine how much CFME is required to inhibit tree growth in various sizes of each species. It was also necessary to learn the distribution of the CFME in the trees. Bark absorption of the applied chemicals in various carriers has been studied to learn the influence of the bark characteristics (thickness, texture, and composition) on the movement of the chemicals through the bark to the tree transport systems.

Field tests have been useful to determine the long-term influences of annual applications of CFME on tree survival. Residual activity of CFME has also been evaluated. A number of other compounds that inhibit growth of woody plants have been screened for effectiveness with bark-banding applications. Data obtained from field evaluations have been used for California registration of Maintain CF 125 (one brand of CFME).

Application and observation on a wide variety of species will be continued during the remaining term of this contract. *Project Manager: Robert Tackaberry*

SYSTEM PLANNING AND OPERATION

In recent years a number of investigators have become concerned over the adequacy of traditional synchronous machine models and their associated parameters that are being applied to a variety of system stability evaluations. The parameters for these conventional models are calculated by the manufacturer in accordance with standards that existed 40–50 years ago. They no longer reflect present and future simulation needs.

The growth and development of power systems and their equipment characteristics have introduced fundamental changes in the simulation requirements for analytic studies. Power systems of today have much shorter switching times, so that stability performance is affected more by the post-disturbance system configuration than by the initial disturbance conditions. Estimates of stability performance required for a number of U.S. and Canadian systems call for simulations of up to several seconds. Such simulations are very dependent upon the correctness of models, particularly where instability may appear some time after the initial disturbance.

Accordingly, studies of stability have become increasingly complex. Analysis techniques are needed for both nonlinear, large-disturbance situations and problems characterized by linearized, small-disturbance assumptions, where linear system analysis techniques are used.

It is clear that the choice of data used in any model is sometimes more important than the complexity of the model in attaining accurate results.

A major goal is to improve the accuracy of computer stability studies for study periods up to approximately one minute (RP997). The determination of parameters for synchronous machine models is of primary interest. The work performed in the project should result in improved mathematical models of a synchronous machine's dynamic behavior. The successful completion of this work is required to improve the overall accuracy of dynamic system simulation.

The project consists of six interrelated parts, with performance to be coordinated among four separate contractors. All four contractors will have some involvement in all six parts. As a general guideline, EPRI will consider the following as the principal roles of the four participants:

- C. A. Parsons & Co., Ltd.: Determination of model parameters by shop and field tests, development of model structure, and validation of model performance
- Ontario Hydro: Determination of model parameters by field tests of system behavior, validation of model performance, and evaluation of model adequacy
- Power Technologies, Inc.: Determination of model parameters by the deMello method, validation of model performance, and evaluation of model adequacy
- Westinghouse Electric Corp.: Determination of model parameters by shop and field tests, field tests of system behavior, and validation of model performance

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

New Technical Reports

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

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

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ELECTRICAL SYSTEMS

Bipolar HVDC transmission system study between ± 600 kV and ± 1200 kV: insulation studies

EL-395 Final Report (RP430-1)

This report, prepared by Hydro-Quebec Institute of Research, describes insulation strengths for line and station insulators tested with various switching surges in the presence of dc voltage bias. It is part of a larger research effort to pinpoint technical problem areas in overhead line design and operation at voltages of ±600 kV–±1200 kV.

Results in this report can be used to determine conductor-to-tower clearances, length of the insulator column supporting a station bus, and clearance between buses. *EPRI Project Manager: F. S. Young*

Bipolar HVDC transmission system study between ± 600 kV and ± 1200 kV: power supply study for insulator pollution tests

EL-397 Final Report (RP430-1)

The objective of this project, conducted by Hydro-Quebec Institute of Research, was to determine the required capacity of a dc power supply to be used for flashover tests on contaminated insulators. For this purpose the rectifier parameters were adjusted over an appropriate range and the variation of the 50% flashover voltage as a function of the power supply parameters was measured. This measurement was then used to determine the effect of the rectifier parameters. In addition, the nature of the leakage current of the contaminated insulators was studied to determine the expected maximum loading of the rectifier.

The present state of the art was based on a survey of the literature, which showed that neither the loading effect (maximum leakage current) of the contaminated insulators nor the necessary rectifier parameters have yet been clearly determined. The theoretical investigation revealed the critical factors influencing the flashover voltage. Extensive laboratory studies were performed in a small fog chamber, where the flashover voltage of heavily contaminated insulators was measured by the clean fog method, in which the contaminated and dried insulators were installed in the fog chamber and energized. Clean fog was applied and the voltage maintained until the flashover occurred or until the leakage current was reduced to a few mA. The voltage and the leakage current were recorded by a magnetic-tape recorder.

The test was repeated several times to determine the dependence of the 50% flashover voltage on the rectifier parameters. The majority of the contamination tests were performed at the heavy pollution level of about 0.5 mg/cm² of equivalent salt (NaCl) deposit density. *EPRI Project Manager: F. S. Young*

Development of polymer-bonded silica (Polysil*) for electrical applications

EL-488 Final Report (RP480-1)

This report, prepared by the Westinghouse Electric Corp., Research and Development Center, deals with the development for high-voltage electrical insulation applications of a new family of composite materials systems, which can effectively replace electrical porcelain, with significant technical and cost advantages and considerable savings in total energy consumption.

These materials systems (Polysil*) are essentially polymer concrete and polymer-impregnated concrete reinforced with randomly dispersed, chopped alkali-resistant glass or organic (aramid) fibers. Both cross-linked, low-viscosity acrylic and polyester resins were used as the organic phase of the composites. Such coatings as plasma-sprayed fluorocarbon and inorganic glass-resins were examined to enhance the surface characteristics and performance of the composite insulation, especially in polluted environments.

Data on the dielectric, mechanical, and physical properties of Polysil* are presented and discussed in detail, together with examples of insulator prototypes made with these promising and versatile materials systems. *EPRI Project Manager: E. R. Perry*

EPRI polymer concrete workshop

EL-492-SR Special Report

The purpose of the Polymer Concrete Workshop was to exchange information on polymer concretes and their application as an electrical insulating material, to identify requirements of the electric utilities, and to outline a program for future development of this material.

Participants included those actively developing polymer concretes as an electrical insulating material, as well as those working with the basic materials, which can be used for purposes other than electrical insulation. Formulations, manufacturing methods, testing procedures, and designs of insulators were discussed. Electric utility representatives were present for orientation and to provide inputs into the requirements for the ultimate use of polymer concretes.

The new material, which has the EPRI trademark of Polysil* when formulated for electrical insulation purposes, was developed as a replacement for electrical porcelains, which are presently used for indoor and outdoor applications. Polysil* is a low-energy-intensive material using less than one-fourth the processing energy of porcelain with less than half the finished-product cost, twice the dielectric strength, and one-half the dielectric constant of electrical porcelain. It exceeds the mechanical strength of presently produced electrical porcelain, can be cast in simple molds, and can be produced in large cross sections, as it has a very low exotherm during its curing stage. *EPRI Coordinator: E. R. Perry*

*Polysil is an EPRI trademark.

ENERGY ANALYSIS AND ENVIRONMENT

Biological effects of static and low-frequency electromagnetic fields: an overview of U.S. literature

EA-490-SR Special Report

This report was prepared for the U.S.–USSR scientific exchange program on the biological effects of static and low-frequency electromagnetic fields. The purpose of the exchange is to evaluate current knowledge and to develop cooperative research programs with the Soviet Union to assess the possible health hazards of exposure to static and low-frequency electromagnetic fields.

Following an exchange of national literature surveys, of which this document is a part, there will be an exchange of visits by experts of both countries. Six experts from each country will then meet in a joint workshop to review the state of knowledge and current research on this topic and propose a cooperative research program to solve unanswered problems. The cooperative research program proposed at the joint workshop will be initiated in 1978. *EPRI Project Manager: H. A. Kornberg*

Economic analysis of coal supply: an assessment of existing studies

EA-496 Final Report, Vol. 2 (RP335-2)

Coal appears destined to play a major role in energy supply in the future, although its precise role is still uncertain. Coal's share in the future will depend primarily on coal supply, that is, availability and cost, including environmental costs, through time; the results of research and development on coal conversion and utilization technology sponsored by the electric utility industry (through EPRI), other private interests, and the government; and developments in competing energy sources and conversion technologies.

The Supply Program of EPRI's Energy Analysis and Environment Division has undertaken an extensive effort aimed at better defining and estimating the future role of coal and coal technologies, as well as other fuels and their associated technologies, in order to facilitate the planning of research and development. Such information should also be of major interest in utility planning.

A prudent part of any attempt to project the future is to review recent and ongoing work by others in order to provide a basis for future research and to avoid unknowing duplication. In order to do this in an efficient manner, EPRI's Supply Program has contracted with Pennsylvania State University to survey and evaluate recently completed coal supply studies and to meet with people currently conducting studies of coal supply. *EPRI Project Manager: T. E. Browne*

FOSSIL FUEL AND ADVANCED SYSTEMS

An overview of stoppering of open magnetic containment systems for controlled fusion

ER-394-SR Special Report

Although the tokamak reactor concept is currently closest to a feasibility experiment, a number of limitations of the configuration make it desirable to pursue alternative plasma containment devices. Among these limitations inherent to the toroidal tokamak concept are: (1) low β (ratio of plasma pressure to magnetic field pressure), leading to inherently large devices; (2) difficulty of access in a toroidal configuration; and (3) enhanced diffusion arising from the toroidal geometry, coupled with various instabilities that may further increase the system size.

Among the alternative approaches are a wide variety of open magnetic containment geometries. An open magnetic geometry is understood as one in which magnetic field lines that intercept hot reacting plasma leave the plasma volume and intersect material walls. This is in contrast to closed systems like such toroidal configurations as the tokamak and stellarator geometries, in which the magnetic field lines close upon themselves within the plasma volume.

In all magnetic confinement systems, the plasma is confined by the magnetic field lines. However, charged particles in the plasma moving parallel to the field lines in open geometries can escape from the reacting region, resulting in loss of particles and, more seriously in some circumstances, a loss of energy from the hot reacting plasma.

All confinement systems with magnetic field lines leaving the confinement region apparently need end stoppering, either to raise the reactor Q or to reduce the reactor size to reasonable dimensions. For purposes of discussion in this report the types of stoppering were divided into five categories: electrostatic stoppering, radio frequency electromagnetic stoppering, magnetic stoppering, stoppering with material end boundaries, and closure of field lines. *EPRI Project Manager: W. Gough*

Characterization of mineral matter in coals and coal liquefaction residues

AF-417 Annual Report (RP366-1)

The aim of this investigation by Pennsylvania State University is to characterize the organic and mineral fractions of coals and coal liquefaction residues. Relationships are sought between the composition and properties of these components and the behavior of specific coals during liquefaction. Characterization is achieved by a wide range of techniques. These methods include optical and scanning electron microscopy, X-ray diffraction, infrared spectroscopy, chemical analyses, magnetic measurements, and particle-size analysis.

From an investigation of the composition of coals and residues, it has been shown that most of the mineral components remain essentially unchanged during liquefaction. The major exceptions are the reduction of pyrite to pyrrhotite and the production of calcium salts from exchangeable calcium cations contained within low-rank coals.

From an investigation into the composition of solids removed from liquefaction reaction vessels, it is shown that they are composed of two distinct components: one, a carbonaceous, cokelike material and the other, an inorganic material. The cokelike solids are produced by dehydrogenation and condensation reactions of organic precursors. In the case of liquefaction of low-rank coals, inorganic solids are produced by the reaction of exchangeable calcium cations with carbon dioxide. For higher-rank coals, these solids are predominantly composed of pyrrhotite, quartz, and calcium salts—all intimately associated with carbonaceous phases. Knowledge of the formation of these reactor solids is important as their presence constitutes a definite processing problem for noncatalytic hydrogenative coal liquefaction. *EPRI Project Manager: W. C. Rovesti*

The influence of limestone calcination on the utilization of the sulfur-sorbent in atmospheric-pressure fluidized-bed combustors

FP-426 Final Report (RP720-1)

The purpose of this project by Westinghouse Electric Corp. was to determine the effects of calcination parameters on limestone utilization (sulfation) in an atmospheric fluidized-bed combustion (AFBC) system. A primary objective was to specify calcining procedures and conditions for improved limestone utilization in AFBC.

It was demonstrated in the project that retarded precalcination of limestone, in a carbon-dioxide-rich atmosphere, creates a superior pore-volume distribution in the resulting calcine (lime) so that its sulfation capacity is effectively doubled. An outline for applying precalcination to AFBC was developed.

Fluidized-bed combustion for electric power generation is a direct combustion process for coal, with the potential for improved thermal conversion efficiency, reduced costs, and acceptable environmental impact. By using limestone to capture the sulfur in the combustion bed, current EPA new source performance standards for SO_x emissions can be met, but the process as currently practiced requires a >3:1 mole ratio of calcium to sulfur, instead of the theoretical limiting value of 0.9:1. *EPRI Project Managers: M. Maaghoul and T. E. Lund*

Hydrogen conductors based on the beta alumina structure

EM-449 Final Report (RP730-1)

Current fuel cell technologies operate either at temperatures below 200°C where reaction rates are slow and limit performance or at temperatures above 500°C where material problems are severe and limit life. No electrolyte exists that allows fuel cells to operate at 300–500°C, where both performance and life might be satisfactory.

This study by General Electric Co. addressed three issues critical to establishing the feasibility of using beta alumina as a fuel cell electrolyte. The issues concerned producibility of hydronium beta alumina, conductivity at 300–500°C and at the steady-state water content, and stability at 300–500°C at water vapor pressures of 10–20 kPa (75–150 torr).

The study concluded that while small crystals could be produced that were stable over the required water vapor pressure and temperature ranges, the conductivity was much too low for use as a fuel cell electrolyte. *EPRI Project Manager: A. Fickett*

Development of lithium-metal sulfide batteries for load leveling

EM-460 Interim Report (RP116)

This report describes the work carried out at Atomics International Division, Rockwell International Corp., for the development of high-temperature lithium-silicon–iron-sulfide batteries for electric utility off-peak energy storage. The program consisted of a number of tasks directed to specific aspects of battery development, which are separately funded by EPRI, Argonne National Laboratory (ANL), and Rockwell.

Research efforts were directed to the development of lithium-silicon negative electrodes, FeS positive electrodes, and ceramic separators that are stable in contact with lithium-metal and lithium-silicon alloys. Compact cells with capacities up to 1 kWh were built and operated. Engineering studies of cell and battery costs were performed, and estimates of the parasitic power requirements for heat dissipation of large battery systems were made. A supporting effort to examine the feasibility of using corrosion-resistant coatings for low-cost positive FeS_2 electrode structures was initiated. *EPRI Project Manager: J. Birk*

Process synthesis and innovation in flue gas desulfurization

FP-463-SR Special Report

This report is a case study of process synthesis of aqueous scrubbing/aqueous regeneration technologies for removal of SO_2 from waste gases. Three specific aqueous regeneration technologies have been considered: crystallization and disposal of $CaSO_3/CaSO_4$ (throwaway scrubbing), reaction with H_2S to produce elemental sulfur (H_2S regeneration), and steam stripping or evaporation of aqueous solution to produce concentrated SO_2 (steam regeneration). The progress of process development and innovations in these technologies has been reviewed, evaluated, and structured to form a basis for the critical considerations of process synthesis. Additional innovations have been generated by further systematic analysis and synthesis.

Given a basic process concept or objective, process synthesis is the first step of process design. It may precede or be parallel to process development. It must define the basic flowsheet, reactants, and important equipment types. To ensure a reasonable chance of success, process synthesis must also include preliminary evaluation of the defined process or processes.

Previous efforts at systematic process synthesis concentrated primarily on the evaluation of large numbers of alternatives defined by combination/permutation of simple subalternatives, as in heat-exchanger networks and heat recovery/separation networks. Synthesis of more complicated, real-process systems would require evaluation of a very large number of alternatives. Furthermore, the subalternatives of a real process with several different unit operations are not usually clearly identified and must themselves

be defined or invented. For these more complex processes, more qualitative methods, such as evolutionary synthesis and morphological analysis, become useful. *EPRI Project Manager: K. Yeager*

Evaluations of fusion-fission (hybrid) concepts

ER-469-SY Summary Report (RP268-1)

This report summarizes the findings of the fusion-fission studies conducted for EPRI by Battelle, Pacific Northwest Laboratories.

The studies focused on two areas where fusion systems may complement fission systems: one to burn actinides present in high-level waste and the other to produce fissionable materials.

A concept that is receiving increasing interest is to surround a fusion plasma with fissile and/or fertile material in a blanket to beneficially use the 14-MeV neutrons produced by the controlled thermonuclear reaction. Concepts that involve the use of fusion-produced neutrons to ultimately produce fission and/or fissionable material are generally referred to as fusion-fission (hybrid) systems. *EPRI Project Manager: W. C. Gough*

Silicon photovoltaic cells in thermophotovoltaic conversion

ER-478 Progress Report (RP790-1)

This report provides a preliminary assessment of the feasibility of a solar-electric thermophotovoltaic (TPV) system. In concept the proposed system uses concentrating mirrors focused on a TPV converter that operates at high power density and potentially high efficiency. Within the TPV converter, the concentrated sunlight heats a refractory radiator. A photovoltaic cell faces the radiator, receives incandescent radiation from it, and converts the radiation to electricity. Stanford University is the contractor.

TPV conversion has several features that may make it economically attractive. First, on the basis of preliminary theoretical and experimental results, the achievable cell conversion efficiency is expected to be 30–50%. This high efficiency may be attractive in light of high support-structure costestimates for proposed photovoltaic systems. Second, the system runs with a concentration ratio of 300:1 to 500:1 at the photocell. This permits the use of an expensive and sophisticated converter that will be needed to obtain high efficiency.

A numeric model of TPV conversion was developed to assess TPV conversion and to facilitate an initial design of TPV photocells. Also, a facility for experimentally evaluating TPV photocells was designed and built.

Three runs of TPV cells were fabricated and tested. These runs achieved efficiencies of 7%, 10%, and 12%, respectively. The cells have negligible resistance loss at currents up to 50 A/cm², or 1000 suns. The low efficiency was caused primarily by anomalously high parasitic absorption, which probably can be eliminated by design modifications in progress.

When proper electrical and geometrical parameters for the photovoltaic cell were assumed, the numeric model was found to describe correctly all aspects of the observed behavior of the TPV cells. The model predicts that reduction of parasitic absorption to levels considered achievable will yield TPV cell efficiencies in excess of 30%. *EPRI Project Manager: E. A. DeMeo*

The nature and origin of asphaltenes in processed coals

AF-480 Annual Report (RP410-1)

Mobil Research and Development Corp. aimed to obtain fundamental understanding of the chemical nature and structure of solubilized coals and the kinetics and mechanisms by which they are formed from coal by specific interactions under typical solvent-refining conditions. Four coals were investigated: three bituminous and one subbituminous.

Several techniques were used that were unique to this project. These included conversions of coal fractions and model compounds in autoclaves capable of achieving contact times as short as 15 s under reaction conditions. The equipment also has facilities for sample withdrawal at selected times. Solvent-refined coals (SRCs) were isolated from withdrawn samples by microvacuum distillation. Synthetic recycle solvents were used that were composed of pure compound mixtures, which simulated the chemistry of true recycle solvents but could be readily distinguished from coal products. This allowed the simultaneous study of the chemistry of the solvent and of the coal.

Detailed characterization of SRCs and true recycle solvents was conducted by two liquid chromatographic techniques specifically designed for the fractionation of SRCs and solvents, respectively, into discrete chemical classes. These techniques are sequential elution by specific solvents chromatography (SESC) for SRCs and recycle solvent multiple characterization (RSMC) for solvents. Further characterization was done by a variety of wet chemical, spectroscopic, and polarographic techniques, including solid-state CP–^{13}C–NMR, which allowed characterization of parent coals and residues in addition to soluble products. Consumption of hydrogen from both gas phase and solvents was also determined. *EPRI Project Manager: W. C. Rovesti*

Substructure and properties of sodium beta alumina solid electrolytes

EM-494 Interim Report (RP252-2)

This report covers investigations by Cornell University into the relation between substructure and properties of sodium beta alumina.

The investigation aims at a clarification and quantification of the relation between microstructural imperfections, impurities, and properties of sodium beta alumina solid electrolytes. Microstructural imperfections have been studied by means of transmission and scanning electron microscopy, as well as by optical microscopy. Their relation to problems in ionic conductivity, such as inhomogeneous current distributions, is discussed. Impurity effects were studied on a prereacted, commercially available beta alumina powder. These studies thus relate to problems that result from contamination during the electrolyte preparation. The investigations focused on the detailed examination of ionic conductivities by a dispersive method.

The report concludes that significant, and possibly deleterious, ion current inhomogeneities can result from microstructural imperfections; that Ca is a more deleterious impurity than Si but the magnitude and the nature of the effect depend significantly on the sintering heat treatment; and that Zn in low concentrations can be an effective sintering aid. *EPRI Project Manager: R. H. Richman*

Indirect measurement of particle association effects in coal-derived liquids by X-ray photography

AF-502 Final Report (RP774-1)

Association of mineral matter particles in coal-derived liquids can be employed to improve separation processes for removing particles from coal liquefaction products. The primary objective of this research by West Virginia University was to investigate mechanisms by which particles can associate in coal-derived liquids.

Particle association was observed experimentally by measuring the initial sedimentation rate in batch-settling experiments. An experimental technique for achieving this has been developed based on X-ray photography. Experiments have been conducted with both antisolvents and chemical additives, which cause charge neutralization resulting in coagulation or flocculation.

Theoretical investigations have been initiated to identify the mechanism by which antisolvents function and to identify the possibility of charge neutralization of mineral matter particles. *EPRI Project Manager: N. Stewart*

Magnetic separation of mineral matter from coal liquids

AF-508 Final Report (RP365-1, RP779-3)

This study was undertaken by the Massachusetts Institute of Technology to investigate the thermal and controlled atmosphere pretreatment of coal liquefaction residual solids to enhance their magnetic separability. Such treatment is intended to convert the iron-sulfur minerals of these solids into a more magnetic state before removal by high-gradient magnetic separation at a practical temperature relative to the liquefaction and refining process.

Thermal treatments of dry filter cake from the solvent-refined coal (SRC) process were carried out in inert and sulfide atmospheres over a wide range of conditions. Extensive characterization of the processed filter cake was undertaken, using magnetization measurements as a function of field and temperature and Mössbauer spectrometry. These characterization techniques provide sensitive indicators of the magnetic state of the material. Magnetization enhancement at practical process temperatures of a factor of 4–10 has been achieved.

This study is one of the first to focus on the magnetic characteristics of the SRC mineral residue, a knowledge of which is essential to magnetic separation studies. It is recommended that the present characterization methods be incorporated into any future magnetic desulfurization effort. *EPRI Project Manager: H. E. Lebowitz*

Fusion power: status and options

ER-510-SR Special Report

The attainment of economic and safe fusion power has been described as one of the most sophisticated scientific problems ever attacked. In recent years there have been a number of experimental achievements whose cumulative impact has given confidence that practical fusion power can probably be demonstrated by the mid- to late 1990s.

This report, prepared for a round-table discussion at the World Energy Conference, presents the status of fusion, its most demanding challenges, its potential applications, and its assessment from a safety and environmental standpoint. It is unique in its broad, up-to-date coverage of the worldwide fusion program. In addition to elec-

tric power production, other potential applications of fusion are described. The utility requirements as currently perceived are presented, as well as safety and environmental issues.

The report has been reviewed in the U.S. as well as by international reviewers. It has been written for an audience with diverse backgrounds and should prove useful to many people seeking a more complete understanding of the current world effort to develop the essentially unlimited energy available from fusion. *EPRI Project Manager: W. C. Gough*

NUCLEAR POWER

Improved evaluation of nozzle corner cracking

NP-339 Final Report (RP-700, RP498)

Within the past few years, flaws have been discovered at the inside corners of feedwater nozzles of several operating BWRs. The significance of these flaws has been evaluated for structural safety, using linear elastic fracture mechanics. The evaluations have been based on stress intensity factors, K(a), which were obtained for a single flaw location and pressure loading only. Conservative assumptions were made to account for other flaw locations and the effect of thermal stresses.

This report was prepared by Teledyne Engineering Services and Failure Analysis Associates. It provides stress intensity factors for 15 postulated corner flaw locations in a typical feedwater nozzle subjected to pressure and thermal stresses and considers the effect of a residual stress caused by the weld-deposited cladding. The use of these data permits more accurate fracture mechanics evaluations of nozzle corner flaws. *EPRI Project Managers: T. Oldberg and F. Gelhaus*

Sensitivity analysis of TRX-2 lattice parameters with emphasis on epithermal ^{238}U capture

NP-346 Final Report (RP612)

To use our nuclear fuel resources most efficiently, it is necessary to have an accurate knowledge of the nuclear properties and cross sections of most materials used in the design of reactor cores. Having such information available on a national standard data file would also be useful for simplifying the dialogue between the utility industry and the regulatory agencies and/or vendor organizations.

In an attempt to achieve this dual objective, EPRI has been supporting and participating in the activities of the Cross Section Evaluation Working Group (CSEWG) responsible for the development of the national reference data library, ENDF/B. Sensitivity analysis is an important tool in the development of such a library because it can provide information on which cross-section features are most likely to affect the results of benchmark calculations. In the past, such information was obtained in a parametric fashion by doing a series of calculations, each with a modified cross section data base. Such an approach permitted a very limited set of modifications to be tested.

Recent advances in computing capability have enabled a few laboratories to implement more powerful methods based on perturbation theory. In particular, the method of sensitivity analysis implemented at Oak Ridge National Laboratory is capable of simultaneously determining the dependence of a calculated parameter of interest to variations in all relevant cross sections over all energy ranges in great detail.

This method of sensitivity analysis has been used extensively by ERDA and the Department of Defense for determining priorities in cross section development for fast breeder reactor and weapons applications. The present project is the first attempt to apply the method to the relatively more complex problem of thermal reactor benchmarks. *EPRI Project Manager: O. Ozer*

RETRAN—a program for one-dimensional transient thermal-hydraulic analysis of complex fluid flow systems

NP-408 Final Report, Vol. 1 (RP342-1-2, RP889-2)

RETRAN represents a new computer code approach for analyzing the thermal-hydraulic response of nuclear steam supply systems (NSSS) to hypothetical LOCAs and operational transients and in contrast to the conservative approach, provides best-estimate solutions.

RETRAN is a computer code package developed from the RELAP series of codes, reference data, and extensive analytic and experimental work previously conducted on the thermal-hydraulic behavior of LWR systems that were subjected to postulated LOCAs and operational transients.

The RETRAN computer code is constructed in a semimodular and dynamic-dimensioned form where additions to the code can be easily carried out as new and improved models are developed. This report, prepared by Energy Incorporated, presents the derivation of the general equations, the constitutive models, and numeric solution schemes that form the bases of the RETRAN computer code. *EPRI Project Manager: L. J. Agee*

A study of in-service ultrasonic inspection practice for BWR piping welds

NP-436-SR Special Report (TP575-609)

Periodic maintenance inspection of the primary and secondary pressure boundary of the commercial light water moderated nuclear reactor system is an NRC requirement. The detailed requirements for these in-service inspections are set forth in the ASME Boiler and Pressure Vessel Code, Section XI, "Rules for In-Service Inspection of Nuclear Power Plant Components," and in various supplemental directives issued by NRC.

One of the major nondestructive evaluation (NDE) inspection methods used to satisfy the requirements of the code is ultrasonic inspection. This technique has the ability to interrogate large volumes of the pressure-containing structure for service-inducted flaws without the need for access to the inside surface. This EPRI study represents the first nuclear in-service NDE performance evaluation program conducted in the U.S. *EPRI Project Manager: E. R. Reinhart*

RETRAN sensitivity studies of LWR transients

NP-454 Final Report (RP887-1)

This report, prepared by Energy Incorporated, presents the results of sensitivity studies that used the RETRAN/RELAP-4 transient analysis code to identify critical parameters and models influencing LWR transient predictions. Various plant transients for BWRs and PWRs are examined.

These studies represent the first detailed evaluation of the RETRAN/RELAP-4 transient code capability to predict a variety of plant transient responses. The wide range of transients analyzed in conjunction with the parameter and modeling studies identifies several sensitive areas, as well as areas requiring future study and model development.

This project greatly benefited from the Nuclear Safety Analysis Task Force's subcommittee on system analysis, which assisted the EPRI staff and the contractor in defining the particular incidents to be analyzed. Assistance was also obtained from two utilities, which supplied operating characteristics from their plants to make this study more meaningful. *EPRI Project Manager: L. J. Agee*

Additional methodology development for statistical evaluation of reactor safety analyses

NP-483 Topical Report (RP768-1)

This report, prepared by Westinghouse Electric Corp., quantifies uncertainties and identifies conservatisms in nuclear power plant safety analyses.

Regulations require simultaneous application of a number of individual model and parameter conservatisms, or penalties, in the computer code models used for design evaluation. These codes conservatively model the behavior of a core during the operation of the ECCS after a hypothetical LOCA and are forced to give highly pessimistic results. The level of conservatism resulting from this approach may be excessive.

One way to address this concern is to analyze the problem in a more realistic manner. This would require the use of best-estimate codes, which would attempt to predict more realistically what happens when given specific details of the reactor, its ECCS, and the LOCA are evaluated. These codes could then be used to study the distribution of output that is induced by input uncertainties. With this approach it might be found that a code-predicted output value (e.g., peak cladding temperature) actually has an extremely small probability.

The EPRI project uses simple codes (e.g., THERM) to develop methodology for studying the effects of uncertainties. A range of uncertainties associated with the various input parameters is first established. A study is then made of the distribution of outputs that are induced, using the various input uncertainties. Finally, having achieved a representation of the probability distribution of the code output, the probability of an event (given a range of uncertainties) can be realistically estimated. *EPRI Project Manager: B. Chu*

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